JAST (Journal of Animal Science and Technology) TITLE PAGE

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ARTICLE INFORMATION	Fill in information in each box below
Article Type	Research
Article Title (within 20 words without abbreviations)	Effects of BSFL on growing-finishing pigs in growth performance, nutrient digestibility, blood profiles, and gas emission
Running Title (within 10 words)	Effect of BSFL on growing-finishing pigs
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Competing interests	No potential conflict of interest relevant to this article was reported.
Funding sources State funding sources (grants, funding sources, equipment, and supplies). Include name and number of grant if available.	This work was carried out with the support of the “Cooperative Research Program for Agriculture Science and Technology Development (Project No. RS-2022-RD009981)” from the Rural Development Administration, Republic of Korea.
Acknowledgements	Not applicable.
Availability of data and material	All data generated or analyzed during this study are included in this published article.
Authors' contributions Please specify the authors’ role using this form.	Conceptualization: Cho J, Park Y. Data curation: Chang S, Lee J. Formal analysis: Song D. Methodology: Jeon K. Software: Kim H. Validation: Yang J. Investigation: Kim H, Yang J, Chang S.

	Writing - original draft: Chang S, Park Y, Lee J, Cho J. Writing - review & editing: Chang S, Park Y, Lee J, Song D, Jeon K, Kim H, Yang J, Cho J.
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Abstract

This study was conducted to analyze the effects of replacing fishmeal in the diet of growing-finishing pigs with black soldier fly larvae (*Hermetia illucens* L., BSFL) on growth performance, nutrient digestibility, blood profiles, and gas emissions, and to determine whether BSFL can be effectively applied as an alternative protein source. A total of 36 10-week-old crossbred growing pigs [(Landrace × Yorkshire) × Duroc] with initial body weight (BW) 34.82 ± 0.43 kg were used in this study. Each treatment had 6 replicate pens, and 2 pigs were assigned to each pen. The three treatments were as follows: a basal diet containing 1% fishmeal (FM); a basal diet without fishmeal and included with 1% BSFL powder (BSFL1); a basal diet without fishmeal and included with 2% BSFL powder (BSFL2). There were no significant differences among treatment groups in BW, average daily gain, average daily feed intake, and feed efficiency during the entire experimental period. The BSFL2 group in weeks 6 and 9 showed significantly higher ($p < 0.05$) crude protein (CP) digestibility than the FM group. In all indispensable amino acids except arginine, the BSFL1 and BSFL2 groups showed significantly higher ($p < 0.05$) digestibility than the FM group at week 6. The BSFL2 group showed significantly higher ($p < 0.05$) digestibility of threonine, valine, isoleucine, leucine, lysine, arginine, and methionine than the BSFL1 group. In the dispensable amino acids, the BSFL2 group showed significantly higher ($p < 0.05$) digestibility of proline, glycine, alanine, tyrosine, and cystine than the FM and BSFL1 groups. In all indispensable amino acids, the BSFL1 and BSFL2 groups showed significantly higher ($p < 0.05$) digestibility than the FM group at week 9. There were no significant differences among treatment groups in blood profiles and gas emissions during the entire experimental period. Therefore, it is thought that BSFL can be used to replace fishmeal in diets for growing-finishing pigs, and when 2% of BSFL is included, it is thought to be an appropriate amount to include in diets for growing-finishing pigs, as it has the effect of improving the digestibility of CP and amino acids.

Keywords (3 to 6): Alternatives, Fishmeal, *Hermetia illucens*, Pig, Protein sources

Introduction

Recently, developing a diet that simultaneously considers economic feasibility, and environmental sustainability has emerged as an important task in responding to climate change and operating a sustainable livestock industry [1]. The pig growing period is characterized by physiological development of the skeleton and muscles, during which protein synthesis occurs actively [2]. Since protein synthesis is influenced by the protein level in the diet, an appropriate supply of protein is a crucial factor in determining growth in growing-finishing pigs [3]. Fishmeal, the primary animal protein source in diets for growing-finishing pigs, contains approximately 60-70% protein. However, due to declining fish catches and a continuous increase in prices driven by climate change, there is a pressing need to develop sustainable protein sources to replace it [4, 5].

Black soldier fly larvae (*Hermetia illucens* L., BSFL) contain 7-39% fat and 37-63% protein on a dry matter (DM) basis, and their essential amino acid profile is comparable to that of fishmeal [6]. BSFL is garnering attention as an alternative protein source due to its potential for resource circulation and environmental benefits, as it reduces greenhouse gas emissions during the rearing process, boasts a rapid growth rate, and can utilize various organic wastes as feed [7]. A previous study reported that replacing 50-100% of fishmeal with BSFL in the diet of growing-finishing pigs resulted in increased carcass weight and protein content in pork compared to diets containing only fishmeal [8]. Go et al. [9] found that when 100% of poultry offal meal in the diet for growing-finishing pigs was replaced with BSFL, there was no significant difference in odor emissions compared to the use of poultry offal meal. However, research on the application of BSFL in the diets of growing-finishing pigs is still in the preliminary development stage, and further studies are needed for the industrialization of BSFL.

Therefore, this study was conducted to analyze the effects of replacing fishmeal in the diet of growing-finishing pigs with BSFL on growth performance, nutrient digestibility, blood profiles, and gas emissions, and to determine whether BSFL can be effectively applied as an alternative protein source.

Materials and Methods

Ethics approval and consent to participate

The protocol for this study was reviewed and approved by the Institutional Animal Care and Use Committee of Chungbuk National University, Cheongju, Korea (approval no. CBNUA-2184-23-02).

Animals and experimental designs

A total of 36 10-week-old crossbred growing pigs [(Landrace × Yorkshire) × Duroc] with initial body weight (BW) of 34.82 ± 0.43 kg were used in this study. All pigs were assigned to a completely randomized three treatment groups based on the initial BW. Each treatment had 6 replicate pens, and 2 pigs were assigned to each pen. The three treatments were as follows: a basal diet containing 1% fishmeal (FM); a basal diet without fishmeal and included with 1% BSFL powder (BSFL1); a basal diet without fishmeal and included with 2% BSFL powder (BSFL2). All experimental diets were formulated to meet and exceed the National Research Council [10] nutrient requirements for pigs (Table 1). The experiment was conducted for a total of 9 weeks, including 6 weeks of growing period and 3 weeks of finishing period. Pigs had free access to water and diet throughout the experiment.

Preparation black soldier fly larvae

The BSFL was harvested by producing third-instar larvae hatched from eggs and feeding them wet feed (food waste; 70% moisture) for 10 days. The harvested last-instar larvae were dried once in a microwave dryer (M-200, Entomo, Siheung, Korea) and then dried a second time using a roaster (M-201, Entomo) to reach a total moisture content of 1% or less. The dried BSFL was milked using a screw-type insect oil press machine (M-202, Entomo) and then ground to 100 mesh or less using a pulverize (M-205, Entomo). The BSFL powder was provided by the Agricultural Research and Extension Services (Cheongju, Korea). The nutritional components of the fishmeal and BSFL powder are shown in Table 2.

Growth performance

All pigs were weighed at the beginning of the experiment, at the 3 weeks, 6 weeks, and at the end of the experiment (9 weeks) to calculate the average daily body weight gain (ADG). Feed intake was documented by subtracting the remaining amount from the diet supply amount until measuring BW and calculated the average daily feed intake (ADFI). The feed efficiency (G:F) was calculated by dividing ADG by ADFI.

Nutrient digestibility

At 6 and 9 weeks, 0.2% chromium oxide (Cr_2O_3) was added as an indigestible indicator in all pig diets for fecal sampling. Feces were collected using the rectal massage method. While collecting feces, the diet was also collected, and immediately stored in a freezer at -20℃. Before analyzing nutrient digestibility, fecal samples were dried at 60℃ for 72 h and then crushed on a 1 mm screen. The DM (method 930.15) and crude protein (CP; method 984.13) of diet and feces samples were all analyzed according to the method of AOAC [11]. An adiabatic oxygen bomb calorimeter (6400 Automatic Isoperibol calorimeter, Parr, USA) was used to measure gross energy (GE) in diets and feces. Amino acids were analyzed using the high-performance liquid chromatography (HPLC; Shimadzu model LC-10AT, Shimadzu, Kyoto, Japan) method. Cysteine and methionine were oxidized with performic acid for 16 h at 0℃, after that, using cysteic acid and methionine sulfone, respectively, was for analysis. Chromium levels were determined via UV absorption spectrophotometry (UV-1201, Shimadzu, Kyoto, Japan) using Williams et al. [12] method. The following equation was used to calculate the apparent total tract digestibility (ATTD).

Digestibility = 1 – [(Concentration of nutrient in feces × Concentration of Cr_2O_3 in the diet)/(Concentration of nutrient in diet × Concentration of Cr_2O_3 in feces)] × 100.

Blood profile

Blood samples were collected from the jugular vein at 6 and 9 weeks, 6 pigs per treatment (1 pig per pen). Blood samples were collected into serum separator tube for serum analysis. After collection, serum samples were centrifuged at 12,500 × g at 4℃ for 20 min. Total protein (TP) level was measured using a colorimetric method, and blood urea nitrogen (BUN) level was analyzed using the urease glutamate dehydrogenase method. The TP and BUN in blood were measured using a fully automated chemistry analyzer (Cobas C702, Hofmann-La Roche, Switzerland).

Gas emission

The fresh feces were collected from each pen at 6 and 9 weeks. The feces (150 g) and slurry (100 g) were mixed and stored in a plastic box and fermented at 34°C for 72 hours. The amount of hydrogen sulfide (H_2S), ammonia (NH_3), acetic acid, and methyl mercaptan was analyzed using a gas detector (GV-110S, Gastec Corp., Ayase, Japan) using each gas detector tube.

Statistical analysis

All data was analyzed through the general linear model procedure in JMP pro 16.0 (SAS Institute, Cary, NC, USA), using each pen as the experimental unit. Differences between treatment means were determined using Tukey's multiple range test. A probability level of $p < 0.05$ was indicated to be statistically significant, and a level of $0.05 \leq p < 0.10$ was considered to have such a tendency.

Results

Growth performance

There were no significant differences ($p > 0.05$) among treatment groups in BW, ADG, ADFI, and G:F during the entire experimental period (Table 3).

Nutrient digestibility

The BSFL2 group in weeks 6 and 9 showed significantly higher ($p < 0.05$) CP digestibility than the FM group (Table 4). The BSFL2 group in week 9 showed a higher tendency ($p = 0.093$) in GE digestibility than the FM group. There was no significant difference in DM digestibility among the treatment groups in weeks 6 and 9 ($p > 0.05$).

In all indispensable amino acids except arginine, the BSFL1 and BSFL2 groups showed significantly higher ($p < 0.05$) digestibility than the FM group at week 6 (Table 5). The BSFL2 group showed significantly higher ($p < 0.05$) digestibility of threonine, valine, isoleucine, leucine, lysine, arginine, and methionine than the BSFL1 group. In the dispensable amino acids, the BSFL2 group showed significantly higher ($p < 0.05$) digestibility of proline, glycine, alanine, tyrosine, and cystine than the FM and BSFL1 groups.

In all indispensable amino acids, the BSFL1 and BSFL2 groups showed significantly higher ($p < 0.05$) digestibility than the FM group at week 9 (Table 6). In all indispensable amino acids except phenylalanine, arginine, and tryptophan, the BSFL2 group showed significantly higher ($p < 0.05$) digestibility than the BSFL1 group. In the dispensable amino acids, the BSFL2 group showed significantly higher ($p < 0.05$) proline, alanine, tyrosine, and cystine digestibility than the FM and BSFL1 groups.

Blood profile

There were no significant differences ($p > 0.05$) among treatment groups in TP and BUN during the entire experimental period (Table 7).

Gas emission

There were no significant differences ($p > 0.05$) among treatment groups in H_2S, NH_3, acetic acid, and methyl mercaptans during the entire experimental period (Table 8).

Discussion

Protein is an important component of the animal diet required for growth and development [13]. The source of protein is crucial because it affects the availability and utilization of essential amino acids [14]. Growing-finishing pigs experience active protein synthesis and are significantly influenced by the protein level in their diet; thus, an appropriate protein supply is necessary [2, 3]. The crude protein (CP) content of black soldier fly larvae (BSFL) used in this study was 56%, which is higher than the average CP content of BSFL reported in previous studies, which ranges from 39% to 44% [15]. The phenylalanine, valine, tyrosine, and proline contents of BSFL were also higher than those found in fish meals. The nutrient content of BSFL can vary greatly depending on factors such as the substrate used to raise the larvae, the age of the harvested larvae, and the processing method. In some cases, BSFL shows nutrient content similar to or superior to that of fish meal [16]. The BSFL used in this study exhibited a high CP content and an excellent amino acid profile, suggesting it has sufficient potential as a substitute for fish meal.

In this study, there was no significant difference in growth performance when BSFL was used to replace fishmeal. This indicates that adding 1-2% BSFL after excluding fishmeal from the diet can provide sufficient nutrients to growing-finishing pigs as a compound feed. According to Nekrasov et al. [17], supplementing 0.8% BSFL in the diet for growing pigs did not negatively affect growth performance compared to diets without BSFL supplementation. This finding is consistent with the results of this study. Incorporating BSFL into the pig diet can increase average daily feed intake (ADFI) by enhancing palatability, thereby improving growth performance [18]. Although ADFI did not increase significantly in this study, it is believed that ADFI increased numerically compared to the fishmeal diet due to improved palatability from the addition of BSFL and that there was no negative effect on growth performance.

In this study, including 2% BSFL increased CP digestibility compared to fish meal, with all indispensable amino acids except arginine demonstrating high digestibility. When BSFL was fed to growing pigs, the standardized ileal digestibility of lysine was reported to be higher than that of soybean meal, blood meal, and fish meal [10, 19, 20]. BSFL contains lauric acid (a medium-chain fatty acid), which can account for up to 70% of the total saturated fatty acid content, depending on the rearing substrate [21, 22]. Chitin, a component of the larval exoskeleton, acts as a prebiotic and has been reported to increase the abundance and diversity of beneficial bacteria in the intestinal microflora [23]. Monounsaturated fatty acids, medium-chain fatty acids, and chitin can collectively enhance nutrient absorption and inhibit the growth of harmful bacteria in the intestines of pigs [24]. It is believed that as the BSFL content increases, so do the levels of lauric acid and chitin, further improving digestibility. However, chitin is not digested or absorbed in the small intestine of pigs due to the β1-4 linkage between the N-acetylglucosamine subunits that constitute chitin, meaning that all proteins encapsulated in chitin remain undigested and unabsorbed [25]. In this study, the increased digestibility observed when BSFL was fed compared to fish meal may be attributed to the small amount of BSFL added (1-2%), which was not significantly affected by chitin. However, in this study, the increase in nutrient digestibility did not lead to an increase in growth performance. This may be because the digested amino acids were used as energy sources rather than for protein synthesis. Similarly, the inclusion of BSFL may have increased the metabolic activity of animals, which may have increased the maintenance energy requirement. Although growth performance did not increase despite the increase in nutrient digestibility due to several external factors, further research on the effect of BSFL on growth performance is needed.

The BUN level is influenced by the nutritional status of animals and is used to predict trends in growth performance and nutrient digestibility [26]. Elevated BUN levels indicate that excess amino acids are being metabolized and are circulating in the bloodstream [27]. Similarly, a decrease in TP indicates inadequate protein intake [28]. Both TP and BUN serve as indicators of the efficiency of digestion and utilization of protein and amino acids in the body [26, 29]. In this study, TP and BUN levels did not differ significantly from those observed with fishmeal throughout the experimental period, suggesting that BSFL did not adversely affect protein metabolism in the body.

Fecal gas emissions are linked to nutrient digestibility [9]. The fermentation of undigested or endogenous proteins can either result in reabsorption for protein synthesis or lead to ammonia production, which may be eliminated as urea [30]. Enhancing digestibility can reduce gas emissions. However, in this study, despite the improvements in nutrient digestibility, gas emissions did not show a significant difference between fishmeal and BSFL. To date, most research on gas emissions related to BSFL has focused on their use in efficiently processing manure [31-33]. Therefore, further studies are needed to evaluate the impact of BSFL feeding on fecal gas emissions in pigs.

CONCLUSION

When completely replacing fishmeal in the diet of growing-finishing pigs and including BSFL, the digestibility of most of the indispensable amino acids was improved compared to that of fishmeal. When included with 2% BSFL, CP digestibility increased compared to fishmeal, and threonine, valine, isoleucine, leucine, lysine, and methionine digestibility increased compared to 1% inclusion. There was no significant difference among the fishmeal and BSFL groups in the TP and BUN levels in the blood and in the growth performance and gas emission, suggesting that BSFL does not have a negative effect on growing-finishing pigs.

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Therefore, it is thought that BSFL can be used to replace fishmeal in diets for growing-finishing pigs, and when 2% of BSFL is included, it is thought to be an appropriate amount to include in diets for growing-finishing pigs, as it has the effect of improving the digestibility of CP and amino acids. However, while BSFL offers significant environmental benefits, the industry is still in its early stages, resulting in high production costs. Further research is needed to stabilize the BSFL industry, reduce unit costs, and conduct economic evaluations for the practical application of BSFL in a pig diet.

Competing Interests

No potential conflict of interest relevant to this article was reported.

Funding

This work was carried out with the support of the "Cooperative Research Program for Agriculture Science and Technology Development (Project No. RS-2022-RD009981)" from the Rural Development Administration, Republic of Korea.

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Tables and Figures

Table 1. Compositions of basal diet and feeding experimental diets (as-fed-basis)

Items	FM	BSFL1	BSFL2
Ingredients, %			
Corn	54.25	54.25	54.25
Soybean meal, 44% CP	15.66	15.66	15.57
Wheat	3.75	3.75	3.75
Rice bran	6.50	6.50	6.50
DDGS	11.50	11.50	11.50
Fishmeal	1.00	-	-
BSFL	-	1.00	2.00
Vegetable oil	1.32	1.27	0.38
Sugar	3.27	3.27	3.27
Monocalcium phosphate	0.06	0.06	0.06
Limestone	1.27	1.27	1.27
L-Lysine-HCl, 78%	0.72	0.75	0.74
DL-Methionine, 50%	0.08	0.10	0.09
Choline chloride, 25%	0.04	0.04	0.04
Vitamin and mineral premix[1]	0.22	0.22	0.22
Salt	0.36	0.36	0.36
Total	100.00	100.00	100.00
Calculated value			
ME, kcal/kg	3,385	3,385	3,385
CP, %	15.90	15.90	15.90
Lysine, %	1.35	1.35	1.35
Methionine, %	0.36	0.36	0.36
Ca, %	0.72	0.72	0.72
P, %	0.49	0.49	0.49

Abbreviation: DDGS, dried distiller's grains with solubles; BSFL, black soldier fly larvae; FM, basal diet with 1% fishmeal; BSFL1, basal diet without fishmeal and included 1% BSFL; BSFL2, basal diet without fishmeal and included 2% BSFL; CP, crude protein; ME, metabolize energy; Ca, calcium; P, phosphorus.

[1]Provided per kilogram of complete diet: vitamin A, 11,025 U; vitamin D_3,1103 U; vitamin E, 44 U; vitamin K, 4.4 mg; riboflavin, 8.3 mg; niacin,50 mg; thiamine, 4 mg; d-pantothenic, 29 mg; choline, 166 mg; and vitamin B_{12}, 33 µg; Cu (as $CuSO_4 \cdot 5H_2O$), 12 mg; Zn (as $ZnSO_4$), 85 mg; Mn (as MnO_2), 8 mg; I (as KI), 0.28 mg; and selenium (as $Na_2SeO_3 \cdot 5H_2O$), 0.15 mg.

Table 2. Nutrient components of fishmeal and black soldier fly larvae (BSFL)

Items, %	Content	
	Fishmeal	BSFL
Moisture	7.00	6.75
CP	65.00	56.02
EE	8.85	6.26
Ash	15.02	16.93
Essential Amino Acids		
Lysine	5.60	3.51
Threonine	3.10	2.20
Tryptophan	0.62	0.61
Methionine	2.56	1.03
Phenylalanine	2.22	2.27
Isoleucine	2.71	2.29
Leucine	4.42	3.80
Histidine	2.21	1.70
Arginine	4.37	2.77
Valine	3.48	3.85
Non-Essential Amino Acids		
Aspartic acid	5.86	5.03
Serine	2.65	2.38
Glutamic acid	6.95	6.11
Glycine	3.70	3.08
Alanine	3.73	3.55
Tyrosine	3.10	3.28
Cysteine	0.61	0.55
Proline	2.91	3.27

Abbreviation: BSFL, black soldier fly larvae; CP, crude protein; EE, ether extract.

Table 3. Effect of replacement dietary of fishmeal with black soldier fly larvae (BSFL) on growth performance in growing-finishing pigs

Items	FM	BSFL1	BSFL2	SE	*p*-value
BW, kg					
initial	34.779	34.830	34.858	0.612	0.996
3w	54.267	54.433	54.258	1.102	0.992
6w	75.908	76.008	75.608	1.467	0.980
9w	102.200	101.925	101.775	1.406	0.977
0 to 3w					
ADG, kg	0.928	0.933	0.924	0.040	0.986
ADFI, kg	2.535	2.645	2.610	0.071	0.549
G:F	0.366	0.353	0.354	0.013	0.714
3 to 6w					
ADG, kg	1.031	1.027	1.017	0.040	0.968
ADFI, kg	2.615	2.530	2.590	0.102	0.833
G:F	0.398	0.407	0.395	0.021	0.915
6 to 9w					
ADG, kg	1.252	1.234	1.246	0.056	0.974
ADFI, kg	3.287	3.332	3.450	0.063	0.195
G:F	0.380	0.370	0.361	0.013	0.603
0 to 6w					
ADG, kg	0.979	0.980	0.970	0.032	0.971
ADFI, kg	2.573	2.587	2.608	0.063	0.925
G:F	0.382	0.379	0.372	0.014	0.883
0 to 9w					
ADG, kg	1.070	1.065	1.062	0.018	0.948
ADFI, kg	2.812	2.835	2.892	0.048	0.501
G:F	0.381	0.376	0.368	0.009	0.572

Abbreviation: BW, body weight, ADG, average daily gain; ADFI, average daily feed intake; G:F, feed efficiency; FM, basal diet with 1% fishmeal; BSFL1, basal diet without fishmeal and included 1% BSFL; BSFL2, basal diet without fishmeal and included 2% BSFL.

Table 4. Effect of replacement dietary of fishmeal with black soldier fly larvae (BSFL) on nutrient digestibility in growing-finishing pigs

Items, %	FM	BSFL1	BSFL2	SE	*p*-value
6w					
DM	87.55	88.71	89.03	0.488	0.111
CP	72.05b	74.61ab	77.54a	0.854	0.002
GE	83.70	84.82	85.05	0.608	0.274
9w					
DM	87.30	87.74	87.70	0.271	0.474
CP	70.54b	75.31a	78.33a	0.886	<0.001
GE	78.82	80.56	81.10	0.713	0.093

Abbreviation: DM, dry matter; CP, crude protein; GE, gross energy; FM, basal diet with 1% fishmeal; BSFL1, basal diet without fishmeal and included 1% BSFL; BSFL2, basal diet without fishmeal and included 2% BSFL; SE, standard error

a,b Means within a row with different letters are significantly different at $p < 0.05$.

Table 5. Effect of replacement dietary of fishmeal with black soldier fly larvae (BSFL) on amino acid digestibility in growing pigs (6w)

Items, %	FM	BSFL1	BSFL2	SE	*p*-value
Indispensable amino acids					
Threonine	72.15c	73.42b	74.82a	0.272	<0.001
Valine	71.31c	73.04b	74.71a	0.346	<0.001
Isoleucine	74.28c	76.95b	79.17a	0.257	<0.001
Leucine	76.06c	77.01b	77.90a	0.239	<0.001
Phenylalanine	81.72b	83.02a	83.42a	0.129	<0.001
Histidine	71.61b	73.16a	73.33a	0.420	0.020
Lysine	75.29c	76.55b	77.41a	0.221	<0.001
Arginine	80.48b	80.83b	82.46a	0.251	<0.001
Methionine	76.62c	78.30b	79.87a	0.206	<0.001
Tryptophan	75.32b	76.83a	77.34a	0.305	<0.001
Dispensable amino acids					
Aspartic acid	81.11b	81.65ab	82.12a	0.154	0.001
Serine	73.13	73.25	73.29	0.427	0.965
Glutamic acid	77.32	77.24	77.65	0.296	0.598
Proline	82.28c	82.89b	83.38a	0.132	<0.001
Glycine	71.08b	71.97b	73.54a	0.295	<0.001
Alanine	72.23c	73.60b	74.84a	0.191	<0.001
Tyrosine	77.55c	78.42b	79.41a	0.214	<0.001
Cystine	71.88c	73.09b	74.52a	0.259	<0.001

Abbreviation: FM, basal diet with 1% fishmeal; BSFL1, basal diet without fishmeal and included 1% BSFL; BSFL2, basal diet without fishmeal and included 2% BSFL; SE, standard error
a-c Means within a row with different letters are significantly different at $p < 0.05$.

Table 6. Effect of replacement dietary of fishmeal with black soldier fly larvae (BSFL) on amino acid digestibility in finishing pigs (9w)

Items, %	FM	BSFL1	BSFL2	SE	*p*-value
Indispensable amino acids					
Threonine	72.22c	73.68b	75.04a	0.279	<0.001
Valine	71.56c	73.97b	75.18a	0.281	<0.001
Isoleucine	74.67c	77.25b	79.44a	0.253	<0.001
Leucine	76.83c	77.56b	78.33a	0.183	<0.001
Phenylalanine	82.01b	83.25a	83.65a	0.125	<0.001
Histidine	71.54c	73.12b	74.39a	0.267	<0.001
Lysine	75.85c	76.88b	77.78a	0.220	<0.001
Arginine	80.70b	81.57a	82.17a	0.217	<0.001
Methionine	83.56c	85.18b	85.70a	0.133	<0.001
Tryptophan	75.39b	77.18a	77.31a	0.379	0.004
Dispensable amino acids					
Aspartic acid	81.23b	81.76ab	82.23a	0.153	0.001
Serine	73.14	73.34	73.44	0.330	0.804
Glutamic acid	77.36	77.24	77.40	0.250	0.898
Proline	82.43c	83.02b	83.50a	0.130	<0.001
Glycine	71.10b	72.57a	73.33a	0.338	0.001
Alanine	72.24c	73.70b	74.93a	0.293	<0.001
Tyrosine	78.04c	79.74b	80.66a	0.201	<0.001
Cystine	71.04c	73.22b	75.45a	0.381	<0.001

Abbreviation: FM, basal diet with 1% fishmeal; BSFL1, basal diet without fishmeal and included 1% BSFL; BSFL2, basal diet without fishmeal and included 2% BSFL; SE, standard error
a-c Means within a row with different letters are significantly different at $p < 0.05$.

Table 7. Effect of replacement dietary of fishmeal with black soldier fly larvae (BSFL) on blood profile in growing-finishing pigs

Items	FM	BSFL1	BSFL2	SE	*p*-value
6w					
TP, g/dL	6.18	6.02	6.27	0.096	0.206
BUN, mg/dL	9.00	9.33	9.83	1.317	0.904
9w					
TP, g/dL	6.13	6.13	6.38	0.145	0.395
BUN, mg/dL	10.67	10.33	11.33	1.291	0.857

Abbreviation: BUN, blood urea nitrogen; FM, basal diet with 1% fishmeal; BSFL1, basal diet without fishmeal and included 1% BSFL; BSFL2, basal diet without fishmeal and included 2% BSFL; TP, total protein; BUN, blood urea nitrogen; SE, standard error

Table 8. Effect of replacement dietary of fishmeal with black soldier fly larvae (BSFL) on gas emission in growing-finishing pigs

Items, ppm	FM	BSFL1	BSFL2	SE	*p*-value
6w					
H_2S	5.54	5.47	5.31	0.159	0.588
NH_3	8.08	7.92	7.95	0.133	0.691
Acetic acid	3.11	3.07	3.09	0.100	0.931
Methyl mercaptans	4.95	4.87	4.83	0.150	0.858
9w					
H_2S	6.50	6.42	6.30	0.233	0.830
NH_3	9.38	9.20	9.23	0.148	0.654
Acetic acid	3.55	3.17	3.18	0.148	0.610
Methyl mercaptans	5.20	5.06	5.11	0.136	0.747

Abbreviation: H_2S, hydrogen sulfide; NH_3, ammonia; FM, basal diet with 1% fishmeal; BSFL1, basal diet without fishmeal and included 1% BSFL; BSFL2, basal diet without fishmeal and included 2% BSFL; SE, standard error