p-ISSN 2615-787X e-ISSN 2615-790X
Accredited by Directorate General of Higher Education, Research, and Technology, Republic of Indonesia, No. 225/E/KPT/2022

Tropical Animal Science Journal, January 2025, 48(1):19-26
DOI: https://doi.org/10.5398/tasj.2025.48.1.19
Available online at https://journal.ipb.ac.id/index.php/tasj

Production Performance, Meat Quality, and Lipid Profile of Broiler Duck Fed Diets Containing Selenium-Rich *Hermentia illucens* Larval

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(Received 22-08-2024; Revised 23-10-2024; Accepted 28-10-2024)

ABSTRACT

The purpose of this study was to determine the effects of Se-enriched *Hermetia illucens* larvae meal (Se-BSFL) on the production performance, meat quality, and lipid profile of broiler ducks. A total of 250 one-day-old, unsexed hybrid broiler ducklings were randomly allocated into five dietary treatment groups, each with five replications of 10 ducklings, namely a control diet (T1), and control with added 5% (T2), 7.5% (T3), and 10% (T4) Se-BSFL, and a positive control diet with 10 mg/kg Se-Yeast (T5) for 42-days. Feed intake and body weight were measured on a weekly basis. At the end of the trial, one bird was selected from each replicate and sacrificed to determine carcass composition and blood serum profiles. The results indicated that dietary supplementation of 5% Se-BSFL resulted in higher final body weight, body weight gain, feed intake, and lower feed conversion ratio than the Se-yeast supplemented diet. Supplementation of Se-BSFL at 5% to 10% significantly affected ($p<0.05$) high-density lipoprotein, low-density lipoprotein, cholesterol, and triglyceride compared to those of T1 and T5. Supplementation with 5% and 7.5% Se-BSFL ($p<0.05$) has higher levels of monounsaturated fatty acids in comparison to T1 and T5. Moreover, the supplementation of Se-BSFL did not influence the physical quality of the meat. In conclusion, feeding Se-BSF at 5% is recommended in diets as it does not negatively affect production performance and carcass traits. These findings suggest that the inclusion of Se-BSFL in broiler duck diets enhances their fatty acid and serum lipid profiles, indicating potential benefits from the use of Se-BSFL as a feed component in poultry production.

Keywords: BSF larvae meal; fatty acid profile; feed additive; organic selenium

INTRODUCTION

Food production of animal origin is expected to increase by 60%-70% to meet the needs of the world's population by 2050, according to the Food and Agriculture Organization (FAO, 2022). This rise in consumption will inevitably lead to an expansion in livestock production. The cost of animal feed in the livestock industry contributes about 60%-75% of the total cost of animal feed, while the need for protein-source feeds accounts for more than 15% of the total cost of animal feed (Khan *et al.,* 2016). Currently, the search for innovative and sustainable alternative feed sources, especially those derived from insects, is an essential challenge in the animal feed industry. Feeding insects to animals in their diet impacts their growth performance and the product's chemical composition (Sogari *et al.,* 2023). Black soldier flies (BSF), or *Hermetia illusion* L., have been studied for their potential to feed a range of livestock. BSF larvae contain elevated protein levels (37%-63%) and other macro and micronutrients essential for animal feed. Existing research on BSF larvae in poultry, pigs, and fish feed shows that larvae can only partially replace conventional feed ingredients (Cullere *et al.,* 2016). Vilela *et al.* (2021) reported that up to 20% full-fat BSF larvae could be incorporated into broiler diets without negatively impacting performance or health, with 15%-20% inclusion positively influencing immune parameters. Heuvel *et al.* (2021) reported that BSFL meal and fat could completely replace soybean feed in the diets of high-performance laying hens.

Selenium, an essential trace mineral, is pivotal in numerous physiological processes, including immune function, metabolism, antioxidant activity, and growth (Gu & Gao, 2022). As a key component of selenoproteins, selenium contributes to the synthesis of at least twenty-five selenoproteins, which are integral to various physiological mechanisms that may enhance animal production (Silva *et al.,* 2019). Wang *et al.* (2021) reported that supplemental selenium could enhance growth performance and improve the meat quality of broilers. Dietary supplementation of selenium might improve meat quality, possibly due to the enhanced antioxidative ability and selenium deposition in the muscles of broilers. Selenium was present in both inorganic and organic forms. Organic selenium has better bioavailability, which makes it safer than inorganic selenium (Surai *et al.,* 2018). Due to their natural propensity to accumulate selenium, insects have been the subject of many studies that explored the possibility of biofortifying insects with selenium as an alternative source of selenium in future feeds (Ferrari *et al.*, 2022). Selenium conjugated to insect protein (SCIP) is a novel form of organic selenium exploited for laying hens to produce selenium-enriched eggs. SCIP is obtained through two biotransformation steps, including microbial fermentation and insect synthesis, to increase selenium concentration and ensure safety without toxic side effects of the diets (Qiu *et al.*, 2021). Ferrari *et al.* (2022) reported that the biofortification of selenium in BSF prepupae reared on selenium-supplemented diets was more than five times higher than in the control group fed plant-based ingredients, indicating that BSF prepupae can convert inorganic selenium to organic selenium. Zhang *et al.* (2024) reported that selenium-riches BSF supplementation in diets for laying hens improved antioxidant capacity and increased the selenium content of eggs.

Broiler ducks represent a poultry type with significant development potential. In 2022, the global duck (*Anas spp*.) population reached 1.15 billion, and 1.0 billion (89%) were found in Asia (FAO, 2022). Duck meat production in Indonesia averaged 37,878 tons/year over the past 5 years, contributing less than 1% of the meat production of all animals nationwide (Directorate General of Animal Husbandry and Animal Health Indonesia, 2023). Duck meat has high nutritional value because it contains all the essential amino acids and has a healthy fatty acid profile. The content and composition of fatty acids in muscle are one of the main factors affecting meat quality, including meat color, juiciness, taste, and nutritional value (Kamal *et al.*, 2022). Currently, there are no reports on the application of selenium-enriched black soldier fly larvae meal (Se-BSFL) in the diets of broiler ducks. It has been hypothesized that dietary supplementation of Se-BSFL can improve the growth, carcass traits, and meat quality of broiler ducks. The purpose of this study was to determine the effects of Se-enriched *Hermetia illucens* larvae meal (Se-BSFL) on the production performance, meat quality, and lipid profile of broiler ducks.

MATERIALS AND METHODS

Ethical Approval

This experiment methodology was conducted according to the Animal Care and Research Ethics Committee guidelines at the Institut Biosains Universitas Brawijaya, Indonesia, under the ethical number (No 004-KEP-UB-2024).

Processing of Se-BSFL Meal

Dried and bio-synthesized Se-BSFL meal was obtained from the Department of Poultry Product Processing, Community College State of Putra Sang Fajar Blitar, Indonesia. The procedure for producing Se-BSFL meal by enriching sodium selenite through two biotransformation steps refers to the research of Qui *et al.* (2021). First, larval growth media enriched with sodium selenite was fermented using yeast *Saccharomyces cerevisiae* under optimal conditions. Rice bran and soybean meal were used as raw materials, with 400 mg of sodium selenite supplemented into the medium (Kurniawan *et al.*, 2024). The fermented growth media (Se-rich protein yeast) was given as larval feed. Upon harvesting, the selenium-enriched larvae were dried and ground to give Se-BSFL meal. Selenium content was measured using the inductive plasma plus mass spectrometer (ICP-MS) technique. The nutritional and selenium content of a Se-BSFL meal is shown in Table 1. The morphology and particle size of the Se-BSFL meal were analyzed using scanning electron microscopy (a) and analysis of EDX elementary oxide (b), respectively (Figure 1).

Experimental Design and Bird Management

A total of 250 (one-day-old) hybrid unsexed broiler ducklings were randomly allocated into five dietary treatments in five replicates, with 10 ducklings per replicate. All ducklings in each replicate were raised in communal cages (100 cm-width × 200 cm-length × 60 cm-height) with similar conditions. The experimental compartment was equipped with waterers and feeders. Throughout the rearing period, fresh water and feed were given daily. There were two phases to the feeding plan during the trial period: starter (day 1:21) and finisher (day 22:42). Five experimental diets were formulated as starter-finisher diets to iso-nitrogenic as recommended by NRC (1994). The diets provided included a controlled diet with 5% BSFL meal (T1) and positive control with 5% BSFL meal + 10 mg/kg Se-yeast (T5). The remaining three groups (T2, T3, and T4) received diets containing Se-BSFL meal at 5%, 7.5%, and 10%, respectively. Table 2 indicates that all nutrients were taken and provided.

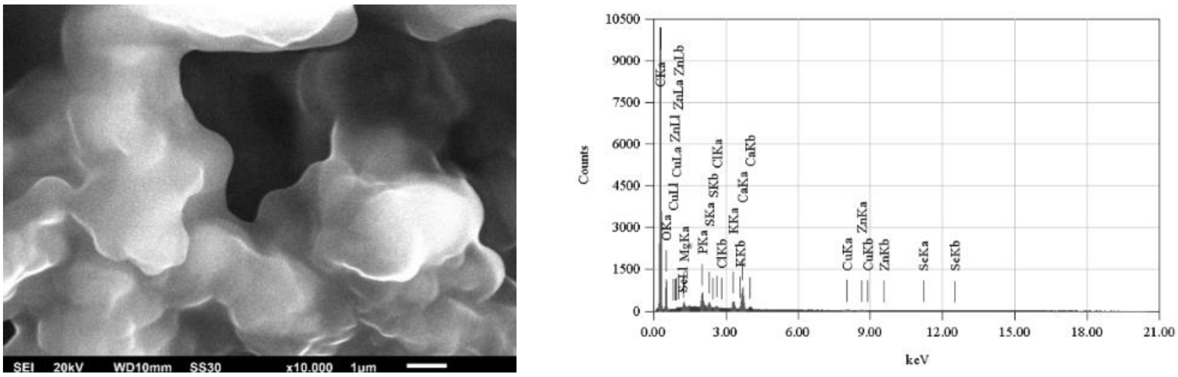
Production Performance Measurement

Recording the ducks' initial weight and tracking their average body weight gain (BWG) and feed intake (FI) for each replicate to determine the feed conversion ratio (FCR) were done weekly. Following a random selection process, each replica's representative birds were slaughtered by hand when they reached 42 days of age. Prior to slaughter, the birds were given a 12-hour fasting period, scalded in a hot water bath, and

Table 1. Nutritional and selenium contents of BSFL and Se-BSFL meal

Nutrient content	BSFL meal	Se-BSFL meal
Dry matter (%)	94.85	94.65
Ash (%)	6.15	6.58
Crude protein (%)	41.71	41.81
Crude lipid (%)	36.90	36.80
Selenium content (mg/kg)	1.26[a]	223.61[b]

Note: Test result of Laboratory Nutrition and Feed Technology, University of Brawijaya. [a, b] Means within a line with different superscripts are different ($p<0.05$). BSFL= *Hermetia illucens* larvae meal; Se-BSFL= Se-enriched *Hermetia illucens* larvae meal.



(a) (b)

Figure 1. Morphological and size verification of Se-enriched *Hermetia illucens* larvae meal (Se-BSFL) was performed using scanning electron microscopy (a) and analysis of EDX elementary oxide (b).

Table 2. Composition of the experimental broiler duck diets containing different levels of Se-BSFL meal

Item	Starter (0-21 days)					Finisher (22-42 days)				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Corn (%)	10.05	10.05	9.67	9.29	10.05	19.03	19.03	18.65	8.03	19.03
Soybean meal (%)	29.05	29.05	26.93	24.81	29.05	20.07	20.07	17.95	25.07	20.07
Rice bran (%)	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00
Fish meal (%)	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Palm oil (%)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00	2.00
Premix* (%)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Salt (%)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Lysine (%)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DL-methionine	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
BSF meal	5.00	-	-	0.00	5.00	5.00	-	-	0.00	5.00
Se-BSFL meal	-	5.00	7.50	10.00	-	-	5.00	7.50	10.00	-
Nutrient composition										
ME (kcal/kg)	2,860	2,860	2,859	2,859	2,860	2,945	2,945	2,944	2,943	2,945
CP (%)	20.00	20.00	20.00	20.00	20.00	18.00	18.00	18.00	18.00	18.00
CL (%)	7.96	8.17	9.00	9.83	7.96	9.08	9.30	10.12	10.95	9.08
CF (%)	3.00	3.00	2.87	2.74	3.00	2.92	2.92	2.78	2.65	2.92
Ca (%)	0.60	0.60	0.59	0.58	0.60	0.55	0.55	0.54	0.53	0.55
P (%)	0.33	0.33	0.31	0.30	0.33	0.28	0.28	0.27	0.25	0.28
Lys (%)	1.58	1.58	1.57	1.57	1.58	1.38	1.38	1.38	1.37	1.38
Met (%)	0.65	0.65	0.66	0.67	0.65	0.60	0.60	0.61	0.62	0.60
Se (mg/kg)	0.06	11.15	16.73	22.36	10.00	0.06	11.15	16.73	22.36	10.00

Note: *Premix (per kg of diet)= Vitamin A, 10,000 IU; Vitamin D3, 4000 IU; Vitamin E, 20 mg; Vitamin K3, 3 mg; Vitamin B1, 2.2 mg; Vitamin B2, 8 mg; Vitamin B6, 5 mg; Vitamin B12, 9 g; folic acid, 1.5 mg; biotin, 130 g; calcium pantotenate, 25 mg; nicotinic acid, 65 mg; iron, 80 mg; copper, 8 mg; manganese, 60 mg; zinc, 40 mg; iodine 0.33 mg. T1= control diet with 5% BSFL, T2= 5% Se-BSFL, T3=: 7.5 % Se-BSFL, T4= 10% Se-BSFL, T5= Control with 5% BSFL + 10 mg/kg Se-yeast. Se-enriched *Hermetia illucens* larvae meal (Se-BSFL), Metabolizable energy (ME), Crude Protein (CP), Crude Lipid (CL), Crude Fiber (CF), Calcium (Ca), Phosphorus (P), Lysine (Lys), Methionine (Met).

their feathers were mechanically removed following bleeding. The broiler duck carcass attributes were then determined by weighing the carcass, the muscles in the breast and legs, and calculating the relative weight as a percentage of the live body weight.

Lipid Profile of Blood Serum

At the end of the experiment, blood samples were collected from each replicate, selected based on average body weight. Serum separation was achieved by centrifuging the blood samples in sterile, non-heparinized tubes for 15 minutes at 4 °C at 3000 rpm. Before being subjected to additional biochemical examination, the serum was divided into Eppendorf tubes and kept at -20 °C (Abdel-moneim *et al.*, 2022). Serum cholesterol, high-density lipoprotein (HDL), and low-density lipoprotein (LDL) levels were measured using a commercial kit and spectrophotometer analysis.

Meat Quality and Fatty Acid Profile

Samples of the pectoralis major muscle were collected to assess the physical quality of the meat and analyze its fatty acid (FA) composition, following the methodology used by Vilela *et al.* (2021). For the following cooking loss analysis, vacuum-packed 65 g blocks of meat were weighed (fresh sample weight) and kept at -20 °C. The frozen samples were tested for cooking loss by immersing them in a water bath set at 85 °C for 25 minutes. The cooking process was stopped by running cold tap water for 30 minutes. After being taken out of the bag, the samples were dried out by wrapping them in paper towels, and they were weighed to determine the amount of cooking loss. A handheld pH meter was used to measure the samples› pH in duplicate. The pH meter was calibrated at room temperature, and buffers with pH values of 4.0 and 6.88 were used. Gas chromatography was used to determine the FA profile (GC). FAME, or fatty acid methyl esters, are formed by converting the fatty acids. Gas chromatography was used to determine the FAME of the related fatty acids. The retention times of individual standards were compared to identify fatty acid methyl esters. They were found by comparing the retention durations of the fatty acids with the chosen standards. The chromatographic peak regions were used to compute the relative quantities of fatty acids. Guldas *et al.* (2022) present the results as the mean plus standard deviation of three independent samples.

Statistical Analysis

All the data were presented as means, and the means were analyzed statistically using the SPSS program based on one-way ANOVA with a completely randomized design. Mean differences were assessed with the least significant difference (LSD) test, with statistical significance set at p<0.05.

RESULTS

Effect of Se-BSFL Meal on the Production Performance

The growth performances of broiler ducks fed the experimental diets are presented in Table 3. No mortality was observed throughout the experiment. There were significant differences (p<0.05) between treatments for any production performance parameters measured throughout the study's duration. In the starter period (0-21 d), the 10% Se-BSFL meal-supplemented diets significantly decreased (p<0.05) FI, FBW, and BWG, followed by those administered 7.5% Se-BSFL and Se-yeast. In the finisher period (22-42 d), birds that were fed 5% Se-BSFL in the diet showed improved body weight gain and a superior feed conversion ratio (p<0.05). On the other hand, diets with more than 7.5% Se-BSFL significantly (p<0.05) reduced FI and FBW. Over the 42-day trial, the 5% Se-BSFL supplemented diet showed a higher FBW, BWG, and FI and lower FCR than the Se-yeast supplemented diet. Nonetheless, no significant differences were observed between the 5% Se-BSFL and control diets. Overall, the 5% Se-BSFL diet did not negatively affect the growth performance of broiler ducks.

Effect of Se-BSFL Meal on Carcass Trait and Meat Quality

Carcass traits, visceral organs, and meat quality of the broiler ducks are shown in Table 4. The Se-BSFL meal-supplemented diets at 5% showed higher slaughter weight, carcass yield, breast yield, breast percentage, and thigh yield compared to the 7.5% Se-BSFL and Se-yeast diets. However, no significant differences were observed in carcass traits between the 5% Se-BSFL and control diets. The Se-BSFL meal-supplemented diets at 7.5% significantly decreased (p<0.05) slaughter weight, carcass yield, breast yield, breast percentage, thigh yield, and thigh percentage. There was no significant carcass percentage among all experimental groups. Se-BSFL supplementation significantly affected (p<0.05) visceral organs such as the liver and gizzard but had no significant effect on the heart or abdominal fat. Meat quality, including

Table 3. Broiler duck production performance with dietary Se-BSFL meal

Variables	Treatments					SEM	p value
	T1	T2	T3	T4	T5		
0-21 d							
IBW (g)	47.00	46.88	46.58	46.56	46.60	0.191	0.942
FI (g)	1598^{d}	1538^{c}	1276^{b}	786^{a}	1385^{c}	59.95	<0.0001
FBW (g)	791^{d}	575^{c}	470^{b}	244^{a}	485^{b}	37.44	<0.0001
BWG (g)	745^{d}	527^{c}	422^{b}	198^{a}	438^{b}	37.47	<0.0001
FCR	2.15^{a}	2.95^{b}	3.08^{b}	4.08^{c}	3.17^{b}	0.150	<0.0002
22-42 d							
FI (g)	2964^{c}	2785^{bc}	2704^{b}	1928^{a}	2543^{b}	87.01	<0.0001
FBW (g)	1822^{c}	1707^{c}	1488^{b}	839^{a}	1413^{b}	72.78	<0.0001
BWG (g)	$1,031^{b}$	$1,132^{b}$	$1,019^{b}$	595^{a}	928^{b}	101.4	<0.0001
FCR	2.88^{b}	2.46^{a}	2.70^{ab}	3.23^{c}	2.78^{ab}	0.070	<0.0083
0-42 d							
FI (g)	4561^{c}	4324^{c}	3980^{bc}	2715^{a}	3928^{b}	139.11	<0.0001
FBW (g)	$1,822^{c}$	$1,707^{c}$	$1,488^{b}$	839^{a}	$1,413^{b}$	72.78	<0.0001
BWG (g)	1776^{c}	1660^{c}	1441^{b}	792^{a}	1366^{b}	72.80	<0.0001
FCR	2.57^{a}	2.60^{a}	2.77^{a}	3.42^{c}	2.90^{b}	0.070	<0.0001

Note: $^{a, b, c}$ Means within a line with different superscripts are different (p<0.05). T1= Control diet with 5% BSFL, T2= 5% Se-BSFL, T3= 7.5 % Se-BSFL, T4= 10% Se-BSFL, T5= control with 5% BSFL + 10 mg/kg Se-yeast. Se-enriched *Hermetia illucens* larvae meal (Se-BSFL), Initial body weight (IBW), Feed intake (FI), Final body weight (FBW), Body weight gain (BWG), and Feed conversion ratio (FCR).

pH, tenderness, and cooking loss, was not significantly affected by Se-BSFL supplementation.

Effect of Se-BSFL Meal on the Blood Lipid Profile

The blood lipid profiles of broiler ducks are presented in Table 5. By day 42, the Se-BSFL meal-supplemented diets significantly affected ($p<0.05$) HDL, LDL, cholesterol, and triglyceride in the serum of broiler ducks. Moreover, both Se-BSFL and Se-yeast diets significantly reduced ($p<0.05$) cholesterol, triglycerides, LDL, and HDL levels compared to those of control diets (T1).

Effect of Se-BSFL Meal on the Fatty Acid Profile

The fatty acid composition of the breast meat in broiler ducks fed the experimental diets are presented in Table 5. There were significant differences ($p<0.05$) between treatments for any fatty acid profile of the

Table 4. Broiler duck carcass trait, visceral organs, and meat quality are affected by dietary Se-BSFL meal

Variables	Treatments				SEM	p value
	T1	T2	T3	T5		
Carcass traits						
Slaughter weight (g)	1880^{b}	1886^{b}	1708^{ab}	1519^{a}	49.39	0.011
Carcass yield (g)	1157^{b}	1159^{b}	1028^{ab}	906^{a}	35.10	0.015
Carcass percentage (%)	62.11	62.57	60.86	60.66	0.562	0.360
Breast yield (g)	318^{c}	305^{bc}	258^{ab}	231^{a}	10.87	0.004
Breast percentage (%)	17.06^{c}	16.18^{bc}	15.01^{a}	15.48^{ab}	0.332	0.010
Thigh yield (g)	238^{b}	243^{b}	233^{b}	208^{a}	6.004	0.041
Thigh percentage (%)	13.09^{a}	13.73^{ab}	14.73^{bc}	14.31^{c}	0.213	0.034
Visceral organs						
Heart (%)	0.55	0.51	0.59	0.60	0.015	0.088
Liver (%)	2.33^{a}	2.52^{ab}	2.74^{bc}	2.92^{c}	0.084	0.017
Gizzard (%)	2.69^{a}	2.77^{b}	3.24^{c}	3.41^{c}	0.103	0.011
Abdominal fat (%)	1.38	1.59	1.39	1.45	0.068	0.704
Physical quality of meat						
pH	6.15	5.59	6.21	6.53	0.136	0.079
Tenderness	14.07	13.43	13.56	13.45	0.179	0.569
Cooking loss (%)	45.74	47.81	45.54	48.67	0.009	0.613

Note: [a, b, c] Means within a line with different superscripts are different ($p<0.05$). T1= Control diet with 5% BSFL, T2= 5% Se-BSFL, T3= 7.5 % Se-BSFL, T4= 10% Se-BSFL, T5= control with 5% BSFL + 10 mg/kg Se-yeast. Se-enriched *Hermetia illucens* larvae meal (Se-BSFL).

Table 5. The blood lipid and fatty acid profiles of meat with dietary Se-BSFL meal on broiler duck

Variables	Treatments				SEM	p value
	T1	T2	T3	T5		
Blood lipid profile						
HDL (mg/dl)	147.96^{d}	93.01^{b}	100.90^{c}	89.40^{a}	7.10	< 0.001
LDL (mg/dl)	152.89^{d}	89.78^{a}	93.94^{b}	107.72^{c}	7.56	< 0.001
Cholesterol (mg/dl)	166.00^{a}	90.90^{b}	88.47^{b}	88.83^{b}	10.01	< 0.001
Triglyceride (mg/dl)	36.93^{c}	36.83^{c}	35.32^{b}	33.58^{a}	0.44	< 0.001
Fatty acid profile (%)						
Caprylic (C8:0)	0^{a}	0.06^{a}	0^{a}	7.09^{b}	1.13	<0.001
Decanoic (C10:0)	0.04^{a}	0^{a}	0^{a}	4.74^{b}	0.76	<0.001
Lauric (C12:0)	1.05^{b}	0.13^{a}	1.27^{b}	19.60^{c}	3.01	<0.001
Myristic (C14:0)	0.72^{b}	0.06^{a}	2.63^{b}	8.13^{c}	1.17	<0.001
Palmitic (C16:0)	16.89^{b}	12.68^{a}	17.19^{b}	11.67^{a}	1.07	0.002
Stearic (C18:0)	4.66^{a}	7.24^{b}	9.94^{c}	6.62^{b}	0.69	0.001
Oleic (C18:1n9)	38.41^{b}	44.69^{c}	46.59^{c}	29.35^{a}	2.47	<0.001
Linoleic (C18:2n6)	31.75^{c}	30.42^{c}	21.90^{b}	11.44^{a}	2.90	<0.001
Alfa Linolenic (C18:3n3)	0.87^{c}	1.38^{d}	0^{a}	0.34^{b}	0.20	<0.001
SFA	27.89^{b}	20.44^{a}	32.67^{c}	40.63^{d}	5.48	<0.001
USFA	72.11^{b}	79.50^{c}	67.29^{b}	59.34^{a}	5.39	<0.001
MUFA	36.71^{b}	44.83^{c}	45.52^{c}	34.24^{a}	2.53	0.001
PUFA	28.81^{c}	31.57^{c}	21.40^{b}	22.32^{a}	2.99	0.001

Note: [a, b, c] Means within a line with different superscripts are different ($p<0.05$). T1= Control diet with 5% BSFL, T2= 5% Se-BSFL, T3= 7.5 % Se-BSFL, T4= 10% Se-BSFL, T5= control with 5% BSFL + 10 mg/kg Se-yeast. Se-enriched *Hermetia illucens* larvae meal (Se-BSFL), high-density lipoprotein (HDL), and low-density lipoprotein (LDL), saturated fatty acid content (SFA), unsaturated fatty acid content (USFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acid (PUFA).

breast meat in broiler ducks. The groups fed diets supplemented with Se-BSFL meal 5% Se-BSFL showed higher unsaturated fatty acid followed by those administered 7.5% Se-BSFL, control diet, and Se-yeast supplemented diet. Dietary supplementation of Se-BSFL meal at 7.5% and Se-yeast significantly increased ($p<0.05$) total saturated fatty acid compared to the control diet and 5% Se-BSFL. Supplementation of Se-BSFL meal at 5% and 7.5% ($p<0.05$) showed higher monounsaturated fatty acids (MUFA) compared to control and Se-yeast diet, which led to an increase in total MUFA of breast meat was oleic acid (C18:1 v9). Meanwhile, the Se-BSFL meal-supplemented diets 7.5% and control diet significantly decreased ($p<0.05$) polyunsaturated fatty acid (PUFA) compared to control and 5% BSFL diets: mainly due to a decrease in linoleic acid (C18:2 v6).

DISCUSSION

In this study, dietary supplementation of Se-BSFL meal at 5% showed higher FBW, BWG, and FI and lower FCR than the Se-yeast supplemented diet. However, the 5% Se-BSFL supplemented diet showed no difference compared to the control diet. Overall, the 5% Se-BSFL diet did not negatively affect the growth performance of broiler ducks during the feeding period (0-42 days). This difference may be attributed to changes in feed intake. According to Souza *et al*. (2021), broiler FCR increased when BSFL meal amounts increased in the diets. The current study has shown that supplementation of Se-BSFL meal decreased feed intake. Several factors can cause this decrease. The oil content of Se-BSFL meal is indicated to affect the color, smell, and aroma of the feed, thereby influencing its palatability.

Marono *et al.* (2017) suggested that the browner, darker flavor of BSFL oil can change the flavor and aroma of feed. Hens' responses to feeding quantity are influenced by their ability to distinguish between different meal colors. Kieronczyk *et al.* (2023) observed that broilers' feed consumption was decreased while using BSFL oil during the starter period but had no effect during the finisher period. This study revealed that supplementing Se-BSFL meal at 5% significantly improved the growth performance of broiler ducks compared to Se-yeast diets at the end of the rearing period. Previous research (Khan *et al.,* 2022; Al-Quwaie, 2023) has shown that feeding selenium enhanced body weight, feed intake, and feed conversion ratio. These findings suggest that Se-BSFL, as an organic selenium source, offers growth performance benefits, possibly due to better intestinal absorption. Organic selenium may have an advantage in intestinal absorption as it is absorbed by active transport compared to inorganic selenium, which is absorbed by passive diffusion. However, Bami *et al.* (2022) reported no significant effect of Se supplementation on the body weight gain of broiler chickens.

The carcass traits are essential markers in poultry production because they aid in evaluating meat production measurements and explaining the quantity of nutrients deposited in the body. The Se-BSFL meal-supplemented diets at 5% and control diets showed higher slaughter weight, carcass yield, breast yield, breast percentage, and thigh yield than the 7.5% Se-BSFL and Se-yeast supplemented diets. However, there was no significant carcass percentage among all diet groups. The supplementation of Se-BSFL at 7.5% and Se-yeast higher liver and gizzard compared to 5% Se-BSFL and control diets. This result supports previous findings (Elkhateeb *et al.,* 2022; Al-Quwaie, 2023) reported that broilers fed a diet supplemented with different forms of selenium exhibited a more significant proportion of carcass traits. However, internal organs did not differ between treatments. The elements that influence the carcass traits include the body mass or weight and the size of the non-carcass components (Bai *et al.,* 2022). The poultry industries have made meat quality a primary objective in determining the meat products' nutritional and economic worth (Yao *et al.,* 2023). Physical attributes used to evaluate the sensory components of meat quality that affect consumers' inclination to purchase meat products were pH level, color, cooking loss, and shear force (Xie *et al.,* 2022). In the present study, the broiler ducks fed the diets supplemented with Se-yeast had numerically higher pH compared with those fed diets supplemented with Se-BSFL meal ($p>0.05$). Wei *et al.* (2024) reported that selenium could significantly reduce drip loss and shear force and increase the pH value of the breast muscle of broilers. The reason for the more significant increase in pH by Se yeast may be that Se yeast had a high bioavailability.

Lipid metabolism in the body is evaluated using serum lipid profiles, which comprise TG, LDL, HDL, and total cholesterol (El-katcha *et al.,* 2021). In this study, the supplementation of Se-BSFL meal and Se-yeast decreased HDL, LDL, cholesterol, and triglyceride serum levels compared to the control diets. Previous studies have also demonstrated that different selenium sources or levels significantly decreased LDL cholesterol, triglycerides, and blood cholesterol (Sun *et al.,* 2020; Abdel-Moneim *et al.,* 2022). Triglycerides and serum total cholesterol are commonly used indicators of lipid metabolism. The reduction in serum total cholesterol and triglyceride levels in the Se-BSFL meal group indicates that dietary supplementation with Se-BSFL significantly influences lipid metabolism and promotes fat reduction in broiler ducks.

In the current study, dietary supplementation of Se-BSFL meal at 7.5% and Se-yeast showed higher total saturated fatty acid content (SFA) and lower total PUFA compared to the control diet and 5% Se-BSFL. Meanwhile, supplementation of Se-BSFL meal at 5% and 7.5% showed higher MUFA compared to control and Se-yeast diet. This result is similar to previous findings; Daszkiewicz *et al.* (2022) found more SFAs in the muscles of birds fed a BSFL diet. Kim *et al.* (2020) reported that the concentration of PUFA decreased with the addition of Se-BSFL. According to Cullere *et al.* (2019), broiler meat's n-6/n-3 content increased when BSFL oil was added to chicken diets. The higher content of n-6 PUFA and lower concentration of n-3 PUFA are the causes of these findings. The proportion of MUFAs in the breast muscle of broiler ducks was significantly affected by Se-BSFL meal in the current study, which is in line with the findings of Culler *et al.* (2018), which showed that the proportion of MUFAs increased in the thigh muscles of birds fed BSFL meal compared to the control group. The fatty acid content of feed is known to influence the fatty acid composition of broiler meat (Verge-Merida *et al*., 2022). This study further supports the inverse relationship between the total PUFA concentration in broiler chicken meat and the dietary composition.

CONCLUSION

The study demonstrated that dietary supplementing of broiler duck diets with various levels (0%, 5%, 7.5%, and 10%) of Se-BSFL, compared to 10 mg/kg of Se-yeast, affected production performance but did not affect meat quality. Dietary Se-BSFL supplementation at 5% is recommended in diets as it does not negatively affect production performance and carcass traits. In addition, treatment with Se-BSFL supplementation resulted in markedly lower LDL and total cholesterol in blood serum and higher levels of MUFA in broiler duck meat, suggesting that the poultry industry may benefit from using Se-BSFL as a feed supplement.

CONFLICT OF INTEREST

All authors declare no conflicts of interest or financial, personal, or other relationships with other individuals or organizations involved in the study.

ACKNOWLEDGEMENT

The authors acknowledge the Higher Education Financing Center, Ministry of Education, Culture, Research, and Technology (Balai Pembiayaan Pendidikan Tinggi), and the Indonesia Endowment Fund for Education, Ministry of Finance of the Republic of Indonesia (Lembaga Pengelola Dana Pendidikan) for providing funding (Number: 0531/J5.2.3/BPI.06/10/2021).

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