JOURNAL OF ANIMAL SCIENCE
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*J Anim Sci* 2009.87:2282-2290.
doi: 10.2527/jas.2008-1414 originally published online Mar 13, 2009;

# Amino acid digestibility and concentration of digestible and metabolizable energy in soybean meal produced from conventional, high-protein, or low-oligosaccharide varieties of soybeans and fed to growing pigs[1]

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**ABSTRACT:** Two experiments were conducted to determine AA digestibility and the concentration of DE and ME in 5 sources of soybean meal (SBM). The 5 sources included hexane-extracted SBM produced from high-protein soybeans (SBM-HP) and conventional soybeans (SBM-CONV), and mechanically extruded-expelled SBM produced from high-protein soybeans (EE-SBM-HP), low-oligosaccharide soybeans (EE-SBM-LO), and conventional soybeans (EE-SBM-CONV). Five diets that each contained 1 source of SBM and a N-free diet were used in Exp. 1 to determine AA digestibility in each meal. Twelve growing barrows (initial BW: 67.7 ± 1.34 kg) were allotted to a replicated 6 × 6 Latin square design with 6 periods and 6 diets in each square. Each period lasted 7 d, and ileal digesta were collected on d 6 and 7 of each period. Results of the experiment showed that the standardized ileal digestibility (SID) of all AA except Trp was similar for SBM-HP and SBM-CONV, but EE-SBM-HP and EE-SBM-LO had greater ($P < 0.05$) SID of His, Ile, Lys, Thr, and Val than EE-SBM-CONV. The SID of all indispensable AA in EE-SBM-HP was greater ($P < 0.05$) than in SBM-HP. The SID of Arg, Ile, Leu, and Phe in EE-SBM-CONV was greater ($P < 0.05$) than in SBM-CONV, but the SID of Trp was also greater ($P < 0.05$) in SBM-CONV than in EE-SBM-CONV. Experiment 2 was conducted to measure DE and ME in the same 5 sources of SBM as used in Exp. 1. Forty-eight growing barrows (initial BW: 38.6 ± 3.46 kg) were placed in metabolism cages and randomly allotted to 6 diets with 8 replicates per diet. A corn-based diet and 5 diets based on a mixture of corn and each source of SBM were formulated. Urine and feces were collected during a 5-d collection period, and values for DE and ME in each source of SBM were calculated using the difference procedure. Results showed that the ME in SBM-HP tended to be greater ($P = 0.10$) than in SBM-CONV (4,074 vs. 3,672 kcal/kg of DM). The ME in EE-SBM-HP also tended to be greater ($P = 0.10$) than in EE-SBM-CONV and in EE-SBM-LO (4,069 vs. 3,620 and 3,721 kcal/kg of DM), but there was no difference in ME between extracted and extruded-expelled meals. It is concluded that SBM-HP has a greater feeding value than SBM-CONV because of greater concentrations of digestible AA and ME. Likewise, EE-SBM-LO has a greater concentration of most indispensable AA than EE-SBM-CONV, but the concentration of ME is similar in these 2 meals. Results of this experiment also showed that AA digestibility values in extruded-expelled SBM are greater than in hexane-extracted SBM.

**Key words:** amino acid, digestibility, energy, high-protein soybean meal, low-oligosaccharide soybean meal, pig



J. Anim. Sci. 2009. 87:2282–2290
doi:10.2527/jas.2008-1414

## INTRODUCTION

Soybeans can be fed to swine as full-fat soybeans or they can be de-oiled and made into soybean meal (**SBM**) after grinding of the de-oiled flakes (Johnson, 2008). The removal of oil can be accomplished using the solvent extraction method or the extruded-expeller method (Wang and Johnson, 2001). Less than 1.5% oil is usually left in the meal if the extraction method is used, but up to 8% oil is left in the meal if they are extruded-expelled (Zhang et al., 1993; Wang and Johnson, 2001). Extracted meals are usually dehulled, but that is not the case for extruded-expelled meals and the concentration of nonstarch polysaccharides is, therefore, greater in extruded-expelled meals than in extracted meals. The concentration of CP is greater in extracted SBM than in extruded-expelled SBM, but the AA composition of the protein and the relative AA

[1]Financial support for this research from Schillinger Seeds Inc., Des Moines, IA, is appreciated.
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Received August 18, 2008.
Accepted February 16, 2009.

concentration is similar in the 2 types of meal (Wang and Johnson, 2001).

New varieties of high-protein soybeans that contain 6 to 10% more CP than conventional soybeans, and low-oligosaccharide varieties that contain 70 to 90% less oligosaccharides than conventional soybeans have recently been introduced to the feed industry. Soybean meal produced from low-oliogosaccharide varieties of soybeans contains 7 to 9% more ME if fed to poultry (Parsons et al., 2000), but there are no data on the digestibility of energy or AA in low-oligosaccharide SBM fed to pigs. The digestibility of most indispensable AA in high-protein full-fat soybeans is greater than in conventional full-fat soybeans (Cervantes-Pahm and Stein, 2008), but there is no information on the digestibility of AA or on the energy concentration in SBM produced from high-protein soybeans fed to pigs. Therefore, the objective of the present work was to test the hypothesis that SBM produced from high-protein or low-oligosaccharide soybeans have different digestibilities of AA and energy than SBM produced from conventional soybeans.

## MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for the experiments.

### General

Two experiments were conducted. Pigs used in the experiments were the offspring of line 337 boars that were mated to C 22 females (Pig Improvement Company, Hendersonville, TN). Five SBM were used (Table 1). Two of the SBM were produced via hexane extraction of high-protein or conventional soybeans (**SBM-HP** and **SBM-CONV**, respectively). Three extruded-expelled meals produced from high-protein, low-oligosaccharide, and conventional soybeans (**EE-SBM-HP**, **EE-SBM-LO**, and **EE-SBM-CONV**, respectively) were also used. The same batch of high-protein soybeans (446F.HP, Schillinger Seeds Inc., Des Moines, IA) was used to produce SBM-HP and EE-SBM-HP. The beans were grown in southern Indiana in 2006, and their identities were preserved throughout the process. The low-oligosaccharide soybeans and the commercial soybeans (247F.HD and 435.TCS, respectively, Schillinger Seeds Inc.) were grown in northeast Indiana in 2006. The identities of these beans were also preserved throughout the process. The solvent extracted SBM were produced at a commercial facility (Rose Acre Farms Inc., Seymour, IN). The extruded-expelled SBM were extruded at 145°C on a double flight screw extruder with a 1.59-cm nose cone (model 2000, Insta Pro, Urbandale, IA) and oil was subsequently expelled using a mechanical oil press (model 5005, Insta Pro). The expelled cake was then ground in a hammer mill and cooled using a counter flow cooler.

### *AA Digestibility*

Experiment 1 was designed to measure the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) for CP and AA in the 5 SBM. Twelve growing barrows (initial BW: 67.7 ± 1.34 kg) were randomly allotted to a replicated 6 × 6 Latin square design with 6 diets and 6 periods in each square. A T-cannula was surgically installed in the distal ileum of each pig (Stein et al., 1998) when they reached a BW of approximately 25 kg, and all pigs had been used in a 6-wk experiment before being used in the present experiment. Pigs were housed individually in pens (0.9 × 1.8 m) that had fully slatted concrete floors. A feeder and a nipple drinker were installed in each pen.

Six diets were prepared (Tables 2 and 3). Five of the diets contained 1 of the SBM and starch, sugar, and soybean oil. The last diet was a N-free diet that was used to measure basal endogenous losses of AA and CP. All diets contained 0.4% chromic oxide as an indigestible marker. Solka floc (Fiber Sales and Development Corp., Urbana, OH) was included in the N-free diet (4%) 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 all diets to meet or exceed current requirement estimates (NRC, 1998). Pig BW were recorded at the beginning and at the end of each period. Pigs were fed once daily at 3 times the estimated maintenance energy requirement (i.e., 106 kcal of ME per $kg^{0.75}$; NRC, 1998), and water was available at all times throughout the experiment.

Each experimental period lasted 7 d, and the initial 5 d was considered an adaptation period to the diet. On d 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 8 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 subsample 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 before chemical analysis. All samples of feed ingredients, diets, and ileal digesta were analyzed for DM (method 930.15; AOAC, 2005) and CP (method 990.03; AOAC, 2005). Chromium concentrations of diets and ileal digesta were also analyzed (method 990.08; AOAC, 2005), and the 5 sources of SBM were analyzed for sucrose, raffinose, and stachyose (Janauer and Englmaier, 1978), ADF (method 973.18; AOAC, 2005), NDF (Holst, 1973), Ca (method 978.02; AOAC, 2005), and P (method 946.06; AOAC, 2005). Ingredients were

**Table 1.** Analyzed energy and nutrient composition of high-protein (HP), low-oligosaccharide (LO), and conventional (CONV) soybean meals (SBM), as-fed basis

| | Extracted SBM | | Extruded-expelled SBM | | |
|---|---|---|---|---|---|
| Item | SBM-HP | SBM-CONV | SBM-HP | SBM-LO | SBM-CONV |
| DM, % | 89.20 | 89.10 | 94.50 | 94.60 | 96.70 |
| GE, kcal/kg | 4,253 | 4,197 | 4,784 | 4,737 | 4,725 |
| CP, % | 55.65 | 48.36 | 55.97 | 49.33 | 47.09 |
| Ether extract, % | 0.30 | 0.83 | 5.13 | 4.62 | 4.26 |
| Ca, % | 0.56 | 0.35 | 0.29 | 0.29 | 0.28 |
| P, % | 0.77 | 0.72 | 0.63 | 0.63 | 0.66 |
| NDF, % | 5.50 | 6.74 | 9.99 | 9.98 | 14.42 |
| ADF, % | 2.95 | 3.87 | 6.30 | 6.81 | 7.17 |
| Sucrose, % | 4.28 | 7.82 | 4.91 | 7.10 | 7.10 |
| Raffinose, % | 0.68 | 1.05 | 0.67 | 0.18 | 0.77 |
| Stachyose, % | 3.12 | 4.72 | 4.58 | 1.55 | 4.88 |
| Trypsin inhibitor activity, TIU/mg | 6.40 | 5.90 | 6.00 | 4.90 | 4.60 |
| Indispensable AA, % | | | | | |
| Arg | 4.30 | 3.62 | 4.13 | 3.77 | 3.48 |
| His | 1.47 | 1.30 | 1.39 | 1.29 | 1.26 |
| Ile | 2.56 | 2.30 | 2.42 | 2.24 | 2.19 |
| Leu | 4.31 | 3.81 | 4.09 | 3.75 | 3.65 |
| Lys | 3.51 | 3.20 | 3.33 | 3.12 | 2.93 |
| Met | 0.78 | 0.70 | 0.72 | 0.68 | 0.65 |
| Phe | 2.85 | 2.50 | 2.71 | 2.47 | 2.39 |
| Thr | 2.09 | 1.86 | 1.96 | 1.81 | 1.76 |
| Trp | 0.75 | 0.69 | 0.71 | 0.66 | 0.68 |
| Val | 2.74 | 2.45 | 2.59 | 2.43 | 2.40 |
| Dispensable AA, % | | | | | |
| Ala | 2.35 | 2.14 | 2.21 | 2.07 | 2.03 |
| Asp | 6.47 | 5.58 | 6.10 | 5.66 | 5.36 |
| Cys | 0.91 | 0.77 | 0.80 | 0.78 | 0.68 |
| Glu | 10.39 | 8.93 | 9.82 | 8.94 | 8.51 |
| Gly | 2.35 | 2.11 | 2.27 | 2.11 | 2.06 |
| Pro | 2.86 | 2.51 | 2.74 | 2.47 | 2.38 |
| Ser | 2.64 | 2.25 | 2.50 | 2.24 | 2.09 |
| Tyr | 1.98 | 1.79 | 1.88 | 1.71 | 1.67 |

**Table 2.** Ingredient composition (as-fed basis) of experimental diets containing high-protein (HP), low-oligosaccharide (LO), and conventional (CONV) soybean meals (SBM) and used in the AA experiment (Exp. 1)

| | Extracted SBM | | Extruded-expelled SBM | | | |
|---|---|---|---|---|---|---|
| Ingredient, % | SBM-HP | SBM-CONV | SBM-HP | SBM-LO | SBM-CONV | N-free |
| SBM-HP[1] | 32.50 | — | — | — | — | — |
| SBM-CONV[1] | — | 38.00 | — | — | — | — |
| EE-SMB-HP[1] | — | — | 35.00 | — | — | — |
| EE-SMB-LO[1] | — | — | — | 35.00 | — | — |
| EE-SMB-CONV[1] | — | — | — | — | 40.00 | — |
| Cornstarch | 51.15 | 45.75 | 50.10 | 50.10 | 45.35 | 68.60 |
| Soybean oil | 3.70 | 3.60 | 2.25 | 2.25 | 2.00 | 4.00 |
| Sugar | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 20.00 |
| Solka-Floc[2] | — | — | — | — | — | 4.00 |
| Limestone | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.60 |
| Monocalcium phosphate | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 1.20 |
| Magnesium oxide | — | — | — | — | — | 0.10 |
| Potassium carbonate | — | — | — | — | — | 0.40 |
| Chromic oxide | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Salt | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Vitamin mineral premix[3] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |

[1]SBM-HP = extracted high-protein SBM; SBM-CONV = extracted conventional SBM; EE-SBM-HP = extruded-expelled high-protein SBM; EE-SBM-LO = extruded-expelled low-oligosaccharide SBM; and EE-SBM-CONV = extruded-expelled conventional SBM.

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

[3]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A, 11,120 IU; vitamin $D_3$, 2,204 IU; vitamin E, 66 IU; vitamin K, 1.41 mg; thiamin, 0.24 mg; riboflavin, 6.6 mg; pyridoxine, 0.24 mg; vitamin $B_{12}$, 0.031 mg; D-pantothenic acid, 24 mg; niacin, 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 (HP), low-oligosaccharide (LO), and conventional (CONV) soybean meals (SBM) and used in the AA experiment (Exp. 1)

| | Extracted SBM | | Extruded-expelled SBM | | | |
|---|---|---|---|---|---|---|
| Item | SBM-HP | SBM-CONV | SBM-HP | SBM-LO | SBM-CONV | N-free |
| DM, % | 90.35 | 88.74 | 92.32 | 92.13 | 93.12 | 91.25 |
| CP, % | 19.68 | 18.65 | 18.41 | 18.59 | 19.23 | 0.57 |
| Indispensable AA, % | | | | | | |
| Arg | 1.47 | 1.38 | 1.47 | 1.44 | 1.44 | 0.01 |
| His | 0.51 | 0.50 | 0.51 | 0.50 | 0.52 | 0.01 |
| Ile | 0.89 | 0.87 | 0.87 | 0.88 | 0.87 | 0.01 |
| Leu | 1.51 | 1.48 | 1.49 | 1.48 | 1.53 | 0.03 |
| Lys | 1.23 | 1.23 | 1.21 | 1.22 | 1.23 | 0.02 |
| Met | 0.25 | 0.26 | 0.24 | 0.25 | 0.25 | 0.01 |
| Phe | 0.99 | 0.96 | 0.98 | 0.97 | 0.99 | 0.02 |
| Thr | 0.73 | 0.73 | 0.71 | 0.71 | 0.77 | 0.01 |
| Trp | 0.24 | 0.37 | 0.24 | 0.26 | 0.30 | 0.01 |
| Val | 0.95 | 0.94 | 0.95 | 0.94 | 0.94 | 0.01 |
| Dispensable AA, % | | | | | | |
| Ala | 0.83 | 0.83 | 0.82 | 0.82 | 0.86 | 0.02 |
| Asp | 2.23 | 2.17 | 2.23 | 2.22 | 2.25 | 0.03 |
| Cys | 0.32 | 0.30 | 0.30 | 0.32 | 0.30 | 0.01 |
| Glu | 3.66 | 3.46 | 3.63 | 3.55 | 3.60 | 0.08 |
| Gly | 0.82 | 0.82 | 0.83 | 0.83 | 0.86 | 0.01 |
| Pro | 1.02 | 0.96 | 1.00 | 0.97 | 1.02 | 0.01 |
| Ser | 0.92 | 0.89 | 0.90 | 0.88 | 0.96 | 0.01 |
| Tyr | 0.59 | 0.62 | 0.56 | 0.58 | 0.62 | 0.01 |

also analyzed for trypsin inhibitors (method Ba 12–75; AOCS, 1998). Ingredients and diets were also analyzed for ether extract (method 920.39; AOAC, 2005). Ingredients, diets, and digesta were analyzed for AA on a Beckman 6300 Amino Acid Analyzer (Beckman Instruments Corp., Palo Alto, 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; AOAC, 2005) before analysis. Methionine and Cys were determined as Met sulfone and cysteic acid, respectively, after cold performic acid oxidation overnight before hydrolysis (method 982.30; AOAC, 2005). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (method 982.30; AOAC, 2005).

Values for AID of CP and AA in digesta samples obtained from feeding the 5 diets containing SBM were calculated. Because SBM was the only feed ingredient contributing CP and AA in each of the diets, these digestibility values also represent the digestibility values for CP and AA in each source of SBM. The basal endogenous losses of CP and AA were calculated using the data from pigs fed the N-free diet, and these values were used to correct AID values for endogenous losses to calculate SID values for CP and AA in each source of SBM. All calculations were completed using published equations (Stein et al., 2007).

Data were analyzed using the GLM procedure (SAS Institute Inc., Cary, NC). An ANOVA was conducted with pigs, periods, and diets in the model. If a significant overall treatment effect was detected, means were separated using the least significant difference test. A contrast was used to compare data for the 2 extracted SBM with data for the 3 extruded-expelled SBM. The pig was the experimental unit for all calculations, and a *P*-value of 0.05 was used to assess significant differences among means.

### *Energy Measurements*

Experiment 2 was designed to measure the DE and ME and the apparent total tract digestibility (**ATTD**) of energy in the 5 sources of SBM that were used in the AA digestibility experiment. A total of 48 barrows (initial BW: 38.6 ± 3.46 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 6 diets and 8 replications per diet. The 6 diets were based on corn, or corn and 1 of the 5 sources of SBM (Table 4). Corn and SBM were the sole sources of energy in the diets.

The quantity of feed provided per pig daily was calculated as 2 times the estimated requirement for maintenance energy for the smallest pig in each replicate and divided into 2 equal meals. Water was available at all times. Pigs were fed experimental diets for 14 d, and the initial 5 d was considered an adaptation period to the diet. Chromic oxide (0.5%) and ferric oxide (0.5%) were added to the diet in the morning meals on d 6 and 11, respectively. Collections of fecal samples 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). Fecal samples were collected twice daily during the collection period. Urine collection was initiated after feeding the morning meal on d 6 and ceased after feeding

**Table 4.** Composition (as-fed basis) of experimental diets containing high-protein (HP), low-oligosaccharide (LO), and conventional (CONV) soybean meals (SBM) and used in the energy experiment (Exp. 2)

| | | Extracted SBM | | Extruded-expelled SBM | | |
|---|---|---|---|---|---|---|
| Item | Corn | SBM-HP | SBM-CONV | SBM-HP | SBM-LO | SBM-CONV |
| Ingredient, % | | | | | | |
| Corn | 97.50 | 77.25 | 73.25 | 75.50 | 74.25 | 73.00 |
| SBM-HP[1] | — | 20.50 | — | — | — | — |
| SBM-CONV[1] | — | — | 24.50 | — | — | — |
| EE-SBM-HP[1] | — | — | — | 22.25 | — | — |
| EE-SBM-LO[1] | — | — | — | — | 23.50 | — |
| EE-SBM-CONV[1] | — | — | — | — | — | 24.75 |
| Limestone | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 |
| Dicalcium phosphate | 1.10 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Salt | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Vitamin mineral premix[2] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 |
| Analyzed composition | | | | | | |
| Energy, kcal/kg | 3,684 | 3,838 | 3,833 | 3,905 | 3,901 | 3,908 |

[1]SBM-HP = extracted high-protein SBM; SBM-CONV = extracted conventional SBM; EE-SBM-HP = extruded-expelled high-protein SBM; EE-SBM-LO = extruded-expelled low-oligosaccharide SBM; and EE-SBM-CONV = extruded-expelled conventional SBM.

[2]Provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A, 10,990 IU; vitamin $D_3$, 1,648 IU; vitamin E, 55 IU; vitamin K, 4.4 mg; thiamin, 3.3 mg; riboflavin, 9.9 mg; pyridoxine, 3.3 mg; vitamin $B_{12}$, 0.044 mg; D-pantothenic acid, 33 mg; niacin, 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.

the morning meal on d 11. Urine buckets were placed under the metabolism cages and emptied twice daily. Immediately after collection, fecal samples and 20% of the collected urine were stored at −20°C. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a subsample was collected for analysis.

Fecal samples were dried in a forced-air oven and finely ground before analysis, and urine samples were lyophilized before analysis. Fecal, urine, diet, and ingredient samples were analyzed in duplicate for GE using bomb calorimetry (model 6300, Parr Instruments, Moline, IL). Diets and ingredients were also analyzed for DM (method 930.15; AOAC, 2005). After chemical analysis, the ATTD was calculated for energy in each diet as described previously (Stein et al., 2004). The amounts of energy lost in the feces and urine were calculated as well, and the quantities of DE and ME in each of the 6 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 5 sources of SBM was calculated using the difference procedure (Widmer et al., 2007). Data were analyzed as described for the AA digestibility experiment.

## RESULTS

### Nutrient Composition

The concentrations of CP and AA were greater in SBM-HP and EE-SBM-HP compared with SBM-CONV and EE-SBM-CONV (Table 1). Ether extract concentrations were less in the extracted SBM than in the extruded-expelled SBM, but the concentrations of NDF and ADF were greater in the extruded-expelled SBM compared with the extracted SBM. The concentration of sucrose was less in SBM-HP than in the other SBM, but the concentration of raffinose and stachyose was less in EE-SBM-LO compared with all other SBM.

### AA Digestibility

The AID of CP in SBM-HP (81.0%) was not different from the AID in SBM-CONV (79.8%) and EE-SBM-CONV (81.4%; Table 5). The AID of CP in EE-SBM-HP (82.9%) was greater ($P < 0.05$) than for SBM-CONV, but similar to the other SBM. The AID of CP in SBM-LO (83.6%) was not different from the AID in the other extruded-expelled SBM, but greater ($P < 0.05$) than in SBM-HP and SBM-CONV. The AID of CP in all the extruded-expelled SBM was also greater ($P < 0.05$) than in the extracted SBM.

There were no differences in the AID of the indispensable AA in SBM-HP and SBM-CONV with the exception that the AID of Trp was greater in SBM-CONV than in SBM-HP ($P < 0.001$). The AID of His, Ile, Lys, Val, Asp, and Cys were greater ($P < 0.05$) for EE-SBM-HP and EE-SBM-LO compared with EE-SBM-CONV, but there were no differences between EE-SBM-HP and EE-SBM-LO in the AID of any AA. The AID of all AA in the extruded-expelled SBM were greater ($P < 0.05$) than in the extracted SBM, except for Trp, Cys, Glu, Gly, and Pro.

The SID of CP in EE-SBM-HP (90.9%) and EE-SBM-LO (91.5%) were greater ($P < 0.05$) than in SBM-HP (88.3%) and SBM-CONV (87.3%), but not different from EE-SBM-CONV (89.1%; Table 6). The SID of Trp was greater ($P < 0.05$) in SBM-CONV compared with SBM-HP, but for all other AA, no differences between these 2 meals were observed. The SID of

**Table 5.** Apparent ileal digestibility (%) of CP and AA in high-protein (HP), low-oligosaccharide (LO), and conventional (CONV) soybean meals (SBM) by growing pigs, AA experiment (Exp. 1)[1,2]

| | Extracted SBM | | Extruded-expelled SBM | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | SBM-HP | SBM-CONV | SBM-HP | SBM-LO | SBM-CONV | SEM | *P*-value | Contrast *P*-value[3] |
| CP | 81.0[ab] | 79.8[a] | 82.9[bc] | 83.6[c] | 81.4[abc] | 0.86 | 0.020 | 0.006 |
| Indispensable AA | | | | | | | | |
| Arg | 91.1[a] | 91.0[a] | 93.4[b] | 93.9[b] | 92.6[b] | 0.47 | <0.001 | <0.001 |
| His | 86.4[a] | 87.3[ab] | 89.2[bc] | 89.6[c] | 87.1[a] | 0.72 | 0.009 | 0.009 |
| Ile | 85.0[a] | 85.0[a] | 88.8[c] | 89.2[c] | 87.0[b] | 0.63 | <0.001 | <0.001 |
| Leu | 85.0[a] | 84.8[a] | 89.0[b] | 89.1[b] | 87.6[b] | 0.62 | <0.001 | <0.001 |
| Lys | 86.2[a] | 86.2[a] | 89.2[b] | 89.2[b] | 86.4[a] | 0.80 | 0.006 | 0.006 |
| Met | 85.5[a] | 86.4[ab] | 88.8[c] | 89.4[c] | 87.9[bc] | 0.73 | 0.002 | <0.001 |
| Phe | 85.7[a] | 85.5[a] | 89.7[b] | 89.7[b] | 88.2[b] | 0.59 | <0.001 | <0.001 |
| Thr | 77.8 | 78.1 | 80.6 | 80.6 | 78.4 | 0.92 | 0.071 | 0.025 |
| Trp | 84.5[a] | 90.5[c] | 86.5[b] | 87.6[b] | 87.1[b] | 0.65 | <0.001 | 0.470 |
| Val | 82.2[a] | 82.4[a] | 86.0[b] | 85.8[b] | 83.6[a] | 0.72 | <0.001 | <0.001 |
| Mean | 85.5[a] | 85.7[a] | 88.7[bc] | 88.9[c] | 87.0[ab] | 0.64 | <0.001 | <0.001 |
| Dispensable AA | | | | | | | | |
| Ala | 77.9[a] | 78.1[a] | 83.3[b] | 83.1[b] | 81.2[b] | 1.05 | <0.001 | <0.001 |
| Asp | 82.8[a] | 82.7[a] | 85.8[b] | 86.2[b] | 82.8[a] | 0.93 | 0.010 | 0.011 |
| Cys | 77.1[b] | 76.9[b] | 77.4[b] | 79.2[b] | 73.2[a] | 1.26 | 0.026 | 0.754 |
| Glu | 84.8 | 84.9 | 86.5 | 86.7 | 84.3 | 1.07 | <0.001 | 0.411 |
| Gly | 69.9 | 70.3 | 73.2 | 71.6 | 68.4 | 2.06 | <0.001 | 0.541 |
| Pro | 77.5 | 73.1 | 80.1 | 81.5 | 79.4 | 3.00 | <0.001 | 0.325 |
| Ser | 83.7[a] | 83.4[a] | 85.9[b] | 85.9[b] | 84.5[ab] | 0.67 | 0.021 | 0.003 |
| Tyr | 84.1[a] | 84.8[ab] | 86.6[bc] | 87.0[c] | 86.0[bc] | 0.67 | 0.016 | <0.001 |
| Mean | 81.3 | 81.0 | 83.9 | 84.1 | 81.6 | 1.06 | 0.107 | 0.039 |
| All AA | 83.2[a] | 83.2[a] | 86.1[b] | 86.3[b] | 84.0[ab] | 0.84 | 0.016 | 0.004 |

[a–c]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Data are least squares means of 12 observations per treatment.

[2]Apparent ileal digestibilities (%) were calculated as {1 − [(CP or AA in digesta/CP or AA in feed) × (chromium in feed/chromium in digesta)]} × 100.

[3]*P*-value for the contrast comparing the 2 extracted SBM and the 3 extruded-expelled SBM.

His, Ile, Lys, Thr, Val, Asp, and Cys was greater ($P < 0.05$) for EE-SBM-HP and EE-SBM-LO compared with EE-SBM-CONV, but there were no differences between EE-SBM-HP and EE-SBM-LO. The extruded-expelled SBM had greater ($P < 0.05$) SID of all AA except Trp, Cys, Glu, and Gly compared with the extracted SBM.

### *Energy Measurements*

There were no differences in GE intake among pigs fed any of the diets (Table 7). Pigs fed diets containing SBM-HP or EE-SBM-HP had less ($P < 0.05$) fecal excretion of GE than pigs fed the diet containing EE-SBM-CONV, but pigs fed the corn diet had less ($P < 0.05$) fecal excretion of GE than pigs fed all the SBM-containing diets. There were no differences among treatments for the GE excreted in the urine.

Pigs fed the SBM-HP diet, EE-SBM-HP diet, or the corn diet had greater ($P < 0.05$) ATTD of GE (88.8, 88.9, and 90.6%, respectively) than pigs fed the EE-SBM-CONV diet (86.9%). Pigs fed the corn diet also had a greater ($P < 0.05$) ATTD of GE than pigs fed SBM-CONV (87.2%) and EE-SBM-LO (87.3%) diets. The DE in the EE-SBM-HP diet was greater ($P < 0.05$) than the DE of all other diets, but there were no differences among the other diets. No differences among diets were observed for ME.

The DE for EE-SBM-HP was greater ($P < 0.05$) than the DE for the other 4 SBM and corn (Table 8), and the DE for the extruded-expelled SBM were greater ($P < 0.05$) than for the extracted SBM. The ME was, however, not different among ingredients.

The DE for EE-SBM-HP was greater ($P < 0.05$) than the DE for corn, SBM-CONV, EE-SBM-LO, and EE-SBM-CONV when calculated on a DM basis (4,293 vs. 3,910, 3,845, 3,923, and 3,827 kcal/kg of DM), but not different from the DE for SBM-HP (4,178 kcal/kg of DM). The DE for SBM-HP was also greater ($P < 0.05$) than the DE for EE-SBM-CONV. The ME for SBM-HP (4,074 kcal/kg of DM) and EE-SBM-HP (4,069 kcal/kg of DM) tended to be greater ($P = 0.10$) than the ME of the other SBM (3,672, 3,721, and 3,620 kcal/kg of DM for SBM-CONV, EE-SBM-LO, and EE-SBM-CONV, respectively), but none of these values were different from corn (3,779 kcal/kg of DM). The DE and ME measured on a DM basis were not different between the extracted SBM and the extruded-expelled SBM.

## DISCUSSION

### *Composition of Ingredients*

The nutrient composition of SBM-CONV concurs with published values (NRC, 1998), and the nutrient

**Table 6.** Standardized ileal digestibility (%) of CP and AA in high-protein (HP), low-oligosaccharide (LO), and conventional (CONV) soybean meals (SBM) by growing pigs, AA experiment (Exp. 1)[1,2]

| | Extracted SBM | | Extruded-expelled SBM | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | SBM-HP | SBM-CONV | SBM-HP | SBM-LO | SBM-CONV | SEM | *P*-value | Contrast *P*-value[3] |
| CP | 88.3[a] | 87.3[a] | 90.9[b] | 91.5[b] | 89.1[ab] | 0.86 | 0.006 | <0.001 |
| Indispensable AA | | | | | | | | |
| Arg | 94.7[a] | 94.7[a] | 97.0[b] | 97.6[b] | 96.3[b] | 0.47 | <0.001 | <0.001 |
| His | 89.7[a] | 90.6[ab] | 92.6[bc] | 93.0[c] | 90.4[a] | 0.71 | 0.006 | 0.006 |
| Ile | 88.3[a] | 88.4[a] | 92.3[c] | 92.7[c] | 90.5[b] | 0.63 | <0.001 | <0.001 |
| Leu | 88.3[a] | 88.1[a] | 92.4[b] | 92.5[b] | 91.0[b] | 0.62 | <0.001 | <0.001 |
| Lys | 90.1[a] | 90.0[a] | 93.2[b] | 93.3[b] | 90.4[a] | 0.80 | 0.003 | 0.003 |
| Met | 88.6[a] | 89.3[ab] | 92.1[c] | 92.4[c] | 91.0[bc] | 0.73 | <0.001 | <0.001 |
| Phe | 88.7[a] | 88.6[a] | 92.8[b] | 92.9[b] | 91.3[b] | 0.59 | <0.001 | <0.001 |
| Thr | 85.3[a] | 85.5[a] | 88.5[b] | 88.4[b] | 85.7[a] | 0.92 | 0.020 | 0.012 |
| Trp | 89.6[a] | 93.8[c] | 91.7[b] | 92.5[bc] | 91.3[ab] | 0.65 | <0.001 | 0.802 |
| Val | 86.8[a] | 86.8[a] | 90.6[b] | 90.5[b] | 88.3[a] | 0.72 | <0.001 | <0.001 |
| Mean | 89.4[a] | 89.6[a] | 92.8[b] | 93.0[b] | 91.0[a] | 0.63 | <0.001 | <0.001 |
| Dispensable AA | | | | | | | | |
| Ala | 84.9[a] | 85.0[a] | 90.5[b] | 90.3[b] | 88.1[b] | 1.05 | <0.001 | <0.001 |
| Asp | 86.1[a] | 86.0[a] | 89.2[b] | 89.7[b] | 86.3[a] | 0.93 | 0.007 | 0.008 |
| Cys | 82.9[ab] | 83.0[ab] | 83.8[b] | 85.2[b] | 79.6[a] | 1.26 | 0.045 | 0.927 |
| Glu | 87.5 | 87.7 | 89.3 | 89.5 | 87.2 | 1.06 | 0.394 | 0.283 |
| Gly | 88.1 | 88.2 | 91.6 | 89.9 | 86.3 | 2.06 | 0.433 | 0.551 |
| Pro | 117.1 | 114.4 | 121.4 | 124.0 | 120.2 | 3.00 | 0.198 | 0.030 |
| Ser | 89.2[a] | 89.0[a] | 91.7[b] | 91.8[b] | 89.9[ab] | 0.67 | 0.007 | 0.002 |
| Tyr | 88.3[a] | 88.7[a] | 91.1[b] | 91.4[b] | 90.2[ab] | 0.67 | 0.004 | <0.001 |
| Mean | 89.9 | 89.7 | 92.7 | 93.0 | 90.3 | 1.06 | 0.070 | 0.025 |
| All AA | 89.6[a] | 89.6[a] | 90.8[b] | 93.0[b] | 90.6[ab] | 0.84 | 0.008 | 0.002 |

[a–c]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Data are least squares means of 12 observations per treatment.

[2]Standardized ileal digestibility values were calculated by correcting the values for apparent ileal digestibility for the basal ileal endogenous losses. Basal ileal endogenous losses were determined from pigs fed the N-free diet as (g/kg of DMI): CP, 15.9; Arg, 0.57; His, 0.19; Ile, 0.33; Leu, 0.55; Lys, 0.54; Met, 0.08; Phe, 0.33; Thr, 0.61; Trp, 0.14; Val, 0.48; Ala, 0.64; Asp, 0.83; Cys, 0.21; Glu, 1.11; Gly, 1.65; Pro, 4.47; Ser, 0.56; and Tyr, 0.28.

[3]*P*-value for the contrast comparing the 2 extracted SBM and the 3 extruded-expelled SBM.

composition of EE-SBM-CONV is in agreement with previous data for extruded-expelled SBM (Woodworth et al., 2001; Opapeju et al., 2006). The concentration of ether extract in EE-SBM-CONV was also comparable with published values for extruded-expelled meals (Woodworth et al., 2001). The greater concentrations of NDF and ADF in the extruded-expelled SBM compared with the extracted SBM are likely a result of the fact that the extracted SBM were dehulled, but this was not the case for the extruded-expelled SBM. The concentration of DM was greater in the extruded-expelled SMB than in the extracted SBM, which is likely a result of the heat that is generated during the extrusion process. The differences in DM are not expected to have affected the data for AA digestibility because these data were calculated on a percentage basis, but the DE and ME concentrations were likely affected by the differences in DM concentrations. Data for DE and ME are, therefore, presented on a DM as well as on an as-is basis.

**Table 7.** Daily energy balance (as-fed basis) for pigs fed diets containing high-protein (HP), low-oligosaccharide (LO), and conventional (CONV) soybean meals (SBM), Exp. 2[1]

| | | Extracted SBM | | Extruded-expelled SBM | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | Corn | SBM-HP | SBM-CONV | SBM-HP | SBM-LO | SBM-CONV | SEM | *P*-value |
| GE intake, kcal | 3,395 | 3,918 | 3,972 | 3,905 | 4,062 | 4,227 | 225 | 0.28 |
| GE in feces, kcal | 317[a] | 447[b] | 510[bc] | 446[b] | 514[bc] | 556[c] | 35 | 0.002 |
| GE in urine, kcal | 122 | 109 | 126 | 132 | 129 | 144 | 16 | 0.71 |
| ATTD[2] GE, % | 90.6[c] | 88.8[bc] | 87.2[ab] | 88.9[bc] | 87.3[ab] | 86.9[a] | 0.66 | 0.005 |
| DE, diet, kcal/kg | 3,332[a] | 3,402[a] | 3,340[a] | 3,471[b] | 3,401[a] | 3,394[a] | 25 | 0.006 |
| ME, diet, kcal/kg | 3,220 | 3,294 | 3,219 | 3,338 | 3,272 | 3,261 | 33 | 0.12 |

[a–c]Values within a row lacking a common superscript letter are different ($P \leq 0.05$).

[1]Data are least squares means of 8 observations per treatment.

[2]ATTD = apparent total tract digestibility.

**Table 8.** Energy concentration in corn, high-protein (HP), low-oligosaccharide (LO), and conventional (CONV) soybean meals (SBM), Exp. 2[1]

| Item | Corn | Extracted SBM | | Extruded-expelled SBM | | | SEM | *P*-value | Contrast *P*-value[2] |
|---|---|---|---|---|---|---|---|---|---|
| | | SBM-HP | SBM-CONV | SBM-HP | SBM-LO | SBM-CONV | | | |
| DE, kcal/kg | 3,417[a] | 3,717[a] | 3,418[a] | 4,005[b] | 3,679[a] | 3,632[a] | 108 | 0.005 | 0.04 |
| ME, kcal/kg | 3,303 | 3,625 | 3,265 | 3,795 | 3,490 | 3,436 | 139 | 0.095 | 0.31 |
| DE, kcal/kg of DM | 3,910[ab] | 4,178[bc] | 3,845[ab] | 4,293[c] | 3,923[ab] | 3,827[a] | 118 | 0.025 | 0.98 |
| ME, kcal/kg of DM | 3,779 | 4,074 | 3,672 | 4,069 | 3,721 | 3,620 | 150 | 0.108 | 0.61 |

[a–c]Values within a row lacking a common superscript letter are different ($P \leq 0.05$).

[1]Data are least squares means of 8 observations per treatment.

[2]*P*-value for the contrast comparing the 2 extracted SBM and the 3 extruded-expelled SBM.

The CP concentration in SBM-HP was greater than in SBM-CONV, which agrees with data showing that the concentration of CP in high-protein soybeans is greater than in conventional soybeans (Cervantes-Pahm and Stein, 2008). The concentrations of raffinose and stachyose were less in EE-SBM-LO than in the other SBM, which is a result of this variety being selected for decreased concentrations of oligosaccharides. The concentration of sucrose was least in the 2 high-protein meals, which is also in agreement with previous data (Cervantes-Pahm and Stein, 2008). An adverse relationship between CP and sucrose is often observed in soybeans (Hartwig et al., 1997). The extracted meals contained less raffinose and stachyose than the extruded-expelled meals, which is most likely a result of the extracted meals being dehulled.

### *AA Digestibility*

Values for AID and SID of AA in SBM-CONV agree with previously measured values (NRC, 1998), and the AID of AA in EE-SBM-CONV were in agreement with results from previous studies (Woodworth et al., 2001; Opapeju et al., 2006). The AID and SID of AA in the 2 SBM produced from high-protein soybeans were similar to the AID and SID in the 2 conventional meals, but because of the greater concentration of AA in the high-protein SBM than in conventional SBM, greater quantities of digestible AA are provided by the SBM from high-protein soybeans than in SBM from conventional soybeans. This observation is in agreement with Cervantes-Pahm and Stein (2008) who also reported that concentration of digestible AA in high-protein full-fat soybeans is greater than in conventional full-fat beans.

The reason for the greater digestibility of most AA in EE-SBM-LO and EE-SBM-HP than in EE-SBM-CONV may be that the concentration of NDF and ADF in EE-SBM-CONV is greater than in the other 2 extruded-expelled meals. This observation also indicates that there are no detrimental effects on AA digestibility of removing the oligosaccharides or increasing the protein concentration in soybeans. To our knowledge, there are no other published data on AA digestibility in SBM from low-oligosaccharide or high-protein soybeans fed to pigs.

The greater AID and SID in extruded-expelled meals compared with extracted meals is likely a result of the greater concentration of oil in the extruded-expelled meals because increased concentrations of dietary soybean oil increase AA digestibility in SBM (Cervantes-Pahm and Stein, 2008). In the extruded-expelled meals, there was also an increase in the concentration of NDF and ADF compared with the extracted meals because of the presence of hulls. Soy hulls may reduce AA digestibility (Dilger et al., 2004), but results of this experiment indicate that the positive effect of soy oil in the extruded-expelled meals is greater than the negative effects of NDF and ADF.

### *Energy Measurements*

The values for DE and ME for SBM-CONV that were measured in this experiment are in close agreement with previously published values (NRC, 1998; Woodworth et al., 2001). Likewise, the ME for corn that was measured in this experiment agrees with previous data (NRC, 1998; Pedersen et al., 2007; Widmer et al., 2007). The greater DE and ME in SBM-HP and EE-SBM-HP compared with the DE and ME in SBM-CONV and EE-SBM-CONV, respectively, is most likely a result of the greater protein concentration in the high-protein meals. In contrast, the DE and ME of EE-SBM-LO were not different from the DE and ME in EE-SBM-CONV, but the protein and ether extract concentrations were also similar in these 2 meals. The extruded-expelled meals did not contain more DE and ME than the extracted meals, despite an increased concentration of ether extract. However, the extruded-expelled meals contained more NDF and ADF than the extracted meal, which is likely the reason for this observation.

### *Summary*

Soybean meal produced from high-protein varieties of soybeans has a similar digestibility of AA as SBM produced from conventional soybeans, which results in greater concentrations of digestible AA in SBM produced from high-protein soybeans than in SBM produced from conventional SBM. This is true for extracted SBM as well as for extruded-expelled SBM.

Likewise, SBM produced from high-protein varieties of soybeans contain more DE and ME than conventional SBM. Soybean meal from low-oligosaccharide varieties of soybeans have AID and SID values for most AA that are greater than the AID and SID in conventional SBM, but the DE and ME in low-oligosaccharide SBM is comparable with the DE and ME in conventional SBM. There are no differences in DE and ME between extracted and extruded-expelled SBM, but the digestibility of AA is greater in extruded-expelled SBM.

## LITERATURE CITED

Adeola, O. 2001. Digestion and balance techniques in pigs. Pages 903–916 in Swine Nutrition. 2nd ed. A. J. Lewis and L. L. Southern, ed. CRC Press, New York, NY.

AOAC. 2005. Official Methods of Analysis. 18th ed. Assoc. Anal. Chem., Arlington. VA.

AOCS. 1998. Official Methods and Recommended Practices of the AOCS. 5th ed. Am. Oil Chem. Soc., Champaign, IL.

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.

Dilger, R. N., J. S. Sands, D. Ragland, and O. Adeola. 2004. Digestibility of nitrogen and amino acids in soybean meal with added soyhulls. J. Anim. Sci. 82:715–724.

Hartwig, E. E., T. M. Kuo, and M. M. Kenty. 1997. Seed protein and its relationship to soluble sugars in soybean. Crop Sci. 37:770–778.

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

Janauer, G. A., and P. Englmaier. 1978. Multi-step time program for the rapid gas-liquid chromatography of carbohydrates. J. Chromatogr. A 153:539–542.

Johnson, L. A. 2008. Oil recovery from soybeans. Pages 331–375 in Soybeans, Chemistry, Production, Processing, and Utilization. L. A. Johnson, P. J. White, and R. Galloway, ed. AOCS Press, Urbana, IL.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Opapeju, F. O., A. Golian, C. M. Nyachoti, and L. D. Campbell. 2006. Amino acid digestibility in dry extruded-expelled soybean meal fed to pigs and poultry. J. Anim. Sci. 84:1130–1137.

Parsons, C. M., Y. Zhang, and M. Araba. 2000. Nutritional evaluation of soybean meals varying in oligosaccharide content. Poult. Sci. 79:1127–1131.

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007. Digestibility of energy and phosphorous in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168–1176.

Stein, H. H., G. Benzoni, R. A. Bohlke, and D. N. Peters. 2004. Assessment of the feeding value of South Dakota grown field peas (*Pisum sativum* L*)* for growing pigs. J. Anim. Sci. 82:2568–2578.

Stein, H. H., B. Seve, 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.

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.

Wang, T., and L. A. Johnson. 2001. Survey of soybean oil and meal qualities produced by different processes. J. Am. Oil Chem. Soc. 78:311–318.

Widmer, M. R., L. M. McGinnis, and H. H. Stein. 2007. Energy, phosphorus, and amino acid digestibility of high-protein distillers dried grains and corn germ fed to growing pigs. J. Anim. Sci. 85:2994–3003.

Woodworth, J. C., M. D. Tokach, R. D. Goodband, J. L. Nelssen, P. R. O'Quinn, D. A. Knabe, and N. W. Said. 2001. Apparent ileal digestibility of amino acids and the digestible and metabolizable energy content of dry extruded-expelled soybean meal and its effects on growth performance of pigs. J. Anim. Sci. 79:1280–1287.

Zhang, Y., C. M. Parsons, K. E. Weigartner, and W. Wijeratne. 1993. Effects of extrusion and expelling on the nutritional quality of conventional and Kunitz trypsin inhibitor-free soybeans. Poult. Sci. 72:2299–2308.