Research Article

Evaluation of Black Soldier Fly Larvae Meal on Growth and Hematology of Catfish (*Clarias batrachus*)

Rondius Solfaine[1]*, Olan Rahayu Puji Astuti Nussa[2] and Indra Rahmawati[2]

[1]Laboratory of Pathology, Faculty of Veterinary Medicine, Universitas Wijaya Kusuma Surabaya, Surabaya, 60225, Indonesia; [2]Laboratory of Histology, Faculty of Veterinary Medicine, Universitas Wijaya Kusuma Surabaya, Surabaya, 60225, Indonesia.

Abstract | The increasing demand for sustainable and cost-effective aquaculture feed has driven the search for alternative protein sources in aquaculture. Black soldier fly (*Hermetia illucens*) larvae (maggot) have gained considerable attention due to their high nutritional value and potential to enhance fish growth and health. This study aimed to evaluate the effects of maggot-based feed on hematological profile, body weight, and feed nutritional value in catfish (*Clarias batrachus*). Twenty catfish (2-3 months old, 20-25 cm) were randomly allocated into four groups: natural feed control (X0), dried maggot feed (X1), commercial pellet feed (X2), and maggot-based pellet feed (X3), and maintained under controlled aquaculture conditions for 15 days. Body weight was recorded on days 1 and 15; hematocrit, hemoglobin, and differential leukocyte counts were assessed at the end of the experiment. Proximate analysis of the maggot-based pellet was performed. Data were analyzed using one-way ANOVA with Tukey's HSD post-hoc test. The formulated maggot-based pellet supplemented with eggshell powder showed a favorable nutritional composition, with high crude protein and metabolizable energy. Dietary treatment significantly affected body weight gain ($p \leq 0.05$). Fish fed commercial pellets (X2) and maggot-based pellets (X3) gained significantly more weight than those fed natural feed (X0) or dried maggot alone (X1), with no difference between X2 and X3. Hemoglobin concentration was significantly affected by treatment ($p \leq 0.001$), highest in X3, followed by X2, X1, and X0, while hematocrit did not differ significantly ($p = 0.094$). Lymphocytes predominated the leukocyte profile (68.4-82.2%) in all groups, with no significant treatment effect on WBC count or leukocyte differential percentages ($p \geq 0.05$). Maggot-based feed, especially when supplemented with eggshell powder, is a promising alternative protein source comparable to commercial feed for improving growth and hematological performance in catfish without adverse effects on leukocyte profiles.

Received | June 08, 2026; **Accepted** | July 30, 2026; **Published** | August 26, 2026
***Correspondence** | Rondius Solfaine, Laboratory of Pathology, Faculty of Veterinary Medicine, Universitas Wijaya Kusuma Surabaya, Surabaya, 60225, Indonesia; **Email:** rondius@uwks.ac.id
Citation | Solfaine, R., O.R.P.A. Nussa and I. Rahmawati. 2026. Evaluation of black soldier fly larvae meal on growth and hematology of catfish (*Clarias batrachus*). *Advances in Agriculture and Animal Sciences,* 42(2): 63-72.
DOI | https://dx.doi.org/10.17582/journal.aaas/2026/42.2.63.72
Keywords | Black soldier fly larvae, Maggot-based feed, Catfish, Growth performance, Hematology, differential leukocyte count, Proximate analysis, Aquaculture nutrition

Introduction

Catfish (*Clarias batrachus*) is one of the most important freshwater aquaculture commodities in Indonesia and plays a significant role in fulfilling the increasing demand for animal protein. The species is widely cultivated because of its rapid growth, high tolerance to environmental fluctuations, disease resistance, and relatively simple farming practices (Ashqolani *et al*., 2023). Nevertheless, feed remains the largest operational cost in catfish production and is a critical factor affecting growth performance, feed efficiency, and overall fish health (Liu *et al*., 2024).

Commercial aquaculture feeds predominantly rely on fish meal as the primary protein source due to its high nutritional value and favorable amino acid profile. However, the increasing cost, limited availability, and environmental concerns associated with fish meal production have encouraged the search for alternative and sustainable protein sources (Su *et al*, 2025). In recent years, black soldier fly (*Hermetia illucens*) larvae meal has gained considerable attention as a promising substitute for fish meal in aquaculture diets. Black soldier fly larvae can be mass-produced using organic waste substrates, contributing to waste reduction and environmental sustainability while providing a nutrient-rich feed ingredient (Camperio *et al*., 2026).

Maggot meal contains substantial amounts of crude protein, essential amino acids, lipids, vitamins, and minerals that are beneficial for fish growth and development. Previous studies have reported crude protein contents ranging from 40% to 60%, making maggot meal a viable alternative protein source in aquaculture feed formulations (Sultana *et al*., 2026). Furthermore, fish meal replacement with maggot meal at high inclusion levels has been shown to maintain or improve growth performance and feed utilization efficiency while reducing feed costs (Yakti *et al*., 2024). The utilization of insect-based protein sources therefore represents an important strategy for achieving sustainable aquaculture production.

Besides growth performance, the physiological and health status of fish can be assessed through hematological examinations. Hematological parameters are widely recognized as sensitive indicators of nutritional adequacy, metabolic activity, immune competence, and environmental stress. Hematocrit (packed cell volume, PCV) and hemoglobin concentration are among the most commonly used indicators for evaluating oxygen-carrying capacity and overall physiological condition in fish (Belghit *et al*., 2019). Positive relationships between hematological values and growth performance have been reported, suggesting that improved nutrition can enhance both fish productivity and health status (Bakare *et al*., 2020).

In addition to hematocrit and hemoglobin, differential leukocyte counts provide valuable information regarding the immune status of fish. The proportions of lymphocytes, neutrophils, monocytes, eosinophils, and basophils can reflect immune responses, disease resistance, and physiological adaptation to dietary interventions (Tran *et al*., 2015). Previous studies have demonstrated that dietary supplementation with black soldier fly larvae meal may positively influence hematological and immune-related parameters, thereby supporting fish health and resilience (Xia *et al*., 2021).

The nutritional quality of experimental diets is another important factor influencing fish performance. Therefore, proximate analysis, including the determination of crude protein, crude fat, crude fiber, moisture, ash, and carbohydrate contents, is essential to evaluate the nutritional composition of maggot-based pellets and to ensure that observed biological responses are associated with dietary nutrient profiles (Esmaeili, 2021).

Although the potential of black soldier fly larvae meal as an alternative feed ingredient has been extensively investigated, studies evaluating its effects on growth performance, hematological parameters, differential leukocyte profiles, and nutritional composition of locally produced maggot-based feeds in *Clarias batrachus* remain limited. Therefore, this study aimed to evaluate the effects of maggot-based diets on body weight gain, hematocrit values, hemoglobin concentrations, differential leukocyte counts, and the nutritional composition of maggot-based pellets through proximate analysis in catfish (*Clarias batrachus*).

Materials and Methods

Experimental animals and feed materials

Twenty catfish (*Clarias batrachus*) were randomly assigned to four dietary treatment groups. Each treatment consisted of five fish maintained in a single

aquarium under identical environmental conditions. The aquarium served as the experimental unit in this preliminary study. This study used 20 local catfish (*Clarias batrachus*) aged 2-3 months with an averaged body length of approximately 20 cm and an initial body weight of 95.4 ± 8.7 g. The fish were obtained from a local aquaculture farm in Surabaya, Indonesia. Feed materials used in this study included vegetable-based feed, commercial catfish pellets, dried black soldier fly (*Hermetia illucens*) larvae (maggot), and maggot-based pellets. Materials included clean water, probiotic solution, Indian almond leaves (*Terminalia catappa*), banana leaves, and goat manure used for maggot cultivation.

Preparation of maggot-based pellets

The maggot-based pellets were formulated using dried black soldier fly larvae as the primary protein source (Tran *et al*., 2015). The formulation for 1 kg of feed consisted of 300 g dried maggot meal, 150 g soybean meal, 200 g rice bran, 100 g wheat flour, 80 g tapioca flour, 40 g eggshell powder, 30 g broth powder, 10 g salt, and 10 g vitamin–mineral premix, following a nutrient-balancing approach similar to that used in previous black soldier fly larvae meal–based aquafeed formulations (Jayanegara, 2022; Hwang *et al*., 2021). Approximately 250 mL of water was added to form a homogeneous dough. The ingredients were thoroughly mixed until uniform, molded into pellets, and dried under sunlight until reaching a stable moisture content. The resulting pellets were stored in room-temperature containers for applications.

Experimental design and fish management

The experiment was conducted using a Completely Randomized Design (CRD) consisting of four dietary treatments with five independent replicates per treatment (n= 5). Each replicate consisted of one fish maintained in an individual experimental container, with the container serving as the experimental unit. Individual rearing was intentionally adopted to eliminate the effects of social interaction, competition for feed, and hierarchical behavior, thereby allowing the dietary treatment to be evaluated without interference from stocking density or dominance effects (Ashqolani *et al*., 2023).

Prior to the experiment, all fish were acclimatized for seven days and fed a commercial diet. Plastic gallon containers were thoroughly cleaned and filled with approximately 7 L of dechlorinated water that had been allowed to stand for 24 h before use. During the experimental period, each container contained 5 L of water and housed a single catfish. The dietary treatments were as follows: X0, natural feed (vegetable-based feed; control); X1, dried black soldier fly larvae (maggot); X2, commercial fish pellets; and X3, maggot-based pellets. Fish were fed twice daily at a feeding rate equivalent to 3% of body weight per day for 15 consecutive days.

Water quality was maintained by continuous aeration throughout the study. Partial water replacement (30-50%) was performed every three days, followed by the addition of EM4 probiotic solution. Water temperature and pH were monitored regularly and maintained within the optimal range for catfish culture (27-30°C and pH 6.5-7.5, respectively).

Growth performance assessment

Fish body weight was measured individually at the beginning (Day 1) and end (Day 15) of the feeding trial using a digital balance (Figure 1). Absolute weight gain was calculated using the following equation: WG = Wt – W0, where WG = absolute weight gain (g), Wt = final body weight (g), and W0 = initial body weight (g), following the standard growth-performance assessment procedure commonly applied in black soldier fly larvae meal feeding trials (Bakare *et al*., 2020; Bordoloi *et al*., 2025).

Figure 1: *Final body weight measurement of catfish (Clarias batrachus) from different dietary treatment groups at the end of the experimental period. Fish were individually weighted using a digital balance to evaluate growth performance and compare the effects of dietary treatments on body weight gain.*

Blood collection and hematological examination

Blood samples were collected one day after the completion of the feeding trial. Approximately 1 mL of blood was drawn from the caudal vein using sterile disposable syringes and immediately transferred into EDTA tubes (Witeska *et al.*, 2023). Hematocrit (packed cell volume, PCV) was determined using the microhematocrit method. Blood samples were transferred into capillary tubes up to three-quarters of their volume and centrifuged at 12,000 rpm for 10 min. The percentage of packed erythrocytes was then measured using a hematocrit reader (Witeska *et al.*, 2023). Hemoglobin concentration was determined using the Sahli method and expressed as g/dL (Esmaeili, 2021).

For differential leukocyte analysis, thin blood smears were prepared immediately after collection, air-dried, fixed with methanol, and stained with Giemsa solution. A total of 100 leukocytes were counted under a light microscope (1000× magnification using immersion oil), and the percentages of lymphocytes, neutrophils, monocytes, eosinophils, and basophils were measured (Witeska *et al.*, 2023).

Proximate analysis

Proximate analysis of the maggot-based pellets was conducted according to the standard methods of the Association of Official Analytical Chemists (AOAC, 2019). The analyzed parameters included moisture content, crude protein, crude fat, crude fiber, ash content, and nitrogen-free extract (NFE). Crude protein content was determined using the Kjeldahl method, crude fat by Soxhlet extraction, crude fiber through acid–base digestion, moisture content by oven drying, and ash content by furnace incineration. Nitrogen-free extract was calculated by difference. The proximate composition of the experimental diets, including moisture, crude protein, crude fat, crude fiber, and ash content, was determined according to the standard methods of the Association of Official Analytical Chemists (AOAC, 2019). Carbohydrate content was calculated by difference.

Statistical analysis

Data on body weight gain, hematocrit, hemoglobin concentration, and differential leukocyte counts were expressed as mean ± standard deviation (SD). Statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Normality and homogeneity of variance were assessed prior to analysis. Differences among treatment groups were evaluated using one-way analysis of variance (ANOVA) at a significance level of $P < 0.05$, followed by Tukey's HSD post-hoc test to identify differences among treatment means.

Results

Feed proximate composition

The incorporation of Black Soldier Fly (BSF, *Hermetia illucens*) larvae meal into aquaculture diets has been widely recognized as a sustainable alternative protein source. Previous studies have demonstrated that the inclusion of BSF meal at levels ranging from 20-50% can improve fish growth performance, feed utilization, and immune responses without adverse effects on fish health. According to Solfaine *et al.* (2025), maggot-based fish pellets provide high-quality protein, essential amino acids, and lipid fractions that support growth and physiological functions in cultured fish. The proximate analysis of the formulated maggot-based pellets supplemented with eggshell powder revealed a favorable nutritional composition characterized by high crude protein and metabolizable energy content. The addition of eggshell powder increased the mineral (ash) content, particularly calcium, which may contribute to skeletal development and metabolic regulation. Detailed proximate composition and metabolizable energy values are presented in Table 1.

Table 1: *Proximate composition and metabolizable energy of maggot-based pellets with eggshell supplementation.*

Parameter	Maggot pellet	Maggot Pellet + Eggshell
Dry Matter (%)	82.93	98.92
Ash (%)	12.52	14.69
Crude Protein (%)	11.47	21.83
Crude Fat (%)	7.33	8.05
Crude Fiber (%)	13.83	20.38
Calcium (%)	4.22	2.06
Nitrogen-Free Extract (NFE, %)	37.78	33.96
Metabolizable Energy (kcal/kg)	2332.43	2605.04

Growth performance

Growth performance was evaluated by measuring the difference between initial and final body weights of catfish (*Clarias batrachus*) after 15 days of feeding. Four dietary treatments were tested- a vegetable-based natural feed (X0, control), dried maggot meal (X1), commercial pellet feed (X2), and maggot-based

pellet feed supplemented with eggshell powder (X3) with five replicates per treatment.

Dietary treatment significantly affected body weight gain ($p \leq 0.05$), with mean weight gains of 14.20 ± 5.97 g for X0, 11.80 ± 3.03 g for X1, 25.40 ± 3.91 g for X2, and 30.60 ± 2.96 g for X3 (Table 2). Catfish fed commercial pellets (X2) and maggot-based pellets (X3) exhibited significantly greater weight gain than fish receiving natural feed (X0) or dried maggot feed alone (X1), while no significant difference was observed between X2 and X3, indicating that the formulated maggot-based pellet was comparable to commercial feed in promoting growth performance.

One-way ANOVA followed by Tukey's HSD test classified the treatments into two homogeneous subsets (Table 2). Treatments X0 and X1 formed the lower subset (superscript a), with mean weight gains of 14.20 ± 5.97 g and 11.80 ± 3.03 g, respectively, whereas X2 and X3 formed a second, significantly higher subset (superscript b), with mean weight gains of 25.40 ± 3.91 g and 30.60 ± 2.96 g, respectively increases of approximately 79% and 115% relative to X0. These findings suggest that processing maggot meal into a balanced pellet formulation enhances nutrient utilization and growth efficiency compared with feeding dried maggot alone.

Table 2: *Body weight gain of catfish fed different dietary treatments.*

Treatment	Mean ± SD (g)
X0 (Control)	14.20 ± 5.97[a]
X1 (Dried Maggot)	11.80 ± 3.03[a]
X2 (Commercial Pellet)	25.40 ± 3.91[b]
X3 (Maggot-Based Pellet)	30.60 ± 2.96[b]

Different superscript letters within the same column indicate significant differences ($p \leq 0.05$) according to Duncan's Multiple range test.

The improved growth observed in the X3 group may be attributed to the high protein content of black soldier fly (BSF) larvae meal, improved feed palatability, and the additional mineral contribution from eggshell supplementation, which may support metabolic processes and skeletal growth. Furthermore, the balanced nutrient composition of the maggot-based pellet likely enhanced feed digestibility and nutrient absorption, resulting in improved growth performance.

Hematological profile

The erythrocytic profile of *Clarias batrachus* fed different dietary treatments is presented in Table 3. Dietary treatment significantly affected hemoglobin concentration ($p \leq 0.001$), whereas hematocrit values showed no statistically significant differences among groups ($p = 0.094$). Fish fed maggot-based pellets supplemented with eggshell powder (X3) exhibited the highest hemoglobin concentration, followed by fish receiving commercial pellets (X2), dried maggot feed (X1), and the vegetable-based control diet (X0). Tukey's HSD test confirmed significant differences among all treatment groups.

Although hematocrit values were not significantly different, a progressive increase was observed from X0 to X3, indicating a tendency toward improved oxygen-carrying capacity in fish receiving diets containing maggot meal. Similarly, erythrocyte count (RBC), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) were not significantly affected by dietary treatment ($P > 0.05$), suggesting that the experimental diets maintained normal erythrocyte morphology and physiological status.

The elevated hemoglobin concentration observed in the X3 group indicates improved hematopoietic performance and oxygen transport efficiency, which may contribute to the superior growth performance recorded in fish receiving maggot-based pellets. These findings suggest that the incorporation of Black Soldier Fly (BSF) larvae meal and eggshell supplementation can enhance blood quality without inducing hematological abnormalities.

The differential leukocyte profile of *Clarias batrachus* is summarized in Table 4. Lymphocytes constituted the predominant leukocyte population in all treatment groups, accounting for 68.4–82.2% of total leukocytes. One-way ANOVA revealed no significant differences in total leukocyte count (WBC), neutrophil, lymphocyte, monocyte, eosinophil, or basophil percentages among dietary treatments ($p \geq 0.05$).

Despite the absence of statistical significance, fish fed maggot-based pellets (X3) tended to exhibit the highest lymphocyte percentage and lower eosinophil counts compared with the other treatment groups.

Table 3: *Hematology profile of Clarias batrachus fed different dietary treatments.*

Parameter	X0 (Natural Feed)	X1 (Dried Maggot)	X2 (Commercial Pellet)	X3 (Maggot-Based Pellet)
Hemoglobin (g/dL)	8.68 ± 0.33[a]	10.04 ± 0.65[b]	12.00 ± 0.64[c]	13.20 ± 0.83[d]
Hematocrit (%)	22.00 ± 7.17[a]	25.00 ± 5.95[ab]	31.00 ± 9.46[ab]	34.00 ± 7.77[b]
RBC ($\times 10^6$ cells/µL)	0.42 ± 0.09	0.39 ± 0.08	0.41 ± 0.07	0.43 ± 0.08
MCV (fL)	524 ± 216	640 ± 302	487 ± 191	537 ± 328
MCH (pg)	212 ± 74	258 ± 96	289 ± 101	316 ± 55
MCHC (g/dL)	40.2 ± 8.3	41.5 ± 11.2	38.8 ± 7.6	38.3 ± 5.6

Values are presented as mean ± SD (n = 5). Different superscript letters within the same row indicate significant differences (p≤ 0.05) according to Duncan's Multiple Range Test.

Table 4: *Differential leukocytic profile of Clarias batrachus fed different dietary treatments.*

Parameter	X0 (Natural Feed)	X1 (Dried Maggot)	X2 (Commercial Pellet)	X3 (Maggot-Based Pellet)
WBC ($\times 10^4$ cells/µL)	1.42 ± 0.88	1.68 ± 1.12	1.95 ± 1.03	1.63 ± 1.22
Neutrophils (%)	10.0 ± 5.8	15.0 ± 10.8	14.4 ± 6.8	9.4 ± 6.3
Lymphocytes (%)	81.0 ± 7.3	68.4 ± 18.3	76.0 ± 5.4	82.2 ± 6.8
Monocytes (%)	5.0 ± 7.4	7.8 ± 5.9	6.2 ± 4.8	4.4 ± 3.4
Eosinophils (%)	4.8 ± 5.8	6.0 ± 8.4	2.4 ± 2.3	1.6 ± 0.9
Basophils (%)	1.2 ± 1.3	2.8 ± 3.2	1.0 ± 1.0	2.4 ± 2.5

In contrast, fish receiving dried maggot feed (X1) showed relatively lower lymphocyte values and higher eosinophil percentages. Neutrophil, monocyte, and basophil counts remained within normal physiological ranges and displayed only minor variations among treatments. Hematocrit values showed no statistically significant differences among the experimental groups (p = 0.094).

Overall, the leukocytic profile indicates that dietary inclusion of maggot-based pellets did not induce adverse immune reactions or physiological stress. The tendency toward higher lymphocyte proportions in the X3 group may reflect enhanced immune competence associated with the nutritional and bioactive components of BSF larvae meal. Furthermore, the absence of leukocytosis, neutrophilia, or eosinophilia suggests that the experimental diets were well tolerated and did not trigger inflammatory or pathological responses in the fish.

Discussion

The proximate analysis showed that supplementation with eggshell powder improved the nutritional quality of the maggot-based pellet. The eggshell-supplemented pellet contained higher dry matter, ash, crude protein, crude fat, and metabolizable energy compared with the maggot pellet alone. The increase in crude protein (21.83%) is particularly important because protein is the primary nutrient supporting fish growth, tissue development, and metabolism (Jayanegara, 2022). Likewise, the higher metabolizable energy value (2605.04 kcal/kg) indicates a greater nutrient density that may contribute to improved growth performance (Tran *et al.*, 2015).

The increased ash content reflects a higher mineral concentration resulting from eggshell inclusion, while the slight increase in crude fat provides additional energy for metabolic activities. Conversely, nitrogen-free extract (NFE) decreased due to the proportional increase in protein and fiber fractions. Overall, the proximate composition suggests that the maggot pellet supplemented with eggshell powder provides a more balanced and nutrient-rich diet (Su *et al.*, 2025), which may explain the superior growth and hematological responses observed in *Clarias batrachus*.

The present study demonstrated that dietary treatments significantly affected body weight gain and hemoglobin concentration in *Clarias batrachus*, whereas hematocrit and leukocyte profiles were not significantly influenced by the tested diets. Among the treatments, fish fed maggot-based pellets (X3) exhibited the highest growth performance and the most favorable hematological profile.

Growth performance is one of the most important indicators of feed quality and nutritional adequacy in

aquaculture (Ashqolani *et al.*, 2023; Bakare *et al.*, 2020). The significantly higher weight gain observed in fish receiving maggot-based pellets (X3) and commercial pellets (X2) compared with fish fed natural feed (X0) and dried maggot (X1) suggests that pelletized diets provided more balanced nutrients for growth (Liu *et al.*, 2024). Protein is the primary nutrient required for tissue synthesis, enzyme production, hormone formation, and energy metabolism in fish. Therefore, adequate protein intake directly contributes to increased growth rates and feed utilization efficiency. The superior performance of the maggot-based pellet may be attributed to the high protein content of black soldier fly (*Hermetia illucens*) larvae meal, which has been reported to contain approximately 40-60% crude protein and a favorable amino acid profile (Tran *et al.*, 2015; Belghit *et al.*, 2019). Furthermore, the combination of maggot meal with soybean meal, rice bran, and vitamin-mineral premix in the formulated pellet likely improved nutrient balance and digestibility, resulting in enhanced growth performance (Jayanegara, 2022; Bhusare *et al.*, 2026).

Although hematocrit values tended to increase from X0 to X3, statistical analysis indicated that the differences among treatments were not significant ($P = 0.094$). The mean hematocrit values ranged from 22.00% in the control group (X0) to 34.00% in the maggot-based pellet group (X3). This trend suggests that improved dietary quality may have supported erythropoiesis and blood cell production (Esmaeili, 2021); however, the relatively high variation among individuals and the limited sample size may have reduced the statistical power to detect significant differences. Hematocrit is influenced not only by nutrition but also by environmental conditions, hydration status, physiological adaptation, and stress responses (Witeska *et al.*, 2023). Therefore, the absence of a significant effect indicates that all dietary treatments were generally capable of maintaining hematological homeostasis during the experimental period.

In contrast to hematocrit, hemoglobin concentration was significantly affected by dietary treatment. Fish fed maggot-based pellets (X3) exhibited the highest hemoglobin concentration, followed by fish fed commercial pellets (X2), dried maggot (X1), and natural feed (X0). Tukey's HSD test indicated significant differences among all treatment groups. Hemoglobin plays a crucial role in oxygen transport and metabolic activity; therefore, increased hemoglobin levels may reflect improved nutritional status and physiological condition (Adeoye *et al.*, 2020; Bordoloi *et al.*, 2025). The hemoglobin concentrations observed in the pellet-fed groups were within or close to the normal range reported for healthy catfish, whereas the control group exhibited values below the optimal range. These findings suggest that diets containing balanced protein sources, particularly maggot meal, may support hemoglobin synthesis more effectively than natural feed alone (Teye-Gaga *et al.*, 2026).

The erythrocytic profile further indicated that RBC count, MCV, MCH, and MCHC did not differ significantly among treatments. This finding suggests that the dietary treatments primarily influenced hemoglobin concentration without substantially altering erythrocyte morphology or red blood cell indices (Bordoloi *et al.*, 2025; Ikechukwu *et al.*, 2026). The maintenance of these parameters within comparable ranges across treatments indicates that the tested diets did not induce hematological abnormalities such as severe anemia or erythrocyte dysfunction (Witeska *et al.*, 2023).

Analysis of the leukocytic profile showed no significant differences in total leukocyte count, neutrophils, lymphocytes, monocytes, eosinophils, or basophils among treatment groups. Lymphocytes were the predominant leukocyte population in all groups, representing the typical leukocyte distribution reported in healthy freshwater fish. Although fish receiving maggot-based pellets (X3) tended to exhibit higher lymphocyte percentages and lower eosinophil percentages than fish fed dried maggot alone (X1), these differences were not statistically significant. The absence of significant changes in leukocyte distribution suggests that the dietary treatments did not induce adverse immune responses, inflammation, or physiological stress during the 14-day feeding period (Hwang *et al.*, 2021; Xia *et al.*, 2021).

The present study has several limitations that should be considered when interpreting the findings. First, the relatively small sample size may have reduced the statistical power to detect subtle differences among dietary treatments. Second, the feeding trial was conducted over a relatively short period (15 days), which may not have been sufficient to fully evaluate the long-term effects of black soldier fly larvae meal on growth performance and hematological

responses in catfish. Third, each dietary treatment was conducted using a single aquarium containing five fish, without independent tank replication. Consequently, potential tank effects could not be separated from treatment effects, which may limit the robustness and generalizability of the results. Therefore, the findings of this study should be regarded as preliminary. Future studies should employ larger sample sizes, longer experimental durations, and multiple independent tanks per treatment to provide stronger evidence regarding the nutritional value and physiological effects of black soldier fly larvae meal in aquaculture.

Overall, the results indicate that maggot-based pellets can serve as an effective alternative protein source for catfish culture (Camperio *et al*., 2026). The diet represented by X3 promoted superior growth performance and significantly improved hemoglobin concentration while maintaining normal hematological and leukocytic profiles. These findings support the potential utilization of locally produced black soldier fly larvae meal as a sustainable and nutritionally valuable feed ingredient for freshwater aquaculture (Su *et al*., 2025).

The present study has several limitations that should be considered when interpreting the findings. First, the relatively small sample size may have reduced the statistical power to detect subtle differences among dietary treatments. Second, the feeding trial was conducted over a relatively short period (14 days), which may not have been sufficient to fully evaluate the long-term effects of black soldier fly larvae meal on growth performance and hematological responses in catfish. Third, each dietary treatment was conducted using a single aquarium containing five fish, without independent tank replication. Consequently, potential tank effects could not be separated from treatment effects, which may limit the robustness and generalizability of the results. Therefore, the findings of this study should be regarded as preliminary. Future studies should employ larger sample sizes, longer experimental durations, and multiple independent tanks per treatment to provide stronger evidence regarding the nutritional value and physiological effects of black soldier fly larvae meal in aquaculture.

Conclusion

Dietary supplementation with maggot-based pellets significantly improved the growth performance of catfish (*Clarias batrachus*), as demonstrated by greater body weight gain and higher hemoglobin concentrations compared with the control group ($p \leq 0.05$). These findings indicate that black soldier fly (*Hermetia illucens*) larvae meal is a nutritionally valuable protein source capable of supporting growth and maintaining hematological health. However, hematocrit values were not significantly affected ($p \geq 0.05$), suggesting that the day 15 feeding period was insufficient to induce changes in erythrocyte volume. Overall, maggot-based pellets represent a promising sustainable alternative to conventional fish feed.

This study was limited by the short experimental duration and the use of a single fish per experimental unit. Therefore, further studies with longer feeding periods, larger sample sizes, and multiple fish per independently replicated tanks are recommended to validate these findings and better evaluate the long-term effects of black soldier fly larvae meal on catfish growth and health.

Acknowledgement

This research was supported by the Enimas Research Grant Scheme, Institute for Research and Community Service (LPPM), Universitas Wijaya Kusuma Surabaya, Grant No. 131/PL/LPPM/UWKS/V/2026.

Novelty Statement

This study demonstrates the development and evaluation of a maggot-based pellet supplemented with eggshell powder as a sustainable alternative feed for catfish (*Clarias batrachus*). Unlike previous studies that primarily focused on growth performance, this research simultaneously evaluates the pellet's proximate composition, growth response, and hematological profile. The findings show that the formulated maggot-based pellet provides growth performance and hemoglobin levels comparable to commercial feed without adversely affecting leukocyte profiles, highlighting its potential as a low-cost, nutritionally balanced, and environmentally sustainable aquaculture feed

Author's Contribution

R.S. conceived and designed the study, conducted the laboratory experiments, and supervised the

research activities. O.R. performed the statistical analyses, validated the data, and contributed to data interpretation. I.R. prepared the initial draft of the manuscript and assisted with data compilation. All authors contributed to manuscript preparation, critically revised the manuscript for important intellectual content, and approved the final version of the manuscript.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

References

Adeoye, A.A., Akegbejo-Samsons, Y., Fawole, F.J. and Davies, S.J., 2020. Preliminary assessment of Black Soldier Fly (*Hermetia illucens*) larval meal in the diet of African catfish (*Clarias gariepinus*): Impact on growth, body index, and hematological parameters. J. World Aquacult. Soc., 51(4): 1024–1033. https://doi.org/10.1111/jwas.12691

AOAC, 2019. Official methods of analysis of AOAC international. 21st ed. Rockville, MD: AOAC International.

Ashqolani, M.M., Haetami, K., Maulina, I. and Mulyani, Y., 2023. The effect of Black Soldier Fly (*Hermetia illucens*) larvae feeding on the growth of Mutiara catfish seeds (*Clarias gariepinus*). Asian J. Fish. Aquat. Res., 21(4): 48–54. https://doi.org/10.9734/ajfar/2023/v21i4548

Bakare, C., Adewolu, M.A. and Olukunle, O.A., 2020. Growth performance and nutrient utilization of *Clarias gariepinus* fed diets containing maggot meal as a replacement for fishmeal. Int. J. Fish. Aquat. Stud., 8(3): 286–290.

Belghit, I., Liland, N.S., Gjesdal, P., Ornsrud, R. and Lock, E.J., 2019. Black Soldier Fly larvae meal can replace fish meal in diets of Atlantic salmon (*Salmo salar*) without affecting performance, health, or sensory quality of fillets. Aquaculture, 511: 734387. https://doi.org/10.1016/j.aquaculture.2018.12.032

Bhusare, S., Halpati, R.P., Sawant, K.S. and Dkk., 2026. Black soldier fly larvae meal as an alternative to fishmeal in aquaculture nutrition. Eur. J. Nutr. Food Saf., 18(3): 87–98. https://doi.org/10.9734/ejnfs/2026/v18i31977

Bordoloi, B., Saharia, K.P., Pokhrel, H., Debnath, D., Singha, S. and Talukdar, A., 2025. Efficiency of black soldier fly larvae meal (BSFLM) as partial or total replacement of fishmeal (FM) on growth performance, nutrient utilization and haematological changes in walking catfish *Clarias magur* (Hamilton, 1822). Indian J. Anim. Res., pp. 1-6.

Camperio, J., Carroza-Meza, C.H., Suarez, J. and Benetti, D., 2026a. Global research trends of Black Soldier Fly larvae meal in aquaculture from a scientometric perspective (2007–2025). Aquacult. Nutr., 2026 Jan 6;2026:5560332. https://doi.org/10.1155/anu/5560332

Camperio, J., Carroza-Meza, C.H., Suarez, J. and Benetti, D., 2026b. Global research trends of Black Soldier Fly larvae (*Hermetia illucens*) meal in aquaculture from a scientometric perspective (2007–2025). Aquacult. Nutr., Article ID 5560332. https://doi.org/10.1155/anu/5560332

Esmaeili, N., 2021. Blood performance: A new formula for fish growth and health. Tasmania: Institute for Marine and Antarctic Studies, University of Tasmania.

Hwang, D., Lim, C.H., Lee, S.H., Goo, T.W. and Yun, E.Y., 2021. Effect of feed containing Hermetia illucens larvae immunized by Lactobacillus plantarum injection on the growth and immunity of rainbow trout (*Oncorhynchus mykiss*). Insects, 12(9): 801. https://doi.org/10.3390/insects12090801

Ikechukwu, C.C., Okeke, P.A. and Okoye, T.C., 2026. Effects of replacement of fish meal with Black Soldier Fly larvae meal on antioxidants and enzymes activities in the serum of Clarias gariepinus. Res. J. Pure Sci. Technol., 9(2): 68–82.

Jayanegara, A., 2022. Use of black soldier fly (*Hermetia illucens* L.) larvae meal in aquafeeds for a sustainable aquaculture industry: A review of past and future needs. Aquaculture, 553: 738095. https://doi.org/10.1016/j.aquaculture.2022.738095

Li, S., Ji, H., Zhang, B., Zhou, J. and Yu, H., 2017. Defatted Black Soldier Fly (*Hermetia illucens*) larvae meal in diets for juvenile Jian carp (*Cyprinus carpio* var. Jian): Growth performance, digestive enzyme activities, antioxidant

enzyme activities and hepatopancreas histology. Aquaculture, 477: 62–70. https://doi.org/10.1016/j.aquaculture.2017.04.015

Liu, Y., Andin, V.C., Chor, W.K., Gunasekaran, B., Chong, C.-M., Lee, P.T., and Loh, J.-Y. 2024. Effects of substituting fishmeal with defatted Black Soldier Fly (*Hermetia illucens*) larval meal on Asian seabass. J. Fish Biol., 105(6): 1681–1693. https://doi.org/10.1111/jfb.15908

Solfaine, R., D. Haryanta, M. Revitriani, K. Desiandura, A. Candra. 2025. Penerapan Teknologi Produksi Pelet Ikan Berbasis Maggot Di Kampoeng Oase Ondemohen Surabaya Sebagai Upaya Pengembangan Ekonomi Sirkular, jurnal Pepadu: Vol. 6 No. 3 (2025): Jurnal Pepadu

Su, H., Zhang, B., Shi, J., He, S., Dai, S., Zhao, Z., Wu, D., Li, J. 2025. Black soldier fly larvae as a novel protein feed resource promoting circular economy. Insects, 16(8): 830. https://doi.org/10.3390/insects16080830

Sultana, S., Ali, O., Biró, J., Szabó, A., Ardó, L., Szűcs, A., Gura, T., Tammajedy, V., Hancz, C., Agyarko, E. 2026. Effects of dietary supplementation with Black Soldier Fly larvae on common carp. Animals, 16(4): 693. https://doi.org/10.3390/ani16040693

Teye-Gaga, C., Molnár, P.I., Kertész, A., Maina, J.K., Mohammed, E.A.H., Gulyás, G., Fehér, M. and Bársony, P., 2026. Combined substitution of fishmeal and fish oil with black soldier fly larval meal and corn oil: Effects on growth, hematology, hematobiochemical, amino and fatty acid composition, and fillet nutritional quality of hybrid African catfish (Clarias gariepinus × Heterobranchus longifilis). Anim. Nutr., 2026: Article 4880013. https://doi.org/10.1155/anu/4880013

Tran, G., Gnaedinger, C. and Meliet, C., 2015. Black Soldier Fly larvae (*Hermetia illucens*). Feedipedia. Available at: https://www.feedipedia.org/node/16388 (Accessed 20 May 2024).

Wiharti, T. and Hanik, N.R., 2022. Identification of types of fish captured by fishermen at TPI Wuryantoro Wonogiri that are consumed by the community. J. Biol. Trop., 22(4): 1177–1187. https://doi.org/10.29303/jbt.v22i4.4137

Williams, A.I. and Abaje, M.C., 2026. Evaluation of catfish raised with wholesome Black Soldier Fly larvae in Port Harcourt, Nigeria. Asian J. Food Res. Nutr., 5(1): 171–180. https://doi.org/10.9734/ajfrn/2026/v5i1369

Witeska, M., Kondera, E. and Bojarski, B., 2023. Hematological and hematopoietic analysis in fish toxicology: A review. Animals, 13(16): 2625. https://doi.org/10.3390/ani13162625

Xia, X., Yang, J. and Wang, S., 2021. Antimicrobial peptides from Black Soldier Fly (*Hermetia illucens*) as potential alternatives to antibiotics in aquaculture. Fish Shellf. Immunol., 119: 210–217.

Yakti, W., Shaw, C., Müller, M. Mewis I, Kloas W and Ulrichs C. 2024. Nutrient flow from fish feed to Black Soldier Fly larvae in aquaculture systems. Front. Sustain. Food Syst., 8: 1298885. https://doi.org/10.3389/fsufs.2024.1298885