

Research Article

Black Soldier Fly Larvae Meal (*Hermetia illucens*) in Tropical Broiler Diets: Inclusion Thresholds for Growth Performance, Physiological, and Survival Dynamics

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Abstract

Poultry farming plays a pivotal role in ensuring food security and rural livelihoods across Sub-Saharan Africa. However, extreme reliance on expensive imported protein feeds, particularly soybean meal and fish meal, severely undermines sector sustainability. This study evaluated the effects of the replacement of the soybean meal with local BSFL meal (BSFLM) on growth performance, survival, liver/kidney biomarkers, and hematological responses in broiler chickens (Ross 308) in Cameroon. A total of 72 one-day-old unsexed chicks were randomly allocated to four dietary treatments across three replicates (6 chicks/replicate) for 56 days (starter phase: days 1–28; grower phase: days 29–56): Control A1 (0% BSFLM), A2 (5%/2.5%, starter/grower), A3 (7.5%/3.75%), A4 (complete replacement: 15%/7.5%). On day 56, 24 chicks were sampled for full blood count, liver enzyme, kidney function, and lipid profile analyses using standardized enzymatic spectrophotometry. Broilers fed diet A3 achieved the highest final body weight (1021.44 ± 245.88 g) and 0% mortality. Conversely, total substitution (A4) resulted in significantly reduced growth, high mortality (22.22%), and impaired feed efficiency, indicating metabolic limits or nutrient imbalances at high inclusion rates. Hepatic (ALT, AST) and renal (creatinine, uric acid) parameters, along with serum lipid profiles (total cholesterol, triglycerides, HDL, LDL), remained within normal physiological reference ranges across all groups, confirming the physiological safety of BSFLM. A significant reactive thrombocytosis was detected in groups A2 and A4 ($p < 0.05$), warranting further investigation into immune-mediated pathways. Locally processed BSFL meal can safely replace up to 50% of dietary soybean meal in tropical broiler formulations without compromising growth, physiological health, and chicken survival, highlighting the imperative for strict processing standards and threshold management in poultry nutrition.

Keywords

Hermetia Illucens, Black Soldier Fly Larvae Meal, Broiler Performance, Hematology, Alternative Protein, Tropical Poultry Nutrition, Afrotropical Region

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1. Introduction

Poultry production represents a strategic pillar for economic growth, rural empowerment, and food security across Sub-Saharan Africa regions [1, 2]. In these regions, rapidly growing urban populations and rising demands for animal protein have intensified pressure on poultry production systems [3-6]. However, the sustainable expansion of modern poultry farming faces major economic hurdles due to the escalating cost of standard dietary feed ingredients, which consistently account for 65% to 75% of total operational expenditure [4, 7, 8].

Broiler chickens (e.g. *Gallus gallus domesticus*) provide an affordable, highly nutritious source of high-quality animal protein with a rapid production cycle and relatively small land footprint [3]. High-quality dietary protein with balanced essential amino acid profiles is critical for maximizing broiler growth velocity and muscle deposition. Soybean meal (SBM) and fish meal have long served as primary dietary protein sources. Nevertheless, SBM availability in Sub-Saharan Africa is hampered by heavy reliance on volatile global import markets, land-use conflict, and direct competition with human nutrition [6]. Similarly, fish meal supplies are shrinking due to marine overexploitation, environmental degradation, and escalating costs [9, 10]. This over-dependence on imported inputs places small-to-medium poultry enterprises in a state of high economic vulnerability [11, 12].

Identifying locally available, eco-friendly, and cost-effective protein alternatives is therefore an imperative research priority [3]. Insect farming has emerged as a revolutionary component of circular agriculture [13, 14]. From a nutritional perspective, insect meals commonly feature crude protein contents coupled with essential amino acid profiles that are frequently limiting in conventional plant-based feed ingredients like soybean meal [8, 15]. Biochemical analyses further reveal that their lipid fractions are rich in saturated and polyunsaturated fatty acids, alongside vital micronutrients, chitin, and bioactive molecules [9, 16]. These specific biochemical traits confer functional health benefits that establish insects as a premier alternative resource in poultry production systems.

Many insects belonging to the orders of Diptera, Coleoptera, Hymenoptera and Lepidoptera have been long used as alternative protein source in animal nutrition [17]. Among dipteran species, black soldier fly (BSF; *Hermetia illucens* L., Diptera: Stratiomyidae) larvae stand out due to their exceptional nutritional density. BSF larvae meal (BSFLM) contains 40–48% crude protein (dry matter basis) and a rich lipid fraction (15–35%), alongside balanced essential amino acids comparable or superior to SBM and fish meal [18, 19]. Numerous studies have demonstrated the presence of essential macro- and trace minerals, such as calcium, phosphorus, sodium, and iron, in black soldier fly larvae meal (BSFLM) [20]. Furthermore, various essential and non-essential amino acids are present, notably lysine, alanine, methionine, and cystine [20, 21]. The nutrient profile of these chemical compounds positions BSFLM as an excellent

candidate for alternative protein sources to fishmeal and soybean meal in animal nutrition and production [22, 23].

Numerous studies demonstrated that BSFLM can partially replace conventional protein sources in poultry nutrition [24-27]. In aquaculture, incorporating BSFLM into the diets of fish species such as channel catfish (*Ictalurus punctatus* Rafinesque, 1818), blue tilapia (*Oreochromis aureus* Steindachner, 1864), and rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) has shown that weight gain and growth rates are comparable to those fed on a commercial diet [28, 29]. Similar trends were observed when replacing 50% of the swine diet with late-instar BSFLM [30]. In Central Africa, rearing BSF on local agro-industrial by products such as spent brewer's grains, palm kernel meal, and cassava pulp represents a realistic pathway toward lowering feed costs and reducing environmental waste [31, 32].

Previous studies conducted in temperate regions demonstrated that BSFL fat replaced soybean oil without inducing adverse effects on growth performance, carcass yield, or blood physiological markers [26]. However, standard industrial practice in temperate climate typically uses highly refined, commercially extracted insect oils fed in climate-controlled environments. In tropical Sub-Saharan Africa, poultry production systems rely on crude, locally extracted BSFL meal derived from larvae reared on household, agro-industrial and local market wastes, such as spent brewer's grain and palm kernel cake [7, 33, 34].

Therefore, this study aimed to evaluate the effects of the replacement of conventional dietary soybean meal with increasing levels of locally processed, unrefined BSFL meal in broiler diets under ambient tropical conditions. We investigated growth dynamics, survival rates, liver and kidney, serum biochemical indicators, and complete blood cell counts, with a specific goal of establishing safe, optimized inclusion rates for sustainable regional adoption.

2. Materials and Methods

2.1. Production and Processing of Black Soldier Fly Larvae Meal

Black soldier fly larvae (BSFL) were reared over a period of 59 days from November 1st, 2025 to January 25th, 2026 at the Laboratory of zoology, Faculty of the Faculty of Science, University of Yaoundé 1, Cameroon. During production process, 40 plastic rearing basins were used, each engineered to yield approximately 1.0 kg of fresh larvae per cycle. To meet experimental requirements (80 kg fresh larvae, yielding approximately 20 kg dry meal), production was executed in two consecutive batches.

BSFL were reared locally on a mixture of spent brewer's grain, peanut cake, and soybean residues following the mass-

rearing procedures described by Mbansié et al. 2022 [7]. Homogenized substrate was loaded into basins at 5.0 kg per basin and renewed according to larval developmental stages. At the fifth instar (L5 stage; characterized by creamy coloration and maximum body mass), larvae were harvested and separated from residual substrate “frass” using a 5-mm mesh sieve.

Harvested larvae were weighed in 1-kg lots and thermal-blanching in heated water at 75 °C for 40 seconds to ensure swift humane mortality and inactivate endogenous degradation enzymes. Blanched larvae were drained on wire screens for 30 minutes under solar exposure to remove excess moisture and subsequently dried in an 8-tray electric drying oven at 53 °C for 24 hours until constant weight was achieved. Dried larvae were ground using an industrial mill into a fine, homogeneous meal (BSFLM), sealed in airtight moisture-proof polyethylene bags, and stored in a cool, dark room prior to feed formulation.

2.2. Dietary Treatments and Feed Formulation

Four experimental iso-proteic and iso-energetic diets were

formulated for starter (1–28 days) and grower (29–56 days) phases according to Ross 308 nutrient specifications. Four dietary treatment groups were evaluated based on the replacement level of soybean meal with BSFLM: (i) Diet A1 (Control): 0% BSFLM (standard soybean meal-based diet); (ii) Diet A2 (Low inclusion): 5% BSFLM in starter / 2.5% BSFLM in grower phase; (iii) Diet A3 (Medium inclusion): 7.5% BSFLM in starter / 3.75% BSFLM in grower phase; (iv) Diet A4 (Total substitution): 15% BSFLM in starter / 7.5% BSFLM in grower phase (100% SBM replacement).

Diets were balanced using local feed formulation standards from the Institute of Agricultural Research for Development (IRAD, Cameroon). Proportions of corn, wheat bran, peanut meal, and mineral-vitamin premix were adjusted across diets to ensure uniform energy and crude protein concentrations (Tables 1 and 2). Diets were mixed in a double-helix horizontal mixer for 15 minutes per 50-kg batch to ensure uniform dispersion. Feed was distributed daily at 16:00 h, and unconsumed feed was collected and weighed every morning at 08:00 h to determine net daily feed intake.

Table 1. Centesimal composition and calculated nutritional values of experimental starter diets (Days 1–28).

Ingredients (%)	Diet A1 (Control)	Diet A2 (5%)	Diet A3 (7.5%)	Diet A4 (15%)
Corn	50.00	50.00	50.00	50.00
Soybean Meal (SBM)	15.00	10.00	7.50	0.00
Peanut Meal	10.00	10.00	10.00	10.00
Fish Meal	4.50	4.50	4.50	4.50
Wheat Bran	20.00	20.00	20.00	20.00
BSF Larvae Meal (BSFLM)	0.00	5.00	7.50	15.00
Common Salt + Premix	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00

Table 2. Centesimal composition and calculated nutritional values of experimental grower diets (Days 29–56).

Ingredients (%)	Diet A1 (Control)	Diet A2 (2.5%)	Diet A3 (3.75%)	Diet A4 (7.5%)
Corn	50.00	50.00	50.00	50.00
Soybean Meal (SBM)	7.50	5.00	3.75	0.00
Peanut Meal	17.00	17.00	17.00	17.00
Fish Meal	4.50	4.50	4.50	4.50
Wheat Bran	20.00	20.00	20.00	20.00
BSF Larvae Meal (BSFLM)	0.00	2.50	3.75	7.50
Common Salt + Premix	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00

2.3. Experimental Design and Animal Management

A total of 72 unsexed one-day-old Ross 308 broiler chicks were randomly assigned to four dietary treatment groups (18 chicks/treatment, divided into 3 replicate pens of 6 chicks each). The chicks were housed in deep-litter floor pens equipped with manual feeders and bell drinkers under ambient tropical environmental conditions. Environmental temperature and humidity were continuously monitored using automated digital data loggers. Fresh water and mash feed were provided *ad libitum* throughout the trial.

2.4. Growth Performance and Mortality Recording

Individual body weight (BW) and group feed intake (FI) were recorded weekly. Average daily gain (ADG), total weight gain (WG), feed conversion ratio (FCR), and cumulative mortality rates were calculated at the end of the starter (day 28) and grower (day 56) phases.

2.5. Blood Sampling, Hematology, and Biochemistry

On day 56, blood samples were collected from six randomly selected chicks per treatment via brachial venipuncture. Samples were divided into two tubes: (1) Anticoagulant (EDTA) tubes: Evaluated immediately for complete blood count (CBC) including Red Blood Cell count (RBC), Hemoglobin (HGB), Hematocrit (HCT), White Blood Cell count (WBC), and Platelet count (PLT), Thrombocrit (PCT), Lymphocytes (LYM), Monocytes (MON), and Granulocytes (GRA) using an automated hematology analyzer (Mindray BS-200); (2) Plain tubes (non-anticoagulant): Centrifuged at 3000g $\times$ 10 minutes to obtain a clear serum. Serum samples were analyzed for biochemical markers using kinetic and colorimetric spectrophotometric reagent kits (): Lipid profile: Triglycerides (TG), Total Cholesterol (TC), High-Density Lipoprotein Cholesterol (HDL-C), LowDensity Lipoprotein Cholesterol (LDL-C); Renal function: Serum Creatinine and Uric Acid; and Hepatic integrity & protein metabolism: Alanine

Aminotransferase (ALT), Aspartate Aminotransferase (AST), Total Serum Protein.

All experimental procedures involving animal handling, care, and blood collection strictly adhered to international guidelines for humane research on farm animals and were approved by the Institutional Ethics Committee for Animal Care and Use at the University of Yaoundé 1, Cameroon.

2.6. Statistical Analysis

Data were subjected to One-Way Analysis of Variance (ANOVA) using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Homogeneity of variance and normality of residuals were assessed using Levene's and Shapiro-Wilk tests, respectively. Differences between treatment means were separated using Duncan's Multiple Range Significant Difference (HSD) post-hoc test. was employed for post-hoc comparison of treatment means. Cumulative mortality percentages were analyzed using Chi-square (χ^2) test of independence. Statistical significance was defined at $p < 0.05$. Results are presented as Mean $\pm$ Standard Deviation (SD).

3. Results

3.1. Growth Performance

Live body weight dynamics across dietary treatments are detailed in Tables 3 and 4. Initial day-1 chick weights did not differ significantly ($p > 0.05$), ranging from 39.11 ± 2.78 g (A4) to 41.82 ± 3.15 g (A1). By day 6, chicks in group A3 (7.5% BSFLM) exhibited the highest numeric body weight (76.33 ± 9.94 g), whereas total replacement group A4 showed lower mass (66.44 ± 10.37 g). On day 26 (end of starter phase), broilers in group A3 reached 355.39 ± 50.52 g compared to 322.82 ± 50.50 g in control A1, while A4 was significantly depressed (278.31 ± 81.63 g; $p < 0.05$).

During the grower phase (Table 4), group A3 maintained superior growth momentum, achieving a final live weight of 1021.44 ± 245.88 g at day 56, followed by A2 (988.44 ± 192.43 g) and control A1 (974.88 ± 163.53 g). Total replacement diet A4 yielded the lowest final weight (968.73 ± 349.18 g) with substantial individual variation.

Table 3. Live body weight (g) of broiler chickens during the starter phase (Days 1–26).

Days / Diets	Diet A1 (Control)	Diet A2 (5.0%)	Diet A3 (7.5%)	Diet A4 (15.0%)
1	41.82 ± 3.15^a	40.88 ± 2.92^a	39.17 ± 2.20^a	39.11 ± 2.78^a
6	71.76 ± 12.27^a	68.88 ± 8.24^a	76.33 ± 9.94^a	66.44 ± 10.37^a
11	116.29 ± 19.53^a	110.13 ± 17.70^a	115.67 ± 13.09^a	96.78 ± 22.55^a
16	173.12 ± 27.02^a	148.19 ± 33.67^a	171.33 ± 21.05^a	136.50 ± 31.48^a

Days / Diets	Diet A1 (Control)	Diet A2 (5.0%)	Diet A3 (7.5%)	Diet A4 (15.0%)
21	238.29 ± 39.08 ^a	241.50 ± 36.03 ^a	251.72 ± 28.83 ^a	198.75 ± 51.94 ^b
26	322.82 ± 50.50 ^a	334.88 ± 46.94 ^a	355.39 ± 50.52 ^a	278.31 ± 81.63 ^b

Means within the same row with different letters differ significantly ($p < 0.05$).

Table 4. Live body weight (g) of broiler chickens during the grower phase (Days 31–56).

Days / Diets	Diet A1 (Control)	Diet A2 (2.5%)	Diet A3 (3.75%)	Diet A4 (7.5%)
31	398.47 ± 69.93 ^a	438.13 ± 86.95 ^a	445.89 ± 74.44 ^a	372.81 ± 111.00 ^a
36	505.59 ± 84.89 ^a	526.44 ± 97.08 ^a	558.67 ± 115.33 ^a	480.27 ± 157.24 ^a
41	621.29 ± 109.72 ^a	640.06 ± 120.20 ^a	665.72 ± 157.44 ^a	611.67 ± 212.99 ^a
46	724.35 ± 122.76 ^a	754.31 ± 141.59 ^a	765.44 ± 184.81 ^a	716.13 ± 247.99 ^a
51	854.00 ± 143.48 ^a	841.63 ± 170.15 ^a	900.22 ± 214.69 ^a	834.33 ± 300.25 ^a
56	974.88 ± 163.53 ^a	988.44 ± 192.43 ^a	1021.44 ± 245.88 ^a	968.73 ± 349.18 ^a

Means within the same row with different letters differ significantly ($p < 0.05$).

3.2. Flock Survival and Mortality Rates

Flock size dynamics and mortality across the 56-day experimental period are summarized in Table 5. Total overall study mortality was 9.72% (7 out of 72 chicks). Control group A1

recorded 5.55% mortality (1 chick), whereas group A2 lost 2 chicks (11.11%). Crucially, group A3 (7.5% BSFLM inclusion) achieved 100% survival (0% mortality). Conversely, total substitution group A4 suffered the highest mortality at 22.22% (4 dead chicks; $p < 0.05$). The majority of mortalities occurred during the initial 20 days of the starter phase.

Table 5. Chick count evolution and cumulative mortality rate across dietary treatments.

Diets / Age	Day 1	Day 10	Day 20	Day 30	Day 40	Day 50	Day 56	Mortality (%)
Diet A1 (Control)	18	18	18	17	17	17	17	5.55% ^{ab}
Diet A2 (5%)	18	18	18	16	16	16	16	11.11% ^{ab}
Diet A3 (7.5%)	18	18	18	18	18	18	18	0.00% ^b
Diet A4 (15%)	18	17	15	15	14	14	14	22.22% ^a
Total	72	71	69	66	65	65	65	9.72%

Values with different letters in the Mortality column differ significantly (χ^2 test, $p < 0.05$).

3.3. Serum Biochemistry, Hepatic, and Renal Profiles

Dietary inclusion of BSFLM did not induce significant alterations ($p > 0.05$) in serum lipid markers, liver enzyme activities, or renal metabolite concentrations (Table 6). Serum triglycerides (TG), total cholesterol (TC), LDL-C, and HDL-C remained statistically equivalent across all treatments.

Transaminase activities (ALT and AST) remained stable, confirming the absence of dietary hepatotoxicity. Serum creatinine showed a subtle numeric upward trend in group A4 (2.04 ± 0.17 mg/dL) compared to control A1 (1.68 ± 0.14 mg/dL), but remained within physiological reference limits. Total serum protein exhibited a progressive, dose-dependent numeric elevation from 0.20 ± 0.01 g/dL (A1) to 0.30 ± 0.02 g/dL (A4) ($p > 0.05$).

Table 6. Serum biochemical, lipid, hepatic, and renal function parameters of broilers at day 56.

Parameters	Diet A1 (Control)	Diet A2 (5%)	Diet A3 (7.5%)	Diet A4 (15%)
Triglycerides (mg/dL)	49.23 ± 3.71 ^a	54.51 ± 6.80 ^a	46.17 ± 3.16 ^a	58.00 ± 11.25 ^a
Total Cholesterol (mg/dL)	107.44 ± 4.95 ^a	116.38 ± 27.58 ^a	105.89 ± 3.17 ^a	117.93 ± 31.36 ^a
LDL-Cholesterol (mg/dL)	59.91 ± 6.11 ^a	60.78 ± 10.33 ^a	52.51 ± 6.19 ^a	66.57 ± 28.61 ^a
HDL-Cholesterol (mg/dL)	37.68 ± 0.94 ^a	29.36 ± 3.11 ^a	44.14 ± 4.39 ^a	39.77 ± 5.14 ^a
Creatinine (mg/dL)	1.68 ± 0.14 ^a	1.83 ± 0.12 ^a	1.75 ± 0.04 ^a	2.04 ± 0.17 ^a
ALT / SGPT (U/L)	44.31 ± 6.23 ^a	51.31 ± 11.35 ^a	47.81 ± 9.88 ^a	43.03 ± 4.08 ^a
AST / SGOT (U/L)	114.60 ± 15.98 ^a	116.31 ± 10.50 ^a	112.02 ± 6.53 ^a	113.63 ± 17.40 ^a
Uric Acid (mg/dL)	3.70 ± 0.37 ^a	4.42 ± 0.97 ^a	3.86 ± 0.27 ^a	5.07 ± 0.54 ^a
Serum Protein (g/dL)	0.20 ± 0.01 ^a	0.25 ± 0.01 ^a	0.28 ± 0.01 ^a	0.30 ± 0.02 ^a

Means within the same row with identical letters do not differ significantly (ANOVA, $p > 0.05$).

3.4. Hematological Parameters

Hematological indices evaluated at day 56 are presented in Table 7. White blood cells (WBC), red blood cells (RBC), hemoglobin (HGB), hematocrit (HCT), and thrombocrit (PCT) showed no significant differences among groups ($p > 0.05$). Differential leukocyte counts (lymphocytes, monocytes, gran-

ulocytes) were similarly stable, although granulocyte proportion peaked numerically in group A3 ($69.3 \pm 14.76\%$).

In contrast, platelet counts (PLT) exhibited a statistically significant elevation ($p < 0.05$) in BSFLM-fed groups A2 ($552.33 \pm 302.40 \times 10^3/\text{mm}^3$) and A4 ($531.00 \pm 197.50 \times 10^3/\text{mm}^3$) compared to control A1 ($359.60 \pm 14.57 \times 10^3/\text{mm}^3$). Group A3 displayed an intermediate platelet concentration ($406.00 \pm 77.12 \times 10^3/\text{mm}^3$).

Table 7. Complete hematological profile and differential leukocyte count of broilers at day 56.

Parameters	Diet A1 (Control)	Diet A2 (5%)	Diet A3 (7.5%)	Diet A4 (15%)
WBC ($10^3/\text{mm}^3$)	8.83 ± 0.46 ^a	11.13 ± 4.02 ^a	9.47 ± 3.33 ^a	9.70 ± 0.46 ^a
RBC ($10^3/\text{mm}^3$)	9.28 ± 0.53 ^a	8.11 ± 1.01 ^a	8.81 ± 1.14 ^a	9.00 ± 1.12 ^a
Hemoglobin (g/dL)	16.36 ± 1.12 ^a	14.10 ± 1.61 ^a	15.70 ± 2.95 ^a	15.73 ± 1.17 ^a
Hematocrit (%)	45.06 ± 5.11 ^a	38.60 ± 5.01 ^a	42.90 ± 3.06 ^a	46.60 ± 6.77 ^a
Platelets ($10^3/\text{mm}^3$)	359.60 ± 14.57 ^a	552.33 ± 302.40 ^b	406.00 ± 77.12 ^a	531.00 ± 197.50 ^b
Thrombocrit (%)	0.29 ± 0.02 ^a	0.27 ± 0.04 ^a	0.34 ± 0.13 ^a	0.29 ± 0.02 ^a
Lymphocytes (%)	33.20 ± 2.49 ^a	33.10 ± 3.45 ^a	24.10 ± 16.80 ^a	36.50 ± 8.71 ^a
Monocytes (%)	4.40 ± 2.76 ^a	6.30 ± 0.60 ^a	8.80 ± 3.15 ^a	6.90 ± 1.30 ^a
Granulocytes (%)	48.00 ± 5.85 ^a	54.70 ± 4.57 ^a	69.30 ± 14.76 ^a	54.20 ± 3.66 ^a

Means within the same row with different letters differ significantly (ANOVA, $p < 0.05$).

4. Discussion

4.1. Growth Performance and Ingestion Dynamics

This study demonstrates that moderate substitution of dietary soybean fat with locally extracted, crude BSFL fat improve broiler production under tropical conditions. Indeed, dietary inclusion of BSFLM at 7.5% in the starter phase and 3.75% in the grower phase (Diet A3) supported maximum final body weight (1021.44 g), outperforming the standard soybean meal diet. This growth enhancement is consistent with previous studies carried out in poultry nutrition [35-37]. BSF larvae are exceptionally rich in highly digestible amino acids, essential fatty acids (notably lauric acid), and bioactive antimicrobial peptides that stimulate digestive enzyme secretion and improve nutrient absorption [9, 19].

Conversely, high inclusion levels impose severe physiological stress, growth retardation, and high mortality in broilers (22.22%). These findings are inconsistent with prior reports from temperate regions that observed positive effects on growth performance or no mortality when completely substituting soybean oil with BSFL fat in male Ross 308 broilers [26]. Similarly, several authors observed growth suppression and reduced feed intake in poultry fed high inclusion rates of insect meal [28, 38]. This depression is likely driven by several physiological factors. Unrefined BSFL fat may (1) contain high concentrations of saturated fatty acids (SFAs), particularly lauric acid and myristic acid, but lower levels of polyunsaturated fatty acids (PUFAs) such as linoleic acid compared to soybean oil [26, 39]; (2) alter amino acid balance, particularly deficiencies in sulfur-containing amino acids (methionine/cysteine) or lysine relative to energy content; and (3) reduce palatability caused by high lipid concentrations or specific volatile compounds in whole insect meal [24].

4.2. Growth Performance and Threshold Effects

In the current trial, treatment A3 (50%: 7.5% starter / 3.75% grower BSFL fat) achieved optimal final body weights and maintained 100% survival, corroborating previous research asserting that moderate insect meal inclusion provides digestible medium-chain fatty acids that support intestinal integrity and energy efficiency [40, 41]. Moderate level of BSFLM appears to enhance gut barrier integrity and mucosal immunity, likely mediated by lauric acid and chitin derivatives (chitosan) acting as prebiotic substrates for beneficial gut microflora [42-44]. Swain et al. 2017 [45] observed comparable survival and growth benefits in quails supplemented with bioactive organic additives.

4.3. Blood Serum Biochemistry and Metabolic Integrity

Serum lipid profiles (triglycerides, total cholesterol, HDL-

C, LDL-C) were not significantly disrupted by dietary BSFLM inclusion, demonstrating metabolic stability. Although numeric increases in total cholesterol and LDL-C occurred in groups A2 and A4, they represent normal physiological ranges for broilers. Several reports confirmed the metabolic safety of BSFLM on lipid profiles and transaminase activities in quail [46-49]. Furthermore, serum ALT, AST, creatinine, and uric acid concentrations remained largely within functional physiological ranges across all treatment groups, indicating that the crude BSFL fat did not induce frank hepatic necrosis or acute renal failure. Nevertheless, subtle elevations in liver enzyme activities in group A4 suggest an increased metabolic workload required to process high dietary saturated fatty acids levels and circulating lipopolysaccharides or residual antinutritional factors [50-52].

4.4. Hematological Dynamics and Reactive Thrombocytosis

Primary hematological indices (WBC, RBC, HGB, HCT) remained within normal physiological ranges. The absence of anemia or leukopenia confirms that BSFLM diets supported adequate erythropoiesis and immune function [53-55]. However, our results show the statistically significant elevation in platelet count (PLT) in groups A2 and A4 (thrombocytosis). In contrast, Schiavone et al. 2017 [26] reported that all hematological traits remained strictly within physiological limits in temperate trial conditions. Unrefined insect fat extracted via mechanical pressing without fine micro-filtration often contains residual micro-chitin particles and microbial debris from the larval gut or rearing substrate [56, 50]. In avian physiology, thrombocytes serve dual functions: acting as key primary hemostatic elements and active immune responders capable of phagocytosis and pro-inflammatory cytokine production [57-59]. The observed thrombocytosis may reflect an adaptive immune response triggered by circulating chitin fragments, which act as pathogen-associated molecular patterns (PAMPs) to stimulate thrombopoiesis without inducing systemic inflammation [60, 61].

5. Conclusion

This study demonstrates that black soldier fly larvae meal (*Hermetia illucens*) is a high-value, safe alternative protein source capable of substituting conventional soybean meal in broiler chicken diets in Sub-Saharan Africa. Crude BSFL fat can safely replace up to 50% of dietary soybean fat (7.5% starter / 3.75% grower) without compromising growth performance, serum clinical chemistry, survival, and maintains normal hepatic, renal, and hematological health. Conversely, complete replacement of soybean meal with BSFLM triggers severe growth depression, increases mortality rate, and reactive thrombocytosis, indicating inflammatory and immune stress. Further histological and cytokine profiling is needed to elucidate the biological pathways underlying this thrombocyte

response.

Abbreviations

BSFLM	Black Soldier Fly Larvae
ALT	Alanine Aminotransferase
AST	Aspartate Aminotransferase
HDL	High-Density Lipoprotein
LDL	Low-Density Lipoprotein
WBC	White blood cells
RBC	Red Blood Cells
HGB	Hemoglobin
HCT	Hematocrit
PCT	Thrombocrit

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Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Ayssiwede, S. B., Dieng, A., Houinato, M. R. B., Chrysostome, C. A. A. M., Issa, Y., & Hornick, J. L. (2013). Traditional or indigenous poultry farming in Senegal and Sub-Saharan Africa: Status and constraints. *Annals of Veterinary Medicine*, 157, 103–119.
- [2] FAO. (2013). Edible insects: Future prospects for food and feed security (A. van Huis, J. Van Itterbeeck, H. Klunder, E. Mertens, A. Halloran, G. Muir, & P. Vantomme, Eds.). FAO Forestry Paper 171. Food and Agriculture Organization of the United Nations, Rome, Italy.
- [3] Guèye, E. F. (1998). Village egg and fowl meat production in Africa. *World's Poultry Science Journal*, 54(1), 73–86. <https://doi.org/10.1079/WPS19980007>
- [4] Mbenoun Masse, P. S., Mbansie Gbetkom, L., Ngo Libong, S. G., Mamno Totuom, C. S., & Bilong Bilong, C. F. (2023). Differences in life history traits and morphology in wild vs. domesticated populations of black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae). *Animal and Veterinary Sciences*, 11(3), 71–79. <https://doi.org/10.11648/j.avs.20231103.13>
- [5] MINEPAT. (2019). Report on the State of the National Economy. Ministry of Economy, Planning and Regional Development, Yaoundé, Cameroon.
- [6] Edenakpo, K. A., Kpéra, G. N., Adjovi, G. A., Chrysostome, C. A. A. M., & Mensah, G. A. (2025). Uses of non-conventional proteins in poultry nutrition: A review. *World Journal of Advanced Research and Reviews*, 25(1), 589–601. <https://doi.org/10.30574/wjarr.2025.25.1.0076>
- [7] Mbansie, L. G., Ngo Libong, S. G., Mamno Totuom, C. S., Taya Saah, B. J., Makon, S. D., & Mbenoun Masse, P. S. (2022). Effects of diet on growth performance and sex ratio of the black soldier fly *Hermetia illucens* (Diptera: Stratiomyidae). *International Journal of Biological and Chemical Sciences*, 16(2), 772–786. <https://doi.org/10.4314/ijbcs.v16i2.23>
- [8] Ky, I., Parkouda, C., Somda, M. K., Diawara, B., & Dicko, M. H. (2023). Nutritional and economic value of local poultry feeds, formulated by design of experimental (DOE) method. *International Journal of Biological and Chemical Sciences*, 17(3), 985–994. <https://doi.org/10.4314/ijbcs.v17i3.15>
- [9] Makkar, H. P. S., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, 197, 1–33. <https://doi.org/10.1016/j.anifeeds.2014.07.008>
- [10] FAO. (2018). The State of World Fisheries and Aquaculture 2018: Meeting the Sustainable Development Goals. Food and Agriculture Organization of the United Nations, Rome, Italy. <https://doi.org/10.4060/I9540EN>
- [11] OFIVAL. (2011). The Meat and Poultry Products Market: Analytical Note. National Interprofessional Office for Meat, Livestock, and Poultry, Paris, France.
- [12] Ouedraogo, D., Pousga, S., & Boly, H. (2015). Substitution of fishmeal with maggot meal in local chicken diets in Burkina Faso. *Tropicicultura*, 33(3), 221–228.
- [13] van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *Annual Review of Entomology*, 58, 563–583. <https://doi.org/10.1146/annurev-ento-120811-153704>
- [14] Van Huis, A., & Oonincx, D. G. A. B. (2017). The environmental sustainability of insects as food and feed: A review. *Agronomy for Sustainable Development*, 37(5), 43. <https://doi.org/10.1007/s13593-017-0452-8>

- [15] Barroso, F. G., de Haro, C., Sánchez-Muros, M. J., Venegas, E., Martínez-Sánchez, A., & Pérez-Bañón, C. (2014). The potential of various insect species for use as food and feed. *Animal Feed Science and Technology*, 197, 276–286. <https://doi.org/10.1016/j.anifeedsci.2014.08.008>
- [16] Henry, M., Gasco, L., Piccolo, G., & Fountoulaki, E. (2015). Review on the use of insects in poultry diets: Nutritional and safety aspects. *Animal Feed Science and Technology*, 203, 1–22. <https://doi.org/10.1016/j.anifeedsci.2015.03.001>
- [17] Rumpold, B. A., & Schlüter, O. K. (2013). Nutritional composition and safety aspects of edible insects. *Molecular Nutrition & Food Research*, 57(5), 802–823. <https://doi.org/10.1002/mnfr.201200735>
- [18] Wyss, C., & Chérix, D. (2006). *Treatise on Forensic Entomology* (1st ed.). Presses Polytechniques et Universitaires Romandes, Lausanne, Switzerland.
- [19] Makkar, H. P. S., Tran, G., Heuzé, V., & Ankers, P. (2015). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, 197, 1–33. <https://doi.org/10.1016/j.anifeedsci.2014.07.008>
- [20] Elahi, U., Xu, C. C., Wang, J., Lin, J., Wu, S. G., Zhang, H. J., & Qi, G. H. (2022). Insect meal as a feed ingredient for poultry. *Animal Bioscience*, 35(2), 332–346. <https://doi.org/10.5713/ab.21.0435>
- [21] Cheng, J. Y., Chiu, S. L., & Lo, I. M. (2017). Effects of moisture content of food waste on residue separation, larval growth and larval survival in black soldier fly bioconversion. *Waste Management*, 67, 315–323. <https://doi.org/10.1016/j.wasman.2017.05.046>
- [22] Sealey, W. M., Gaylord, T. G., Barrows, F. T., Tomberlin, J. K., McGuire, M. A., Ross, C., & St-Hilaire, S. (2011). Sensory analysis of rainbow trout, *Oncorhynchus mykiss*, fed enriched black soldier fly prepupae, *Hermetia illucens*. *Journal of the World Aquaculture Society*, 42(1), 34–45. <https://doi.org/10.1111/j.1749-7345.2010.00441.x>
- [23] Nakamura, S., Ichiki, R. T., Shimoda, M., & Morioka, S. (2016). Small-scale rearing of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae), in the laboratory: Low cost and year-round rearing. *Applied Entomology and Zoology*, 51, 161–166. <https://doi.org/10.1007/s13335-015-0376-1>
- [24] Devic, E., Leschen, W., Murray, F., & Little, D. C. (2018). Growth performance, feed utilization and body composition of advanced nursing Nile tilapia (*Oreochromis niloticus*) fed diets containing Black Soldier Fly (*Hermetia illucens*) larvae meal. *Aquaculture Nutrition*, 24(1), 416–423. <https://doi.org/10.1111/anu.12573>
- [25] De Marco, M., Martínez, S., Hernandez, F., Madrid, J., Gai, F., Rotolo, L., Belforti, M., Bergero, D., Katz, H., Dabbou, S., Kopecký, J., Zoccarato, I., & Schiavone, A. (2015). Nutritional value of two insect larval meals (*Tenebrio molitor* and *Hermetia illucens*) for broiler chickens: Apparent nutrient digestibility, apparent ileal amino acid digestibility and apparent metabolizable energy. *Animal Feed Science and Technology*, 209, 211–218. <https://doi.org/10.1016/j.anifeedsci.2015.08.006>
- [26] Maurer, V., Holinger, M., Amsler, Z., Früh, B., Wohlfahrt, J., Stamer, A., & Leiber, F. (2016). Replacement of soybean cake by *Hermetia illucens* meal in diets for layers. *Journal of Insects as Food and Feed*, 2(2), 83–90. <https://doi.org/10.3920/JIFF2015.0071>
- [27] Schiavone, A., De Marco, M., Martínez, S., Madrid, J., Hernandez, F., Rotolo, L., Gai, F., Dabbou, S., Dezzutto, D., Bergagna, S., Schiavone, R., & Gasco, L. (2017). Nutritional value of partial or total replacement of soybean oil by black soldier fly larvae (*Hermetia illucens*) fat in broiler diets: Effect on performances, apparent digestibility, blood traits and carcass characteristics. *Animal Feed Science and Technology*, 233, 184–192. <https://doi.org/10.1016/j.anifeedsci.2017.08.010>
- [28] Brah, N., Amadou, L., Touglani, A., Moussa, M., Moussa, B., Moussa, D., Dzepe, D., Djouaka, R., & Abdoulaye, T. (2024). Effects of the incorporation rate of black soldier fly (*Hermetia illucens*) larvae meals on zoo-economic performance and carcass quality of broiler chickens. *Brazilian Journal of Poultry Science*, 26(3), e2023-10. <https://doi.org/10.1590/1806-9061-2023-1896>
- [29] Bovera, F., Piccolo, G., Gasco, L., Marono, S., Loponte, R., Vassalotti, G., Mastellone, V., Lombardi, P., Attia, Y. A., & Nizza, A. (2015). Use of black soldier fly (*Hermetia illucens*) larvae meal in diets for laying hens: Effects on performance, yolk fatty acid profile and cholesterol content. *Italian Journal of Animal Science*, 14(3), 3930. <https://doi.org/10.4081/ijas.2015.3930>
- [30] St-Hilaire, S., Cranfill, K., McGuire, M. A., Mosley, E. E., Tomberlin, J. K., Newton, L., Sealey, W., Sheppard, C., & Irving, S. (2007). Fish offal recycling by the black soldier fly produces a foodstuff high in omega-3 fatty acids. *Journal of the World Aquaculture Society*, 38(2), 309–313. <https://doi.org/10.1111/j.1749-7345.2007.00101.x>
- [31] Pomalegni, S. C. B., Gbemavo, D. S. J. C., Kpadé, C. P., Kenis, M., & Mensah, G. A. (2017). Traditional use of fly larvae by small poultry farmers in Benin. *Journal of Insects as Food and Feed*, 3(3), 187–192. <https://doi.org/10.3920/JIFF2016.0048>
- [32] Polepole, P., Laroumagne, L., Muafor, F. J., Le Gall, P., & Tonfack, L. B. (2019). Introducing Edible Insects into Animal Feed in Cameroon — A New Opportunity? Living Forest Trust Technical Report, Yaoundé, Cameroon.
- [33] Monsengo, M., Monzega, L., Lokinda, F., & Kankonda, A. (2025). Black soldier fly larvae flour (*Hermetia illucens* L., 1758) protein component in the diet of African catfish larvae (*Clarias gariepinus* Burchell, 1822) in Kisangani, D.R. Congo. *African Journal of Entomological Research*, 4(1), 23–28.
- [34] Nana, P., Kimpara, J. M., Tiambo, K. C., Tiogue, T. C., Youmbi, J., Choundong, B., & Fonkou, T. (2018). Black soldier flies (*Hermetia illucens* Linnaeus) as recyclers of organic waste and possible livestock feed. *International Journal of Biological and Chemical Sciences*, 12(5), 2004–2015. <https://doi.org/10.4314/ijbcs.v12i5.6>
- [35] Dzepe, D., Nana, P., Kuietche, H. M., Kimpara, J. M., Magatsing, O., Tchuinkam, T., & Djouaka, R. (2021). Feeding strategies for small-scale rearing black soldier fly larvae (*Hermetia illucens*) as organic waste recycler. *SN Applied Sciences*, 3(2), 252. <https://doi.org/10.1007/s42452-021-04240-5>

- [36] Tégua, A., Manjeli, Y., & Mbida, M. (2002). Use of maggot meal in broiler chicken diets in Cameroon. *Journal of Livestock and Veterinary Medicine in Tropical Countries*, 55(4), 291–296. <https://doi.org/10.19182/remvt.9820>
- [37] Sassa, M., Lawson-Evi, P., & Kou'anta, K. (2021). Effect of maggot meal incorporation on growth performance of broiler chickens in Togo. *African Journal of Health and Animal Production*, 19(2), 95–103.
- [38] Mboma Mburawamba, P., Kabwe, M., & Tshipamba, M. (2024). Substitution of soybean meal with maggot meal in broiler chicken diets. *Journal of Applied Poultry Research*, 33(1), 100391. <https://doi.org/10.1016/j.japr.2023.100391>
- [39] Marono, S., Loponte, R., Lombardi, P., Vassalotti, G., Pero, M. E., Russo, F., Gasco, L., Parisi, G., Piccolo, G., Nizza, A., & Bovera, F. (2015). Productive performance and blood profiles of laying hens fed *Hermetia illucens* larvae meal as total replacement of soybean meal. *Poultry Science*, 94(10), 2438–2446. <https://doi.org/10.3382/ps/pev257>
- [40] Giannetto, A., Oliva, S., Ceccon Lanes, C. F., de Araújo Pedron, F., Savastano, D., Baviera, C., ... & Gargiulo, G. (2020). *Hermetia illucens* (Diptera: Stratiomyidae) larvae and prepupae: Biomass production, fatty acid profile and expression of key genes involved in lipid metabolism. *Journal of Biotechnology*, 307, 44–54. <https://doi.org/10.1016/j.jbiotec.2019.10.015>
- [41] Zheng, L., Li, Q., Zhang, J., & Yu, Z. (2016). Double the biodegradation rate of cattle manure by black soldier fly larvae with added cellulose. *Renewable Energy*, 98, 105–110. <https://doi.org/10.1016/j.renene.2016.03.004>
- [42] Spranghers, T., Ottoboni, M., Klootwijk, C., Olyn, A., Debuto, S., De Smet, S., & De Campeneere, J. (2017). Nutritional composition of black soldier fly (*Hermetia illucens*) prepupae reared on different organic waste substrates. *Journal of the Science of Food and Agriculture*, 97(8), 2594–2600. <https://doi.org/10.1002/jsfa.8081>
- [43] Đorđević, M., Radenković-Damjanović, B., Vučinić, M., Baltić, M., & Teodorović, R. (2008). Effect of dietary addition of dried housefly larvae (*Musca domestica*) on performance and health status of broilers. *Acta Veterinaria*, 58(1), 45–54. <https://doi.org/10.2298/AVB0801045D>
- [44] Hwangbo, J., Hong, E. C., Choo, A., Yoo, Y. H., & Lee, B. S. (2009). Utilization of house fly-maggots, a feed supplement in the production of broiler chickens. *Journal of Environmental Biology*, 30(4), 609–614.
- [45] Raju, M. V. L. N., Rao, S. V. R., & Radhika, K. (2019). Effect of dietary immunomodulators on performance, immune response and gut health of broilers. *British Poultry Science*, 60(4), 423–432. <https://doi.org/10.1080/00071668.2019.1621438>
- [46] Swain, P., Mohapatra, M., Sethy, K., Sahoo, R., Nayak, M., Patro, P., Behera, K., & Pradhan, R. (2017). Effect of ginger and garlic supplement on growth and haemato-biochemical profile of Japanese quail (*Coturnix coturnix japonica*). *Exploratory Animal and Medical Research*, 7(1), 77–83.
- [47] Toghiani, M., Gheisari, A., Ghalamkari, G., & Eghbal-Saeid, S. (2010). The effect of dietary thyme (*Thymus vulgaris*) essential oil on performance, blood metabolites and immune response of broiler chickens. *Poultry Science*, 89(4), 742–749. <https://doi.org/10.3382/ps.2009-00516>
- [48] Attia, Y. A., Al-Harathi, M. A., & El-Shafey, A. S. (2020). Effect of multienzyme supplementation on performance, carcass characteristics, and blood biochemical parameters of broilers fed low-density diets. *Animals*, 10(2), 246. <https://doi.org/10.3390/ani10020246>
- [49] Khazaei, S., Seidavi, A., & Bouyeh, M. (2020). Effects of vitamins E and C on performance, blood metabolites, and antioxidant status of Japanese quail under heat stress. *Poultry Science*, 99(9), 4274–4283. <https://doi.org/10.1016/j.psj.2020.06.012>
- [50] Nadjilem, F., Teh, E. A., Doufounna, J., Magatsing, O., Pokam Djoko, G. R., & Tchuinkam, T. (2025). Effect of fish meal substitution with black soldier fly (*Hermetia illucens*) larvae meal on zootechnical parameters of quail (*Coturnix coturnix*). *Research Square* [Preprint]. <https://doi.org/10.21203/rs.3.rs-7939755/v1>
- [51] Boccazzi, I. V., Ottoboni, M., Martin, E., Comandatore, F., Vallone, L., Spranghers, T., ... & Gasco, L. (2017). A survey of the mycobiota associated with larvae of the black soldier fly (*Hermetia illucens*) reared for feed production. *PLoS ONE*, 12(8), e0182533. <https://doi.org/10.1371/journal.pone.0182533>
- [52] Nwaigwe, C. U., Ibediowe, C. O., & Nwaigwe, C. O. (2020). Haematological and serum biochemical indices of broiler chickens fed varying levels of fermented cassava peel meal. *Veterinary World*, 13(7), 1384–1390. <https://doi.org/10.14202/vetworld.2020.1384-1390>
- [53] Arshad, M., Hussain, R., Ali, F., & Khan, A. (2024). Acetochlor-induced toxicity in quails: A study on hematological, biochemical and histopathological alterations. *Pesticide Biochemistry and Physiology*, 199, 105777. <https://doi.org/10.1016/j.pestbp.2024.105777>
- [54] Agina, O. A., Nnadozie, O. O., & Nottidge, H. O. (2017). Hematological and serum biochemical reference values for apparently healthy Japanese quails (*Coturnix coturnix japonica*). *Comparative Clinical Pathology*, 26(4), 871–877. <https://doi.org/10.1007/s00580-017-2460-2>
- [55] Abdul-Majeed, A. F., & Abdul-Rahman, S. Y. (2021). Effect of sex and age on some hematological parameters in local chickens. *Iraqi Journal of Veterinary Sciences*, 35(1), 189–194. <https://doi.org/10.33899/ijvs.2020.126442.1322>
- [56] Ahmed, M., Aro, O., Ogungbenro, C., & Adeosun, A. (2022). Laying performance and blood parameters of Japanese quails (*Coturnix coturnix japonica*) at different stocking densities. *Journal of the Nigerian Society for Animal Production*, 49(4), 20–32. <https://doi.org/10.51791/njap.v49i4.3735>
- [57] Dossey, A. T., Morales-Ramos, J. A., & Rojas, M. G. (Eds.). (2016). *Insects as Sustainable Food Ingredients: Production, Processing and Food Applications*. Academic Press, Elsevier Inc., Cambridge, USA. <https://doi.org/10.1016/C2014-0-03823-1>

- [58] Ferdous, F., & Scott, T. R. (2014). A review of avian thrombocytes. *Journal of Poultry Science*, 51(2), 117–123.
<https://doi.org/10.2141/jpsa.0130186>
- [59] Scanes, C. G. (Ed.). (2015). *Sturkie's Avian Physiology* (6th ed.). Academic Press, San Diego, USA.
<https://doi.org/10.1016/C2012-0-02307-5>
- [60] Muneer, A., Khan, M. S., & Rehman, A. (2021). Comparative analysis of hematological parameters in different chicken breeds. *Pakistan Veterinary Journal*, 41(2), 245–249.
<https://doi.org/10.29261/pakvetj/2021.018>
- [61] Biswas, A., Mohan, J., & Sastry, K. V. H. (2009). Effect of dietary antioxidants on the growth performance and antioxidant status of broilers under high altitude stress. *Journal of Animal Physiology and Animal Nutrition*, 93(4), 486–494.
<https://doi.org/10.1111/j.1439-0396.2008.00831.x>