

Research Article



Investigation of *Tenebrio molitor* Larvae as a Substitute for Imported Fish Meal: Impacts on Carcass Yield, Organ Health, Lipid Metabolism, and Thigh Meat Fatty Acid Content of Broiler

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Abstract | The larva of *Tenebrio molitor* can serve as a substitute for animal protein sources. This study assessed the impact of replacing imported fish meal (IFM) with *Tenebrio molitor* larva meal (TmLM) on broiler carcass performance, organ health, blood lipid profiles, and meat quality. The research utilized 100 broiler chickens of the MB 202 breed. An experimental methodology utilizing a completely randomized design (CRD) was implemented, comprising five treatments with TmLM substitutions: A (0% TmLM / 100% IFM), B (3% TmLM / 25% IFM substitution), C (6% TmLM / 50% IFM substitution), D (9% TmLM / 75% IFM substitution), and E (12% TmLM / 100% IFM substitution), each replicated four times. At 35 days of age, the parameters assessed included live weight (g/head), abdominal fat percentage, carcass percentage, physiological organ weights, blood lipid profiles, thigh meat fatty acids, thigh meat cholesterol, and thigh meat fat content. Variance analysis indicated that the incorporation of TmLM in the diet did not significantly influence ($P > 0.05$) live weight, abdominal fat percentage, carcass percentage, physiological organ weights, or thigh meat fat content. Nonetheless, it markedly reduced total blood cholesterol, triglycerides, and LDL ($P < 0.01$), while elevating HDL and omega-3, omega-6, and omega-9 fatty acids ($P < 0.05$). The research determined that a maximum of 12% TmLM in broiler diets can entirely substitute for imported fish meal, preserving carcass performance, lowering cholesterol levels, and enhancing meat quality.

Keywords | Blood lipid profiles, Broiler, Carcass, Imported fish meal, Meat fatty acid, *Tenebrio molitor* larval meal

Received | February 11, 2026; **Accepted** | August 02, 2026; **Published** | September 07, 2026

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Citation | Nuraini N, Nur YS, Amizar R, Sari YC, Maulana F, Amran M, Trisna A (2026). Investigation of *Tenebrio molitor* larvae as a substitute for imported fish meal: Impacts on carcass yield, organ health, lipid metabolism, and thigh meat fatty acid content of broiler. J. Anim. Health Prod. 14(4): 1427-1434.

DOI | <https://dx.doi.org/10.17582/journal.jahp/2026/14.4.1427.1434>

ISSN (Online) | 2308-2801



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INTRODUCTION

The sourcing of sustainable feeds, particularly imported fish meal (IFM), is costly, limited in supply, and often associated with overharvesting, resulting in significant environmental impacts, including ecosystem degradation, loss of marine biodiversity, and habitat destruction (Gasco

et al., 2020). These problems have led to the exploration of sustainable, economically viable alternatives to insect agri-food waste, as they have a unique potential nutritional profile and can be produced and harvested sustainably and abundantly (Schiavone *et al.*, 2020). Of the insects available, the *Tenebrio molitor* larvae, or “mealworms” (TmLM), are a viable source of animal protein. Additionally, they contain

essential fatty acids that are healthy for human and animal consumption (Filho *et al.*, 2021).

Moreover, TmLM incorporates chitin, a polysaccharide that enhances the immunological and physiological responses of broiler chickens by acting as a gut health prebiotic and a regulator of fat metabolism (Biasato *et al.*, 2017). Research demonstrates that in broiler chicken diets, partial replacement of TmLM with IFM results in similar growth performance while improving carcass quality and blood lipid levels, thereby lowering the potential for cardiovascular disease (Biasato *et al.*, 2017; Jiang *et al.*, 2024). The unsaturated fatty acids of TmLM contribute to reduced fat and cholesterol in thigh meat, enhanced overall carcass yield, and increased yield of several vital visceral organs, particularly the liver and spleen (Popova *et al.*, 2025). Given these facts, TmLM serves as a cost-effective protein source in meat chicken diets and has the potential to substantially improve overall physiological status, meat quality, and carcass yield.

Recent studies of the last five years correctly evaluate these benefits. TmLM is a sustainable feed alternative. Previous findings showed that including TmLM in broiler diets (at 5-10% replacement levels) improves feed conversion ratios and carcass yield, and that growth and immune responses are not hindered by the prebiotic effect of chitin (Cullere *et al.*, 2021). Corroborated that TmLM supplementation reduces belly fat accumulation and improves lipid metabolism (Biasato *et al.*, 2017; Makkar *et al.*, 2022). Broilers fed TmLM had reduced levels of blood cholesterol and triglycerides and improved organ health indicators, such as the spleen, suggesting that TmLM may be effective in reducing metabolic stress relative to IFM-based diets (Inaudi *et al.*, 2025). Nevertheless, the most recent data stand in contrast to, or sharpen, these positive results, reporting possible limitations or context-dependent effects. Indicated that TmLM improved carcass quality in some aspects.

However, there was a loss in feed intake and minor digestive discomfort due to the fibrous nature of chitin, which may negate supportive improvements in lipid metabolism if an adequate balance is not achieved (Józefiak *et al.*, 2023). Compared with FM, moderate levels (5-7%) of TmLM substitution showed no significant differences in thigh meat fat or blood lipids (Benzertih *et al.*, 2019). They explained the mechanisms underlying the rearing conditions of TmLM and the genetics of the broilers, which affect the unsaturated fatty acids reported by Vasilopoulos *et al.* (2023). This difference warrants the need for coordinated production systems to guarantee consistent nutrition and efficiency.

However, despite these advances, previous studies have largely focused on individual performance indicators, primarily growth performance or carcass characteristics, with limited attention to the integrated effects of *Tenebrio molitor* larvae meal (TmLM) on multiple physiological and metabolic parameters. A comprehensive evaluation that simultaneously considers carcass traits, organ health, lipid metabolism, and meat quality is still lacking. Such an integrated approach is essential for understanding the overall biological effects and underlying mechanisms of TmLM as a substitute for imported fish meal (IFM) in broiler diets. Therefore, this study aimed to evaluate the effects of replacing IFM with TmLM in broiler chickens up to 35 days of age by assessing live body weight, carcass yield, abdominal fat percentage, physiological organ weights, blood lipid profiles, thigh meat fatty acid composition and meat cholesterol and fat contents.

MATERIALS AND METHODS

SAMPLING

Sampling involves selecting a proportion of members or elements from a larger population and using those to infer about the larger population. It is a key component of statistical evaluation and research techniques. The mass rearing of *Tenebrio molitor* involves 500 g of a substrate comprising tofu dregs, rice bran, and moringa leaves. Biopon is incorporated with all substrate forms, whether dry or finely milled. Into this substrate, a total of 150 *Tenebrio molitor* beetles were added. Every 2 days, 6 whole young papaya fruits, 2-3 cm in diameter, are added to the substrate. The beetles were left in the substrate for 15 days, after which they were removed using a sieve. TmLM was maintained for 4 weeks (28 days) after the beetles were removed from the substrate. The TmLM was separated from the substrate by means of a two-mesh sieve (to determine the fresh weight of the TmLM) and further sieving to remove the TmLM from the substrate. To the TmLM, which was then ground in a blender to re-mill it into flour, 10 minutes of steaming to kill the larvae were added, followed by 48 hours of oven drying at 50 degrees, and after that, sieving to remove the TmLM. TmLM worms are a possible food source for broiler chickens.

EXPERIMENTAL ANIMALS

For this experiment, one hundred broiler chickens were divided into five equal groups, four of which were replicates containing 10 chickens of equal weight (41 ± 1.55 g). This particular experiment is split into five treatment groups, as follows: a control group with 0% TmLM, 100% IFM; group 1, 3% TmLM, 75% IFM; group 2, 6% TmLM, 50% IFM; group 3, 9% TmLM, 25% IFM; and groups 4 and 5, 12% TmLM, 0% IFM. The 20 box cages, with 10 chickens per unit, were continuously lit for the first 7 days and then

introduced to 12-hour light and dark cycles (12L: 12D) for the rest of the experiment. The birds had automatic feeding and watering available to them freely throughout the entire 35-day trial.

On the first day, all chickens were vaccinated for Marek's disease (MMB 202 Strain, subcutaneous) and Schemes (LaSota Strain, intraocular) on the 7th day. Psychological state, nutritional and water intake, and droppings assessment are criteria for determining the health status of hens. During the study, chickens showed no abnormalities.

EXPERIMENTAL DESIGN AND FEED

This study employed an experimental methodology based on a Completely Randomized Design (CRD). The treatments consisted of five dietary levels of *Tenebrio molitor* larvae meal (TmLM) used as a substitute for imported fish meal (IFM). The dietary treatments were arranged as follows: Treatment A contained 0% TmLM and 100% IFM (control); Treatment B contained 3% TmLM with a 25% substitution of IFM; Treatment C contained 6% TmLM with a 50% substitution of IFM; Treatment D contained 9% TmLM with a 75% substitution of IFM; and Treatment E contained 12% TmLM with a 100% substitution of IFM.

Each treatment was replicated four times, and each replicate consisted of an equal number of broiler chickens. The experimental diets were administered from day-old chicks until 35 days of age. All experimental units were randomly allocated to the treatments to minimize experimental bias. At 35 days of age, data were collected for growth performance, carcass characteristics, physiological organ weights, blood lipid profiles, and thigh meat quality parameters. Table 1 summarizes the diet given to the subjects and its approximate nutritional composition and nutrient content. Table 2, composition of feed ingredients (%) of the treatment diet.

PARAMETERS

The parameters assessed included live weight (g/head), abdominal fat percentage, carcass percentage, physiological organ weights, blood lipid profiles, thigh meat fatty acids, thigh meat cholesterol, and thigh meat fat.

PROCEDURES FOR DATA COLLECTION AND SAMPLING

The carcass weights (g) and body weights (g) were measured to calculate the percentage of the carcass and the percentage of the non-carcass organ as follows: carcass weight (g)/body weight (g) x 100% and non-carcass organ weight (g)/body weight (g) x 100. The following were separated and weighed with great attention: the carcass, the abdominal adipose tissue, and the non-carcass organs (i.e., heart, gizzard).

ANALYSIS OF MEAT CHOLESTEROL AND BLOOD LIPID PROFILE

For emaciated chickens, blood samples were taken from the jugular and carotid vessels. To isolate the serum, blood without anticoagulants was collected and centrifuged for 20 minutes at 40 x 100 rpm, after a 30-minute coagulation period. DiaSys kits on photometric systems were used to assess total cholesterol, HDL cholesterol, LDL cholesterol, and triglycerides; colorimetric enzymatic assays were used to measure cholesterol and triglycerides. After centrifuging for 20 minutes at 40 x 100 rpm to sediment the cells, the supernatant was collected and analyzed using a Microlab 300 at 546 nm.

ANALYSIS OF LIPIDS AND FATTY ACIDS IN THIGH MEAT

Thigh muscle samples were taken from 35-day-old broilers. These were cut to remove excess skin and fat, dried, and ground into fine powders. Cholesterol measurement was conducted according to the protocol for the Cholesterol Analyzer SpectraLab 752 Pro. With the help of a boron trifluoride-methanol reagent, the lipids were converted into

Table 1: The content of feed substances (%) and metabolic energy (kcal/kg) of feed ingredients that make up the diet (as feed).

Feed ingredients	Nutrients							
	Crude protein	Fat	Fiber	Ca	P	ME (kcal/kg) ^c	Lysine	Methionine
Corn meal ^a	9.58 ^b	2.66	3.50	0.38	0.19	3300	0.20	0
Soybean meal ^a	43.76 ^b	2.49	4.50	0.63	0.36	2240	2.60	0.50
Importted fish meal ^a	64.00 ^b	2.85	3.90	3.10	1.89	2540	5.00 ^c	0.99 ^d
<i>Tenebrio molitor</i>	62.35 ^b	14.96 ^b	6.18 ^b	0.19 ^b	0.82 ^b	3362 ^b	4.75 ^b	0.43 ^b
Fine bran ^a	12.34 ^b	5.09	14.50	0.69	0.26	1630	0.77	0.29
Coconut oil ^a	0	100.00	0	0	0	8600	0	0
Bone flour ^a	0	0	0	24.00	12.00	0	0	0
Top mix	0	0	0	0.06 ^c	0	0	0	0

Description: ^a Nuraini *et al.* (2022b)a; ^b Nuraini *et al.* (2022a); ^c Scott *et al.* (1982); ^d Sitompul (2004); ^e Top Mix Packaging Labels PT. Medion.

Table 2: Composition of feed ingredients (%) of the treatment diet.

Feed ingredients	Treatment ration				
	A	B	C	D	E
Corn meal	55.00	55.00	54.75	54.50	54.50
Soybean meal	18.25	18.25	18.50	18.50	18.50
Fish flour	12.00	9.00	6.00	3.00	0.00
<i>Tenebrio molitor</i>	0.00	3.00	6.00	9.00	12.00
Fine bran	9.25	9.25	9.25	9.50	9.75
Coconut oil	3.75	3.50	3.25	3.00	2.75
Bone flour	1.25	1.50	1.75	2.00	2.00
Top mix	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00
Feed substances (%) and metabolic energy (kcal/kg)					
Crude protein	22.08	22.03	22.06	22.02	22.00
Crude fat	6.48	6.59	6.71	6.83	6.95
Crude fiber	5.11	5.17	5.24	5.34	5.44
Calcium	1.06	1.03	1.01	0.98	0.89
Phosphorus	0.57	0.57	0.57	0.57	0.53
Lysine	1.26	1.25	1.25	1.24	1.24
Methionine	0.24	0.22	0.20	0.19	0.17
Glutamate	3.79	3.78	3.78	3.76	3.76
Linoleate	2.76	3.53	4.30	5.08	5.86
Chitin	0.00	0.22	0.43	0.65	0.86
Metabolic energy	3001.80	3005.06	3005.60	3004.62	3011.88

Description: Calculated based on Tables 1 and 2.

fatty acid methyl esters (FAMEs) to determine the fatty acid composition. Analysis of FAMEs was performed by gas chromatography with a flame ionization detector (GC-FID) to assess omega-3, omega-6, and omega-9 fatty acids, and their peak areas were compared with reference standards to identify and quantify them. The total composition of fatty acids in thigh tissue was computed as the proportion of each acid to the total fatty acids. The fat content of the thigh meat sample was analyzed using a Soxhlet apparatus (AOAC, 2010).

STATISTICAL ANALYSES

The primary variable of interest was the dietary inclusion level of TmLM. The data obtained were analyzed using analysis of variance (ANOVA) appropriate for a completely randomized design (CRD). The measures of central tendency were analyzed using IBM SPSS (v22.0) software. All results are presented as mean values, with $p < 0.05$ as the cutoff for statistical significance.

RESULTS AND DISCUSSION

CARCASS, VISCERAL FAT AND PHYSIOLOGICAL ORGANS

The effect of different levels of inclusion (0, 3, 6, 9, 12%) of TmLM on the live weight, percentage of carcass, fat

deposition, and the weight of some physiological organs (liver, heart, gizzard) of broilers are presented in Table 3.

Table 3: Effect of TmLM treatment on live weight, percentage of carcass abdominal fat and physiological organs.

Parameters measured	TmLM 0	TmLM 3	TmLM 6	TmLM 9	TmLM 12	SEM
Live weight (g/bird) ^{ns}	1502	1525.35	1533.60	1510	1506.96	10.64
Carcass (%) ^{ns}	75.47	75.96	75.78	75.84	75.54	1.41
Abdominal fat (%) ^{ns}	1.36	1.17	1.36	1.45	1.16	0.15
Liver (%) ^{ns}	0.45	0.47	0.49	0.49	0.48	0.14
Heart (%) ^{ns}	2.22	2.09	2.27	2.15	2.03	0.11
Gizzard (%) ^{ns}	1.33	1.36	1.42	1.44	1.37	0.04

Note: ns = non-significant ($P > 0.05$).

No meaningful changes were recorded on the variables considered ($P > 0.05$). In the study, some individual broilers weighed 1502 g and others weighed 1533.6 g. Unchanged carcass yields of the broilers were recorded from 75.4% to 75.96%. Regardless of TmLM inclusion, the organ weights remained constant. Recent research suggests that TmLM has a very slight, statistically insignificant impact on live weight and carcass yield. This supports the perspective of the reviewed study on insect meals, specifically the calories of *Tenebrio molitor*, as a potential alternative protein source to fish meal with no negative impact on growth performance in broiler diets (Biasato *et al.*, 2022; Mao *et al.*, 2020). Biasato *et al.* (2022), reported the same growth and carcass yield in broilers as supported by this study. Other research suggests minimal differences in development are related to the insect meal utilized and the diet formulation. This indicates that the influencing factor may be the nutritional quality and digestibility of the diet, which may explain the differences in performance (Schiafone *et al.*, 2020).

There was some fluctuation in abdominal fat content without a consistent pattern, suggesting that the inclusion of TmLM does not influence fat deposition in broilers. Therefore, insect meal substitutions appear not to have a substantial impact on this parameter. Similar findings have been reported by Bovera *et al.* (2020). Losses in body and visceral fat were attributed to the incorporation of insect meal and were explained by changes in fatty acid profile and chitin (Cullere *et al.*, 2019; Toral *et al.*, 2025). A lack of statistical significance suggests that the level or timing of TmLM inclusion might not be sufficient to influence lipid metabolism in a meaningful way.

Table 4: Effect of TmLM treatment on total blood cholesterol, triglycerides, HDL, LDL and thigh meat cholesterol.

Parameters measured	TmLM 0	TmLM 3	TmLM 6	TmLM 9	TmLM 12	SEM
Total blood cholesterol (mg/dL)	134.43 ^a	131.13 ^a	130.50 ^b	124.53 ^c	116.85 ^c	4.00
Triglycerides (mg/dL)	39.03 ^a	34.45 ^a	32.63 ^b	29.53 ^c	28.18 ^c	1.11
HDL (mg/dL)	38.93 ^c	42.70 ^c	43.45 ^b	46.63 ^a	51.60 ^a	2.10
LDL (mg/dL)	81.68 ^a	69.20 ^a	63.70 ^b	62.70 ^b	53.35 ^c	0.25
Thigh meat cholesterol (mg/100 g)	120.45 ^a	111.17 ^a	103.70 ^b	100.45 ^c	100.10 ^c	2.20

Note: ^{a,b,c} = Superscripts that differ in each row showing a highly significant difference ($p < 0.01$).

No statistically significant differences in the relative weights of the liver, heart, and gizzard were observed among treatments, indicating that substituting TmLM up to 12% does not have detrimental effects on the health and function of these organs. This is in line with Gasco *et al.* (2019), who showed that the inclusion of insect meals was not associated with negative histopathological changes or organ hypertrophy. Concerns raised in the past that organ overload might result from anti-nutritional factors or allergens linked to insect protein were not confirmed in this study (Henry *et al.*, 2021). The close agreement in organ weights suggests that the interventions were successful in providing a balanced substrate that allowed efficient nutrient metabolism and the maintenance of proper dynamic equilibrium.

Including *Tenebrio molitor* larvae meal as a protein replacement in broiler feeds aligns with sustainable animal production trends over the last five years (Van Huis *et al.*, 2021). The rearing substrate and processing of TmLM can affect the fatty acid profile and nutritional composition variables that influence lipid metabolism outcomes and meat quality (Montalbán *et al.*, 2023). The small sample size and non-significant differences in carcass and organ parameters of broilers in this study suggest that TmLM can be included in the diet without adverse effects, at least under these confined conditions.

TOTAL BLOOD CHOLESTEROL, TRIGLYCERIDES, HDL, LDL, AND THIGH MEAT CHOLESTEROL.

The effect of different levels of inclusion (0, 3, 6, 9, 12%) of TmLM (TmLM) on the total blood cholesterol, triglycerides, HDL, LDL and thigh meat cholesterol of broilers are presented in Table 4.

The difference in total blood cholesterol level is highly significant ($p < 0.05$), from 134.43 mg/dL (TmLM 0) to 116.85 mg/dL (TmLM 12), with a 17.58 mg/dL decrease in overall blood cholesterol level (BCL). Continued positive blood lipid-lowering results are precise, with basal triglyceride (TG) levels decreasing from 39.03 mg/dL to 28.18 mg/dL. The (Lipid-lowering) Treatment is confirmed positive-blood: Cardiovascular and lipids. Healthy HCL is identified and increased from 38.93 mg/dL to 51.60 mg/dL (TmLM 0 to 12). Low-Density

Lipids (LDL) (high cardiovascular risk). The remaining cholesterol, 81.68 mg/dL, decreased by 27.63 mg/dL to 53.35 mg/dL, suggesting a reduction in cardiovascular risk. The thigh meat cholesterol (health nutrient quality of meat) is reduced from 120.45 mg/100g to a positive 100.10 mg/100g cholesterol (TmLM 12). The evidence confirms the treatment's improvement, and high-nutrient-quality meat has a moderate overall positive cardiovascular effect. The therapy now significantly improves overall blood lipid profile from (Lipid lowering) to still cardiovascular positive overall blood cholesterol, high to low (restrictive).

Blood lipid profile was significantly improved due to the high and moderate inclusion of *Tenebrio molitor* larva meal (TmLM) in the diets administered to the chickens. Total blood cholesterol was reduced by 14.59 mg/dL, from 134.44 mg/dL to 116.85 mg/dL, and triglycerides by 10.85 mg/dL, from 39.03 mg/dL to 28.18 mg/dL. In comparison, high-density lipoprotein (HDL) cholesterol increased from 38.93 mg/dL to 51.60 mg/dL, and low-density lipoprotein (LDL) cholesterol decreased from 81.68 mg/dL to 53.35 mg/dL. This alteration in the blood lipid profile reduced cardiovascular disease risk by increasing the HDL/LDL ratio.

In addition, there was a reduction in the cholesterol level of thigh meat from 120.45 mg/100 g to 100.10 mg/100 g in the TmLM 12 group (12% TmLM), and this was a potential improvement in the nutritional quality of the meat due to the health benefits derived from the substitutive traditional meat and animal protein. In addition, the TmLM supplement reduced cholesterol levels in thigh meat and improved its nutritional quality, benefiting consumers' health who replace traditional animal protein. The potential health benefits to humans from improved lipid metabolism stemmed from the unbalanced high-protein, low-saturated fat, and high-fiber content of TmLM.

The use of TmLM at levels of 6-12% has been reported to reduce total cholesterol and LDL by 15–20%, and to increase the HDL/LDL ratio, without any negative effects on the growth performance of broiler chickens (Mao *et al.*, 2020). Makkar *et al.* (2022) assessed the antihyperlipidemic effects of TmLM, attributed to omega-3 fatty acids and

other antioxidants, and confirmed a 25% reduction in triglycerides in animals. In TmLM, Cullere *et al.* (2021), reported increases in triglycerides and LDL above 20%, likely due to synergistic effects with other dietary constituents. Van Huis (2022), documented the range of TmLM functionality across various animal species, nutritional formulations, and other climatic conditions, and suggested the need for further research to optimize these.

OMEGA-3, -6, -9, DHA, EPA, AND FAT OF THIGH MEAT

The effect of different levels of inclusion (0, 3, 6, 9, 12%) of TmLM on the on omega-3, -6, -9, DHA, EPA and fat of thigh meat. of broilers are presented in Table 5.

However, at TmLM 12, there is a significant percentage increase ($p < 0.05$) to 0.91 mg/dL, meaning that the additions or treatments of 12 TmLM are beneficial to increasing the Omega-3 fatty acids concentration. There is consistency in omega-6 fatty acid percentages from TmLM 0 to TmLM 9, and from TmLM 0 to TmLM 9 and 17.18 mg/dL to 17.39 mg/dL, and then at TmLM 12, there is a significant increase to 18.65 mg/dL, indicating that this level of treatment increases omega-6 levels. Omega-9 fatty acids percentage consistently increases from TmLM 0 (40.56 mg/dL) to TmLM 12 (42.14 mg/dL). There are significant percentages at each treatment level, indicating that this is significantly facilitated and determined to be a function of omega-9, with increasing percentages of fatty acids. There is a correlation with the proportions of TmLM treatments. The fat content at each TmLM level is minimal, ranging from 8.40% in TmLM 0 to 8.33% in TmLM 12.

Table 5 shows that the addition of TmLM to the diet of broiler chickens improved the omega-3 fatty acid profile of the thigh meat. There was a 0.82 mg/dL to 0.85 mg/dL stabilization at TmLM levels between 0 and 9, followed by a significant elevation to 0.91 mg/dL at 12% TmLM. There were positive effects on the production or deposition of omega-3 fatty acids up to 12% levels of TmLM in TmLM therapy. This may be attributed to the relatively high nutritional profile of TmLM, consisting of preeminent unsaturated fatty acids and high-quality proteins known to optimize lipolysis. According to Cullere *et al.* (2021), dietary supplementation with mealworm (*Tenebrio*

molitor) larva meal resulted in a 15–20% increase in omega-3 fatty acid content in chicken meat. We attribute this phenomenon to higher levels of desaturase-activating enzymes that drive omega-3 synthesis, thus explaining the heightened levels observed in this study at higher TmLM.

A similar pattern was observed with omega-6 fatty acids; however, the levels remained essentially constant from TmLM 0 to TmLM 9 at around 17.18–17.39 mg/dL, before increasing to 18.65 mg/dL at TmLM 12. This positive increase indicates that at this level, TmLM enhanced omega-6 content, presumably due to the exercise of TmLM lipids and antioxidants on omega-6 fatty acids' metabolic routes. This is contrary to the findings of Schiavone *et al.* (2020), who claimed that the supplementation of insect meal in hens' diets did not consistently lead to an increase in omega-6 levels. The findings were contingent on the insect species used and particularities of the basal diet formulation, demonstrating the variability due to the specific details of the study.

The omega-9 fatty acids showed a gradual, consistent increase from TmLM level 0 (40.56 mg/dL) to TmLM level 12 (42.14 mg/dL). Each treatment level showed a significant difference, demonstrating a direct relationship to the strength of the TmLM treatment. Increased monounsaturated fatty acids in TmLM, and the greater increase, likely explain why fatty acids are absorbed and stored in chicken muscle tissue. As noted by Gasco *et al.* (2020), mealworm meal can increase omega-9 fatty acids through increased lipogenic activity, which explains the increase observed in the study. Contrary to Gasco *et al.* (2020), research carried out by Józefiak *et al.* (2023) suggests that the impact of TmLM on omega-9. Across chicken strains, the difference is not significant. Variations in the increase were due to genetics, suggesting that other variables need to be considered.

The fat content of thigh meat at TmLM levels of 0 (8.40%) and 12% (8.33%) was not directly influenced by the inclusion of TmLM in the diet. The observed differences are likely attributable to interactions between TmLM and other dietary ingredients, as well as overall diet balance, which can affect fat deposition. Biasato *et al.* (2017) reported that *Tenebrio molitor* larvae meal does not consistently increase total fat content and may, in certain

Table 5: Effect of TmLM treatment on omega-3, -6, -9, DHA, EPA and fat of thigh meat.

Parameters measured	TmLM 0	TmLM 3	TmLM 6	TmLM 9	TmLM 12	SEM
Omega-3 fatty acids (mg/dL)	0.82 ^b	0.83 ^b	0.84 ^b	0.85 ^b	0.91 ^a	0.01
Omega-6 fatty acids (mg/dL)	17.18 ^b	17.35 ^b	17.39 ^b	17.35 ^b	18.65 ^a	2.34
Omega-9 fatty acids (mg/dL)	40.56 ^c	40.75 ^c	40.79 ^c	41.43 ^b	42.14 ^a	1.25
Thigh meat fat (%) ^{ns}	8.40	8.26	8.34	8.21	8.33	0.39

Note: ^{a,b,c} = Superscripts that differ in each row showing a significant difference ($p < 0.05$). ns = non-significant ($p > 0.05$).

cases, decrease fat deposition due to the anti-obesogenic properties of insect-based feeds, with observed variability likely associated with dose and genetic differences among broilers. The results of this study indicate that including TmLM up to 12% improves the fatty acid composition of broiler thigh meat, with changes observed across several fatty acid types.

CONCLUSIONS

This study demonstrates that dietary inclusion of *Tenebrio molitor* larvae meal (TmLM) up to 12% can effectively replace imported fish meal in broiler diets without adversely affecting growth performance, carcass yield, abdominal fat deposition, or the relative weights of major physiological organs. The absence of significant differences in carcass and organ parameters indicates that TmLM maintains normal physiological function and productive performance in broiler chickens. Furthermore, supplementation with TmLM significantly improved blood lipid profiles by reducing total cholesterol, triglycerides, and low-density lipoprotein (LDL) concentrations while increasing high-density lipoprotein (HDL) levels. In addition, TmLM reduced thigh meat cholesterol content and favorably modified the fatty acid composition, thereby enhancing the nutritional quality of broiler meat without increasing total fat content. These findings support the potential of TmLM as a sustainable and nutritionally valuable alternative to imported fish meal in broiler production. Further studies are recommended to evaluate the long-term effects of TmLM supplementation, investigate its application in different broiler genotypes, assess the influence of rearing substrates and processing methods on its nutritional composition, and conduct economic analyses and large-scale field trials to facilitate its commercial adoption in poultry production systems.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to Universitas Andalas which funded this research with Klaster Riset Publikasi Guru Besar No.: T/20/UN16.17/PP.Pangan/PDU-KRP1GB-Unand/2022. The authors also thank the Dean and the Chancellor for providing the opportunity and facilities to conduct this research.

NOVELTY STATEMENT

This study provides a comprehensive evaluation of *Tenebrio molitor* larvae meal (TmLM) as a complete substitute for imported fish meal in broiler diets by simultaneously assessing carcass yield, physiological organ health, blood lipid metabolism, and thigh meat fatty acid composition. Unlike previous studies that primarily focused on growth

performance or carcass traits alone, this research integrates multiple health and meat quality indicators, demonstrating that TmLM inclusion up to 12% can fully replace imported fish meal without adverse effects while significantly improving lipid profiles and enriching beneficial fatty acids in broiler thigh meat.

AUTHOR'S CONTRIBUTION

Nuraini conceived and designed the study, supervised the experiment, analyzed the data, and drafted and revised the manuscript. YSN contributed to data analysis. RA and YCS contributed to assisted in animal management, data curation and formal analysis. FM contributed to data collection, statistical analysis and manuscript revision. MA contributed to laboratory work, result interpretation, and manuscript revision. AT participated in data validation, literature review, and final manuscript editing. All authors read and approved the final manuscript.

ETHICAL APPROVAL

All experimental protocols were sanctioned by the Animal Care Committee of Universitas Andalas (2019). All investigations were executed in accordance with the International Guiding Principles for Animal Research and Welfare.

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

- AOAC (2010). Official Methods of Analysis of AOAC International (18th ed.). AOAC International.
- Benzertiha A, Kierończyk B, Rawski M, Kołodziejcki P, Bryszak M, Józefiak D (2019). *Tenebrio molitor* and *Zophobas morio* full-fat meals in broiler chicken diets: Effects on nutrients digestibility, cecal microbiome, and immune system traits. *Animals*, 9(12): 1128. <https://doi.org/10.3390/ani9121128>
- Biasato I, De Marco M, Rotolo L, Dabbou S, Meineri G, Capucchio MT, Schiavone A (2022). Effects of insect meal inclusion on broiler performance and carcass traits: A meta-analytical approach. *Poult. Sci.*, 101(6): 101964.
- Biasato I, Gasco L, De Marco M, Renna M, Rotolo L, Dabbou S, Capucchio MT, Biasibetti E, Tarantola M, Bianchi C, Cavallarin L, Gai F, Pozzo L, Dezzutto D, Bergagna S, Schiavone A (2017). Effects of yellow mealworm larvae (*Tenebrio molitor*) inclusion in diets for female broiler chickens: implications for animal health and gut histology. *Anim. Feed Sci. Technol.*, 234: 253–263. <https://doi.org/10.1016/j.anifeedsci.2017.09.014>

- Bovera F, Loponte R, Marono S, Piccolo G, Iaconisi V, Parisi G, Nizza A, Gasco L (2020). Dietary inclusion of *Tenebrio molitor* meal in broiler chickens. Anim. Feed Sci. Technol., 262: 114439.
- Cullere M, Tasoniero G, Lussiana C, Martínez S, Schiavone A (2019). Effects of dietary insect meal on lipid metabolism in poultry species. Front. Physiol., 10: 741.
- Cullere M, Zotte DA, Tasoniero G (2021). Black soldier fly and yellow mealworm larvae for broiler chickens: Effects on growth performance, carcass traits, and meat quality. J. Insects Food Feed., 7(3): 345-356.
- Filho MAN, Pereira RT, Oliveira ABS, Suckeveris D, Junior MAMB, Soares CAP, Menten JFM (2021). Nutritional value of *Tenebrio molitor* larvae meal for broiler chickens: metabolizable energy and standardized ileal amino acid digestibility. J. Appl. Poult. Res., 30: 100102. <https://doi.org/10.1016/j.japr.2020.10.001>
- Gasco L, Biasato I, Dabbou S, Schiavone A, Gai F (2019). Animals fed insect-based diets: State-of-the-art on digestibility, performance and product quality. Animals, 9(4): 170. <https://doi.org/10.3390/ani9040170>
- Gasco L, Biasato I, Dabbou S, Schiavone A, Gai F (2020). *Tenebrio molitor* meal in rainbow trout (*Oncorhynchus mykiss*) diets: Effects on animal performance, nutrient digestibility and chemical composition of fillets. Ital. J. Anim. Sci., 19(1): 128-137.
- Henry M, Gasco L, Piccolo G, Capucchio MT, Dabbou S (2021). Allergens and anti-nutritional components in insect-based feeds: A review. Anim. Nutr., 8(5): 462-470.
- Inaudi NGH, Komi A, Komi A, Gnatepe MK, Vinakpon G, Kokou T (2025). Impacts of *Tenebrio molitor* larval meal on zootechnical performance, biochemical indices, and intestinal morphometry in broiler chickens. World Vet. J., 15(4): 1053-1062. <https://doi.org/10.54203/scil.2025.wvj107>
- Jiang T, Zhao X, Li H, Zhang L, Tang B, Ding Y, Wu Y (2024). Effects of yellow mealworm (*Tenebrio molitor*) larvae meal on the growth performance, serum biochemical parameters and caecal metabolome in broiler chickens. Ital. J. Anim. Sci., 23(1): 813-823. <https://doi.org/10.1080/1828051X.2024.2350230>
- Józefiak D, Józefiak A, Kierończyk B, Rawski M, Świątkiewicz S, Długosz J (2023). Insects as feed materials in poultry nutrition: A review. Anim. Nutr., 14(1): 1-15.
- Makkar HPS, Tran G, Heuzé V, Ankers P (2022). State-of-the-art on the use of insects as animal feed. Anim. Feed Sci. Technol., 285: 115161.
- Mao X, Zhang J, Li Y, Zhang H, Wang X (2020). Evaluation of *Tenebrio molitor* larvae as a protein source in broiler diets. Poult. Sci., 99(9): 4352-4359.
- Montalbán A, Martínez-Miró S, Schiavone A, Madrid J, Hernández F (2023). Growth performance, diet digestibility, and chemical composition of mealworm (*Tenebrio molitor* L.) fed agricultural by-products. Insects, 14: 824. <https://doi.org/10.3390/insects14100824>
- Nuraini N, Nur YS, Djulardi A, Amizar R, Sari YC (2022a). Medium for cultivation *Tenebrio molitor* larvae and its effect as an alternative animal protein source in the diet on performance of broiler. Adv. Anim. Vet. Sci., 10(11): 2335-2346. <https://doi.org/10.17582/journal.aavs/2022/10.11.2335.2346>
- Nuraini N, Nur YS, Djulardi A, Amizar R, Sari YC (2022b). The effect of *Tenebrio molitor* caterpillar in the diet on production performance of laying quail. Adv. Anim. Vet. Sci., 10(10): 2090-2099. <https://doi.org/10.17582/journal.aavs/2022/10.10.2090.2099>
- Popova T, Petkov E, Vlahova-Vangelova D, Kolev N, Balev D, Dragoev S, Dimov K (2025). Meat quality and fatty acid profile in broilers as affected by low-fat *Tenebrio molitor* meal in the diet. Front. Anim. Sci., 6: 1629411. <https://doi.org/10.3389/fanim.2025.1629411>
- Schiavone A, Dabbou S, Petracci M, Zampiga M, Sirri F, Biasato I (2020). Influence of insect meal on broiler growth, nutrient digestibility and meat quality. Animals, 10(6): 1073.
- Scott ML, Nesheim MC, Young RJ (1982). Nutrition of the chicken (3rd ed.). M.L. Scott and Associates. <https://archive.org/details/nutritionofchick00scot>
- Sitompul S (2004). Analisis Asam Amino dalam Tepung Ikan dan Bungkil Kopra. Bull. Teknik Pertanian., 9(1): 33-37.
- Toral PG, Renna M, Frutos P, Gasco L, Hervás G (2025). Insect fat as feed: Potential to modify the fatty acid composition of animal-derived foods. Anim. Nutr., 22: 179-190. <https://doi.org/10.1016/j.aninu.2025.03.016>
- Van Huis A (2022). Edible insects: Challenges and prospects. Entomol. Res., 52(4): 161-177. <https://doi.org/10.1111/1748-5967.12582>
- Van Huis A, Itterbeek JV, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P (2021). Edible insects as a protein source: Current status and prospects. Anim. Front., 11(2): 20-27.
- Vasilopoulos S, Giannenas I, Savvidou S, Bonos E, Rumbos CI, Papadopoulos E, Fortomaris P, Athanassiou CG (2023). Growth performance, welfare traits and meat characteristics of broilers fed diets partly replaced with whole *Tenebrio molitor* larvae. Anim. Nutr., 13: 90-100. <https://doi.org/10.1016/j.aninu.2022.12.002>