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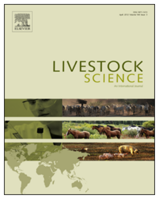

Complete replacement of soybean meal in pig diets with hydrolyzed feather meal with blood by amino acid supplementation based on standardized ileal amino acid digestibility

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ABSTRACT

The current study was conducted to determine the possibility of replacing soybean meal (SBM) in finisher pig diet completely with hydrolyzed feather meal (FM) with blood by supplementing with appropriate amino acids (AA) based on standardized ileal digestible (SID) AA in FM. Corn–SBM, positive control (POS) diets were formulated to contain 6.6 and 5.2 g true ileal digestible (TID) Lys/kg to satisfy the requirements during the finisher-1 and finisher-2 phases, respectively. Corn–FM negative control (NEG) diets were formulated to be iso-N and iso-caloric to the POS diets. The NEG diets were supplemented with Lys and Trp to alleviate AA deficiencies based on TID AA values in FM reported by the NRC in 1998 (NRC). In addition, the NEG diets were supplemented with Lys and Trp to alleviate AA deficiencies based on the determined SID AA in FM (SID). When pigs weighed 50.0 ± 2.9 kg, 32 gilts and 32 castrated males (2 gilts or 2 castrated males/pen) were randomly assigned to 1 of 4 finisher-1 diets with 4 gilt pens and 4 castrated male pens/diet, and they were switched to finisher-2 diets when the average pen weight reached 79.0 ± 2.0 kg. Pigs had ad libitum access to feed and water throughout the study. At the end of the finisher-2 phase (107.7 ± 3.3 kg), blood samples were collected to determine serum metabolite profile and pigs were slaughtered to assess carcass characteristics. Pigs fed the POS diets ended to have greater overall average daily feed intake (ADFI; $P = 0.083$) and had greater total Lys intake ($P = 0.029$) than those fed the SID diets, which may have resulted in a tendency for slightly greater average daily gain (ADG; $P = 0.094$) in pigs fed the POS diets. However, there was no difference in the efficiency of feed or Lys utilization. Pigs fed the SID diets tended to have greater gain:feed (G:F; $P = 0.057$) and had greater gain:total Lys intake ($P < 0.001$) than those fed the NRC diets. Pigs fed the POS diets tended to have greater ADFI ($P = 0.079$) and had greater ADG ($P < 0.001$) and G:F ($P < 0.001$) than those fed the NEG diets, but, as expected, they had lower gain:total Lys intake ($P < 0.001$) mostly because of the increased total Lys intake ($P < 0.001$). Serum glucose was not affected by dietary treatments. Pigs fed the POS diets had greater urea-N ($P = 0.003$) and lower cholesterol ($P = 0.002$) than those fed the SID diets. As expected, pigs fed the NEG diet had reduced total protein ($P < 0.001$) and increased urea-N ($P = 0.001$), triglyceride ($P < 0.001$), and cholesterol ($P < 0.001$) compared with those fed the POS diets. Pigs fed the POS diets had greater fat-free lean gain

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($P=0.020$) that those fed the SID diets, but similar loin muscle area, fat-free carcass percentage, and efficiency of fat-free lean gain. Results indicated that pigs fed the SID diets utilized feed and Lys as efficiently as those fed the POS diets, but they had slightly reduced body weight and fat-free lean gain, perhaps, because of slightly reduced intake of feed and total Lys, as well as other AA.

1. Introduction

The competition between humans and animals, especially nonruminant species, for quality sources of amino acid (AA) is likely to increase continuously in the future because of the ever-increasing world population and an increase in the economic development of both newly industrialized and less economically developed countries (Aherne and Kennely, 1985; Chiba, 2001). Finding new quality sources of AA for pig production is, therefore, important for successful and sustainable swine production in the future. Because of its high protein content, hydrolyzed feather meal (FM) has been of interest in nutritional research (Han and Parsons, 1991) and can be an attractive source of AA for growing pig diets. Unfortunately, FM is low in Lys, Met, His, and Trp (Chiba, 2001), which may have been responsible for relatively little research on FM in swine diets until fairly recently (Apple et al., 2003; Southern et al., 2000; Ssu et al., 2004; van Heugten and van Kempen, 2002).

Supplementation of FM with synthetic AA based on available or ileal digestible AA seems to be the most effective way to utilize FM for pig production. Although the NRC (1998) publication includes both apparent and true ileal digestible (TID) AA in FM, those estimates may not be universally applicable because those estimates are based on the limited data. Therefore, determining the ileal digestibility of AA in FM would be the first step in utilizing FM for pig production in an environmentally friendly manner. In recent years, the use of standardized ileal digestible (SID) AA has become a common practice in describing the value of feed ingredients and formulating diets for pigs and other nonruminant species.

The results of our previous studies indicated that FM produced from pure feathers may not provide a sufficient amount of digestible indispensable AA to support growth as well as soybean meal (SBM; Chiba et al., 1996; Divakala et al., 2009). Contanch et al. (2007) mentioned that FM with blood may be more digestible than those without blood, indicating that FM with blood may provide more digestible AA to pigs than FM without blood. The present study was conducted to determine the possibility of replacing SBM in finisher pig diets completely with FM with blood by AA supplementation based on SID coefficients. The specific objective was to determine the effects of corn-FM diets supplemented with AA based on SID AA in FM on growth performance, serum metabolites, carcass traits, and subjective meat quality scores.

2. Materials and methods

2.1. Animals and facilities

The protocol for this study was approved by the Institutional Animal Care and Use Committee (Auburn University, Auburn, AL, US). A total of 32 gilts and 32 castrated males approaching 50 kg were selected based on body weight (BW) and ancestry and moved to adjacent, open-sided, grower-finisher units. Pigs were allocated to 32 pens (>1.35 m^2/pig) with 2 gilts or 2 castrated males per pen, and pens were randomly assigned to 4 experimental diets with 4 gilt pens and 4 castrated male pens per diet. When the average pen weight reached the target weight (50.0 ± 2.9 kg), pigs were offered 1 of 4 finisher-1 diets. At an average pen weight of 79.0 ± 2.0 kg, pigs were switched to finisher-2 diets. Because of the number of pigs available at one time, the study was conducted in 2 trials. Each trial used 16 gilts and 16 castrated males, with the second trial beginning 5 weeks after the start of the first trial. Pigs were offered ad libitum access to feed and water throughout the study. Pig BW and feed consumption were determined weekly. One pig was removed from the study for a reason unrelated to the treatment. The average minimum and maximum temperatures during the study were 17.7 and 29.0 °C, respectively.

2.2. Experimental diets

One batch of FM with blood was obtained from a member of the Poultry Protein & Fat Council (U.S. Poultry & Egg Association, Tucker, GA, US) and used for the entire study to ensure uniformity of the product. For corn and SBM, the TID AA values reported by the NRC (1998) were used in diet formulation because more than 1 batch of corn and SBM was necessary to complete the study. The analyzed composition of the main ingredients used in the present study and the determined SID values in FM with blood are presented in Table 1. A corn-SBM, positive control (POS) diet was formulated to contain 6.6 g TID Lys/kg to satisfy the requirements during the finisher-1 phase (NRC, 1998; Table 2). A corn-FM negative control (NEG) diet was formulated to be iso-N and iso-caloric to the POS diet. The third diet (NRC) was similar to the NEG diet with the exception that it was supplemented with Lys and Trp to alleviate AA deficiencies based on TID of AA in FM reported by the NRC (1998). The last diet (SID) was formulated by supplementing the NEG diet with Lys and Trp to alleviate AA deficiencies based on the determined SID AA in FM (Sulabo et al., 2013). The finisher-2 diets were formulated using a similar approach but a corn-SBM, positive control diet contained 5.2 g TID Lys/kg (NRC, 1998; Table 3).

To supplement the diets with the appropriate AA, the amount of corn in the diet was adjusted according to the actual AA content of the sources. To avoid the possible confounding effect of energy density, poultry fat was included in the corn-FM diets to maintain a constant DE content across all diets. The DE content of each diet was

Table 1
Composition and standardized ileal digestible values in hydrolyzed feather meal (FM) with blood, and composition of soybean meal and corn (%; as-fed basis).[a,b,c]

Item	FM with blood	SID CP and AA in FM with blood[d]	Soybean meal	Corn
DM	–	–	94.89	88.01
CP	82.81	76.3	47.62	8.02
Arg	5.68	86.0	3.34	0.39
His	1.44	64.8	1.21	0.23
Ile	3.96	96.3	2.11	0.26
Leu	7.35	81.2	3.37	0.89
Lys	2.90	79.4	2.94	0.26
Met	0.69	77.3	0.68	0.18
Cys	3.60	61.0	0.69	0.18
Met+Cys	4.29	–	1.37	0.36
Phe	4.28	83.5	2.30	0.38
Tyr	2.49	78.9	1.18	0.08
Phe+Tyr	6.77	–	–	–
Thr	3.90	76.1	1.90	0.28
Trp	0.69	85.2	0.59	0.06
Val	6.40	83.0	2.14	0.35
Ala	4.27	80.0	2.04	0.58
Asp	5.78	57.1	5.04	0.53
Glu	8.94	73.0	7.75	1.37
Gly	6.02	78.9	2.02	0.32
Pro	7.20	67.7	2.22	0.66
Ser	8.07	81.0	2.30	0.38

[a] SID=standard ileal digestible, CP=crude protein, AA=amino acid, and DM=dry matter.
[b] FM with blood (Sulabo et al., 2013) and corn and soybean meal were analyzed (Ajinomoto Heartland, Inc., Chicago, IL). Hydrolyzed feather meal with blood was hydrolyzed at 517 to 586 kPa with discharge temperature of 21 to 24 °C and blood (approximately 10%) was added after the hydrolyzation process.
[c] For corn and soybean meal, reported the average of several batches of samples; some AA values were not reported.
[d] Sulabo et al. (2013).

Table 2
Composition of finisher-1 diets (as-fed basis).[a,b,c]

Item	POS	NEG	NRC	SID
Ingredient (g/kg)				
Corn	792.9	858.0	854.1	854.5
Soybean meal (47.5% CP)	183.6	–	–	–
FM with blood	–	98.76	98.76	98.76
Poultry fat	–	17.78	17.78	17.78
Dicalcium phosphate	10.88	14.09	14.09	14.09
Limestone	6.65	5.37	5.37	5.37
Salt	3.50	3.50	3.50	3.50
Vitamin–trace mineral premix[d]	2.50	2.50	2.50	2.50
Lys · HCl	–	–	3.767	3.314
Trp	–	–	0.186	0.191
Calculated composition[e]				
DE (Mcal/kg)	3.47	3.47	3.47	3.47
CP (g/kg)	153.0	153.0	153.0	153.0
Ca (g/kg)	6.00	6.00	6.00	6.00
P (g/kg)	5.50	5.50	5.50	5.50
Ca:P	1.09	1.09	1.09	1.09
Lys (g/kg)	6.60	3.66	6.60	6.60
Lys:DE (g/Mcal)	1.90	1.06	1.90	1.90
Trp (g/kg)	1.47	1.02	1.20	1.20
Thr (g/kg)	4.84	5.20	5.20	4.97
His (g/kg)	3.73	2.77	2.77	2.64
Ile (g/kg)	5.46	5.54	5.54	5.86
Val (g/kg)	6.36	8.22	8.22	8.16
Analyzed composition				
CP (g/kg)	147.7	146.0	146.5	149.4

[a] CP=crude protein, FM=hydrolyzed feather meal, and DE=digestible energy.
[b] Finisher-1 diets were fed from 50.1 ± 2.7 to 79.1 ± 1.9 kg.
[c] POS = corn-soybean meal positive control diet; NEG = corn-FM with blood negative control diet formulated to be iso-N and iso-caloric to the POS diet; NRC = NEG+Lys and Trp based on true ileal digestible (TID) amino acids (AA) in FM reported by NRC (1998); and SID = NEG+Lys and Trp based on standardized ileal digestible (SID) AA in FM with blood (Sulabo et al., 2013). Supplemental AA replaced a portion of corn, and the amount was adjusted according to the AA content of the sources.
[d] Provided the following (unit/kg diet): Fe (ferrous sulfate), 150 mg; Zn (zinc oxide), 150 mg; Mn (manganous oxide), 37.5 mg; Cu (copper sulfate), 150 ppm; I (ethylenediamine dihydroiodide), 5 ppm; Se (sodium selenite), 3 ppm; vitamin A, 6,614 IU; vitamin D_3, 1,102 IU; vitamin E, 26 IU; vitamin B_{12}, 0.03 mg; menadione (menadione Na bisulfite complex), 1 mg; riboflavin, 6 mg; D-pantothenic acid (D-Ca pantothenate), 45 mg; niacin, 28 mg; and choline (choline chloride), 110 mg.
[e] Amino acid contents of the SID diet are based on the SID values for FM (Sulabo et al., 2013) and TID values for corn (NRC, 1998), whereas other diets are based on TID values (NRC, 1998). The DE content was estimated based on NRC (1998).

estimated based on DE content of corn, SBM, FM, and poultry fat (NRC, 1998). No attempt was made to maintain a constant AA balance, but the proportion of each indispensable AA relative to Lys in the corn-SBM and AA-supplemented FM diets was above the balanced protein (NRC, 1998). Minerals and vitamins for all diets were provided in amounts calculated to meet or exceed the NRC (1998) recommendations. Feed samples were collected from each batch of feed mixed, and pooled subsamples were analyzed for CP (AOAC, 2000).

2.3. Blood samples

When the average pen weight reached the target BW (107.7 ± 3.3 kg), approximately 10 mL of blood was collected via vena cava puncture using a sterile syringe and needle between 0800 and 1000 h after overnight fast. Blood samples were allowed to clot and serum samples were separated by centrifugation at 1,500 g for 15 min at room temperature to obtain clean serum samples. An aliquot was stored frozen at −20 °C until analyzed for urea-N, albumin, total protein, glucose, triglyceride, and cholesterol using an automatic analyzer at the Auburn University Clinical Pathology Laboratory (Chiba et al., 2002; Mule et al., 2006).

2.4. Slaughter procedures

When average pen BW reached the target weight (107.7 ± 3.3 kg), pigs were slaughtered at the Auburn University Meat Laboratory using conventional procedures. The eviscerated carcasses were split longitudinally through the vertebral midline, and hot carcass weight was recorded. After a chilling period of 24 h at 2 °C, cold carcass weight was measured and the right side of the carcass was cut perpendicularly between the 10th and 11th ribs to measure loin muscle area and 10th rib backfat. Subjective meat quality scores (color, firmness, marbling, and muscling) were then assigned (NPPC, 1991). Meat color, firmness, and marbling were scored on a 5-point scale, whereas muscling was scored on a 3-point scale

Table 3
Composition of finisher-2 diets (as-fed basis).[a,b,c]

Item	POS	NEG	NRC	SID
Ingredients (g/kg)				
Corn	847.5	893.0	890.1	889.5
Soybean meal (48% CP)	128.0	–	–	–
FM with blood	–	68.90	68.90	68.90
Poultry fat	–	12.34	12.34	12.34
Dicalcium phosphate	12.13	14.34	14.34	14.34
Limestone	6.32	5.42	5.42	5.42
Salt	3.50	3.50	3.50	3.50
Vitamin–trace mineral premix[d]	2.50	2.50	2.50	2.50
Lys · HCl	–	–	2.626	2.307
Trp	–	–	0.144	0.148
Calculated composition[e]				
DE (Mcal/kg)	3.46	3.46	3.46	3.46
CP (g/kg)	131.2	131.2	131.2	131.2
Ca (g/kg)	6.00	6.00	6.00	6.00
P (g/kg)	5.50	5.50	5.50	5.50
Ca:P	1.09	1.09	1.09	1.09
Lys (g/kg)	5.20	3.15	5.20	5.20
Lys:DE (g/Mcal)	1.50	0.91	1.50	1.50
Trp (g/kg)	1.18	0.86	1.00	1.00
Thr (g/kg)	4.08	4.33	4.33	4.17
His (g/kg)	3.19	2.52	2.52	2.43
Ile (g/kg)	4.53	4.58	4.58	4.81
Val (g/kg)	5.43	6.73	6.73	6.69
Analyzed composition				
CP (g/kg)	125.9	125.1	126.8	126.5

[a] CP = crude protein, FM = hydrolyzed feather meal, and DE = digestible energy.

[b] Finisher-2 diets were fed from 79.1 ± 1.9 to 107.7 ± 2.8 kg.

[c] POS = corn-soybean meal positive control diet; NEG = corn-FM with blood negative control diet formulated to be iso-N and iso-caloric to the POS diet; NRC = NEG + Lys and Trp based on true ileal digestible (TID) amino acids (AA) in FM reported by NRC (1998); and SID = NEG + Lys and Trp based on standardized ileal digestible (SID) AA in FM with blood (Sulabo et al., 2013). Supplemental AA replaced a portion of corn, and the amount was adjusted according to the AA content of the sources.

[d] Provided the following (unit/kg diet): Fe (ferrous sulfate), 150 mg; Zn (zinc oxide), 150 mg; Mn (manganous oxide), 37.5 mg; Cu (copper sulfate), 150 ppm; I (ethylenediamine dihydroiodide), 5 ppm; Se (sodium selenite), 3 ppm; vitamin A, 6,614 IU; vitamin D_3, 1,102 IU; vitamin E, 26 IU; vitamin B_{12}, 0.03 mg; menadione (menadione Na bisulfite complex), 1 mg; riboflavin, 6 mg; D-pantothenic acid (D-Ca pantothenate), 45 mg; niacin, 28 mg; and choline (choline chloride), 110 mg.

[e] Amino acid contents of the SID diet are based on the SID values for FM with blood (Sulabo et al., 2013) and TID values for corn (NRC, 1998), whereas other diets are based on TID values (NRC, 1998). The DE content was estimated based on NRC (1998).

(NPPC, 1991). The rate and proportion of carcass fat-free lean were estimated using the equations reported by the NPPC (2000).

2.5. Statistical analysis

Data were analyzed using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Initially, treatment, sex, trial, building, and appropriate interactions, along with appropriate BW as a covariate, were included in the statistical model. Covariates considered for the analysis were initial and final BW for growth performance data and final BW for carcass and serum metabolite data. The results indicated that trial and trial × treatment interactions were not an important source of variation, thus, the data for the 2 trials were combined and analyzed accordingly. Interactions and covariates that did not reach statistically significant trend ($P > 0.10$) were then removed from the final model. To assess the effect of treatments, pre-planned contrasts were used: (1) POS vs. NEG, (2) POS vs. SID, and (3) SID vs. NRC. The pen was the experimental unit, and results were considered a statistically significant if $P \leq 0.05$ and a trend if $P \leq 0.10$.

3. Results

3.1. Growth performance

Pigs fed the POS diet during the finisher-1 phase consumed ($P = 0.012$) more feed and total Lys and gained faster ($P = 0.013$) than those fed the SID diet (Table 4). But, there was no difference in gain:feed (G:F) or gain:total Lys intake between pigs fed the POS and SID diets. Although there was no difference in average daily feed intake (ADFI) or total Lys intake, pigs fed the SID diet gained faster ($P = 0.047$) and tended to utilize feed ($P = 0.061$) and utilized total Lys ($P = 0.002$) more efficiently for BW gain than those fed the NRC diet. Pigs fed the POS diets consumed more feed ($P = 0.002$) and total Lys ($P < 0.001$), gained faster ($P < 0.001$), and had a greater G:F ($P < 0.001$) than those fed the NEG diet. As would be expected, however, gain:total Lys intake was greater ($P < 0.001$) in pigs fed the NEG diet than those fed the POS diet.

During the finisher-2 phase, pigs fed the POS diet tended to consume more feed ($P = 0.087$) and total Lys ($P = 0.098$) than those fed the SID diet, but there were no differences in average daily gain (ADG), G:F, or gain:total Lys intake between the 2 treatments. Pigs fed the SID diet utilized total Lys more efficiently for ADG than those fed the NRC diet ($P = 0.049$). Pigs fed the POS diet had greater total Lys intake ($P < 0.001$), ADG ($P = 0.001$), and G:F ($P < 0.001$) than pigs fed the NEG diet. Similar to the finisher-1 phase, pigs fed the NEG diet had greater gain:total Lys intake ($P = 0.006$) compared with those fed the POS diet.

Overall, pigs fed the POS diets tended to consume more feed ($P = 0.083$) and consumed more total Lys ($P = 0.029$) than those fed the SID diets, which may have resulted in a tendency for pigs fed the POS diets to have slightly greater ADG ($P = 0.094$) than those fed the SID diets. However, there was no difference in G:F or gain:total Lys intake between the 2 treatments. Although there were no differences in ADFI, total Lys intake, or ADG, pigs fed the SID diets tended to have greater G:F ($P = 0.057$) and had greater gain:total Lys intake ($P < 0.001$) than those fed the NRC diets. Pigs fed the POS diets tended to have greater ADFI ($P = 0.079$) and had greater total Lys intake ($P < 0.001$), ADG ($P < 0.001$), and G:F ($P < 0.001$) than those fed the NEG diets. As in the finisher-1 and finisher-2 phases, pigs fed the NEG diets had greater gain:total Lys intake ($P < 0.001$) than those fed the POS diets.

3.2. Serum metabolites

Serum urea-N concentration was greater in pigs fed the NEG diets than those fed the POS diets ($P < 0.001$), and it

Table 4
Effect of amino acid (AA) supplementation of corn-hydrolyzed feather meal (FM) with blood diets on growth performance of pigs during the finisher-1 phase, finisher-2 phase, and overall.[a,b,c]

Item	Diet				SEM[d]	*P*-value[e]		
	POS	NEG	NRC	SID		POS vs. NEG	POS vs. SID	SID vs. NRC
Finisher-1 phase								
ADFI (g)	2,661	2,401	2,403	2,477	40	0.002	0.012	0.309
Total Lys intake (g/d)	20.3	12.3	19.3	19.0	1.2	< 0.001	0.012	0.583
ADG (g)	984	674	824	896	44	< 0.001	0.013	0.047
G:F (g/kg)	370	278	343	361	14	< 0.001	0.299	0.061
Gain:total Lys intake (g/g)	48.6	54.3	42.7	47.0	1.5	< 0.001	0.180	0.002
Finisher-2 phase								
ADFI (g)	3,091	2,836	2,848	2,834	41	0.156	0.087	0.918
Total Lys intake (g/d)	18.8	12.4	18.1	17.3	1.0	< 0.001	0.098	0.351
ADG (g)	940	709	876	904	34	0.001	0.489	0.586
G:F (g/kg)	304	244	307	317	11	< 0.001	0.187	0.313
Gain:total Lys intake (g/g)	50.0	56.3	48.3	51.9	1.1	0.006	0.299	0.049
Overall								
ADFI (g)	2,822	2,604	2,626	2,644	33	0.079	0.083	0.860
Total Lys intake (g/d)	19.4	12.3	18.7	18.1	1.0	< 0.001	0.029	0.278
ADG (g)	952	688	843	895	37	< 0.001	0.094	0.137
G:F (g/kg)	338	261	321	337	12	< 0.001	0.902	0.057
Gain:total Lys intake (g/g)	49.1	55.4	44.9	49.3	1.4	< 0.001	0.872	< 0.001

[a] ADFI = average daily feed intake, ADG = average daily gain, and G:F = gain to feed ratio.
[b] Least square means based on 8 pens; finisher 1: 50.1 ± 2.7 to 79.1 ± 1.9 kg; finisher 2: 79.1 ± 1.9 to 107.7 ± 2.8 kg.
[c] POS = corn-soybean meal positive control diet; NEG = corn-FM with blood negative control diet formulated to be iso-N and iso-caloric to the POS diet; NRC = NEG + Lys and Trp based on true ileal digestible AA in FM reported by NRC (1998); and SID = NEG + Lys and Trp based on standardized ileal digestible AA in FM with blood (Sulabo et al., 2013).
[d] Pooled SEM.
[e] Preplanned contrasts.

was less ($P = 0.003$) in pigs fed the SID diets than pigs fed the POS diets (Fig. 1). There was no difference between pigs fed the SID and NRC diets in serum urea-N concentration. Pigs fed the NEG diets had reduced serum total protein ($P < 0.001$) and albumin ($P < 0.001$) concentrations than those fed the POS diets. However, no difference in serum total protein or albumin concentration was observed between pigs fed the POS and SID diets or those fed the SID and NRC diets.

Dietary treatments had no effect on serum glucose concentration in the present study (Fig. 2). Serum triglyceride concentration was greater ($P < 0.001$) in pigs fed the NEG diets than those fed the POS diets, but there was no difference between pigs fed the POS and SID diets or the SID and NRC diets. Pigs fed the NEG diets had greater serum cholesterol concentration ($P < 0.001$) than those fed the POS diets, and it was also greater ($P = 0.002$) in those fed the SID diets compared with pigs fed the POS diets. There was no difference in cholesterol concentration between pigs fed the SID and NRC diets.

3.3. *Carcass traits and subjective meat quality scores*

Dietary treatments had no effect on dressing percentage, last rib backfat, or fat-free lean gain:total Lys intake (Table 5). Pigs fed the SID ($P = 0.10$) and NEG ($P = 0.099$) diets tended to have greater 10th rib backfat than those fed the POS diets. Pigs fed the POS diets had greater loin muscle area ($P = 0.012$) than pigs fed the NEG diets, but there was no difference between pigs fed the POS and SID diets. Similarly, although pigs fed the POS diets had greater fat-free lean percentage ($P = 0.030$) than those fed the NEG diets, there was no difference between pigs fed the POS and those fed the SID diets. Pigs fed the POS diets had greater fat-free lean gain ($P = 0.020$) than those fed the

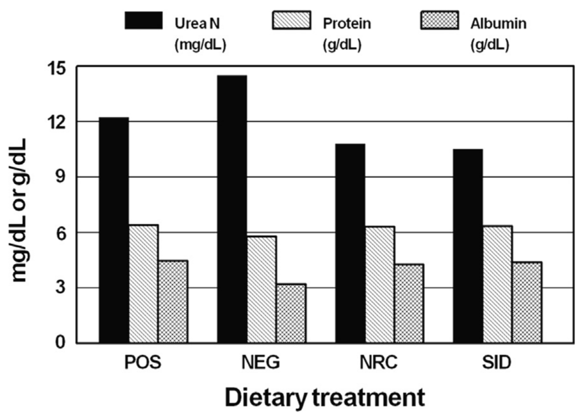

Fig. 1. Effect of hydrolyzed feather meal (FM) with blood and amino acid (AA) supplementation on serum urea N, total protein (protein), and albumin in pigs at the end of the study (final body weight = 107.7 ± 2.8 kg). Each least squares mean was based on 8 pens. POS = corn-soybean meal positive control diet; NEG = corn-FM negative control diet formulated to be iso-N and iso-caloric to the POS diet; NRC = NEG + Lys and Trp based on true ileal digestible AA in FM reported by NRC (1998); and SID = NEG + Lys and Trp based on standardized ileal digestible AA in FM with blood (Sulabo et al., 2013). Pooled SEM: 0.6 mg, 0.09 g, and 0.19 g/dL, for urea-N, total protein (protein), and albumin, respectively. Preplanned contrasts = urea-N: POS vs. NEG, $P < 0.001$, and POS vs. SID, $P = 0.003$; protein: POS vs. NEG, $P < 0.001$; and albumin: POS vs. NEG, $P < 0.001$.

SID diets, however, the efficiency of feed or total Lys utilization for fat-free lean gain was not different between those 2 treatments. Although pigs fed the POS diets had greater fat-free lean gain ($P<0.001$) and efficiency of feed utilization for fat-free lean gain ($P<0.001$) than those fed the NEG diets, there was no difference in the efficiency of total Lys utilization for fat-free lean gain. No differences were observed between the pigs fed the SID and NRC diets in any of the carcass traits. Dietary treatments had no effect on meat color, firmness, marbling, or muscling scores.

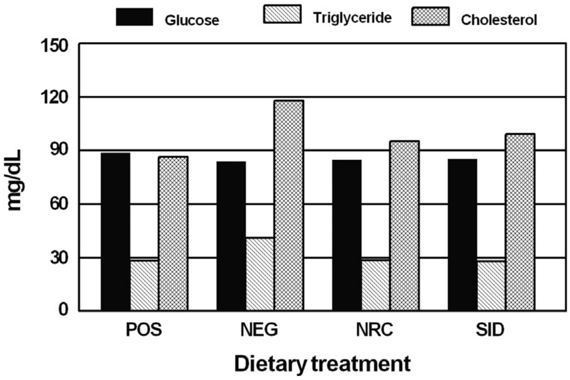

Fig. 2. Effect of hydrolyzed feather meal (FM) with blood and amino acid (AA) supplementation on serum metabolites in pigs at the end of the study (final body weight = 107.7 ± 2.8 kg). Each least squares mean was based on 8 pens. POS = corn-soybean meal positive control diet; NEG = corn-FM negative control diet formulated to be iso-N and iso-caloric to the POS diet; NRC = NEG+Lys and Trp based on true ileal digestible AA in FM reported by NRC (1998); and SID = NEG+Lys and Trp based on standardized ileal digestible AA in FM with blood (Sulabo et al., 2013). Pooled SEM: 0.71, 2.1, and 4.3 mg/dL for glucose, triglyceride, and cholesterol, respectively. Preplanned contrasts = triglyceride: POS vs. NEG, $P<0.001$; and cholesterol: POS vs. NEG, $P<0.001$, and POS vs. SID, $P=0.002$.

4. Discussion

For a competitive and sustainable poultry industry, it is imperative to find viable ways to manage the large volume of poultry feathers produced, mostly by broiler production. Increasing the market demand for FM can contribute greatly to such an effort. It is also important to find alternative sources of AA for future pig production simply because of the competition between humans and pigs for quality sources of protein (Chiba, 2001). Therefore, finding ways to increase the use of FM in pig production is mutually beneficial for successful and sustainable poultry and pig production.

The FM can be an attractive source of AA for growing pig diets (Chiba, 2001), however, the use of FM in swine diets has been rarther limited until fairly recently (Apple et al., 2003; Southern et al., 2000; Ssu et al., 2004; van Heugten and van Kempen, 2002) because of the deficiency in some indispensable AA (Chiba, 2010a, 2010b). Incorporating FM in pig diets based on the AA content would increase the CP content, which can have adverse effects on the environment (Chiba, 2000). Thus, supplementation of FM diets with appropriate AA based on the ileal AA digestibility would be the most effective way to utilize FM in pig diets.

Both apparent ileal digestible and TID values for FM (NRC, 1998) are based on rather limited data (Chiba, 2001), thus, it is necessary to determine the digestibility of AA in FM to formulate effective experimental diets. The SID of AA and protein (Stein et al., 2001) in a wide range of feed ingredients have been reported over the years

Table 5
Effect of amino acid (AA) supplementation of corn-hydrolyzed feather meal (FM) with blood diets on carcass traits, and subjective meat quality scores in pigs at the end of the finisher phase.[a,b]

Item	Diet				SEM[c]	P-value[d]		
	POS	NEG	NRC	SID		POS vs. NEG	POS vs. SID	SID vs. NRC
Carcass traits								
Dressing percentage (%)	74.9	75.8	75.5	75.4	0.1	0.319	0.460	0.952
10th rib backfat (mm)	22.3	26.4	25.2	25.7	0.6	0.099	0.100	0.807
Last rib backfat (mm)	25.4	24.7	27.4	27.2	0.4	0.764	0.339	0.907
Loin muscle area (cm^2)	39.4	33.6	39.1	38.9	0.9	0.012	0.771	0.912
Fat-free lean (%)	50.7	47.3	49.3	49.1	0.5	0.030	0.186	0.833
Fat-free lean gain (g/d)	364	217	312	312	20	<0.001	0.020	0.999
Fat-free lean gain:feed intake (g/kg)	128.9	84.7	119.4	117.7	6.3	<0.001	0.210	0.846
Fat-free lean gain:total Lys intake (g/g)	18.7	17.9	16.7	17.2	0.3	0.576	0.226	0.655
Subjective meat quality scores[e]								
Color	2.58	2.67	2.45	2.45	0.04	0.701	0.525	0.996
Firmness	1.05	1.05	1.00	1.00	0.01	0.994	0.346	0.999
Marbling	2.09	2.26	1.38	1.88	0.12	0.648	0.549	0.135
Muscling	2.03	2.02	2.00	2.06	0.01	0.900	0.771	0.529

[a] Least squares means based on 8 pens; final BW = 107.7 ± 2.8 kg.
[b] POS = corn–soybean meal positive control diet; NEG = corn-FM with blood negative control diet designed to be iso-N and iso-caloric to the POS diet; NRC = NEG+Lys and Trp based on true ileal digestible AA in FM reported by NRC (1998); and SID = NEG+Lys and Trp based on standardized ileal digestible AA in FM with blood (Sulabo et al., 2013).
[c] Pooled SEM.
[d] Preplanned contrasts.
[e] Based on 5-point scores for color, firmness, and marbling, and 3-point scores for muscling (NPPC, 1991).

(Jondreville et al., 1995; Rademacher et al., 1999), and the use of such values may increase in the future. Therefore, in the present study, SID coefficients in FM were determined first (Sulabo et al., 2013) and those values were used in an attempt to replace SBM completely with FM and appropriate AA supplementation.

The results of a previous study (Divakala et al., 2009) indicated that, although pigs fed FM diets supplemented with AA were able to utilize feed and AA for BW gain and lean gain as efficiently as those fed the corn-SBM diets, they were not able to achieve similar BW gain. Those results implied that the corn-FM diets supplemented with AA based on the assumption, the digestibility of 40% for all AA in FM (Knabe et al., 1989), was not able to provide sufficient digestible AA. It is possible that FM with blood may provide more digestible AA to animals than FM without blood (Contanch et al., 2007). Therefore, in the present study, an effort was made to replace SBM completely with FM with blood and appropriate AA supplementation.

Growth performance data in the present study indicated that pigs fed the POS diets tended to gain faster than those fed the SID diets. However, pigs fed the SID diets were able to utilize feed and Lys for BW gain as efficiently as those fed the POS diets. It is likely that the tendency for the decreased rate of BW gain in SID pigs was the result of a tendency to reduce feed and reduced Lys intake (178 and 1.3 g/d, respectively). There were no differences between pigs fed the SID and NRC diets in ADFI, total Lys intake, or ADG. However, pigs fed the SID diets tended to utilize feed for BW gain more efficiently, and utilized Lys more efficiently than those fed the NRC diets. It is possible that the diets based on SID coefficients provided a more optimal balance of indispensable AA than those based on the TID values reported by the NRC (1998), thus, resulting in the improved efficiency of utilization of feed and total Lys in pigs fed the SID diets.

As observed in the previous studies (Chiba et al., 1996; Divakala et al., 2009), pigs fed the NEG diets tended to consume less feed and had reduced total Lys intake, ADG, and G:F compared with those fed the POS diets. Sufficient amounts of necessary AA are required for protein synthesis (Everson et al., 1989) and the NEG diet may have been simply deficient some AA compared with the needs for finisher pigs. However, pigs fed the NEG diets had increased efficiency of Lys utilization for BW gain compared with those fed the POS diets. This is likely a result of the sparing effect of AA in pigs fed diets deficient in Lys and other AA as mentioned by Chiba et al. (1991).

Serum metabolite data may provide insight into the effect of dietary manipulations on metabolic activities. Lowrey et al. (1962) suggested that serum total protein or albumin concentration can be used as an indicator of the adequacy of dietary protein content. Studies have shown that pigs fed protein-deficient or Lys-deficient diets exhibit decreases in both serum total protein and albumin concentrations (Atinmo et al., 1976; Divakala et al., 2009; Kamalakar et al., 2009; Pond et al., 1980). Results of the present study are in agreement with those findings. Pigs fed the NEG diets had reduced total protein and albumin concentrations. No differences in total protein or albumin concentrations were observed between pigs fed the SID and POS diets, indicating that pigs fed the SID diets were, perhaps, provided with sufficient digestible AA and able to utilize those AA as efficiently as pigs fed the POS diets (Mule et al., 2006).

Urea-N is another important indicator of protein and AA adequacy and efficiency. Plasma urea-N levels can be decreased in pigs fed low-protein diets supplemented with AA to alleviate the deficiency (Gomez et al., 2002). In the present study, pigs fed the SID diets had reduced concentrations of serum urea-N compared with those fed the POS diets. This is likely due to the greater availability of crystalline AA compared with the intact protein (Izquierdo et al., 1988; Kerr and Easter, 1995; Knowles et al., 1998; Ward and Southern, 1995) and more balanced protein in the SID diets compared with the POS diets. As expected, pigs fed the POS diets had decreased concentrations of urea-N compared with those fed the NEG diets. Pigs fed the NEG diets were, perhaps, not consuming adequate amounts of AA necessary for protein synthesis, and unutilized AA or N were simply excreted as urea.

Low AA intake may have a hypercholesterolemic effect, and it has been reported that there is a negative relationship between Lys intake and serum cholesterol concentration (Mule et al., 2006). In the present study, serum cholesterol concentrations decreased in pigs fed the POS diets compared with those fed the SID diets. Pigs fed the POS diets consumed slightly more total Lys (and other AA) than those fed the SID diets, which may have been responsible for the results observed. Also, the inclusion of a small amount of poultry fat to the FM diets may have influenced the result (Pond et al., 1992). Pigs fed the NEG diets had increased concentrations of cholesterol compared with those fed the POS diets, which was expected. Serum cholesterol is typically greater in pigs fed a protein- or AA-deficient diet because of the changes in the lipoprotein composition or transport, or both, which can have a hypercholesteremic effect, even though the exact mechanism is unclear (Pond et al., 1986).

Pigs fed the POS diets had a greater fat-free lean gain than those fed the SID diets, perhaps, because of the reduced feed or total Lys intake or both. However, there was no difference in loin muscle area, fat-free lean percentage, or the efficiency of feed or Lys utilization for fat-free lean gain between pigs fed the SID and POS diets. As expected, pigs fed the POS diets had increased loin muscle area, tendency for decreased 10th rib backfat, greater fat-free lean carcass percentage, and fat-free lean gain, and increased efficiency of feed utilization for fat-free lean gain than those fed the NEG diets. The NEG diets were simply deficient in Lys and Trp, as well as other AA, which may explain all those differences. It has been reported that pigs fed protein-deficient diets had increased intramuscular fat (Blanchard et al., 1999; Castell et al., 1994; Cisneros et al., 1996), however, in the present study, marbling scores did not differ between pigs fed the NEG and POS diets. In fact, no differences in any subjective meat quality scores were observed in the present study.

The magnitude of depression of overall BW gain associated with replacing SBM completely with FM seemed to be reduced by using FM with blood in the present study compared with the FM without blood used in the previous study (Divakala et al., 2009). The differences in BW gain between the corn-SBM control and the FM diet supplemented with appropriate AA were 140 and 57 g/d for the previous and current study, respectively. Unfortunately, the rate of fat-free lean accretion was less in the pigs fed the AA-supplemented FM diets. However, the efficiency of feed or Lys utilization for BW gain or fat-free lean gain was not different between pigs fed the corn-SBM diets and the AA-supplemented FM diets based on SID AA values in FM.

5. Conclusion

Pigs fed the SID diets tended to utilize feed for BW gain more efficiently and utilized Lys more efficiently than those fed the NRC diets, indicating that the diets based on SID AA values may have provided a more optimal balance of indispensable AA than those based on the TID values reported by the 1998 NRC. Although the depression in BW gain was alleviated by using FM with blood to a large extent, the FM diets supplemented with appropriate AA based on SID AA values were not as effective as the corn-SBM diets in promoting growth. However, pigs fed the FM diets supplemented with appropriate AA based on SID AA utilized feed and AA for BW gain and fat-free lean gain as efficiently as those fed the corn-SBM diets. It is possible that slightly reduced BW gain and fat-free lean gain in pigs fed the SID diets is associated with slightly reduced intake of feed and Lys and some other AA. Further research is warranted to determine the optimum way to utilize FM for pig production in an environmentally friendly manner.

Conflict of interest statement

The authors certify that there is no financial and(or) personal relationships with other individuals or organizations that can affect the current research project improperly, or no professional or personal interest of any nature or kind in any product, service, and(or) organization that could to construed as influencing the present article.

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