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Nutritional value of soybean meal produced from high protein, low oligosaccharide, or conventional varieties of soybeans and fed to weanling pigs

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ABSTRACT

Three experiments were conducted to evaluate the nutritional value of high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), and conventional soybean meal (SBM-CV) fed to weanling pigs. The three soybean meals (SBM) contained 549, 536 and 475 g/kg crude protein, respectively. In Exp. 1, the coefficient of ileal standardized digestibility (CISD) of amino acids (AA) in the 3 ingredients was measured using eight barrows (initial body weight: 14.3 ± 1.23 kg) that were equipped with a T-cannula in the distal ileum and allotted to a replicated 4×4 Latin square design with four periods (seven days per period) and four diets per square. Three diets contained SBM-HP, SBM-LO, or SBM-CV as the sole source of AA. The fourth diet was a N-free diet that was used to determine basal ileal endogenous losses of AA. Results indicated that the CISD for all AA was not different among the three varieties of SBM. In Exp. 2, the digestible energy (DE) and metabolizable energy (ME) in the three sources of SBM were determined using 24 barrows (initial body weight: 11.9 ± 1.24 kg) that were placed in metabolism cages and randomly allotted to four diets. A corn-based diet and three diets containing corn and one of the three sources of SBM were formulated. No differences were observed for DE (18.20, 17.92, 18.27, and 17.15 MJ/kg dry matter) and ME (17.31, 16.93, 17.76, and 16.96 MJ/kg dry matter) among SBM-HP, SBM-LO, SBM-CV, and corn. In Exp. 3, a total of 120 weanling barrows (initial body weight: 6.76 ± 2.49 kg) were randomly allotted to three dietary treatments with ten pens per treatment and four pigs per pen. Three diets containing each source of SBM were formulated based on the values for CISD of AA and ME that were calculated in the previous two experiments. No differences were observed during the entire experimental period for average daily gain, average daily feed intake, or gain:feed. Results indicate that the greater concentration of digestible AA in SBM-HP and SBM-LO compared with SBM-CV are effectively utilized by weanling pigs, which implies that the nutritional values of SBM-HP and SBM-LO are greater than that of SBM-CV.

Abbreviations: AA, amino acids; ADF, acid detergent fiber; ADFI, average daily feed intake; ADG, average daily gain; CIAD, coefficient of ileal apparent digestibility; CTTAD, coefficient of total tract apparent digestibility; CISD, coefficient of ileal standardized digestibility; CP, crude protein; DE, digestible energy; G:F, gain:feed; GE, gross energy; ME, metabolizable energy; NDF, neutral detergent fiber; SBM, soybean meal; SBM-CV, conventional soybean meal; SBM-HP, high protein soybean meal; SBM-LO, low oligosaccharide soybean meal; SEM, standard error of the mean.

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1. Introduction

New varieties of soybeans with increased protein concentration or low concentrations of oligosaccharides compared with conventional soybeans have recently been introduced (Baker et al., 2010; Yoon and Stein, 2013). Crushing of these varieties results in production of soybean meal (SBM) that has the characteristics of the parent soybeans. Thus, the crude protein (CP) concentrations in high protein SBM (SBM-HP) is greater than in conventional SBM (SBM-CV), but the coefficient of ileal standardized digestibility (CISD) for AA in SBM-HP is not different from the CISD of AA in SBM-CV, if the meals are fed to growing pigs (Baker and Stein, 2009). However, because of the greater concentration of amino acids (AA) in SBM-HP than in SBM-CV, greater quantities of digestible AA are provided in the SBM from high protein varieties than in SBM from conventional soybeans if fed to growing pigs or broiler chicks (Baker and Stein, 2009; Baker et al., 2011). The concentration of digestible energy (DE) and metabolizable energy (ME) in SBM-HP is not different from the DE and ME in SBM-CV when fed to growing pigs (Baker and Stein, 2009). Oligosaccharides in soybeans are poorly digested by pigs because pigs do not secrete α-galactosidase, the enzyme that is needed to digest oligosaccharides in soybeans (Gitzelman and Auricchio, 1965). These oligosaccharides can increase the viscosity of digesta in the intestine, which may result in poor digestion and absorption of nutrients (Bedford, 1995; Dilger et al., 2004). The presence of these oligosaccharides in diets for weanling pigs may result in reduced growth performance and increased diarrhea in weanling pigs (Liying et al., 2003). Therefore, it may be beneficial to reduce the level of oligosaccharides in soybeans and SBM fed to weanling pigs. The concentrations of stachyose and raffinose are less in low oligosaccharide SBM (SBM-LO) than in SBM-CV (Baker and Stein, 2009), but the digestibility of AA in SBM-LO is not different from the digestibility of AA in SBM-CV when fed to growing pigs or broiler chicks (Baker and Stein, 2009; Baker et al., 2011). However, there is no information about the nutritional value of SBM-HP and SBM-LO fed to weanling pigs.

The first objective of this research was, therefore, to test the hypothesis that the digestibility of AA and the concentration of DE and ME in SBM-HP and SBM-LO are not different from the values for SBM-CV when fed to weanling pigs. The second objective was to test the hypothesis that performance of weanling pigs is not affected if SBM-HP or SBM-LO is included in the diets formulated to contain equal quantities of digestible AA and ME.

2. Materials and methods

2.1. General

Three experiments were conducted and the Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for each experiment. Pigs used in Exp. 1 and 2 were the offspring of line 337 boars that were mated to C 22 females (Pig Improvement Company, Hendersonville, TN), but pigs used in Exp. 3 were the offspring of landrace boars mated to a Yorkshire-duroc females (Pig Improvement Company, Hendersonville, TN). The same batches of SBM-HP, SBM-LO, and SBM-CV that were used by Baker et al. (2011) were also used in this experiment. The SBM were produced from high protein, low oligosaccharide, or conventional varieties of soybeans. All three sources of SBM were processed at the Zeeland Farm Services processing plant in Michigan and similar procedures were used to process all three sources of SBM. All diets in these three experiments were fed in a meal form.

The three sources of SBM were analyzed in duplicate (Table 1) for dry matter (DM; method 930.15, AOAC International, 2005), CP (method 990.03), acid–hydrolyzed ether extract (method 920.39), Ca (method 978.02), P (method 946.06), neutral detergent fiber (NDF; Holst, 1973), acid detergent fiber (ADF; method 973.18), sucrose, raffinose, and stachyose (Janauer and Englmaier, 1978), and trypsin inhibitors (method Ba 12-75: AOCS, 1998). They were also analyzed in duplicate for AA on a Hitachi Amino Acid Analyzer (Model No. L8800, Hitachi High Technologies America, Inc., Pleasanton, CA), using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Samples were hydrolyzed with 6 N HCl for 24 h at 110 °C (method 982.30) before analysis. Methionine and cysteine were determined as methionine sulfone and cysteic acid, respectively, after cold performic acid oxidation overnight prior to hydrolysis (method 982.30). Tryptophan was determined after NaOH hydrolysis for 22 h at 110 °C (method 982.30).

2.2. Amino acid digestibility

Experiment 1 was designed to determine the coefficient of ileal apparent digestibility (CIAD) and the CISD AA in SBM-HP, SBM-LO, and SBM-CV. Eight barrows (initial body weight: 14.3 ± 1.23 kg) were randomly allotted to a replicated 4×4 Latin square design with four diets and four periods. A T-cannula was surgically installed in the distal ileum of each pig according to procedures adapted from Stein et al. (1998). Pigs were housed individually in pens (0.9 m × 1.8 m) that had fully slatted concrete floors. A feeder and a nipple drinker were installed in each pen.

Four diets were prepared (Tables 2 and 3). Three of the diets contained one of the three SBM, starch, sugar, and soybean oil with SBM as the sole source of AA. These diets were formulated to contain approximately the same quantities of CP. The last diet was a N-free diet that was used to measure basal endogenous losses of AA. All diets also contained 4 g/kg chromic oxide as an indigestible marker. Solka floc was included in the N-free diet (40 g/kg) to increase the concentration of crude fiber. It was assumed that the ingredients used in the N-free diet contained no Mg and K; therefore, these minerals were included in the form of magnesium oxide and potassium carbonate, respectively. Vitamins and minerals were included in

Table 1
Analyzed energy and nutrient composition of high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), and conventional soybean meal (SBM-CV) (g/kg, as-fed basis unless otherwise indicated).

Item	Ingredient		
	SBM-CV	SBM-HP	SBM-LO
Dry matter	875	887	887
Crude protein	475	549	536
AEE[a]	14.8	7.6	9.6
Calcium	2.4	3.4	3.3
Phosphorus	6.7	7.3	6.8
Neutral detergent fiber	66.8	50.4	49.6
Acid detergent fiber	39.1	35.4	30.9
Sucrose	70.5	42.7	73.5
Stachyose	46.1	49.7	13.8
Raffinose	9.3	9.3	1.8
Trypsin inhibitor activity (TIU[b]/mg)	3.2	4.5	3.5
Indispensable amino acids			
Arginine	35.6	42.7	40.5
Histidine	12.5	14.4	13.5
Isoleucine	22.5	25.4	24.1
Leucine	37.6	43.5	41.0
Lysine	31.4	35.6	33.3
Methionine	6.8	7.8	7.1
Phenylalanine	24.8	28.9	27.2
Threonine	18.3	21.3	19.6
Tryptophan	6.9	7.8	7.2
Valine	23.6	26.4	25.0
Dispensable amino acids			
Alanine	20.7	23.4	21.8
Aspartic acid	54.0	64.2	60.0
Cysteine	6.5	7.8	7.3
Glutamic acid	85.4	103.1	95.1
Glycine	20.0	23.1	21.4
Proline	23.6	27.2	24.2
Serine	21.0	25.7	23.6
Tyrosine	17.0	20.1	18.4
Total amino acids	468	548	510
Calculated value			
Lysine:crude protein	6.49	6.21	6.61

[a] Acid–hydrolyzed ether extract.
[b] Trypsin inhibitor units.

Table 2
Ingredient composition (as-fed basis) of experimental diets containing high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), or conventional soybean meal (SBM-CV), and of the N-free diet, AA experiment (Exp. 1).

Ingredient (g/kg)	Diet			
	SBM-CV	SBM-HP	SBM-LO	N-Free
SBM-CV	395.0	–	–	–
SBM-HP	–	342.5	–	–
SBM-LO	–	–	360.0	–
Cornstarch	427.0	481.0	463.5	671.0
Soybean oil	40.0	40.0	40.0	40.0
Sucrose	100.0	100.0	100.0	200.0
Solka floc[a]	–	–	–	40.00
Limestone	10.0	8.5	8.5	12.0
Monocalcium phosphate	17.0	17.0	17.0	21
Magnesium oxide	–	–	–	1.0
Potassium carbonate	–	–	–	4.0
Chromic oxide	4.0	4.0	4.0	4.0
Salt	4.0	4.0	4.0	4.0
Vitamin mineral premix[b]	3.0	3.0	3.0	3.0

[a] Fiber Sales and Development Corp., Urbana, OH, USA.
[b] Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,120 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.41 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.6 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.031 mg; D-pantothenic acid as D-calcium pantothenate, 24 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 0.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 125 mg as zinc oxide.

Table 3
Analyzed nutrient composition (as-fed basis) of experimental diets containing high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), or conventional soybean meal (SBM-CV), and of the N-free diet, AA experiment (Exp. 1).

Item (g/kg)	Diet			
	SBM-CV	SBM-HP	SBM-LO	N-Free
Dry matter	900.9	901.2	903.8	915.6
Crude protein	194.7	161.9	192.5	5.1
Indispensable amino acids				
Arginine	14.3	11.7	15.6	0.2
Histidine	5.0	4.0	5.3	0.1
Isoleucine	9.0	7.1	9.5	0.2
Leucine	15.2	12.0	16.0	0.3
Lysine	12.6	10.0	12.9	0.2
Methionine	2.5	2.0	2.6	0.0
Phenylalanine	10.0	7.8	10.6	0.2
Threonine	7.4	5.8	7.5	0.1
Tryptophan	3.2	2.4	3.0	<0.4
Valine	9.6	7.6	10.0	0.2
Dispensable amino acids				
Alanine	8.4	6.6	8.6	0.2
Aspartic acid	21.8	17.9	23.4	0.3
Cysteine	2.5	2.1	2.8	0.0
Glutamic acid	34.4	29.4	37.3	0.8
Glycine	8.1	6.5	8.4	0.2
Proline	9.1	7.8	10.0	0.2
Serine	8.6	7.0	8.9	0.1
Tyrosine	6.2	4.6	6.4	0.1

all diets to meet or exceed current requirement estimates (NRC, 1998). All pigs were fed once daily at a level of 3.2 times the maintenance energy requirement (*i.e.*, 0.44 MJ ME per $kg^{0.75}$; NRC, 1998) and water was available at all times throughout the experiment.

Pig weights were recorded at the beginning and at the end of each period. Each experimental period lasted 7 days and the initial 5 days was considered an adaptation period to the diet. On day 6 and 7 of each period, cannulas were opened and a 225-mL plastic bag was attached to the cannula barrel with a cable tie and digesta that flowed into the bag were collected for eight consecutive hours. Bags were removed whenever they were filled with digesta, or at least once every 30 min, and digesta were stored at −20 °C to prevent bacterial degradation of the AA in the digesta.

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a sub-sample was collected for chemical analysis. A sample of each diet and of each of the SBM was collected as well. Digesta samples were lyophilized and finely ground prior to chemical analysis. Diets were analyzed for DM, CP, and AA as described for the ingredients. Chromium concentrations of diets and ileal digesta were also analyzed (method 990.08; AOAC International, 2005).

Values for CIAD of AA in samples obtained from feeding the three diets containing SBM were calculated using the following equation (Stein et al., 2007):

$$\mathrm{CIAD} = 1 - \left[\left(\frac{\mathrm{AA_d}}{\mathrm{AA_f}}\right)\left(\frac{\mathrm{Cr_f}}{\mathrm{Cr_d}}\right)\right] \tag{1}$$

where CIAD is the coefficient of ileal apparent digestibility of an AA, AA_d is the AA concentration in the ileal digesta DM, AA_f is the AA concentration in the feed DM, Cr_f is the chromium concentration in the feed DM, and Cr_d is the chromium concentration in the ileal digesta DM. Because SBM was the only feed ingredient contributing AA in each of the diets, these values also represent the CIAD for AA in each source of SBM.

The basal endogenous losses of AA were calculated from pigs fed the N-free diet using the following equation (Stein et al., 2007):

$$\mathrm{IAA_{end}} = \mathrm{AA_d}\left(\frac{\mathrm{Cr_f}}{\mathrm{Cr_d}}\right) \tag{2}$$

where IAA_{end} is the basal endogenous losses of an AA (mg/kg dry matter intake).

By correcting the CIAD for the IAA_{end} of each AA, CISD were calculated using the following equation (Stein et al., 2007):

$$\mathrm{CISD} = \mathrm{CIAD} + \left(\frac{\mathrm{IAA_{end}}}{\mathrm{AA_d}}\right) \tag{3}$$

where CISD is the coefficients of ileal standardized digestibility.

Data were analyzed using the Proc Mixed of SAS (SAS Institute Inc., Cary, NC). An analysis of variance was conducted with diet as fixed effect and period as random effect. If significant differences were detected, treatment means were separated

Table 4
Composition (as-fed basis) of experimental diets containing corn, high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), or conventional soybean meal (SBM-CV), energy experiment (Exp. 2).

Item	Diet			
	SBM-CV	SBM-HP	SBM-LO	Corn
Ingredient (g/kg)				
Ground corn	617.5	667.5	647.5	964.5
SBM-CV	350.0	–	–	–
SBM-HP	–	300.0	–	–
SBM-LO	–	–	320.0	–
Ground limestone	12.0	12.0	12.0	13.5
Monocalcium phosphate	13.5	13.5	13.5	15.0
Salt	4.0	4.0	4.0	4.0
Vitamin mineral premix[a]	3.0	3.0	3.0	3.0
Analyzed composition				
Gross energy (MJ/kg)	16.13	16.12	16.16	15.56
Dry matter (g/kg)	870.3	872.8	872.8	868.5

[a] Provided the following quantities of vitamins per kilogram of complete diet: Vitamin A as retinyl acetate, 10,990 IU; vitamin D_3 as cholecalciferol, 1,648 IU; vitamin E as DL-alpha tocopheryl acetate, 55 IU; vitamin K as menadione nicotinamide bisulfite, 4.4 mg; thiamin as thiamine mononitrate, 3.3 mg; riboflavin, 9.9 mg; pyridoxine as pyridoxine hydrochloride, 3.3 mg; vitamin B_{12}, 0.044 mg; D-pantothenic acid as D-calcium pantothenate, 33 mg; niacin as nicotinamide and nicotinic acid, 55 mg; folic acid, 1.1 mg; biotin, 0.17 mg; Cu, 16 mg as copper sulfate; Fe, 165 mg as iron sulfate; I, 0.36 mg as potassium iodate; Mn, 44 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 165 mg as zinc oxide.

using the Least Significant Difference test in Proc MIXED. Pig was the experimental unit for all calculations and a P-value of 0.05 was used to assess significance among means.

2.3. Energy measurements

Experiment 2 was designed to determine the DE and ME and the coefficient of total tract apparent digestibility (CTTAD) of gross energy (GE) in SBM-HP, SBM-LO, and SBM-CV. A total of 24 barrows (initial body weight: 11.9 ± 1.24 kg) were placed in metabolism cages equipped with a feeder and a nipple drinker. The experiment was conducted as a randomized complete block design with four diets and six replications per diet. The four diets were based on corn or corn and one of the three sources of SBM (Table 4). Corn and SBM were the sole sources of energy in the diets. The three SBM diets were formulated to have similar concentrations of GE.

The quantity of feed provided per pig daily was calculated as 3.2 times the estimated requirement for maintenance energy (*i.e.*, 0.44 MJ ME per $kg^{0.75}$; NRC, 1998) for the smallest pig in each replicate and divided into two equal meals. Water was available at all times. Pigs were fed experimental diets for 14 days. The initial 7 days was considered an adaptation period to the diet. Chromic oxide (5 g/kg) and ferric oxide (5 g/kg) were added to the diet in the morning meals on day 8 and 13, respectively. Fecal collections were initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared in the feces according to the marker to marker approach (Adeola, 2001). Urine collection was initiated after feeding the morning meal on day 8 and ceased after feeding the morning meal on day 13. Urine was collected in urine buckets over a preservative of 40 mL of 6 N HCl. Fecal samples and 20% of the collected urine were stored at −20 °C immediately after collection. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a sub-sample was collected for analysis.

Fecal samples were dried in a forced air oven and finely ground prior to analysis, and urine samples were lyophilized before analysis as described by Kim et al. (2009). Fecal, urine, and diet samples were analyzed in duplicate for GE using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Diets were also analyzed for DM as explained for the ingredients. Following chemical analysis, the CTTAD was calculated for GE in each diet using the following equation (Stein et al., 2004):

$$\mathrm{CTTAD} = \frac{N_i - N_f}{N_i} \tag{4}$$

where CTTAD is the coefficient of total tract apparent digestibility, N_i is the total intake of energy (MJ), N_f is the total fecal output of energy (MJ). The amount of energy lost in the feces and urine was calculated as well, and the quantities of DE and ME in each of the four diets were calculated (Stein et al., 2004). By subtracting the contribution of corn to the corn-SBM diets, the concentration of DE and ME in each of the three sources of SBM was calculated using the difference procedure (Adeola, 2001). Data were analyzed as described for the AA digestibility experiment.

2.4. Growth performance

Experiment 3 was conducted to measure growth performance of weanling pigs fed diets containing each of the three SBM that were used in the previous two experiments. A total of 120 barrows were weaned at approximately 20 day of age and allotted to a completely randomized design with 3 diets. All pigs were fed a common transition diet for three days post-weaning before being allotted to experimental diets with body weight at 6.76 ± 2.49 kg. Phase 1 diets were fed during

Table 5
Ingredient composition (as-fed basis) of diets containing high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), or conventional soybean meal (SBM-CV), performance experiment (Exp. 3).

Ingredient (g/kg)	Phase 1			Phase 2		
	SBM-CV	SBM-HP	SBM-LO	SBM-CV	SBM-HP	SBM-LO
Ground corn	450.0	474.3	457.5	629.5	664.8	646.5
Whey, dried	200.0	200.0	200.0	–	–	–
SBM-CV	241.5	–	–	265.0	–	–
SBM-HP	–	218.0	–	–	230.0	–
SBM-LO	–	–	235.0	–	–	248.0
Fish meal	60.0	60.0	60.0	40.0	40.0	40.0
Soybean oil	20.0	20.0	20.0	30.0	30.0	30.0
Mecadox premix[a]	10.0	10.0	10.0	10.0	10.0	10.0
L-Lysine HCl	1.5	1.5	1.5	1.5	1.5	1.5
DL-Methionine	1.0	0.8	0.9	1.1	1.0	1.1
L-Threonine	1.0	0.9	0.9	0.9	0.7	0.9
Ground limestone	5.5	5.5	5.2	5.5	5.5	5.5
Dicalcium phosphate	2.5	2.0	2.0	9.5	9.5	9.5
Salt	4.0	4.0	4.0	4.0	4.0	4.0
Vitamin mineral premix[b]	3.0	3.0	3.0	3.0	3.0	3.0

[a] Provided 50 mg of carbadox per kilogram of complete diet, Philbro Animal Health Corp., Teaneck, NJ, USA.
[b] Provided the following quantities of vitamins per kilogram of complete diet: Vitamin A as retinyl acetate, 10,990 IU; vitamin D_3 as cholecalciferol, 1,648 IU; vitamin E as DL-alpha tocopheryl acetate, 55 IU; vitamin K as menadione nicotinamide bisulfite, 4.4 mg; thiamin as thiamine mononitrate, 3.3 mg; riboflavin, 9.9 mg; pyridoxine as pyridoxine hydrochloride, 3.3 mg; vitamin B_{12}, 0.044 mg; D-pantothenic acid as D-calcium pantothenate, 33 mg; niacin as nicotinamide and nicotinic acid, 55 mg; folic acid, 1.1 mg; biotin, 0.17 mg; Cu, 16 mg as copper sulfate; Fe, 165 mg as iron sulfate; I, 0.36 mg as potassium iodate; Mn, 44 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 165 mg as zinc oxide.

Table 6
Analyzed nutrient composition (as-fed basis) of experimental diets containing high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), or conventional soybean meal (SBM-CV), performance experiment (Exp. 3).

Item	Phase 1			Phase 2		
	SBM-CV	SBM-HP	SBM-LO	SBM-CV	SBM-HP	SBM-LO
Crude protein (g/kg)	235.5	238.1	219.1	209.6	231.9	222.8
Gross energy (MJ/kg)	17.21	17.11	17.20	17.12	17.01	16.91
Indispensable amino acids (g/kg)						
Arginine	13.5	13.7	14.3	12.6	12.8	13.5
Histidine	5.4	5.4	5.6	5.1	5.0	5.2
Isoleucine	9.7	9.7	9.8	8.3	8.0	8.2
Leucine	18.3	18.4	18.9	16.3	16.4	17.0
Lysine	14.7	14.5	15.0	12.4	12.1	12.5
Methionine	4.4	4.3	4.3	4.1	4.2	4.0
Phenylalanine	10.2	10.2	10.6	9.4	9.2	9.6
Threonine	9.4	9.2	9.7	8.1	7.7	8.1
Tryptophan	2.9	2.8	2.9	2.4	2.4	2.5
Valine	10.7	10.6	10.8	9.3	9.0	9.5
Dispensable amino acids (g/kg)						
Alanine	11.2	11.1	11.2	10.1	10.0	10.2
Aspartic acid	21.7	22.1	22.7	19.0	19.2	20.0
Cysteine	3.6	3.6	3.5	3.2	3.3	3.1
Glutamic acid	37.3	38.3	38.9	33.4	34.5	35.3
Glycine	10.0	9.9	10.0	9.1	8.9	9.1
Proline	11.4	11.4	11.6	10.4	10.6	10.7
Serine	8.5	8.8	9.0	7.8	8.0	7.9
Tyrosine	6.9	6.8	7.0	6.4	6.2	6.3

the initial 14 days of the experiment and phase 2 diets were fed during the following 19 days. All diets (Table 5) were formulated to contain similar quantities of ME and standardized ileal digestible lysine:ME, and other AA were formulated as a ratio to Lysine. All diets were formulated to meet or exceed estimates for nutrient requirements (NRC, 1998). Values for CISD AA and ME were obtained from Exp. 1 and 2, respectively. The calculated ME values were 14.55 MJ/kg for the SBM-HP diet, 14.49 MJ/kg for the SBM-LO diet, and 14.61 MJ/kg for the SBM-CV diet in phase 1, and 14.65 MJ/kg for the SBM-HP diet, 14.58 MJ/kg for the SBM-LO diet, and 14.73 MJ/kg for the SBM-CV diet in phase 2. Diet samples were analyzed in duplicate for CP, GE, and AA as described for Exp. 1 and 2 (Table 6).

There were four pigs per pen and ten replicate pens per treatment. Pigs were housed in 1.6 m × 1.6 m pens that have fully slatted floors. A feeder and a nipple drinker were installed in each pen. Feed and water were provided on an ad libitum basis throughout the experiment.

Table 7
Coefficient of ileal apparent digestibility of AA of high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), and conventional soybean meal (SBM-CV) by weanling pigs, AA experiment (Exp. 1).[a]

Item	Ingredient			SEM	P-value
	SBM-CV	SBM-HP	SBM-LO		
Indispensable amino acids					
Arginine	0.93	0.92	0.93	0.006	0.18
Histidine	0.90	0.89	0.91	0.012	0.61
Isoleucine	0.88	0.87	0.89	0.015	0.57
Leucine	0.88	0.87	0.89	0.015	0.61
Lysine	0.88	0.87	0.88	0.015	0.83
Methionine	0.89	0.88	0.90	0.014	0.77
Phenylalanine	0.89	0.88	0.90	0.014	0.58
Threonine	0.82	0.80	0.83	0.022	0.68
Tryptophan	0.90	0.90	0.89	0.016	0.98
Valine	0.85	0.84	0.86	0.018	0.64
Dispensable amino acids					
Alanine	0.82	0.80	0.83	0.025	0.60
Aspartic acid	0.86	0.85	0.87	0.019	0.87
Cysteine	0.79	0.80	0.82	0.030	0.72
Glutamic acid	0.88	0.88	0.89	0.023	0.94
Glycine	0.73	0.66	0.71	0.050	0.37
Proline	0.67[x]	0.37[y]	0.61[x]	0.091	<0.01
Serine	0.86	0.85	0.87	0.017	0.74
Tyrosine	0.88	0.86	0.89	0.015	0.50
All amino acids	0.86	0.83	0.86	0.020	0.39

[x,y] Values within a row lacking a common superscript letter are different ($P<0.05$).
[a] Data are means of 8 observations per treatment.

Pigs were weighed at the start of the experiment, at the end of phase 1, and at the end of the experiment. Daily feed allotments were recorded as well. The mortality and morbidity of pigs were recorded throughout the experiment. Four pigs from different pens were removed from the experiment, including one dead pig and three sick pigs. The final body weights of removed pigs were recorded and feed consumption data were calculated based on Lindemann and Kim (2007). At the conclusion of the experiment, data were summarized to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G:F) for each pen. Data were analyzed as a completely randomized design by repeated measures ANOVA using the Proc Mixed of SAS (SAS Stat Inst. Inc., Cary, NC) with diet as fixed effect. The pen was the experimental unit for all calculations and an alpha value of 0.05 was used to assess significance among means.

3. Results

3.1. Amino acid digestibility

The CIAD of AA was also not different with the exception that the CIAD of Pro was greater ($P<0.05$) in SBM-LO and SBM-CV compared with SBM-HP (Table 7). The CISD of AA was also not different among SBM-HP, SBM-LO, and SBM-CV (Table 8).

3.2. Energy measurements

There were no differences among pigs fed the three SBM diets or the corn diet for GE intake and GE in feces (Table 9). Pigs fed SBM-HP and SBM-LO diets excreted more ($P<0.05$) GE in the urine than pigs fed the corn diet, but no difference was observed between pigs fed the SBM-CV diet and pigs fed the other diets. There were no differences for CTTAD of GE among the four diets, but the DE of the corn diet (14.35 MJ/kg as-fed basis) was less ($P<0.05$) than the DE of the diets containing SBM-HP (14.77 MJ/kg as-fed) and SBM-CV (14.78 MJ/kg as-fed), whereas the DE of the diet containing SBM-LO (14.72 MJ/kg as-fed) was not different from the DE of any of the other diets.

The DE in SBM-HP, SBM-LO, and SBM-CV were greater ($P<0.05$) than in corn (16.14, 15.90, and 15.99 *vs.* 14.87 MJ/kg as-fed), but the ME values were not different among ingredients (Table 9). Likewise, when DE and ME values were expressed on a DM basis, no differences were observed among ingredients.

3.3. Growth performance

Only one pig died during the experiment. There were no differences among treatments in the initial body weight of the pigs (Table 10). Likewise, pig body weight at the end of phase 1 and at the end of phase 2 were not influenced by dietary treatments. No differences were observed in phase 1, phase 2, or the entire experimental period for ADG, ADFI, and G:F of pigs fed diets containing SBM-HP, SBM-LO, or SBM-CV.

Table 8
Coefficient of ileal standardized digestibility of AA of high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), and conventional soybean meal (SBM-CV) by weanling pigs, AA experiment (Exp. 1).[a,b]

Item	Ingredient			SEM	P-value
	SBM-CV	SBM-HP	SBM-LO		
Indispensable amino acids					
Arginine	0.98	0.98	0.98	0.006	0.97
Histidine	0.94	0.94	0.95	0.012	0.92
Isoleucine	0.92	0.92	0.93	0.015	0.88
Leucine	0.92	0.92	0.93	0.015	0.83
Lysine	0.92	0.92	0.92	0.015	0.98
Methionine	0.92	0.93	0.93	0.014	0.94
Phenylalanine	0.92	0.93	0.93	0.014	0.86
Threonine	0.90	0.90	0.91	0.022	0.92
Tryptophan	0.94	0.95	0.94	0.016	0.76
Valine	0.90	0.91	0.91	0.018	0.90
Dispensable amino acids					
Alanine	0.90	0.91	0.91	0.025	0.98
Aspartic acid	0.90	0.90	0.90	0.019	0.97
Cysteine	0.87	0.89	0.89	0.030	0.81
Glutamic acid	0.91	0.92	0.92	0.023	0.94
Glycine	0.99	0.99	0.97	0.050	0.88
Proline	1.46	1.30	1.33	0.091	0.05
Serine	0.93	0.94	0.93	0.017	0.94
Tyrosine	0.93	0.92	0.93	0.015	0.98
All amino acids	0.95	0.94	0.95	0.020	0.99

[a] Data are least square means of 8 observations per treatment.
[b] Coefficient of ileal standardized digestibility values were calculated by correcting the values for coefficient of ileal apparent digestibility for the basal ileal endogenous losses. Basal ileal endogenous losses were determined from pigs fed the N-free diet as (g/kg dry matter intake): Arginine, 0.98; Histidine, 0.23; Isoleucine, 0.41; Leucine, 0.70; Lysine, 0.67; Methionine, 0.10; Phenylalanine, 0.42; Threonine, 0.77; Tryptophan, 0.16; Valine, 0.73; Alanine, 0.87; Aspartic acid, 1.04; Cysteine, 0.23; Glutamic acid, 1.24; Glycine, 2.51; Proline, 9.17; Serine, 0.73; Tyrosine, 0.34.

Table 9
Digestible energy (DE) and metabolizable energy (ME; as-fed basis) in experimental diets and in high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), conventional soybean meal (SBM-CV), and corn, energy experiment (Exp. 2).[a]

Item	Diet				SEM	P-value
	SBM-CV	SBM-HP	SBM-LO	Corn		
CTTAD GE[b]	0.92	0.92	0.91	0.92	0.01	0.62
DE, diet (MJ/kg)	14.78^{x}	14.77^{x}	14.72^{xy}	14.35^{y}	0.09	<0.05
ME, diet (MJ/kg)	14.52	14.42	14.33	14.18	0.11	0.18
DE, ingredient (MJ/kg)	15.99^{x}	16.14^{x}	15.90^{x}	14.87^{y}	0.25	<0.01
ME, ingredient (MJ/kg)	15.54	15.36	15.02	14.70	0.29	0.22
DE, ingredient (MJ/kg of dry matter)	18.27	18.20	17.92	17.15	0.28	0.05
ME, ingredient (MJ/kg of dry matter)	17.76	17.31	16.93	16.96	0.33	0.27

^{x,y} Values within a row lacking a common superscript letter are different ($P<0.05$).
[a] Data are least square means of 6 observations per treatment.
[b] CTTAD GE = coefficient of total tract apparent digestibility of gross energy.

4. Discussion

4.1. Nutrient composition

The nutrient composition of SBM-CV concurs with published values (Baker and Stein, 2009; NRC, 2012), and the nutrient composition of SBM-HP is in agreement with previous data (Baker and Stein, 2009; NRC, 2012). The CP, acid–hydrolyzed ether extract, ADF, NDF, AA, and oligosaccharide concentrations of SBM-LO was also comparable with published values (Parsons et al., 2000; Baker and Stein, 2009; NRC, 2012; Pangeni, 2012).

The CP and AA concentrations in SBM-HP were greater than in SBM-LO and SBM-CV, which was expected because SBM-HP has been produced from soybeans with a greater concentration of CP (Yoon and Stein, 2013). This observation also agrees with previous experiments using SBM-HP and SBM-LO (Baker and Stein, 2009; Baker et al., 2011). The concentrations of stachyose and raffinose were less in SBM-LO compared with SBM-HP and SBM-CV, which was also expected because SBM-LO was produced from soybeans with low concentrations of oligosaccharides (Yoon and Stein, 2013). The sucrose was least in SBM-HP compared with SBM-LO and SBM-CV, which is in agreement with previous data (Baker et al., 2011). The reason for this observation may be that an adverse relationship between CP and sucrose is often observed in soybeans (Hartwig et al., 1997; Baker et al., 2010; Yoon and Stein, 2013).

Table 10
Performance of weanling pigs fed diets containing high protein soybean meal (SBM-HP), low oligosaccharide soybean meal (SBM-LO), or conventional soybean meal (SBM-CV), performance experiment (Exp. 3).[a]

Item	Diet				P-value
	SBM-CV	SBM-HP	SBM-LO	SEM	
Day 1–14					
Initial body weight (kg)	6.77	6.75	6.77	0.30	0.18
ADFI (g)	354	394	388	18.8	0.20
ADG (g)	250	258	279	15.5	0.41
G:F	0.71	0.66	0.72	0.03	0.21
Body weight at day 14 (kg)	10.45	10.66	10.68	0.41	0.44
Day 15–33					
ADFI (g)	905	920	917	30.8	0.88
ADG (g)	586	607	609	20.2	0.53
G:F	0.65	0.66	0.67	0.01	0.63
Body weight at day 33 (kg)	21.42	21.90	22.26	0.72	0.36
Day 1–33					
ADFI (g)	671	697	693	24.6	0.59
ADG (g)	444	459	469	15.4	0.37
G:F	0.66	0.66	0.68	0.01	0.27

ADG, average daily gain; ADFI, average daily feed intake; G:F, gain:feed.
[a] Values are means of 10 observations per treatment.

4.2. Amino acid digestibility

The observation that there is no difference in the CISD for AA between SBM-HP and SBM-CV is in agreement with data for growing pigs and broiler chicks (Baker and Stein, 2009; Baker et al., 2011), which also indicated that no difference for AA digestibility exist between SBM-HP and SBM-CV. Likewise, no differences were observed in the CISD of AA between high protein full-fat soybeans and conventional soybeans (Cervantes-Pahm and Stein, 2008; Baker et al., 2010). These observations imply that the increased concentration of AA in SBM-HP compared with SBM-CV will result in greater quantities of standardized ileal digestible AA being provided by SBM-HP than by SBM-CV. As a consequence, less quantities of SBM-HP than of SBM-CV will be needed in diets formulated to contain a specified concentration of standardized ileal digestible AA or less quantities of synthetic AA will be needed in SBM-HP diets than in SBM-CV diets.

The observation that there is no difference in CISD for AA between SBM-LO and SBM-CV is in agreement with data for extruded-expelled SBM fed to growing pigs (Baker and Stein, 2009) and for SBM fed to broiler chicks (Baker et al., 2011), which also indicated that no difference for AA digestibility exist between SBM-LO and SBM-CV. By using SBM-LO rather than SBM-CV, it is, therefore, possible to reduce the concentration of oligosaccharides in diets fed to weanling pigs without reducing the quantities of standardized ileal digestible AA or reduce the quantity of synthetic AA that is needed in a diet formulation.

4.3. Energy measurements

The lack of differences in the ME among SBM-HP, SBM-LO, and SBM-CV concurs with data for extruded-expelled SBM from high protein, low oligosaccharide, or conventional varieties of soybeans (Baker and Stein, 2009). However, the true metabolizable energy in SBM-HP is greater than in SBM-LO and SBM-CV fed to broiler chicks (Baker et al., 2011). The greater protein concentration in the SBM-HP may be responsible for the greater DE in the high protein SBM (Baker and Stein, 2009; Baker et al., 2011). However, in this experiment, we did not observed any difference in DE values among different sources of SBM. This observation is consistent with data indicating no differences between the DE of full-fat high-protein soybeans and full-fat conventional soybeans when fed to growing pigs (Yoon and Stein, 2013). The SBM-HP and the SBM-LO used in this experiment had a reduced concentration of acid–hydrolyzed ether extract compared with SBM-CV. Therefore, it appears that the increased DE and ME that were expected for SBM-HP and SBM-LO due to the greater concentration of CP were offset by the reduced concentration of acid–hydrolyzed ether extract in these meals.

The DE and ME for corn used in this experiment are in accordance with the values reported by NRC (2012), but the DE and ME for SBM-CV are greater than values reported by Baker and Stein (2009) and NRC (2012). This may be a consequence of the greater concentration of acid–hydrolyzed ether extract in the SBM-CV used in this experiment compared with the SBM used in previous experiments. The lack of a difference in the ME values between SBM-CV and corn is in accordance with Baker and Stein (2009) and NRC (2012), who also reported similar ME values for SBM-CV and corn.

4.4. Growth performance

There were no differences in growth performance among pigs fed the 3 different diets, although the diets containing SBM-HP and SBM-LO contained less SBM than the diet containing SBM-CV. However, it should be noted that the diets used in this experiment were fortified with carbadox, which is a common praxis in the U.S. swine industry. Based on the present data it is not possible to know if results would have been the same if no carbadox had been included in the diets. Nevertheless, to our knowledge, this is the first time it has been demonstrated that inclusion of SBM in diets fed to weanling pigs may be reduced if SBM-HP or SBM-LO is used, but the present data are in agreement with Hinson et al. (2009) who reported that there is no difference in growth performance between growing-finishing pigs fed SBM-LO and pigs fed SBM-CV. It has also been demonstrated that there are no differences in growth performance of broiler chickens fed diets containing SBM-HP or SBM-LO compared with those fed SBM-CV (Baker et al., 2011). These results indicate that the greater concentration of digestible AA in SBM-HP and SBM-LO compared with SBM-CV are effectively utilized by weanling pigs, and less SBM will be needed if SBM-HP or SBM-LO is used in diets fed to weanling pigs.

5. Conclusion

Results of the present experiments indicate that the CISD of all AA and DE and ME values in SBM-HP and SBM-LO are not different from values for SBM-CV if fed to weanling pigs. This observation confirms that the same values for CISD of AA and DE and ME can be used for SBM-HP and SBM-LO as the values used for SBM-CV. High protein SBM and SBM-LO have a greater nutritional value in diets for weanling pigs because of the increased concentration of digestible AA, which reduces the quantity of SBM that is needed in a diet formulated to contain a specified amount of digestible AA or reduces the quantity of synthetic AA that is needed in a diet formulation.

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