

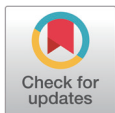
Effects of BSFL on growing-finishing pigs in growth performance, nutrient digestibility, blood profiles, and gas emission

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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 (BSFL; *Hermetia illucens* L.) 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 6 and 9 weeks 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 6 weeks. 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 9 weeks. 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: Alternatives, Fishmeal, *Hermetia illucens*, Pig, Protein sources

Competing interests

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

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Availability of data and material

All data generated or analyzed during this study are included in this published article.

Authors' contributions

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Ethics approval and consent to participate

Institutional Animal Care and Use Committee of Chungbuk National University, Cheongju, Korea (approval no. CBNUA-2184-23-02).

Declaration of generative AI

No AI tools were used in this article.

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 growing period in pigs is characterized by physiological development of the skeleton and muscles, during which protein synthesis occurs actively [2]. Since protein synthesis is influenced by dietary protein levels, an appropriate supply of protein is a crucial factor in determining the growth performance of 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 alternative protein sources [4,5].

Black soldier fly larvae (BSFL; *Hermetia illucens* L.) 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, exhibits 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 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 a sustainable alternative protein source.

MATERIALS AND METHODS

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 NRC [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 rearing third-instar larvae hatched from eggs and feeding them a wet feed (food waste; 70% moisture) for 10 days. The harvested last-instar larvae were dried primarily in a microwave dryer (M-200, Entomo) 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 defatted using a screw-type insect oil press machine (M-202, Entomo) and then ground to a particle size

Table 1. Compositions of basal and 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

¹⁾Provided per kilogram of complete diet: vitamin A, 11,025 U; vitamin D₃, 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 B₁₂, 33 µg; Cu (as CuSO₄ · 5H₂O), 12 mg; Zn (as ZnSO₄), 85 mg; Mn (as MnO₂), 8 mg; I (as KI), 0.28 mg; and selenium (as Na₂SeO₃ · 5H₂O), 0.15 mg.

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.

of 100 mesh or less using a pulverizer (M-205, Entomo). The BSFL powder was provided by the Chungcheongbuk-do Agricultural Research and Extension Services. 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 (Cr₂O₃) was added as an indigestible indicator in all pig diets for fecal sampling. Feces were collected using the rectal massage method. While collecting

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
Indispensable 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
Dispensable 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

CP, crude protein; EE, ether extract.

feces, the diet was also collected, and immediately stored in a freezer at -20°C . Before analyzing nutrient digestibility, fecal samples were dried at 60°C 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) 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) method. Cysteine and methionine were oxidized with performic acid for 16 h at 0°C , after that, using cysteic acid and methionine sulfone, respectively, was for analysis. Chromium levels were determined via UV absorption spectrophotometry (UV-1201, Shimadzu) using Williams et al. [12] method. The following equation was used to calculate the apparent total tract digestibility (ATTD).

$$\text{ATTD} = 1 - \left[\frac{\text{Concentration of nutrient in feces} \times \text{Concentration of Cr}_2\text{O}_3 \text{ in the diet}}{\text{Concentration of nutrient in diet} \times \text{Concentration of Cr}_2\text{O}_3 \text{ in feces}} \right] \times 100.$$

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°C 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, Hoffmann-La Roche).

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 (H₂S), ammonia (NH₃), acetic acid, and methyl mercaptan was analyzed using a gas detector (GV-110S, Gastec) using each gas detector tube.

Statistical analysis

All data was analyzed through the general linear model procedure in JMP pro 16.0 (SAS Institute), 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 6 and 9 weeks showed significantly higher ($p < 0.05$) CP digestibility than the FM group (Table 4). The BSFL2 group in 9 weeks 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 6 and 9 weeks ($p > 0.05$).

In all indispensable amino acids except arginine, the BSFL1 and BSFL2 groups showed significantly higher ($p < 0.05$) digestibility than the FM group at 6 weeks (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 9 weeks (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 H₂S, NH₃, acetic acid,

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
3 wk	54.267	54.433	54.258	1.102	0.992
6 wk	75.908	76.008	75.608	1.467	0.980
9 wk	102.200	101.925	101.775	1.406	0.977
0 to 3 wk					
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 6 wk					
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 9 wk					
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 6 wk					
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 9 wk					
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

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
6 wk					
DM	87.55	88.71	89.03	0.488	0.111
CP	72.05 ^b	74.61 ^{ab}	77.54 ^a	0.854	0.002
GE	83.70	84.82	85.05	0.608	0.274
9 wk					
DM	87.30	87.74	87.70	0.271	0.474
CP	70.54 ^b	75.31 ^a	78.33 ^a	0.886	< 0.001
GE	78.82	80.56	81.10	0.713	0.093

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

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.

and methyl mercaptans during the entire experimental period (Table 8).

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

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

^{a-c}Means within a row with different letters are significantly different at $p < 0.05$.

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.

DISCUSSION

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

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. This finding is consistent with the results of this study. Incorporating BSFL into the pig diet can increase 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 FM diet

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

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

^{a-c}Means within a row with different letters are significantly different at $p < 0.05$.

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.

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
6 wk					
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
9 wk					
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

TP, total protein; 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; SE, standard error.

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 fishmeal, with all indispensable amino acids except arginine demonstrating higher 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 fishmeal [10,19,20]. The 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

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
6 wk					
H ₂ S	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 mercaptan	4.95	4.87	4.83	0.150	0.858
9 wk					
H ₂ S	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 mercaptan	5.20	5.06	5.11	0.136	0.747

H₂S, hydrogen sulfide; NH₃, 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.

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 β -1,4-glycosidic 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 in the BSFL-fed groups compared to the fishmeal group may be attributed to the minimal inclusion level of BSFL (1%–2%), which minimized the adverse effects of 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 transported through 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 of the FM group 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 nitrogen reabsorption for protein synthesis or lead to ammonia production, which may be eliminated as urea [30]. While enhancing digestibility can reduce gas emissions, in this study, gas emissions did not show a significant difference between the fishmeal and BSFL treatments, despite the observed improvements in nutrient digestibility. To date, most research on gas emissions related to BSFL has focused on their application in processing manure [31–33]. Therefore, further studies are needed to evaluate the impact of dietary BSFL inclusion 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 were no significant differences between the fishmeal and BSFL groups in blood TP and BUN levels, growth performance, or gas emissions, suggesting that BSFL inclusion has no adverse effects on growing-finishing pigs.

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.

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