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Evaluation of the inclusion of soybean oil and soybean processing by-products to soybean meal on nutrient composition and digestibility in swine and poultry

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ABSTRACT: This experiment was designed to evaluate the effects of selected soybean (SB) processing by-products (gums, oil, soapstock, weeds/trash) when added back to soybean meal (SBM) during processing on the resulting nutrient composition, protein quality, nutrient digestibility by swine, and true metabolizable energy (TME_n) content and standardized AA digestibility by poultry. To measure ileal DM and nutrient digestibility, pigs were surgically fitted with a T-cannula in the distal ileum. The concentration of TME_n and the standardized AA digestibility by poultry were determined using the precision fed cecectomized rooster assay. Treatments in the swine experiment included SBM with no by-products; SBM with 1% gum; SBM with 3% gum; SBM with 0.5% soapstock; SBM with 1.5% soapstock; SBM with 2% weeds/trash; SBM with a combination of 3% gum, 1.5% soapstock, and 2% weeds/trash; SBM with 5.4% soybean oil; and roasted SB. A 10 × 10 Latin square design was utilized. The experiment was conducted at the University of Illinois, Urbana-Champaign, and at The Ohio State University, Columbus. In the swine experiment, apparent ileal DM, OM, CP, and AA digestibilities were reduced ($P < 0.05$) when pigs consumed the combination by-product diet compared with the diet containing no by-products. Apparent ileal digestibilities of DM, CP, and total essential, total nonessential, and total AA were lower ($P < 0.05$) for any diet containing by-products compared with the diet with no by-products. Apparent ileal digestibilities of DM, OM, CP, and AA were lower ($P < 0.05$) for the roasted SB-compared with the SB oil-containing diet. In the rooster experiment, TME_n values were greater ($P < 0.05$) for roasted SB compared with SBM with no by-products and increased linearly as the addition of soapstock increased. Individual, total essential, total nonessential, and total AA digestibilities were lower ($P < 0.05$) for roosters fed roasted SB versus SBM devoid of by-products. Gums, soapstock, and weeds/trash reduce the nutritive value of the resultant meal when they are added back during processing.

Key words: amino acid, by-product, digestibility, pig, rooster, soybean meal

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INTRODUCTION

The high usage of soybean meal (**SBM**) in poultry and swine diets can be attributed to its relatively high concentration of protein (44 to 49%) and its excellent profile of highly digestible AA. Soy protein is a rich source of many AA that are deficient in most cereal grains commonly fed as energy sources to poultry and swine. Soybean meal is often referred to as the gold standard to which all other protein sources are compared (Cromwell, 2000), but it contains antinutritional factors that require processing to lower their activity.

During the extraction of oil from soybeans (**SB**), there is a substantial number of by-products produced. Specifically, these by-products include SB gums and soapstocks. These by-products become potentially valuable to the manufacturer when they are efficiently recovered and processed. By-products that have no value but are part of SB processing include weed seeds and trash. One practice commonly used in SB processing plants that may affect nutrient content and quality of the resultant meal is the addition of these by-products back to the meal.

The objectives of this study were to determine the effects of addition of SB oil or by-products individually or in combination to SBM on the ileal AA digestibilities by pigs, to determine the standardized AA digestibilities and true metabolizable energy (**TME_n**) of these SBM when fed to roosters, and to compare these SBM to a roasted SB.

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MATERIALS AND METHODS

Soybean Procurement

Soybeans were procured by Frazier Barnes and Associates (Memphis, TN). Soybean meal was prepared (Texas A & M University, College Station, TX) devoid of processing by-products and divided into smaller batches. Subsequently, the SB oil and by-products were mixed into individual batches of SBM. To prepare the SBM, the SB were initially cracked using 2 serrated Ferrel Ross Cracking Rolls (Ferrel Ross, Oklahoma City, OK). The cracked SB were dehulled using the Kice Aspirator (Kice Industries, Wichita, KS), whereupon they were screened (Smico vibratory screener; Simco Manufacturing Co., LLC, Oklahoma City, OK) to remove whole SB and large hull particles. The SB were heated in a French stack cooker (The French Oil Mill Machinery Co., Piqua, OH) and flaked using Bauer flaking rolls (Sprout-Bauer Inc., Muncy, PA). The flakes were extracted using a Crown Model 2 extractor using hexane as the solvent at ambient temperature. The hexane solvent was removed, and toasting was completed in a Crown desolventizer/toaster (Crown Iron Works Co., Minneapolis, MN) that contained 3 trays (top, middle, and bottom).

Soybean meal produced included SBM with no by-products; SBM with 1% gum; SBM with 3% gum; SBM with 0.5% soapstock; SBM with 1.5% soapstock; SBM with 2% weeds/trash; and SBM with 3% gum, 1.5% soapstock, and 2% weeds/trash. Additionally, a SBM was prepared with SB oil added to approximately the same concentration found in roasted SB. The specific inclusion level of each by-product reflected the minimum and maximum amount that might be added back to the meal by the SB processing industry (R. Frazier, Frazer Barnes and Associates, Memphis, TN, personal communication). Soybean meals were shipped to The Ohio State University (**OSU**; Wooster, OH) where they were stored in a cool, dry location. Chemical composition of the whole SB and resultant SBM treatments is presented in Table 1.

A batch of whole SB (4,500 kg) was sent to the Ohio Agricultural Research and Development Center, Wooster, and roasted for the experiment. These SB were not the same that were used in the production of the SBM but were representative of a typical quality of SB. The roaster used for these SB was a Jet-Pro (Des Moines, IA) with the SB cracked before roasting at 143°C. The roasted SB were cooled for 8 h in a bin that had 2 fans, during which time the SB returned to room temperature. Roasted SB were ground before addition to the swine diets. Chemical composition of roasted SB also is reported in Table 1.

Protein Quality Assays

Before their analysis, subsamples of SBM, roasted SB, and whole SB were ground through a 2-mm screen using a Wiley mill (Thomas-Wiley, Swedesboro, NJ; samples for KOH protein solubility analysis required an additional grind through a 0.5 mm screen). Soybeans were ground with dry ice to avoid loss of oil and were stored at –20°C until analyzed. Urease activity, protein solubility in KOH, and protein dispersibility index were determined on all SBM, roasted SB, and whole SB samples. Urease activity and protein dispersibility index were determined according to American Oil Chemists Society procedures (1980a,b). Protein solubility in KOH was determined according to Araba and Dale (1990a) and Parsons et al. (1991).

Ileal-Cannulated Swine Experiment

The experiment was replicated at the University of Illinois, Urbana-Champaign (**UIUC**), and OSU. It was conducted during the same season at both locations. The experiment evaluated SBM with no by-products; SBM with 1% gum; SBM with 3% gum; SBM with 0.5% soapstock; SBM with 1.5% soapstock; SBM with 2% weeds/trash; SBM with a combination of 3% gum, 1.5% soapstock, and 2% weeds/trash; SBM with 5.4% soybean oil; and roasted SB.

Diets. The ingredient composition of the experimental semipurified diets is presented in Table 2. Soybean meal without added by-products was used as a positive control. Diets were formulated such that a relatively constant concentration of Lys was used in all experimental treatments. The roasted SB were added to the diet such that the same calorie:Lys ratio as that of the control SBM treatment group was achieved. The treatment group with refined SB oil used the SBM without added by-products and was calculated to have the same calorie:Lys ratio as the roasted SB treatment. These ratios were 339.6 kcal:1 g and 333.3 kcal:1 g, respectively. The SB oil (refined with no by-products) has an ME of 8,400 kcal/kg (NRC, 1998). One treatment contained enzymatically hydrolyzed casein as the sole protein source and was included to enable calculation of standardized AA digestibilities. This diet was formulated to contain 5% casein. Any N-containing materials arriving at the ileum of pigs fed the casein diet were assumed to be endogenous secretions as the casein itself should be 100% digestible (Chung and Baker, 1992). All other ingredients in the diet were highly available, purified nutrient sources. A mycotoxin binding agent (MTB-100, Alltech, Lexington, KY) was included in all diets, even though the SB tested negative for the presence of mycotoxins. In addition, all diets contained 0.4% chromic oxide as a digestibility index. All diets were formulated to meet or exceed the vitamin and mineral requirements of growing pigs according to NRC (1998). Diets were mixed at OSU and a portion shipped to UIUC.

Animals. Each university's animal care and use committee approved all experimental procedures before experiment initiation. Twelve crossbred pigs [PIC 326 sire line × C22 dams (PIC, Franklin KY) at UIUC; and

Table 1. Chemical composition of soybean meal with and without by-products included, whole soybeans, and roasted soybeans

Item	No by-products	Soybean meal with:						Whole soybeans	Roasted soybeans[2]
		Gums		Soapstock		Weeds/trash	Combination[1]		
		1%	3%	0.5%	1.5%	2%	6.5%		
Dry matter	88.6	88.4	88.4	88.3	87.8	88.4	87.2	89.9	94.3
	DM basis, %								
Organic matter	92.7	92.8	92.9	92.9	92.8	92.5	92.6	94.7	94.8
Crude protein	50.3	49.9	48.9	50.3	49.6	49.9	48.2	37.8	40.1
Total dietary fiber	20.8	20.8	22.5	17.5	18.3	20.4	20.4	34.4	28.5
Acid-hydrolyzed fat	3.8	4.1	5.1	4.2	4.3	4.1	5.9	16.2	16.4
Gross energy, kcal/g	4.7	4.8	4.8	4.7	4.8	4.7	4.7	5.8	5.7
Essential AA									
Arg	3.67	3.73	3.68	3.77	3.63	3.86	3.63	2.71	2.96
His	1.35	1.38	1.36	1.38	1.30	1.42	1.30	1.01	1.08
Ile	2.15	2.14	2.13	2.15	2.08	2.33	2.08	1.64	1.73
Leu	3.68	3.72	3.70	3.82	3.66	4.04	3.66	2.83	2.99
Lys	3.05	3.11	3.22	3.14	3.01	3.23	3.00	2.33	2.42
Met	0.67	0.68	0.69	0.69	0.68	0.73	0.67	0.52	0.55
Phe	2.46	2.49	2.47	2.53	2.39	2.55	2.40	1.85	1.97
Thr	1.82	1.86	1.83	1.89	1.86	1.94	1.83	1.39	1.48
Trp	0.54	0.57	0.50	0.49	0.55	0.53	0.67	0.33	0.39
Val	2.35	2.35	2.32	2.36	2.25	2.47	2.29	1.80	1.92
Nonessential AA									
Ala	1.93	1.96	1.92	1.98	1.92	2.13	1.92	1.46	1.56
Asp	5.37	5.46	5.38	5.55	5.35	5.73	5.32	4.07	4.33
Cys	0.72	0.75	0.76	0.74	0.73	0.78	0.72	0.60	0.59
Glu	9.12	9.26	9.11	9.43	9.34	9.61	9.26	6.71	7.10
Gly	1.97	2.01	1.96	2.02	1.95	2.16	1.95	1.51	1.60
Pro	2.26	2.30	2.27	2.36	2.31	2.69	2.26	1.66	1.75
Ser	1.96	2.03	1.99	2.08	2.28	2.12	2.22	1.54	1.61
Tyr	1.68	1.69	1.69	1.73	1.68	1.86	1.65	1.32	1.38
Total essential AA	21.74	22.03	21.90	22.22	21.41	23.10	21.53	16.41	17.49
Total nonessential AA	25.01	25.46	25.08	25.89	25.56	27.08	25.30	18.87	19.92
Total AA	46.75	47.49	46.98	48.11	46.97	50.18	46.83	35.28	37.41

[1] Combination = gums, soapstock, and weeds/trash at the greatest dietary inclusion level.

[2] Roasted soybeans were not the same as those used in the production of the soybean meal but were representative of a typical variety.

(Yorkshire × Landrace) × Duroc at OSU] were cannulated at each site. Ten were used in each experiment with 2 additional animals cannulated in case of need of replacement. Initial BW of pigs averaged 27.1 ± 0.7 kg at UIUC and 24.5 ± 0.4 kg at OSU. Pigs were surgically fitted with a T-cannula (17 mm i.d.; 23 mm o.d.; 70-mm barrel length; 50-mm ileal flange length) at the distal ileum according to procedures adapted from Sauer et al. (1983). Adaptations included the cannula design and anesthetics. Nylon cannulas, with a smooth outer ring and screw cap, were used. The cannula barrel diameter was widened to allow for collection of greater volumes of digesta. The flange was widened and smoothed to allow increased stability when the cannula was exteriorized. Before use of halothane anesthesia, pigs were sedated with 1.0 mL of an i.m. mixture of telazol HCl (100 mg/mL), ketamine HCl (50 mg/mL), and xylazine HCl (50 mg/mL; Fort Dodge Animal Health, Fort Dodge, IA). A period of 7 d was allowed for surgical recovery of the pigs before experiment initiation. Pigs were housed individually in galvanized metal metabolism crates at UIUC and stainless steel metabolism crates at OSU in a temperature-controlled room. Water was available ad libitum via a low-pressure drinking nipple.

Experimental Design. Pigs were randomly assigned to diets in a 10 × 10 Latin square design with 7-d periods. During each period, d 1 to 4 constituted the diet adaptation phase, fecal samples were collected for 24 h beginning in the morning on d 5, and ileal samples were collected on d 6 and 7. Pigs were fed twice daily at 12-h intervals. The amount of feed provided each day during the first period was calculated on the basis of 0.09 × kg of $BW^{0.75}$ but was equalized for animals within each experimental treatment period. To account for increased nutrient needs because of growth of the pigs, the feeding level was increased by approximately 150 g in each subsequent period.

Sampling Procedures. Total fecal material was collected continuously for 24 h on d 5 of each period. Feces were collected and pooled for each pig, and samples were frozen at –20°C in plastic containers.

Ileal effluent was collected continuously for two 12-h intervals on d 6 and 7 of each period. Digesta were

Table 2. Ingredient composition (%, as-is basis) of experimental diets fed to pigs

	Diet[1]									
	1	2	3	4	5	6	7	8	9	10
			Soybean meal with:							
			Gums		Soapstock		Weeds/trash	Combination		
Ingredient	Casein	No by-products	1%	3%	0.5%	1.5%	2%	6.5%	Soybean oil	Roasted soybeans[2]
Cornstarch	52.65	30.80	31.55	32.80	31.95	30.50	32.85	30.30	32.65	21.05
Test soybean meal	—	35.00	34.25	33.00	33.85	35.30	32.95	35.50	37.20	—
Soybeans, roasted	—	—	—	—	—	—	—	—	—	44.75
Sucrose	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Dextrose	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Soybean oil	1.00	—	—	—	—	—	—	—	5.95	—
Solka floc	5.00	—	—	—	—	—	—	—	—	—
Casein, hydrolyzed	5.00	—	—	—	—	—	—	—	—	—
Dicalcium phosphate	3.00	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
$KHCO_3$ (55% K)	1.40	—	—	—	—	—	—	—	—	—
Salt	0.45	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Limestone	0.30	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[3]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Se premix[4]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
MgO (58% Mg)	0.15	—	—	—	—	—	—	—	—	—
MTB-100[5]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral mix[6]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

[1] Diet 2 = soybean meal with no by-products; diet 8 = combination of gums, soapstock, and weeds/trash at the greatest dietary inclusion level.

[2] Roasted soybeans were not the same as those used in the production of the soybean meal but were representative of a typical variety.

[3] Provided per kilogram of diet: 2,000 IU of vitamin A; 300 IU of vitamin D_3; 20 IU of vitamin E; 1.0 mg of vitamin K (menadione); 4 mg of thiamine; 15 mg of niacin; 4 mg of riboflavin; 12 mg of pantothenic acid; 15 μg of vitamin B_{12}; 2 mg of pyridoxine; 0.1 mg of D-biotin; 0.5 mg of folic acid; and 0.6 g of choline.

[4] Provided per kilogram of diet: 0.30 mg of Se with limestone carrier.

[5] MTB 100 = Mycotoxin binder (Alltech, Nicholasville, KY).

[6] Provided per kilogram of diet: 180 mg of Fe (ferrous sulfate); 10 mg of Mn (manganese oxide); 16 mg of Cu (copper sulfate); 40 mg of I (potassium iodate); 42 mg of Se (sodium selenite); and 180 mg of zinc sulfate.

collected by attaching polyethylene tubing (5 × 25 cm; Rand Materials Handling Equipment Co. Inc., Pawtucket, RI) to the cannula barrel using a cable tie. The tubing was changed and emptied at least once every hour. Ileal digesta samples were frozen at −20°C to eliminate microbial activity and, thus, N loss until the end of collection. At the end of each collection period, ileal samples were thawed, pooled by pig, and a subsample taken for lyophilization.

Precision-Fed Cecectomized Rooster Assay

Apparent and standardized digestibility of AA and TME_n were calculated according to the procedure outlined by Sibbald (1986) using the precision-fed rooster assay. This experiment was conducted only at UIUC. All surgical and animal care procedures were approved by the UIUC Institutional Animal Care and Use Committee. Thirty-six Single Comb White Leghorn roosters that had been cecectomized previously (Parsons, 1985) were utilized in this experiment. The roosters ranged in age from 1 to 2 yr of age and were allotted so that each treatment group was of similar age (n = 4 per treatment; 9 treatments). Roosters were crop-intubated with 30-g samples of SBM with no by-products; SBM with 1% gum; SBM with 3% gum; SBM with 0.5% soapstock; SBM with 1.5% soapstock; SBM with 2% weeds/trash; SBM with 3% gum, 1.5% soapstock, and 2% weeds/trash; and roasted SB.

The roosters were housed in individual cages with raised wire floors in an environmentally controlled room and an average temperature of approximately 24°C, with continuous lighting for 17 h/d (0400 to 2100). Feed was withdrawn from the roosters for 24 h before the experiment to remove any residual feed from the gastrointestinal tract. After the 24-h withdrawal, roosters were crop-intubated with 30 g of each SBM sample and roasted SB, and excreta were collected for 48 h after intubation. To correct for endogenous AA excretion, excreta were collected from 4 cecectomized roosters that had been deprived of feed during the experimental period. All excreta samples were lyophilized, weighed, ground, and analyzed for GE and AA concentrations.

Chemical Analyses

Subsamples of the SB, SBM, diets, ileal digesta, and feces were ground through a 2-mm screen using a Wiley mill (Thomas-Wiley, Swedesboro, NJ). Soybeans were ground with dry ice to avoid loss of oil and were stored at −20°C until analyzed. At UIUC, SB, SBM, feed, ileal samples, and fecal samples were analyzed for DM and ash concentrations according to AOAC (1995). Crude protein was determined according to AOAC (1995) using a Leco Nitrogen/Protein Determinator (model FP-2000, Leco Corporation, St. Joseph, MI). Total dietary fiber content was analyzed according to Prosky et al. (1984). Gross energy content was determined by oxygen bomb calorimetry according to Parr Instrument Manuals No. 203M, 205M, 207M, and 246M (Parr Instrument Co., Moline, IL). Fat content of the SBM and diets was determined by acid hydrolysis (AACC, 1983) followed by ether extraction, according to Budde (1952).

Ileal samples collected at both sites were analyzed at the University of Missouri Experiment Station Chemical Laboratories to eliminate variation between laboratories. Chromium was measured in diet and ileal samples by atomic absorption spectrophotometry after wet ashing in hydrochloric acid (AOAC, 1995). Diet and ileal samples were analyzed for AA using a Beckman 6300 amino acid analyzer (Beckman Coulter Inc., Fullerton, CA) by the method outlined by AOAC [AOAC, 1995; methods 988.15 (sulfur and regular) and 994.12 (Trp)].

Calculations

Nutrient digestibilities were calculated using the DM basis concentrations of all nutrients. Nutrient digestibilities for both locations were calculated using the analyzed Cr and AA values on diet samples obtained at UIUC.

Apparent ileal nutrient digestibility (**AID**) and apparent total tract nutrient digestibility (**ATTD**) values were calculated according to the following formula:

$$\text{AID or ATTD, \%} = 100 - ([N_D/N_F] \times [Cr_F/Cr_D] \times 100),$$

where N_D is the nutrient concentration present in ileal digesta or feces, N_F is the nutrient concentration in feed, Cr_F is the Cr concentration in feed, and Cr_D is the Cr concentration in ileal digesta or feces.

To calculate standardized ileal digestibilities (**SID**) of CP and AA, endogenous nutrient losses (**ENL**) were calculated according to Moughan et al. (1992) using the following equation:

$$\text{ENL, mg/kg of DMI} = N_D \times (Cr_F/Cr_D).$$

In each experiment, values for the pig fed the enzyme-hydrolyzed casein diet during each period were used to calculate the ENL for all pigs within the same period. Finally, SID values were calculated using the following equation:

$$\text{SID, \%} = \text{AD} + ([\text{ENL}/N_F] \times 100).$$

For the poultry experiment, standardized AA digestibilities were calculated by subtracting the amount of the AA in the excreta from the AA intake and correcting this value for endogenous losses by subtracting the average amount of the AA in the excreta of the roosters deprived of food during the experiment divided by the AA intake. True metabolizable energy was calculated as according to the method of Sibbald (1986).

Statistics

Data from OSU and UIUC were combined into one data set and analyzed together as a replicated 10 × 10 Latin square design using the Mixed models procedure of SAS (SAS Inst. Inc., Cary, NC). The fixed effect of the model was treatment. The random effects included in the model were location, pig within location, and period within location. Treatment effects on AID, SID, and ATTD were evaluated using the following nonorthogonal contrasts: diet 2 (no by-products) vs. diet 8 (combination of all by-products added at the greatest inclusion level); diet 2 (no by-products) vs. diets 3 to 8 (all diets with by-products); diet 2 (no by-products) vs. diet 7 (2% weeds/trash); diet 9 (SB oil) vs. diet 10 (roasted SB); linear effect of gums added at 0, 1, and 3% (diets 2, 3, and 4); quadratic effect of gums added at 0, 1, and 3% (diets 2, 3, and 4); linear effect of soapstock added at 0, 0.5, and 1.5% (diets 2, 5, and 6); and quadratic effect of soapstock added at 0, 0.5, and 1.5% (diets 2, 5, and 6). All data were compared using least squares means with an alpha level of 0.05 used to determine statistical significance.

RESULTS AND DISCUSSION

Chemical Composition and Protein Quality Indices

Chemical composition of SBM with by-products included, whole SB, and roasted SB are presented in Table 1. The DM content of whole SB and SBM was relatively constant (87.2 to 89.9%), whereas roasted SB were greater (94.3%) in DM due to water removal during the roasting process. Organic matter content varied little among treatments. Crude protein concentrations were similar among SBM (48.2 to 50.3%); whole SB (37.8%) and roasted SB (40.1%) had considerably lower CP concentrations because of high oil content. Total dietary fiber content varied little among SBM (17.5 to 22.5%), whereas whole SB (34.4%) and roasted SB (28.5%) had somewhat greater total dietary fiber concentrations. Acid-hydrolyzed fat concentrations varied slightly among SBM (3.8 to 5.9%) but were much greater in whole SB (16.2%) and roasted SB (16.4%). Gross energy values were similar among SBM (4.7 to 4.8 kcal/g), whereas roasted SB and whole SB were similar to each other and somewhat greater than SBM (5.7 and 5.8 kcal/g, respectively). The total AA concentration of all SBM samples were similar (46.75 to 50.18%), whereas whole SB (35.28%) and roasted SB (37.41%) were much lower in total AA concentration than SBM. A similar pattern was evident for total essential, total nonessential, and most individual AA.

Table 3. Protein quality characteristics of soybean meal with and without by-products included, whole soybeans, and roasted soybeans

		Soybean meal with:							
		Gums		Soapstock		Weeds/trash	Combination[1]		
Item	No by-products	1%	3%	0.5%	1.5%	2%	6.5%	Whole soybeans[2]	Roasted soybeans[2]
Protein solubility in KOH,[3] % of CP	87.5	91.1	85.3	87.5	82.7	90.8	89.9	89.4	66.1
Protein dispersibility index,[4] % of CP	32.3	31.9	30.9	31.5	30.6	30.3	19.4	88.6	18.6
Urease activity,[3] pH units	0.04	0.02	0.00	0.04	0.02	0.04	0.00	2.17	0.04

[1] Combination = gums, soapstock, and weeds/trash at the greatest dietary inclusion level.

[2] Roasted soybeans were not the same as those used in the production of the soybean meal but were representative of a typical variety.

[3] Protein solubility in KOH and urease activity assays were replicated twice. Values were accepted provided they were within 5% of each other.

[4] Protein dispersibility index assay was replicated 4 times. Values were accepted provided they were within 5% of each other.

Overall, whole SB and roasted SB were similar in composition to each other and very different than that of SBM. These results were expected because both are whole unextracted substrates. Nutrient profiles were similar for all SBM samples tested. Total dietary fiber concentrations varied little but were approximately 2 percentage units lower in SBM with soapstock included as compared with the remaining treatments, but the reason for this is unknown. Acid-hydrolyzed fat concentrations varied among SBM. With the addition of high lipid by-products to the SBM, fat concentrations reflected the increased inclusion levels of gums and soapstock, with the greatest acid-hydrolyzed fat concentration occurring for the combination treatment.

Protein quality characteristics of SBM with no by-products included, with by-products included, whole SB, and roasted SB are presented in Table 3. Protein solubility in KOH and protein dispersibility index (**PDI**) were used as indicators of protein quality. The latter assay measures the percentage of protein soluble in water. In this experiment, KOH solubility values ranged from a low of 66.1% for the roasted SB to a high of 91.1% for the SBM containing 1% gums. All but one (1.5% soapstock treatment) KOH value was above 85%. Growth depression of chicks has been reported when animals consumed SBM that was underprocessed, with a KOH value greater than 85% (Araba and Dale, 1990a), and when chicks consumed SBM that was overprocessed, with a KOH value less than 70% (Araba and Dale, 1990b). These data suggest that, according to assay guidelines, the roasted SB were potentially overprocessed and the experimental SBM were perhaps underprocessed.

The PDI was 18.6% for roasted SB, 19.4 to 32.3% for the SBM (30.3 to 32.3% for all but the combination treatment), and 88.6% for unprocessed whole SB. When SB flakes were autoclaved, the PDI value dropped to 45% and was associated with increased growth of chicks as compared with SB flakes that were not autoclaved and had a PDI value of 63% (Batal et al., 2000). Batal et al. (2000) indicated that a SBM with a PDI of 45% or lower was adequately heat processed. The PDI value for the combination treatment was low compared with the other SBM treatments. The assay was repeated on 4 different occasions and resulted in similar low values. Why a 6.5% concentration of by-products added to SBM would affect the value to this extent is not known. Overall, these results suggest that the roasted SB and SBM appeared to be adequately processed.

Because the destruction of the urease enzyme in SB is correlated with the destruction of trypsin inhibitors, urease activity was used as a third indicator of protein quality. In this experiment, urease activity was relatively similar for all of the processed and roasted SB, ranging from 0.00 to 0.04 units of pH change, whereas the unprocessed whole SB had a value of 2.17. The acceptable range of change in pH units to assess urease activity in processed SB substrates is 0.05 to 0.20 (Parsons, 2000); urease values greater than 0.20 reflected underprocessed SBM and inadequate inactivation of trypsin inhibitor activity, as occurred for whole SB. The values for these SBM (0.00 to 0.04) imply that they were adequately processed for the inactivation of trypsin inhibitor activity.

Ileal-Cannulated Swine Experiment

The chemical composition of diets fed to ileal-cannulated pigs at UIUC is presented in Table 4. Dry matter and OM concentrations of all diets were relatively similar. All diets that contained SBM, SB oil, or roasted SB had similar CP concentrations. The low protein casein diet contained 4.2% CP. Total dietary fiber ranged from 7.1% in the no by-products diet to 13.5% in the roasted SB diet. This resulted because the roasted SB diet contained the entire SB, including the SB hull, which has greater fiber concentrations. The presence of this high fiber fraction significantly decreases digestibility of nutrients such as DM, protein, and GE (Kornegay, 1978). Amino acid composition of the soy-containing diets was relatively homogeneous across treatments.

In general, pigs remained healthy and consumed their meals throughout the experiment. In cases where pigs did not consume their meals or became ill, they were removed from the trial and replaced with another cannulated pig to ensure that digestibility estimates

Table 4. Chemical composition of semipurified diets fed to ileal cannulated pigs

	Diet									
	1	2	3	4	5	6	7	8	9	10
			Soybean meal with:							
			Gums		Soapstock		Weeds/trash	Combination[1]		
Item	Casein	No by-products	1%	3%	0.5%	1.5%	2%	6.5%	Soybean oil	Roasted soybeans[2]
Dry matter	92.6	92.1	91.8	91.5	91.9	91.5	92.0	91.4	92.1	93.7
	DM basis, %									
Organic matter	96.8	96.1	97.1	96.2	96.0	96.4	96.9	96.5	96.7	97.0
Crude protein	4.2	20.6	19.4	17.5	18.4	18.4	16.9	18.6	18.1	18.3
Total dietary fiber	5.3	7.1	11.1	10.0	10.5	9.1	8.2	9.6	9.0	13.5
Gross energy, kcal/g	3.9	4.0	4.1	3.9	4.0	4.0	4.0	4.1	4.1	4.5
Essential AA										
Arg	0.16	1.55	1.44	1.32	1.40	1.43	1.28	1.32	1.34	1.37
His	0.13	0.55	0.55	0.47	0.50	0.50	0.45	0.47	0.47	0.48
Ile	0.24	0.98	0.98	0.84	0.89	0.90	0.83	0.81	0.85	0.85
Leu	0.45	1.66	1.66	1.42	1.50	1.51	1.38	1.42	1.45	1.47
Lys	0.33	1.26	1.18	1.07	1.14	1.16	1.05	1.08	1.09	1.10
Met	0.09	0.23	0.23	0.21	0.20	0.21	0.21	0.20	0.20	0.24
Phe	0.21	0.99	0.93	0.85	0.90	0.92	0.83	0.86	0.88	0.88
Thr	0.18	0.76	0.70	0.63	0.68	0.69	0.63	0.65	0.66	0.68
Trp	0.06	0.28	0.27	0.26	0.28	0.27	0.24	0.24	0.26	0.25
Val	0.30	0.99	0.92	0.85	0.90	0.90	0.84	0.81	0.85	0.87
Nonessential AA										
Ala	0.14	0.87	0.80	0.73	0.77	0.78	0.72	0.74	0.75	0.77
Asp	0.31	2.22	2.04	1.87	2.00	2.03	1.85	1.90	1.94	2.00
Cys	0.02	0.27	0.27	0.25	0.25	0.23	0.33	0.23	0.25	0.26
Glu	0.99	3.78	3.51	3.20	3.41	3.44	3.15	3.25	3.34	3.31
Gly	0.09	0.84	0.76	0.70	0.74	0.75	0.68	0.71	0.71	0.74
Pro	0.44	1.09	0.99	0.93	0.98	0.99	0.89	0.92	0.94	0.96
Ser	0.21	0.89	0.82	0.70	0.76	0.77	0.70	0.75	0.76	0.78
Tyr	0.19	0.60	0.58	0.52	0.55	0.57	0.51	0.54	0.51	0.56
Total essential AA	2.15	9.25	8.86	7.92	8.39	8.49	7.74	7.86	8.05	8.19
Total nonessential AA	2.39	10.56	9.77	8.90	9.46	9.56	8.83	9.04	9.20	9.38
Total AA	4.76	20.05	18.64	17.06	18.08	18.27	16.80	17.13	17.48	17.79

[1] Combination = gums, soapstock, and weeds/trash at the greatest dietary inclusion level.

[2] Roasted soybeans were not the same as those used in the production of the soybean meal but were representative of a typical variety.

were based on healthy animals. One pig at UIUC was replaced on the experiment, but none were replaced at OSU. There were no statistical effects of experimental location on any parameter measured.

Apparent ileal DM, OM, CP, and most AA digestibilities were lower ($P < 0.05$) for pigs consuming the combination by-product diet compared with the diet containing no by-products (Table 5). Apparent ileal digestibilities of DM, CP, total essential, total nonessential, total, and most individual AA were lower ($P < 0.05$) for diets containing by-products compared with the diet with no by-products. Apparent ileal digestibility of CP was lower ($P < 0.05$) when the weeds/trash treatment was compared with the no by-products treatment. Apparent ileal digestibilities of all components were lower ($P < 0.05$) for roasted SB compared with the SB oil treatment. There was a linear decrease in digestibility of DM, CP, total nonessential AA, and total AA when increasing concentrations of gums were added to the diet. There was a quadratic decrease in AID of DM, CP, and 5 AA (Ile, Phe, Trp, Gly, and Ser) when increasing concentrations of soapstock were included.

The combination by-product treatment consistently resulted in the lowest digestibilities as compared with by-product treatments considered individually. The roasted SB treatment was the only other treatment that resulted in lower digestibilities. Crude protein digestibilities were lower for pigs consuming the weeds/trash treatment compared with the no by-product treatment potentially due to the presence of antinutritional factors present in weeds. These antinutritional factors, such as phenolics and tannins, are known to decrease protein digestibility (Reed, 1995). Roasted SB resulted in lower digestibilities compared with the SB oil diet because, along with the oil that is present in both roasted SB and in the SB oil treatment, roasted SB also contain the SB hulls. Soybean hulls contain high concentrations of dietary fiber known to decrease nutrient digestibilities (Kornegay, 1978). With the addition of gums to the diet, there were decreases in DM, CP,

Table 5. Apparent ileal digestibilities (%) of pigs fed semipurified diets containing soybean meal with no by-products included, or with gums, soapstock, weeds/trash, all by-products, and soybean oil included, or roasted soybeans

	Diet									
	2	3	4	5	6	7	8	9	10	
		Soybean meal with:								
		Gums		Soapstock		Weeds/trash	Combination^{1}			
Item	No by-products	1%	3%	0.5%	1.5%	2%	6.5%	Soybean oil	Roasted soybeans^{2}	SEM^{3}
Dry matter^{4,5,7,8,9}	85.9	86.3	83.9	83.7	85.0	85.7	81.7	82.9	76.7	0.78
Organic matter^{4,7}	89.0	89.7	87.7	87.5	88.3	89.1	85.8	86.9	80.0	0.74
Crude protein^{4,5,6,7,8,9}	87.2	86.4	82.4	82.9	85.1	84.0	80.8	82.6	74.8	1.14
Essential AA										
Arg^{4,5,7,8}	93.0	92.0	91.0	91.3	91.9	92.0	90.6	92.1	85.7	0.73
His^{4,5,7}	88.5	87.1	86.6	86.7	86.9	86.7	84.7	87.3	77.8	2.74
Ile^{4,5,7,9}	86.0	84.7	84.3	83.7	85.0	84.4	81.9	85.5	74.3	3.06
Leu^{4,5,7}	85.8	84.3	84.0	83.7	84.6	84.1	82.1	85.4	75.1	3.03
Lys^{4,5,7}	87.6	86.4	85.5	85.2	86.2	86.0	83.9	86.7	76.9	2.66
Met^{7}	84.5	83.9	87.1	85.4	85.0	86.6	84.6	84.5	75.7	3.09
Phe^{4,5,7,9}	87.0	85.6	85.1	84.7	85.8	84.8	83.3	86.4	76.4	2.44
Thr^{4,5,7,8}	80.2	78.6	77.0	77.5	78.6	77.8	75.7	79.2	68.2	3.93
Trp^{7,9}	86.9	86.3	85.1	83.5	86.0	84.5	85.9	87.2	75.9	6.67
Val^{4,5,7}	84.3	82.5	82.0	81.6	82.5	82.2	79.4	83.3	71.5	3.07
Nonessential AA										
Ala^{4,5,7}	81.0	79.1	78.0	77.8	79.1	78.7	75.5	80.3	68.5	3.23
Asp^{4,5,7}	85.2	84.3	82.8	83.2	84.1	83.2	81.0	84.3	74.8	3.20
Cys^{4,7}	78.2	77.3	75.8	74.9	75.4	78.6	71.6	74.6	66.1	4.74
Glu^{4,5,7}	87.1	86.2	84.8	84.8	85.9	84.9	83.4	86.1	77.8	3.46
Gly^{4,5,7,8,9}	76.3	73.7	68.6	70.9	72.6	74.6	66.9	74.1	61.4	3.17
Pro^{4,5,7,8}	78.7	75.9	72.4	75.3	74.6	77.1	69.6	73.8	64.1	3.97
Ser^{4,5,7,8,9}	83.8	83.3	81.0	81.3	83.4	81.5	80.8	82.4	73.3	2.38
Tyr^{4,5,7}	86.7	85.6	84.6	84.6	86.0	85.2	83.0	85.3	76.4	1.02
Total essential AA^{4,5,7}	86.0	84.6	84.2	83.8	84.7	84.3	82.4	85.5	75.1	3.62
Total nonessential AA^{4,5,7,8}	84.8	83.5	81.6	82.1	83.1	82.9	79.9	83.2	74.0	1.69
Total AA^{4,5,7,8}	85.3	84.0	82.7	82.9	83.9	83.5	81.0	84.2	74.6	2.50

[1] Combination = gums, soapstock, and weeds/trash at the greatest dietary inclusion level.

[2] Roasted soybeans were not the same as those used in the production of the soybean meal but were representative of a typical variety.

[3] SEM = weighted standard error of the mean (n = 20).

[4] Diet 2 vs. diet 8 ($P < 0.05$).

[5] Diet 2 vs. diets 3 through 8 ($P < 0.05$).

[6] Diet 2 vs. diet 7 ($P < 0.05$).

[7] Diet 9 vs. diet 10 ($P < 0.05$).

[8] Linear effect of gums added at 0, 1, and 3% ($P < 0.05$).

[9] Quadratic effect of soapstock added at 0, 0.5, and 1.5% ($P < 0.05$).

and some AA digestibilities. These results differ from those of Overland et al. (1993) who noted no significant effects on AID or ATTD of DM, nitrogen, GE, or crude fiber with gum addition to SBM fed to pigs. This difference was likely due to the greater level of inclusion in our experiment (0.24 vs. 1 and 3%). The addition of soapstock resulted in decreased DM, CP, and certain AA digestibilities because soapstocks, like gums, have chemical bonding properties that can chelate AA during the digestion process and reduce AA availability to the animal (Woerfel, 1981).

Endogenous nitrogen and AA losses are reported in Table 6. The mean endogenous losses of nitrogen and AA were similar to those reported by Dilger et al. (2004), Smiricky et al. (2002), and Traylor et al. (2001). Mean endogenous losses of all AA fell into the ranges reported by these studies. The most prominent AA in the endogenous fraction were the nonessential AA.

Standardized ileal digestibility data are presented in Table 7. Standardized ileal digestibilities of CP, total essential, total nonessential, total, and most individual AA were lower ($P < 0.05$) when comparing the no by-product and the combination by-product treatments. Standardized ileal digestibilities of CP and 8 individual AA (Arg, His, Leu, Lys, Phe, Val, Ala, and Gly) were lower ($P < 0.05$) for diets containing any by-products compared with the diet with no by-products. Standardized ileal digestibilities of CP and all AA were lower ($P < 0.05$) for the roasted SB- compared with the SB oil-containing diet, which might be due to the roasted SB being from a different source of SB than the SBM. Standardized ileal digestibilities of CP, Arg, and Gly decreased linearly when pigs were fed increasing concentrations of gums, and CP digestibility decreased quadratically when pigs were fed increasing concentrations of soapstocks.

Table 6. Endogenous losses (mg/kg of DMI) of nitrogen and AA at the terminal ileum of swine

Item	Mean	Range (minimum to maximum)	SEM[1]
Nitrogen	3,007.9	2,066.6 to 4,444.1	244.1
Essential AA			
Arg	452.7	288.4 to 1,006.3	53.3
His	207.7	181.3 to 259.9	5.6
Ile	529.7	435.4 to 651.7	12.8
Leu	646.1	435.4 to 909.6	22.8
Lys	498.9	335.0 to 623.7	15.8
Met	112.8	89.3 to 136.0	3.1
Phe	306.9	223.3 to 376.8	6.9
Thr	602.9	430.5 to 740.7	15
Trp	115.7	68.0 to 155.9	5.2
Val	583.2	491.3 to 675.7	10.4
Nonessential AA			
Ala	590.2	516.8 to 896.6	28.2
Asp	883.5	826.2 to 1,065.5	15.8
Cys	176.8	156.3 to 233.9	4.4
Glu	1,935.9	1,665.5 to 2,504.4	48.1
Gly	1,056.4	634.5 to 2,200.5	124.6
Pro	3,140.4	709.0 to 9,459.9	713.9
Ser	793.8	566.5 to 1,078.5	33.7
Tyr	338.0	230.1 to 574.1	23.0
Total essential AA	4,225.2	3,360.7 to 5,483.6	111.8
Total nonessential AA	8,914.9	5,638.0 to 17,555.4	944.2
Total AA	13,513.5	10,372.9 to 23,311.9	978.6

[1] SEM = weighted standard error of the mean (n = 20).

Proline was by far the most abundant and most variable AA quantified in ileal digesta with standardized digestibility coefficients over 100%. This is perhaps the result of an overestimation of endogenous Pro loss and, thus, an overestimation of standardized Pro digestibility. Use of a low-protein casein diet to estimate endogenous losses perhaps may result in mobilization of glutamine from muscle, which can be metabolized into Glu for use by the enterocytes to synthesize ammonia, citrulline, and Pro. Therefore, caution must be exercised when interpreting standardized ileal Pro digestibilities due to the endogenous abundance (De Lange et al., 1989).

When comparing standardized ileal digestibilities, the combination treatment consistently resulted in the lowest values among the diets containing SBM. This combination by-product treatment resulted in lower values than did all diets that contained individual by-products. The roasted SB treatment resulted in an even lower digestibility coefficient than did the combination treatment. Roasted SB resulted in lower digestibilities possibly due to the greater fiber fraction present in this treatment or the different variety of SB used in its production. Standardized ileal digestibilities of CP and a few AA decreased when pigs were fed increasing concentrations of gums and soapstock. As was the case for AID, these results may be attributed to the fact that both gums and soapstocks commonly added to SBM have chemical bonding properties that can chelate AA, thus potentially reducing digestibility.

Apparent and standardized ileal digestibility data were relatively similar in rank. One specific difference noted was the lower ($P < 0.05$) AID of CP for the weeds/trash treatment compared with the no by-product treatment that was not evident in the standardized ileal digestibility data. Overall, SID coefficients were greater than AID values, reflecting the contribution of endogenous losses. Also, SID coefficients were more homogeneous compared with AID values. In some cases, such as for Arg, Trp, Gly, Pro, and Ser, pig-to-pig variation was greater than for other AA.

Total tract digestibility data are presented in Table 8. As a result of the presence of highly digestible ingredients in the semipurified diets fed to pigs, ATTD values were very high. Total tract DM digestibility was lower ($P < 0.05$) for pigs fed the combination by-product diet compared with the no by-products diet. Total tract DM, OM, CP, and GE digestibilities were lower ($P < 0.05$) for the roasted SB treatment compared with the SB oil treatment. This reduction was due to the much greater dietary fiber concentration present in this diet compared with that of the others and perhaps to the presence of Maillard products resulting from the roasting process itself. When gums were included at 1 and 3% concentrations in the diet, ATTD of DM decreased linearly ($P < 0.05$).

Precision-Fed Cecectomized Rooster Assay

Data reporting TME_n content and standardized AA digestibilities by roosters are presented in Table 9. True

Table 7. Standardized ileal digestibilities (%) of pigs fed semipurified diets containing soybean meal with no by-products included, or with gums, soapstock, weeds/trash, all by-products, and soybean oil included, or roasted soybeans

	Diet									
	2	3	4	5	6	7	8	9	10	
		Soybean meal with:								
		Gums		Soapstock		Weeds/trash	Combination[1]			
Item	No by-products	1%	3%	0.5%	1.5%	2%	6.5%	Soybean oil	Roasted soybeans[2]	SEM[3]
Crude protein[4,5,6,7,8]	96.2	96.0	93.0	93.0	95.2	95.2	90.9	92.9	85.0	1.22
Essential AA										
Arg[4,5,6,7]	96.0	95.1	94.5	94.5	95.0	95.4	93.9	95.3	88.9	1.77
His[4,5,6]	92.4	91.1	91.0	90.8	91.1	91.1	89.0	91.4	81.9	3.12
Ile[4,6]	91.9	90.9	90.9	90.0	91.2	90.8	88.6	91.7	80.6	3.12
Leu[4,5,6]	90.1	88.7	88.7	88.1	89.0	88.7	86.7	89.7	79.4	2.96
Lys[4,5,6]	91.7	90.7	89.9	89.5	90.5	90.5	88.4	91.0	81.3	2.47
Met[6]	89.2	88.6	92.0	90.4	89.9	91.5	89.6	89.4	80.1	3.17
Phe[4,5,6]	90.2	88.9	88.6	88.0	89.1	88.4	86.7	89.6	79.7	2.43
Thr[4,6]	88.6	87.2	86.4	86.2	87.3	86.9	84.6	87.8	76.8	3.97
Trp[6]	91.7	91.2	90.5	88.8	90.9	89.9	90.6	92.1	81.3	5.83
Val[4,5,6]	90.5	89.0	89.0	88.2	89.1	89.0	86.4	89.8	78.0	3.14
Nonessential AA										
Ala[4,5,6]	88.3	86.7	86.2	85.5	86.8	86.7	83.5	88.0	76.1	3.99
Asp[4,6]	89.3	88.6	87.5	87.5	88.4	87.8	85.5	88.6	79.1	3.47
Cys[4,6]	84.7	83.7	82.6	81.7	82.3	84.4	78.7	81.2	72.6	5.27
Glu[4,6]	92.4	91.8	90.9	90.4	91.5	90.8	89.2	91.7	83.6	3.88
Gly[4,5,6,7]	89.3	87.6	83.6	84.9	86.6	89.6	81.4	88.3	75.3	8.52
Pro[6]	107.9	107.6	106.5	107.0	106.4	111.8	103.6	106.8	96.6	21.21
Ser[4,6]	93.5	93.4	92.3	91.6	93.4	92.4	90.8	92.7	83.5	3.74
Tyr[4,6]	92.1	91.2	90.5	90.2	91.6	91.0	88.8	91.1	81.9	1.36
Total essential AA[4,6]	91.2	90.0	90.0	89.3	90.2	90.0	88.1	90.9	80.5	3.20
Total nonessential AA[4,6]	96.0	95.2	94.1	93.9	94.8	95.1	91.9	94.8	85.8	2.55
Total AA[4,6]	94.1	93.1	92.5	92.1	93.0	93.1	90.4	93.3	83.7	2.46

[1] Combination = gums, soapstock, and weeds/trash at the greatest dietary inclusion level.
[2] Roasted soybeans were not the same as those used in the production of the soybean meal but were representative of a typical variety.
[3] SEM = weighted standard error of the mean (n = 20).
[4] Diet 2 vs. diet 8 ($P < 0.05$).
[5] Diet 2 vs. diets 3 through 8 ($P < 0.05$).
[6] Diet 9 vs. diet 10 ($P < 0.05$).
[7] Linear effect of gums added at 0, 1, and 3% ($P < 0.05$).
[8] Quadratic effect of soapstock added at 0, 0.5, and 1.5% ($P < 0.05$).

Table 8. Apparent total tract digestibilities (%) of pigs fed semipurified diets containing soybean meal with no by-products included, or with gums, soapstock, weeds/trash, all by-products, and soybean oil included, or roasted soybeans

	Diet									
	2	3	4	5	6	7	8	9	10	
		Soybean meal with:								
		Gums		Soapstock		Weeds/trash	Combination[1]			
Item	No by-products	1%	3%	0.5%	1.5%	2%	6.5%	Soybean oil	Roasted soybeans[2]	SEM[3]
Dry matter[4,5,6]	93.7	93.7	92.8	93.1	93.7	93.1	92.5	92.9	89.3	0.36
Organic matter[5]	96.2	96.4	95.6	96.0	96.2	95.8	95.5	95.7	92.1	0.29
Crude protein[5]	92.8	92.1	89.7	91.3	91.3	90.9	91.2	91.1	84.9	1.26
Gross energy[5]	94.9	95.2	94.0	94.6	94.9	94.0	93.9	94.1	87.7	0.48

[1] Combination = gums, soapstock, and weeds/trash at the greatest dietary inclusion level.
[2] Roasted soybeans were not the same as those used in the production of the soybean meal but were representative of a typical variety.
[3] SEM = weighted standard error of the mean (n = 20).
[4] Diet 2 vs. diet 8 ($P < 0.05$).
[5] Diet 9 vs. diet 10 ($P < 0.05$).
[6] Linear effect of gums added at 0, 1, and 3% ($P < 0.05$).

Table 9. True ME (kcal/g) and AA digestibilities (%) of roosters precision-fed soybean meal with no by-products included, or with gums, soapstock, weeds/trash, and all by-products included, or roasted soybeans

Item	Diet								
	2	3	4	5	6	7	8	10	
		Soybean meal with:							
		Gums		Soapstock		Weeds/trash	Combination[1]		
	No by-products	1%	3%	0.5%	1.5%	2%	6.5%	Roasted soybeans[2]	SEM[3]
True ME[4,5]	2.688	2.588	2.792	2.873	2.878	2.613	2.643	3.185	0.05
Essential AA									
Arg[4]	89.4	90.3	91.7	92.8	93.1	91.2	92.8	85.2	1.52
His[4]	88.1	90.4	89.7	89.5	89.4	88.6	88.5	78.8	1.11
Ile[4]	91.0	92.7	92.3	91.9	91.8	91.8	90.5	79.0	1.16
Leu[4]	90.9	92.2	92.1	92.0	91.7	91.6	90.5	79.3	1.17
Lys[4]	87.0	88.2	89.9	89.4	90.8	89.0	88.4	80.4	1.63
Met[4]	92.8	94.3	94.2	93.9	94.0	94.2	92.4	81.6	1.15
Phe[4]	92.2	93.4	93.0	92.9	92.6	92.4	91.6	81.0	1.11
Thr[4]	87.1	88.0	88.2	88.4	87.6	87.3	86.4	76.3	1.45
Trp[4]	93.8	96.0	94.6	94.0	94.6	90.9	94.9	86.1	1.20
Val[4]	89.9	91.3	91.3	90.8	90.6	90.4	89.1	78.0	1.27
Nonessential AA									
Ala[4]	86.4	88.2	88.3	87.7	87.5	87.7	86.0	74.3	1.28
Asp[4]	90.2	91.3	90.9	91.0	90.6	90.5	89.1	79.3	1.00
Cys[4]	86.0	84.8	86.0	84.5	86.2	84.9	84.0	71.9	1.86
Glu[4]	92.7	94.0	93.5	93.4	93.3	92.7	91.7	81.7	1.15
Pro[4]	91.9	92.7	92.8	92.7	92.5	92.8	90.7	79.0	1.52
Ser[4]	89.9	91.1	90.7	90.6	91.4	90.1	91.4	76.5	1.43
Tyr[4]	93.0	94.0	94.0	93.6	93.6	93.9	93.2	82.6	0.98
Total essential AA[4]	90.2	91.7	91.7	91.6	91.6	90.7	90.5	80.6	1.10
Total nonessential AA[4]	90.2	90.9	90.9	90.5	90.7	90.4	89.5	77.9	1.27
Total AA[4]	90.1	91.4	91.4	91.1	91.3	90.6	90.1	79.5	1.16

[1] Combination = gums, soapstock, and weeds/trash at the greatest dietary inclusion level.

[2] Roasted soybeans were not the same as those used in the production of the soybean meal but were representative of a typical variety.

[3] n = 10.

[4] Diet 2 vs. diet 10 ($P < 0.05$).

[5] Linear effect of soapstock added at 0, 0.5, and 1.5% ($P < 0.05$).

metabolizable energy values were greater ($P < 0.05$) for roasted SB compared with SBM containing no by-products and increased linearly with the addition of increased concentrations of soapstock. Also, the digestibilities of individual, total essential, total nonessential, and total AA were lower ($P < 0.05$) for the roasted SB treatment compared with the no by-product treatment.

Roasted SB and soapstock provided the roosters with more ME as they provide greater lipid concentrations that appear to be available to the animal. Individual, total essential, total nonessential, and total AA digestibilities were lower ($P < 0.05$) for roosters fed roasted SB vs. SBM with no by-products, in agreement with the pig data. Interestingly, the combination by-product treatment did not result in lower standardized AA digestibilities as was noted for pigs. Perhaps the greater extent of mechanical manipulation of feedstuffs in the rooster digestive tract could render the diet containing 6.5% by-products more digestible as compared with the pigs.

The precision-fed cecectomized rooster assay and the ileal-cannulated pig assay have been shown to be sensitive indicators of the differences in protein quality and AA digestibilities exemplified in both plant and animal protein sources. The precision-fed rooster assay is less expensive and much faster than the pig assay and can be used to predict general differences in AA digestibilities by pigs (Parsons, 2000). However, differences were noted in this experiment for standardized ileal digestibilities of total essential, total nonessential, and total AA, which were greater in pigs than in roosters. Whereas there was a decrease in standardized ileal digestibilities of total essential, total nonessential, total, and most individual AA in pigs with the addition of gums and soapstock to diets, rooster AA digestibilities increased.

According to NRC (1998), the first 3 limiting AA in a corn-SBM diet fed to growing pigs are Lys, Thr, and Trp. The combination by-product treatment resulted in lower ($P < 0.05$) AID and SID of both Lys and Thr. However, this was not the case for roosters. The first 3 limiting AA in poultry, Lys, Met, and Cys, were not affected when fed the combination by-product treatment. Roasted SB resulted in lower ($P < 0.05$) AID and SID of Lys, Thr, and Trp in pigs and lower ($P < 0.05$) Lys, Met, and Cys digestibilities in roosters. The roasted SB treatment was more detrimental than the combination by-product treatment and resulted in decreased digestibilities of the first 3 limiting AA in both swine and poultry.

In conclusion, addition of common by-products such as gums, soapstock, and weeds/trash to semipurified diets fed to pigs affected both AID and SID AA digestibilities and, to a much more limited extent, ATTD of CP. Overall, the combination by-product treatment resulted in consistently lower digestibilities of DM, OM, CP, and AA compared with the no by-products treatment or the by-products grouped collectively. Roasted SB resulted in even lower AID, SID, and ATTD of these same nutrients compared with the combination treatment. If these constituents are to be disposed of by returning them to the SBM, it must be recognized that the nutritive value of the resultant meal may be compromised somewhat. The addition of a combination of gums, soapstock, and weeds/trash to swine diets resulted in a 6 percentage unit decrease in ileal digestible CP, and an 11 percentage unit decrease in CP digestibility when fed roasted SB. Total essential, total nonessential, and total AA digestibilities decreased by 11 percentage units when pigs were fed a roasted SB diet. In roosters, roasted SB resulted in a 10 percentage unit decrease in digestible total essential AA, a 13 percentage unit decrease in digestible total nonessential AA, and an 11 percentage unit decrease in digestible total AA. These reductions in AA digestibilities with the addition of by-products or with the use of roasted SB could result in potential AA deficiencies and lead to a reduction in feed intake, increased feed wastage, impaired growth, reduced feed efficiency, and reduced animal growth performance.

LITERATURE CITED

AACC. 1983. Approved Methods. 8th ed. Am. Assoc. Cereal Chem., St. Paul, MN.

American Oil Chemists Society. 1980a. Urease activity. Official Method Ba 9-58. Am. Oil Chem. Soc., Champaign, IL.

American Oil Chemists Society. 1980b. Protein dispersibility index. Official Method Ba 10-65. Am. Oil Chem. Soc., Champaign, IL.

AOAC. 1995. Official Methods of Analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Araba, M., and N. M. Dale. 1990a. Evaluation of protein solubility as an indicator of overprocessing of soybean meal. Poult. Sci. 69:76–83.

Araba, M., and N. M. Dale. 1990b. Evaluation of protein solubility as an indicator of underprocessing of soybean meal. Poult. Sci. 69:1749–1752.

Batal, A. B., M. W. Douglas, A. E. Engram, and C. M. Parsons. 2000. Protein dispersibility index as an indicator of adequately processed soybean meal. Poult. Sci. 79:1592–1596.

Budde, E. F. 1952. The determination of fat in baked biscuit type of dog foods. J. Assoc. Off. Anal. Chem. 35:799–805.

Chung, T. K., and D. H. Baker. 1992. Apparent and true amino acid digestibility of a crystalline amino acid mixture and of casein: Comparison of values obtained with ileal-cannulated pigs and cecectomized cockerels. J. Anim. Sci. 70:3781–3790.

Cromwell, G. L. 2000. Utilization of soy products in swine diets. Pages 258–282 in Soy in Animal Nutrition. J. K. Drackley, ed. Fed. Anim. Sci. Soc., Savoy, IL.

De Lange, C. F. M., W. C. Sauer, and W. Souffrant. 1989. The effect of protein status of the pig on recovery and amino acid composition of endogenous protein in digesta collected from the distal ileum. J. Anim. Sci. 67:755–762.

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.

Kornegay, E. T. 1978. Feeding values and digestibility of soybean hulls for swine. J. Anim. Sci. 47:1272–1280.

Moughan, P. J., G. Schuttert, and M. Leenaars. 1992. Endogenous amino acid flow in the stomach and small intestine of the young growing pig. J. Sci. Food Agric. 60:437–442.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. National Academy Press, Washington, DC.

Overland, M., M. D. Tokach, S. G. Cornelius, J. E. Pettigrew, and M. E. Wilson. 1993. Lecithin in swine diets: II. Growing-finishing pigs. J. Anim. Sci. 71:1194–1197.

Parsons, C. M. 1985. Influence of caecectomy on digestibility of amino acids by roosters fed distillers' dried grains with solubles. J. Agric. Sci. (Camb.) 104:469–472.

Parsons, C. M. 2000. Assessment of nutritional quality of soy products. Pages 90–105 in Soy in Animal Nutrition. J. K. Drackley, ed. Fed. Anim. Sci. Soc., Savoy, IL.

Parsons, C. M., K. Hashimoto, K. J. Wedekind, and D. H. Baker. 1991. Soybean protein solubility in potassium hydroxide: An in vitro test of in vivo protein quality. J. Anim. Sci. 69:2918–2924.

Prosky, L., N. G. Asp, I. Furda, J. W. DeVries, T. F. Schweizer, and B. F. Harland. 1984. Determination of total dietary fiber in foods and products: Collaborative study. J. Assoc. Off. Anal. Chem. 67:1044–1052.

Reed, J. D. 1995. Nutritional toxicology of tannins and related polyphenols in forage legumes. J. Anim. Sci. 73:1516–1528.

Sauer, W. C., H. Jørgensen, and R. Berzins. 1983. A modified nylon bag technique for determining apparent digestibilities of protein in feedstuffs for pigs. Can. J. Anim. Sci. 63:233–237.

Sibbald, I. R. 1986. The TME system of feed evaluation: Methodology, feed composition data, and bibliography. Animal Research Centre Contribution 85-19. Agriculture Canada, Ottawa, ON, Canada.

Smiricky, M. R., C. M. Grieshop, D. M. Albin, J. E. Wubben, V. M. Gabert, and G. C. Fahey Jr. 2002. The influence of soy oligosaccharides on apparent and true ileal amino acid digestibilities and fecal consistency in growing pigs. J. Anim. Sci. 80:2433–2441.

Traylor, S. L., G. L. Cromwell, M. D. Lindemann, and D. A. Knabe. 2001. Effects of level of supplemental phytase on ileal digestibility of amino acids, calcium, and phosphorus in dehulled soybean meal for growing pigs. J. Anim. Sci. 79:2634–2642.

Woerfel, J. B. 1981. Processing and utilization of by-products from soy oil processing. J. Am. Oil Chem. Soc. 58:188–191.