Published August 30, 2016

Digestibility of energy, amino acids, and phosphorus in a novel source of soy protein concentrate and in soybean meal fed to growing pigs[1]

M. S. Oliveira*† and H. H. Stein*‡[2]

*Department of Animal Sciences, University of Illinois at Urbana-Champaign, Urbana 61801; †Departamento de Zootecnia, Universidade Estadual Paulista, Jaboticabal, Brazil; and ‡Division of Nutritional Sciences, University of Illinois at Urbana-Champaign, Urbana 61801

ABSTRACT: Three experiments were conducted to determine standardized ileal digestibility (SID) of CP and AA, DE and ME, and apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P in a new source of soy protein concentrate (SPC) and in soybean meal (SBM). In Exp. 1, 9 barrows (initial BW: 13.08 ± 1.98 kg) were prepared with a T-cannula in the distal ileum and allotted to a triplicated 3 × 3 Latin square design with 3 diets and 3 periods. A nitrogen-free diet and 2 diets that contained corn starch and SPC or SBM as the sole source of CP and AA were formulated. Each period lasted 7 d, and ileal digesta were collected on d 6 and 7 of each period. The SID for Ile, Leu, Phe, Pro, and Tyr was greater ($P < 0.05$) in SPC than in SBM, but for CP and all other AA, no difference between SPC and SBM was observed. In Exp. 2, 24 barrows (initial BW: 13.94 ± 1.34 kg) were housed individually in metabolism crates and randomly allotted to 1 of 3 diets. A corn-based diet (96.9% corn) and 2 diets that contained corn and SPC or corn and SBM were formulated. Each diet was fed to 8 pigs. Feces and urine samples were collected using the marker to marker method with 5-d adaptation and 5-d collection periods. The DE and ME in SPC and SBM were calculated using the difference procedure. Results indicated that the ATTD of GE was lower ($P < 0.05$) in SBM than in corn and the DE and ME in SPC were greater ($P < 0.01$) than in corn and SBM. In Exp. 3, 40 barrows (initial BW: 14.12 ± 2.08 kg) were placed in metabolism crates and allotted to 4 diets in a randomized complete block design with 10 pigs per diet. Two diets were based on SPC or SBM as the sole source of P. Two additional diets were formulated by adding microbial phytase to diets that were otherwise similar to the 2 initial diets. Feces were collected for 5 d after a 5-d adaptation period and values for ATTD and STTD of P were calculated. No differences were observed in ATTD and STTD of P between SPC and SBM, but the ATTD and STTD of P of both SPC and SBM were greater ($P < 0.01$) if microbial phytase was added to the diets. In conclusion, the concentrations of DE and ME are greater in SPC than in SBM, but the SID of most AA and the STTD of P are not different between SPC and SBM.

Key words: amino acid digestibility, energy, phosphorus digestibility, pigs, soybean meal, soy protein concentrate

 J. Anim. Sci. 2016.94:3343–3352
doi:10.2527/jas2016-0505

INTRODUCTION

Soybean meal (**SBM**) is the main protein source used in diets for pigs in most countries, and effects of different forms of processing have been studied. Soybean meal contributes high-quality protein to diets fed to pigs, but the presence of antinutritional factors such as trypsin inhibitors and oligosaccharides may decrease nutrient availability and has limited the application of SBM in diets for weaned pigs (Huisman and Jansman, 1991).

Soy protein concentrate (**SPC**) is a source of SBM that has been processed by removing some of the nonprotein components, including the soluble carbohydrates, using an alcohol extraction process (Lusas and Rhee, 1995; Endres, 2001). Thus, SPC contains fewer trypsin inhibitors, sucrose, raffinose, and stachyose

[1]Financial support for this research was provided by Midwest Ag Enterprises Inc., Marshall, MN.

[2]Corresponding author: hstein@illinois.edu

Received March 26, 2016.
Accepted June 2, 2016.

than SBM (Lenehan et al., 2007), and the concentrations of CP and AA are greater than in most other soybean products. Results of studies by Cervantes-Pahm and Stein (2008) and Zhang et al. (2013) indicate that SPC has greater digestibility of most AA and greater DE and ME than SBM. However, a new nonalcohol-based technology for producing SPC was recently introduced, but the nutritional value of SPC produced using this technology has not been determined.

Therefore, 3 experiments were conducted to test the hypothesis that the digestibility of AA, energy, and P in this new source of SPC is greater than in SBM. The objective was to compare the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of AA, the concentrations of DE and ME, and the apparent total tract digestibility (**ATTD**) and the standardized total tract digestibility (**STTD**) of P in SPC and SBM.

MATERIALS AND METHODS

Three experiments were conducted, and the Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for all experiments. Pigs used in the experiments were the offspring of Line 359 boars and F-46 sows (PIC, Hendersonville, TN). The main ingredients that were used in the experiments included SPC, SBM, and corn (Table 1). The source of SPC was Nutrivance (Midwest Ag Enterprises Inc., Marshall, MN), which is produced using a process combining nonalcohol extraction of carbohydrates and enzymatic treatment of SBM. The SBM was from the same source as that used to produce the SPC and was produced by cracking and dehulling full-fat soybeans that were subsequently defatted using a hexane solvent, desolventized, toasted, and ground. The corn was obtained from the University of Illinois feed mill (Champaign, IL), and the same batch of corn was used to produce all 3 diets in Exp. 2.

Experiment 1: Amino Acid Digestibility

Diets, Animals, and Experimental Design. Experiment 1 was designed to determine the AID and the SID of CP and AA in SPC and SBM fed to pigs. Nine growing barrows (initial BW: 13.08 ± 1.98 kg) were equipped with a T-cannula in the distal ileum according to procedures adapted from Stein et al. (1998). Pigs were allotted to a triplicated 3 × 3 Latin square design with 3 periods and 3 pigs in each square. Pigs were housed individually in pens (1.2 × 1.5 m) in an environmentally controlled room. Pens had fully slatted tribar floors, and a feeder and a nipple drinker were installed in each pen.

Three cornstarch-based diets were prepared (Table 2). Two diets contained SPC (35%, as-fed basis) or SBM (46.5%, as-fed basis) as the only source of AA, and the third diet was a nitrogen-free (**N-free**) diet that was used to estimate basal endogenous losses of CP and AA. Chromic oxide (0.4%) was included in all diets as an indigestible marker, and vitamins and minerals were included to meet or exceed estimated nutrient requirements for weanling pigs (NRC, 2012).

Feeding and Sample Collection. Pigs were fed at a daily level of 3 times the estimated maintenance requirement for energy (i.e., 197 kcal of ME/kg of $BW^{0.60}$; NRC, 2012), and the daily allotment of feed was provided at 0800 h each day. Water was available at all times. The BW of each pig was recorded at the beginning of each period, and the amount of feed supplied each day was also recorded. Each experimental period lasted 7 d. The initial 5 d were an adaptation period to the diet, whereas ileal digesta were collected for 8 h on d 6 and 7. A 225-mL plastic bag was attached to the cannula barrel by a zip tie, and digesta that flowed into the bag were collected. Bags were removed whenever they were filled with digesta or at least once every 30 min and stored at −20°C to prevent bacterial degradation of AA in the digesta.

Chemical Analysis. At the conclusion of the experiment, ileal samples collected from each pig in each period were thawed and mixed, and a subsample was collected for chemical analyses. All ileal digesta samples were lyophilized and finely ground before chemical analysis. Soy protein concentrate, SBM, and all samples of digesta and diets were analyzed in duplicate for DM (method 930.15; AOAC Int., 2007), for CP by combustion (method 999.03; AOAC Int., 2007) using a Rapid N cube apparatus (Elementar Americas Inc., Mt. Laurel, NJ), and for AA with an AA analyzer (model L8800 Hitachi Amino Acid Analyzer, Hitachi High Technologies America Inc., Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before AA analysis, samples were hydrolyzed with 6 *N* HCl for 24 h at 110°C (method 982.30 E(a); AOAC Int., 2007). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (method 982.30 E(b); AOAC Int., 2007). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (method 982.30 E(c); AOAC Int., 2007). Diets and digesta samples were also analyzed for chromium using inductively coupled plasma spectroscopy (method 990.08; AOAC Int., 2007). Soy protein concentrate, SBM, and diet samples were also analyzed for GE using bomb calorimetry (model 6300; Parr Instruments, Moline, IL), ADF (method 973.18; AOAC Int., 2007), and NDF (Holst, 1973). Soy protein concentrate and SBM were also analyzed for acid-hydrolyzed ether extract (**AEE**), which was determined by acid hydrolysis using 3 *N* HCl (Sanderson, 1986) followed by crude fat extraction with

Table 1. Analyzed nutrient composition of soybean meal, soy protein concentrate, and corn (as-fed basis)[1]

	Ingredient		
Item	Soybean meal	Soy protein concentrate	Corn
DM,%	87.47	92.10	84.93
GE, kcal/kg	4,133	4,636	3,765
CP, %	47.67	61.21	7.18
AEE,[2] %	1.56	1.79	3.94
NDF, %	6.28	9.68	8.04
ADF, %	3.26	5.00	2.18
Starch, %	ND	2.70	72.80
Ash, %	6.77	4.06	1.24
Ca, %	0.43	0.50	0.01
P, %	0.63	0.62	0.26
Phytate, %	1.62	1.41	—
Phytate bound P,[3] %	0.45	0.39	—
Nonphytate P,[4] %	0.18	0.23	—
Carbohydrates, %			
Glucose	0.00	0.00	0.20
Sucrose	9.20	0.97	1.57
Maltose	0.18	ND	ND
Fructose	ND	ND	0.15
Stachyose	6.07	0.76	ND
Raffinose	0.95	0.15	0.21
Indispensable AA,%			
Arg	3.43	4.28	0.34
His	1.23	1.59	0.21
Ile	2.17	2.86	0.25
Leu	3.68	4.87	0.85
Lys	3.08	3.91	0.28
Met	0.61	0.80	0.16
Phe	2.48	3.22	0.35
Thr	1.78	2.34	0.26
Trp	0.64	0.86	0.05
Val	2.32	3.18	0.35
Total	21.42	27.91	3.10
Dispensable AA, %			
Ala	2.02	2.67	0.52
Asp	5.17	6.56	0.47
Cys	0.63	0.82	0.15
Glu	8.69	10.92	1.34
Gly	2.55	1.96	0.29
Pro	2.47	3.25	0.62
Ser	2.01	2.58	0.34
Tyr	1.80	2.26	0.19
Total	22.79	29.09	3.63

[1]Phytate was not analyzed in corn because corn was not used in the phosphorus digestibility experiment. ND = not detectable.

[2]AEE = acid-hydrolyzed ether extract.

[3]Phytate-bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[4]Nonphytate P was calculated as the difference between total P and phytate-bound P.

Table 2. Composition of experimental diets containing soy protein concentrate or soybean meal (as-fed basis), Exp. 1

	Diet		
Item	Soy protein concentrate	Soybean meal	N free
Ingredient, %			
Soy protein concentrate	35.00	—	—
Soybean meal	—	46.50	
Soybean oil	3.00	3.00	4.00
Corn starch	38.95	27.55	67.8
Milk lactose	20.00	20.00	20.00
Solka-Floc[1]	—	—	4.00
Sodium chloride	0.40	0.40	0.40
Dicalcium phosphate	1.10	1.10	2.15
Limestone	0.85	0.75	0.45
Magnesium oxide	—	—	0.10
Potassium carbonate	—	—	0.40
Vitamin-mineral premix[2]	0.30	0.30	0.30
Chromium oxide	0.40	0.40	0.40
Analyzed composition			
DM, %	91.83	90.96	88.83
GE, kcal/kg	4077	3987	3756
CP, %	21.64	23.50	0.16
NDF, %	3.07	3.37	0.36
ADF, %	2.16	2.12	0.46
Indispensable AA,%			
Arg	1.48	1.66	0.01
His	0.57	0.61	0.00
Ile	0.99	1.04	0.01
Leu	1.73	1.82	0.03
Lys	1.42	1.54	0.03
Met	0.29	0.30	0.01
Phe	1.11	1.19	0.02
Thr	0.85	0.90	0.01
Trp	0.28	0.30	0.02
Val	1.07	1.11	0.01
Total	9.79	10.47	0.15
Dispensable AA,%			
Ala	0.98	1.03	0.02
Asp	2.38	2.59	0.02
Cys	0.28	0.30	0.01
Glu	3.85	4.22	0.04
Gly	0.96	1.02	0.02
Pro	1.09	1.14	0.06
Ser	0.94	1.00	0.01
Tyr	0.64	0.73	0.01
Total	11.12	12.03	0.19

[1]Fiber Sales and Development Corp., Urbana, OH.

[2]Provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-**α**-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 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, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 3. Composition of experimental diets containing corn, soy protein concentrate, or soybean meal (as-fed basis), Exp. 2

	Diet		
Item	Corn	Soy protein concentrate	Soybean meal
Ingredient, %			
Corn	96.90	70.30	61.40
Soy protein concentrate	—	27.00	—
Soybean meal	—	—	36.00
Limestone	0.80	0.85	0.90
Dicalcium phosphate	1.60	1.15	1.00
Sodium chloride	0.40	0.40	0.40
Vitamin-mineral premix[1]	0.30	0.30	0.30
Analyzed composition			
DM, %	85.94	87.65	86.65
GE, kcal/kg	3,666	3,942	3,802
CP, %	7.41	21.75	21.44
AEE, %	1.07	1.51	1.27
NDF, %	7.60	8.90	7.32
ADF, %	2.64	3.34	2.89

[1]Provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-**α**-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 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, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

petroleum ether (method 2003.06; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Samples of SPC and SBM were also analyzed for ash (method 975.03; AOAC Int., 2007), for phytic acid (Ellis et al., 1977), and for Ca and P using inductively coupled plasma spectroscopy (method 985.01 A, B, and C; AOAC Int., 2007) after wet ash sample preparation (method 975.03 B(b); AOAC Int., 2007). These samples were also analyzed for starch (method 979.10; AOAC Int., 2007), and monosaccharides and oligosaccharides were analyzed as described by Cervantes-Pahm and Stein (2010).

Calculations and Statistical Analysis. Values for AID, endogenous losses, and SID of CP and AA in the diets containing SPC and SBM were calculated (Stein et al., 2007). Phytate-bound P in SPC and SBM was calculated as 28.2% of phytic acid (Tran and Sauvant, 2004), and nonphytate P was calculated as the difference between total P and phytate-bound P. Normality of data was verified, and outliers were tested using the UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC). Data were analyzed by ANOVA using the MIXED procedure with diet as the fixed effect and period as a random effect. An α value of 0.05 was used to assess significance among means, and the pig was the experimental unit for all analyses.

Experiment 2: Energy Digestibility and Concentrations of DE and ME

Diets, Animals, and Experimental Design. Experiment 2 was designed to determine the digestibility of energy and concentrations of DE and ME in SPC and SBM. Twenty-four growing barrows (initial BW: 13.94 ± 1.34 kg) were placed individually in metabolism crates equipped with a feeder and a nipple drinker in a randomized complete block design with 3 diets and 8 replicate pigs per diet. The BW of each pig was used as the blocking factor. Three diets were formulated (Table 3). The basal diet contained 96.9% corn (as-fed basis), the SPC diet contained 70.3% corn and 27.0% SPC (as-fed basis), and the SBM diet contained 61.4% corn and 36.0% SBM (as-fed basis). Vitamins and minerals were included in the diets to meet or exceed requirements for weanling pigs (NRC, 2012).

Feeding and Sample Collection. Feed was supplied in a daily amount of 3 times the maintenance energy requirement of the smallest pig in each replicate. The daily amount of feed was divided into 2 equal meals that were provided at 0800 and 1700 h. Water was available at all times. Pigs were fed experimental diets for 12 d, including 5 d for adaptation and 5 d for fecal sampling. Fecal markers (10 g/kg) were included in the morning meal on d 6 (chromic oxide) and in the morning meal on d 11 (ferric oxide) to mark the beginning and the end, respectively, of fecal collections (Adeola, 2001). Feces were collected quantitatively twice daily and stored at −20°C immediately after collection. Urine collections were initiated on d 6 at 1700 h and ceased on d 11 at 1700 h. Urine buckets were placed under the metabolism crates to permit total collection. They were emptied in the morning and afternoon, and a preservative of 50 mL of 3 *N* HCL was added to each bucket when it was emptied. The collected urine was weighed, and a 10% subsample was stored at −20°C.

Chemical Analyses. After completing sample collections, urine samples were thawed and mixed, and a subsample was collected for chemical analysis. Fecal samples were dried at 65°C in a forced-air oven and ground through a 1-mm screen in a Wiley mill (model 4; Thomas Scientific, Swedesboro, NJ) before analyses. Urine samples were prepared and lyophilized before GE analysis as previously described (Kim et al., 2009). Fecal samples were analyzed in duplicate for GE, and GE in urine was analyzed in triplicate. Diets and corn were analyzed for GE, DM, CP, ash, ADF, NDF, and AEE. Corn was also analyzed for starch, Ca, P, monosaccharides, oligosaccharides, and AA. All analyses for Exp. 2 were conducted as explained for Exp. 1.

Calculations and Statistical Analysis. Energy values that were determined from the excretion of GE in the feces and in urine were subtracted from the intake

of GE to calculate DE and ME for each diet (Adeola, 2001). The DE and ME in the corn diet were divided by 0.969 to calculate the DE and ME in corn. The contributions of DE and ME from corn to the diets containing SPC and SBM were then calculated and subtracted from the total DE and ME of these diets, and the concentrations of DE and ME in SPC and SBM were calculated by difference (Adeola, 2001). The DE and ME in all ingredients were calculated on an as-fed basis as well as on a DM basis. The ATTD of GE was also calculated for each diet and for SPC and SBM.

Data were analyzed by ANOVA using the Mixed Procedure (SAS Inst. Inc.); the statistical model included diet or ingredient as the fixed effect and replicate as the random effect. Treatment means were calculated using the LSMEANS statement, and means were separated using the PDIFF option PROC MIXED. Significance was considered at $P < 0.05$, and the experimental unit was the pig.

Experiment 3: Phosphorus Digestibility

Diets, Animals, and Experimental Design. Experiment 3 was designed to measure ATTD and STTD values for P in SPC and SBM fed to weanling pigs. Forty growing barrows (initial BW 14.12 ± 2.08 kg) were placed in metabolism crates and allotted to 4 diets in a randomized complete block design with 10 replicate pigs per diet. Two diets contained 46.7% (as-fed basis) SPC and either 0 or 2,000 units of microbial phytase (**FTU**; Optiphos 1000, Huvepharma, Sofia, Bulgaria) per kilogram (Table 4). Two additional diets contained 54% (as-fed basis) SBM and either 0 or 2,000 FTU of phytase/kg. The only sources of P in the diets were SPC and SBM. Vitamins and minerals, except P, were included in all diets to meet or exceed the requirements for weanling pigs (NRC, 2012).

Feeding and Sample Collection. Feed was supplied in the amount of 3 times the daily maintenance energy requirement of the smallest pig in each replicate. The daily amount of feed was divided into 2 equal meals that were fed at 0800 and 1700 h. Water was available at all times. Individual pig BW were recorded at the beginning and at the end of the experiment, and the amount of feed supplied each day was also recorded. Pigs were fed their experimental diets for 12 d. The initial 5 d were considered an adaptation period to the diet. Indigo carmine and ferric oxide were added to the diet as indigestible markers in the morning meals on d 6 and 11, respectively. The fecal collections started when indigo carmine appeared in the feces and ceased when ferric oxide appeared as described previously (Adeola, 2001). Feces were collected twice daily and stored at −20°C immediately after collection.

Table 4. Composition of experimental diets containing soy protein concentrate or soybean meal without or with microbial phytase (as-fed basis), Exp. 3

	Diet[1]			
	Soy protein concentrate		Soybean meal	
Item	0 FTU/kg	2,000 FTU/kg	0 FTU/kg	2,000 FTU/kg
Ingredient, %				
Soy protein concentrate	46.70	46.70	—	—
Soybean meal	—	—	54.00	54.00
Corn starch	33.60	33.58	33.30	33.28
Sucrose	15.00	15.00	8.00	8.00
Soybean oil	3.00	3.00	3.00	3.00
Limestone	1.00	1.00	1.00	1.00
Sodium chloride	0.40	0.40	0.40	0.40
Phytase premix[2]	—	0.02	—	0.02
Vitamin-mineral premix[3]	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Analyzed composition				
DM, %	92.63	92.25	89.67	89.46
GE, kcal/kg	4,248	4,273	4,047	3,989
Ca, %	0.64	0.63	0.73	0.59
P, %	0.30	0.32	0.39	0.37
Ash, %	4.58	4.80	3.04	4.48
NDF, %	4.48	4.29	4.57	4.41
ADF, %	3.05	3.17	3.21	3.57
Phytase, FTU/kg	<70	1900	<70	2,000

[1]FTU = phytase units.

[2]Optiphos 1000 (1,000 FTU/g; Huvepharma, Sofia, Bulgaria).

[3]Provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-**α**-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 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, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Chemical Analysis. All samples were analyzed in duplicate. Fecal samples were dried and ground as described for Exp. 2. Diets and fecal samples were analyzed for DM, Ca, and P as described for Exp. 1. Diets were also analyzed for GE, ADF, NDF, and ash as described for Exp. 1 and for phytase activity (Phytex Method, Version 1, Eurofins, Des Moines, IA).

Calculations and Statistical Analysis. The ATTD and STTD in each diet were calculated as described previously (Almeida and Stein, 2010). The basal endogenous loss of P was assumed to be 190 mg/kg DMI (NRC, 2012). Data were analyzed as a 2 × 2 factorial using the MIXED procedure (SAS Inst. Inc.). The fixed effects were source of soy protein, phytase, and the interaction between source of soy protein and phytase. Replicate was considered a random effect. The pig was

Table 5. Apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of CP and AA in soy protein concentrate (SPC) and soybean meal (SBM) fed to weanling pigs, Exp. 1[1]

	AID				SID			
Item	SPC	SBM	Pooled SEM	*P*-value	SPC	SBM	Pooled SEM	*P*-value
CP	82.8	80.3	1.8	0.19	93.6	89.2	1.8	0.09
Indispensable AA								
Arg	90.0	91.4	1.8	0.48	95.5	95.4	1.7	0.9
His	85.7	86.8	1.8	0.57	92.5	91.8	1.8	0.74
Ile	87.4	85.6	1.0	0.16	93.3[a]	89.9[b]	1.0	<0.05
Leu	87.5	84.8	1.2	0.06	93.1[a]	89.0[b]	1.2	<0.05
Lys	83.0	87.3	2.9	0.09	88.7	91.4	2.9	0.30
Met	88.1	88.1	1.1	0.87	93.2	92.1	1.1	0.52
Phe	87.8	85.5	1.5	0.06	93.6[a]	89.5[b]	1.5	<0.05
Thr	78.4	78.9	2.4	0.81	91.5	88.5	2.4	0.30
Trp	86.7	87.3	1.7	0.59	93.2	92.0	1.7	0.29
Val	85.2	83.2	1.4	0.19	92.6	88.8	1.4	0.05
Mean	86.1	85.4	1.6	0.66	92.7	90.2	1.4	0.21
Dispensable AA								
Ala	82.7	82.4	2.0	0.87	91.6	89.4	1.7	0.39
Asp	82.2	83.9	2.1	0.35	89.3	88.9	2.0	0.84
Cys	66.0[b]	75.9[a]	4.7	<0.05	84.1	90.1	4.3	0.20
Glu	82.3[b]	86.4[a]	3.1	<0.05	87.8	90.3	2.6	0.15
Gly	73.1	76.0	3.3	0.21	93.9	92.4	2.9	0.57
Pro	83.4	80.6	1.6	0.25	122.6[a]	108.6[b]	4.8	<0.05
Ser	84.1	83.3	1.9	0.67	93.7	90.4	1.8	0.09
Tyr	87.1	85.0	1.1	0.11	94.1[a]	89.9[b]	1.0	<0.05
Mean	81.6	83.7	2.3	0.23	93.6	93.0	2.0	0.81
Total AA	83.7	85.0	2.0	0.87	93.5	92.3	1.7	0.62

[a,b]Values within a row and digestibility procedure lacking a common superscript letter are different ($P < 0.05$).

[1]Data are expressed as least squares mean values ($n = 9$). Standardized ileal digestibility values were calculated by correcting the AID values for the basal ileal endogenous losses. Basal ileal endogenous losses were determined as (g/kg DMI): CP, 26.69; Arg, 0.87; His, 0.42; Ile, 0.63; Leu, 1.07; Lys, 0.88; Met, 0.16; Phe 0.70; Thr, 1.21; Trp, 0.20; Val, 0.86; Ala, 0.95; Asp, 1.84; Cys, 0.55; Glu, 2.32; Gly, 2.59; Pro, 4.66; Ser, 0.98; Tyr, 0.49.

the experimental unit for all analyses, and an α-value of 0.05 was used to assess significance among means.

RESULTS

Experiment 1: Amino Acid Digestibility

For CP and most AA, no differences in the AID and SID were observed between SBM and SPC (Table 5). However, the AID for Cys and Glu was greater ($P < 0.05$) in SBM than in SPC, and the SID for Ile, Leu, Phe, Pro, and Tyr in SPC was greater ($P < 0.05$) than in SBM.

Experiment 2: Energy Measurements

Pigs fed the corn diet had less ($P < 0.05$) GE intake than pigs fed the SPC or SBM diets, but there was no difference between SPC and SBM (Table 6). However, pigs fed the corn diet had the least ($P < 0.01$) fecal GE output and therefore, had greater ($P < 0.05$) ATTD of GE compared with pigs fed the SBM diet, but no difference between the SPC diet and the other diets was observed for ATTD of GE. In contrast, the diet containing SPC contained more ($P < 0.05$) DE and ME than diets containing corn or SBM.

The ATTD of GE was less ($P < 0.05$) in SBM than in corn, but there was no difference in ATTD between corn and SPC or between SPC and SBM (Table 7). On an as-fed basis, the DE and ME in SPC were greater ($P < 0.05$) than in corn and SBM, and the ME in corn was greater ($P < 0.05$) than in SBM. On a DM-basis, the DE and ME in SPC were also greater ($P < 0.05$) than in the other ingredients, and the DE in corn was less ($P < 0.05$) than in SBM, but no difference in ME between corn and SBM was observed.

Experiment 3: P Digestibility

Neither the source of soy protein nor microbial phytase influenced daily feed intake or basal EPL (Table 8). However, daily P intake was greater ($P < 0.05$) for pigs fed the diet containing SBM without phytase compared with pigs fed the SBM diet with phytase, but pigs fed the SPC diet without phytase did not have different P

Table 6. Apparent total tract digestibility of energy and concentrations of DE and ME in experimental diets (as-fed basis), Exp. 2[1]

	Diet[2]				
Item	Corn	SPC	SBM	SEM	*P*-value
GE intake, kcal/5 d	13,695[b]	15,665[a]	16,103[a]	510.93	<0.01
Fecal GE output, kcal/5 d	1,518[b]	1,842[a]	2,055[a]	126.30	<0.01
ATTD,[3] GE %	89.05[a]	88.27[a,b]	87.29[b]	0.53	<0.05
DE in diet, kcal/kg	3,264[c]	3,479[a]	3,319[b]	20.15	<0.01
Urinary GE output, kcal/5 d	352[c]	671[b]	932[a]	62.47	<0.01
ME in diet, kcal/kg	3,170[b]	3,299[a]	3,093[c]	25.44	<0.01

[a–c]Least squares within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Each least squares mean represents 8 observations. Total feed intake, GE intake, dry feces output, fecal GE output, urine output, and urine GE output were based on 5 d of collection.

[2]SPC = soy protein concentrate; SBM = soybean meal.

[3]ATTD = apparent total tract digestibility.

intake compared with pigs fed SPC with phytase (interaction, $P < 0.05$). Pigs fed diets with added microbial phytase had lower ($P < 0.01$) P concentration in feces than pigs fed diets without phytase, but the reduction was greater for SBM than for SPC (interaction, $P < 0.05$). The ATTD and STTD of P were greater ($P < 0.05$) if microbial phytase was added to the diets than if no phytase was used, but there were no differences in ATTD and STTD of P between SPC and SBM.

The intake of Ca was less ($P < 0.05$) for pigs fed the SBM diet with added phytase compared with pigs fed the SBM diet without phytase, but no difference between the 2 SPC diets was observed for Ca intake (interaction $P < 0.05$). The concentration of Ca in feces was reduced ($P < 0.05$) in pigs fed diets with added microbial phytase, but the reduction was greater ($P < 0.05$) for SBM than for SPC diets (interaction, $P < 0.05$). The ATTD of Ca was greater ($P < 0.05$) for pigs fed SBM than for pigs fed SPC, but the addition of phytase to the diet increased ($P < 0.05$) ATTD of Ca.

DISCUSSION

Composition of Ingredients

The concentrations of GE, CP, and all AA that were observed in SBM in this experiment are in agreement with reported values (NRC, 2012). The concentrations of AEE, NDF, sucrose, raffinose, and stachyose in SBM also concur with values reported by Rojas and Stein (2012). The concentrations of GE, AEE, starch, NDF, sucrose, and all AA that were observed in the SPC are in agreement with the values reported by NRC (2012), but concentrations of CP, stachyose, and raffinose in SPC were lower than values reported by NRC (2012). The SPC used in this experiment was obtained using a proprietary process combining nonalcohol extraction and enzymatic treatment of soybean meal. Aqueous alcohol extraction removes the sucrose, raffinose, and stachyose from defatted soy flakes (Eldridge et al., 1979), and it appears that the procedure used to produce the SPC that was included in this experiment is also effective in removing the low-molecular weight carbohydrates from SBM. Removal of low-molecular weight carbohydrates is the reason for the increased concentration of CP and AA in SPC compared with SBM.

Experiment 1: Amino Acid Digestibility

The AID and SID for CP and all AA in the SBM used in this experiment are close to the values reported by NRC (2012). The AID for CP and most AA in SPC was lower than values reported by NRC (2012) but in agreement with values reported by Cervantes-Pahm and Stein (2008). However, the SID for CP and most AA in SPC, except Lys, are greater than values reported by NRC (2012) and in agreement with values reported by Cervantes-Pahm and Stein (2008). It was expected that the SID of CP and AA in SPC would be greater than in SBM because the presence of oligosaccharides in SBM reduces AA digestibility (Cervantes-

Table 7. Concentrations of DE, ME, and apparent total tract digestibility in corn, soy protein concentrate (SPC), and soybean meal (SBM), Exp. 2[1]

	Ingredient				
Item	Corn	SPC	SBM	SEM	*P*-value
ATTD, GE %	89.05[a]	87.31[a,b]	85.49[b]	1.05	<0.05
As-fed basis					
DE, kcal/kg	3,369[b]	4,116[a]	3,474[b]	54.55	<0.01
ME, kcal/kg	3,271[b]	3,701[a]	3,014[c]	73.48	<0.01
DM basis					
DE, kcal/kg	3,851[c]	4,469[a]	4,090[b]	61.77	<0.01
ME, kcal/kg	3,739[b]	4,019[a]	3,549[b]	82.55	<0.01

[a–c]Least squares within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Each least squares mean represents 8 observations.

Table 8. Effects of microbial phytase on the apparent total tract digestibility (ATTD) of P and Ca and the standardized total tract digestibility (STTD) of P in soy protein concentrate and soybean meal, Exp. 3[1]

	Soy protein concentrate[2]		Soybean meal[2]		Pooled	*P*-value		
Item	<70 FTU/kg	1,900 FTU/kg	<70 FTU/kg	2,000 FTU/kg	SEM	Source	Phytase	Source × phytase
Feed intake, g/d	811.01	805.00	828.90	819.20	36.54	0.30	0.61	0.90
P intake, g/d	2.43[c]	2.58[c]	3.23[a]	3.03[b]	0.13	<0.01	0.63	<0.05
P in feces, %	2.66[b]	1.63[d]	3.37[a]	1.88[c]	0.09	<0.01	<0.01	<0.05
ATTD of P, %	50.35	70.93	53.85	74.20	2.16	0.13	<0.01	0.95
Basal EPL,[3] mg/d	142.74	141.09	141.25	139.25	6.28	0.52	0.49	0.85
STTD of P,[4] %	56.22	76.40	58.22	78.79	2.16	0.32	<0.01	0.93
Ca intake, g/d	5.17[b]	5.07[b]	6.04[a]	5.00[b]	0.21	<0.01	<0.01	<0.01
Ca in feces,%	4.63[a]	3.84[b]	4.83[a]	3.06[c]	0.22	0.17	<0.01	<0.05
ATTD of Ca, %	56.94	64.99	64.81	71.90	2.56	<0.01	<0.05	0.85

[a–d]Least squares within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are means of 10 observations per treatment, except for the treatment with SPC without phytase, which had only 8 observations. Values for phytase are indicated as analyzed values.

[2]FTU = phytase units. The phytase used was Optiphos 1000 (1,000 FTU/g; Huvepharma, Sofia, Bulgaria).

[3]EPL = basal endogenous P loss. This value was measured in pigs fed a P-free diet and was determined to be 190 mg/kg DMI (NRC, 2012). The daily basal EPL was calculated by multiplying daily DMI by 190 mg/kg DMI.

[4]Values for STTD were calculated by correcting values for ATTD for basal EPL.

Pahm and Stein, 2010). However, despite the absence of oligosaccharides in SPC, no improvement in the AID and SID of most AA in SPC compared with SBM was observed in this experiment, which is in contrast to previous observations (Cervantes-Pahm and Stein, 2008; NRC, 2012). The reason for this difference may be that different processes were used to produce the SPC used in this experiment compared with previous experiments.

The calculated value for the SID of Pro exceeded 100% for both SPC and SBM. The reason for this apparently impossible value is most likely that Pro is synthesized from other AA in the enterocytes and secreted into the lumen of the small intestine (Mariscal-Landin et al., 1995). As a consequence, endogenous protein has a greater concentration of Pro than of other AA (Holmes et al., 1974; Taverner et al., 1981). Values for the SID of Pro that are greater than 100% have been observed in numerous previous experiments in which the SID of AA in soy proteins or other sources of proteins was determined (Baker and Stein, 2009; Almeida et al., 2011; Liu et al., 2016).

Experiment 2: Energy Measurements

The concentrations of DE, ME, and ATTD of GE in corn obtained in this experiment concur with values reported by Rojas and Stein (2013), Rodríguez et al. (2013), and Rojas et al. (2014). Likewise, the DE and ME and the ATTD of GE that were determined for SBM are in close agreement with values published by Baker and Stein (2009). The concentrations of DE and ME in SPC obtained in this experiment concur with previously reported values (NRC, 2012).

Despite the observation that the ATTD of GE was not different between SPC and SBM, the increased DE and ME in SPC compared with SBM indicate that the process used to remove the carbohydrates such as oligosaccharides was efficient in improving the concentrations of DE and ME in SPC. Pigs do not secrete α-galactosidase, which is the enzyme needed for hydrolysis of raffinose and stachyose; thus, these oligosaccharides are not enzymatically digested in the small intestine of pigs. Therefore, removal of oligosaccharides from SBM resulted in greater concentration of CP, and therefore greater concentration of digestible energy, which is the reason the DE and ME are greater in SPC than in SBM.

Experiment 3: Phosphorus Digestibility

The concentration of P in SBM used in this experiment is in agreement with the concentrations reported by Zhang et al. (2013) and Rojas et al. (2014), and the concentrations of phytate P and nonphytate P in SBM are in agreement with values reported by Rojas et al. (2014). The concentration of P in SPC was lower than values reported by NRC (2012) and Zhang et al. (2013) and very close to the values in SBM. It was expected that P in SPC would be greater than in SBM because of the removal of soluble carbohydrates and the subsequent concentration of noncarbohydrate nutrients. However, the fact that the concentrations of P did not increase may indicate that the process used to remove the carbohydrates may also have resulted in the removal of some P. In contrast, the concentration of Ca was greater in

SPC than in SBM, but the concentration of Ca in SBM is relatively variable because some companies add limestone to SBM to improve flowability. The lack of differences in ATTD and STTD of P between SPC and SBM indicates that P in both ingredients is equally well digested. The values for ATTD and STTD of P in SBM without microbial phytase that were obtained in this experiment concur with previous values (Rodríguez et al., 2013), and the ATTD and STTD of P that were obtained for SBM with microbial phytase were close to values reported by Almeida and Stein (2010). To our knowledge, the effect of microbial phytase on the ATTD and STTD of P in SPC has not been reported, but results of this experiment indicate that the effect of microbial phytase on P digestibility in SPC is similar to the effect in SBM. The observation that the STTD of P in both SPC and SBM was between 79% and 80% if microbial phytase was used indicates that phytase is efficient in hydrolyzing phytate in both ingredients, and SPC and SBM are, therefore, rich sources of digestible P. These results are in agreement with Rojas and Stein (2012).

The ATTD of Ca was increased if microbial phytase was added to both SPC and SBM diets, indicating that phytase reduced the capacity of phytate to chelate Ca, which increased the amount of Ca available for absorption (Selle et al., 2009). The majority of the Ca in both diets was from limestone, and the observation that the ATTD of Ca increased if microbial phytase was used indicates that some of the Ca from limestone is bound to phytate in the intestinal tract of pigs if no phytase is used. This observation is also in agreement with previous data (Almeida and Stein, 2013; González-Vega et al., 2013; Rodríguez et al., 2013).

Conclusions

Results of the present experiment indicate that SPC produced using a nonalcohol extraction process in combination with enzymatic treatment contains less oligosaccharides than conventional SBM. As a consequence, concentrations of DE, ME, and CP in SPC are greater than in SBM, but only minor differences in SID of AA and the STTD of P between SPC and SBM were observed. These results suggest that SPC likely can be used in diets fed to weanling pigs without negatively affecting digestibility of energy or nutrients and without the negative effects associated with feeding diets containing oligosaccharides.

LITERATURE CITED

Adeola, O. 2001. Digestion and balance techniques in pigs. In: A. J. Lewis and L. L. Southern, editors, Swine nutrition. 2nd ed. CRC Press, Washington, DC. p. 903–916.

Almeida, F. N., G. I. Petersen, and H. H. Stein. 2011. Digestibility of amino acids in corn, corn co-products and bakery meal fed to growing pigs. J. Anim. Sci. 89:4109–4115. doi:10.2527/jas.2011-4143

Almeida, F. N., and H. H. Stein. 2010. Performance and phosphorus balance of pigs fed diets formulated on the basis of values for standardized total tract digestibility of phosphorus. J. Anim. Sci. 88:2968–2977. doi:10.2527/jas.2009-2285

Almeida, F. N., and H. H. Stein. 2013. Effects of a novel phytase on the digestibility of phosphorus in corn-soybean meal diets fed to weanling and growing pigs. J. Anim. Sci. Biotechnol. 4:8. doi:10.1186/2049-1891-4-8

AOAC Int. 2007. Official methods of analysis of AOAC Int. 18th ed. Rev. 2. AOAC Int., Gaithersburg, MD.

Baker, K. M., and H. H. Stein. 2009. Amino acid digestibility and concentration of digestible and metabolizable energy in soybean meal produced from high protein or low oligosaccharide varieties of soybeans and fed to growing pig. J. Anim. Sci. 87:2282–2290. doi:10.2527/jas.2008-1414

Cervantes-Pahm, S. K., and H. H. Stein. 2008. Effect of dietary soybean oil and soybean protein concentration on the concentration of digestible amino acids in soybean products fed to growing pigs. J. Anim. Sci. 86:1841–1849. doi:10.2527/jas.2007-0721

Cervantes-Pahm, S. K., and H. H. Stein. 2010. Ileal digestibility of amino acids in conventional, fermented, and enzyme-treated soybean meal and in soy protein isolate, fish meal, and casein fed to weanling pigs. J. Anim. Sci. 88:2674–2683. doi:10.2527/jas.2009-2677

Eldridge, A. C., L. T. Black, and W. J. Wolf. 1979. Carbohydrate composition of soybean flours, protein concentrates, and isolates. J. Agric. Food Chem. 27:799–802. doi:10.1021/jf60224a056

Ellis, R., E. R. Morris, and C. Philpot. 1977. Quantitative determination of phytate in the presence of high inorganic phosphate. Anal. Biochem. 77:536–539. doi:10.1016/0003-2697(77)90269-X

Endres, J. G. 2001. Soy protein products: Characteristics, nutritional aspects, and utilization. Am. Oil Chem. Soc., Urbana, IL.

González-Vega, J. C., C. L. Walk, Y. Liu, and H. H. Stein. 2013. Determination of endogenous intestinal losses of calcium and true total tract digestibility of calcium in canola meal fed to growing pigs. J. Anim. Sci. 91:4807–4816. doi:10.2527/jas.2013-6410

Holmes, J. H., H. S. Bayley, and P. A. Leadbeater. 1974. Digestion of protein in small and large intestine of the pig. Br. J. Nutr. 32:479–489. doi:10.1079/BJN19740102

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. J. Assoc. Off. Anal. Chem. 56:1352–1356.

Huisman, J., and A. J. M. Jansman. 1991. Dietary effects and some analytical aspects of antinutritional factors in peas (*Pisum sativum*), common beans (*Phaseolus vulgaris*) and soybeans (*Glycine max L.)* in monogastric farm animals. A literature review. Nutr. Abstr. Rev. 61:901–921.

Kim, B. G., G. I. Petersen, R. B. Hinson, G. L. Allee, and H. H. Stein. 2009. Amino acid digestibility and energy concentration in a novel source of high-protein distillers dried grains and their effects on growth performance of pigs. J. Anim. Sci. 87:4013–4021. doi:10.2527/jas.2009-2060

Lenehan, N. A., J. M. DeRouchey, R. D. Goodband, M. D. Tokach, S. S. Dritz, J. L. Nelssen, C. N. Groesbeck, and K. R. Lawrence. 2007. Evaluation of soy protein concentrates in nursery pig diets. J. Anim. Sci. 85:3013–3021. doi:10.2527/jas.2007-0071

Liu, Y., N. W. Jaworski, O. J. Rojas, and H. H. Stein. 2016. Energy concentration and amino acid digestibility in high protein canola meal, conventional canola meal, and in soybean meal fed to growing pigs. Anim. Feed Sci. Technol. 212:52–62. doi:10.1016/j.anifeedsci.2015.11.017

Lusas, E. W., and K. C. Rhee. 1995. Soy protein processing and utilization. In: D. E. Ericson, editor, Practical handbook of soybean processing and utilization, Am. Oil Chem. Soc., Urbana, IL. p. 117–160. doi:10.1016/B978-0-935315-63-9.50012-7

Mariscal-Landin, G., B. Seve, Y. Colleaux, and Y. Lebreton. 1995. Endogenous amino nitrogen collected from pigs with end-to-end ileorectal anastomosis is affected by the method of estimation and altered by dietary fiber. J. Nutr. 125:136–146.

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

Rodríguez, D. A., R. C. Sulabo, J. C. González-Vega, and H. H. Stein. 2013. Energy concentration and phosphorus digestibility in canola, cottonseed, and sunflower products fed to growing pigs. Can. J. Anim. Sci. 93:493–503. doi:10.4141/cjas2013-020

Rojas, O. J., Y. Liu, and H. H. Stein. 2014. Concentration of metabolizable energy and digestibility of energy, phosphorus, and amino acids in lemna protein concentrate fed to growing pigs. J. Anim. Sci. 92:5222–5229. doi:10.2527/jas.2014-8146

Rojas, O. J., and H. H. Stein. 2012. Digestibility of phosphorus by growing pigs of fermented and conventional soybean meal without and with microbial phytase. J. Anim. Sci. 90:1506–1512. doi:10.2527/jas.2011-4103

Rojas, O. J., and H. H. Stein. 2013. Concentration of digestible, metabolizable, and net energy and digestibility of energy and nutrients in fermented soybean meal, conventional soybean meal, and fish meal fed to weanling pigs. J. Anim. Sci. 91:4397–4405. doi:10.2527/jas.2013-6409

Sanderson, P. 1986. A new method of analysis of feedingstuffs for the determination of crude oils and fats. In: W. Haresign and D. J. A. Cole, editors, Recent advances in animal nutrition. Butterworths, London. p. 77–81. doi:10.1016/B978-0-407-01162-5.50009-5

Selle, P. H., A. J. Cowieson, and V. Ravindran. 2009. Consequences of calcium interactions with phytate and phytase for poultry and pigs. Livest. Sci. 124:126–141. doi:10.1016/j.livsci.2009.01.006

Stein, H. H., B. Sève, M. F. Fuller, P. J. Moughan, and C. F. M. de Lange. 2007. Invited review: Amino acid bioavailability and digestibility in pig feed ingredients: Terminology and application. J. Anim. Sci. 85:172–180. doi:10.2527/jas.2005-742

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical note: A technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433–1436.

Taverner, M. R., I. D. Hume, and D. J. Farrell. 1981. Availability to pigs of amino acids in cereal grains. 1. Endogenous levels of amino acids in ileal digesta and faeces of pigs given cereal diets. Br. J. Nutr. 46:149–158. doi:10.1079/BJN19810017

Tran, G., and D. Sauvant. 2004. Chemical data and nutritional value. In: D. Sauvant, J. M. Pérez, and G. Tran, editors, Tables of composition and nutritional value of feed materials: Pigs, poultry, cattle, sheep, goats, rabbits, horses, fish. Inst. Natl. Rech. Agron., Assoc. Fr. Zootechnie, Paris. p. 17–24.

Zhang, H. Y., J. Q. Yi, X. S. Piao, P. F. Li, Z. K. Zeng, D. Wang, L. Liu, G. Q. Wang, and X. Han. 2013. The metabolizable energy value, standardized ileal digestibility of amino acids in soybean meal, and the application of these products in early-weaned piglets. Asian-Australas. J. Anim. Sci. 26:691–699. doi:10.5713/ajas.2012.12429