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Chemical Composition and Nutritional Quality of Soybean Meals Prepared by Extruder/Expeller Processing for Use in Poultry Diets

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This research examined variation in chemical composition and nutrient quality of soybeans (SBs) and soybean meals (SBMs) produced at seven commercial extruder/expeller plants in the United States (experiment 1), as well as differences in amino acid digestibilities when roosters were fed SBMs extruded at 121, 135, 150, or 160 °C at a U.S. pilot processing plant (experiment 2). In experiment 1, limited variation existed in the composition of SBs arriving at the plants, whereas substantial differences were noted in amino acid composition and protein quality of the resultant SBMs. In experiment 2, the SBMs extruded at 121 and 135 °C were underprocessed as noted by high urease activities and lower amino acid digestibilities. Soybean meals extruded at 150 and 160 °C resulted in higher amino acid digestibilities and lower urease activities, indicating adequate processing. Large variation exists in the nutritional quality of extruder/expeller SBMs currently in the marketplace. Optimal processing temperatures should be >135 °C, and temperatures as high as 165 °C do not result in overprocessing.

KEYWORDS: Extruder/expeller; poultry; processing; soybean meal

INTRODUCTION

With recent increases in the production of biodiesel fuel, the number of soybean (SB) processing plants that use extruder/expeller processing, rather than solvent extraction, has increased. Multiple studies examining variability in U.S. solvent-exracted soybean meal (SBM) exist (*1*−*3*). Differences in the chemical composition of SBM based on the geographical region in which the SBM was processed have been noted, possibly due to differences in environmental conditions during growth of the SB (*3*). Additionally, it was noted that even if the compositions of the SBs used were similar, conditions used at the processing plant will result in differences in chemical composition (both carbohydrates and amino acids) among the resultant SBMs. However, little to no data on the composition of commercially produced extruder/expeller processed SBMs are available.

Small changes in extruder/expeller processing conditions may result in a SBM that is more digestible when fed to pigs or poultry. Limited data exist examining optimal processing conditions in extruder/expeller SBM processing. Alterations in factors such as temperature, pressure, and time exposed can result in changes in SBM composition and quality.

The objectives of this research were to quantify the variation in chemical composition and protein quality of SBs and the resultant SBMs obtained from extruder/expeller processing plants in the United States and to determine the effects of altering temperatures during extruder/expeller processing on in vivo amino acid digestibilities. In experiment 1, SB and SBM samples were collected over time from seven commercial extruder/expeller plants. In experiment 2, SBMs were produced in a pilot extruder/expeller processing plant with all processing factors held constant except for the temperature of the extruder.

MATERIALS AND METHODS

Soybean and Soybean Meal Samples. Experiment 1 was designed to quantify the variability in SBM produced using extruder/expeller processing in the United States. Seven processing plants were used. Each plant was visited at approximately 2 week intervals over a 4 week period, and a total of three samples from each plant were collected. At each visit, a sample of SB and the resultant SBM was collected and sent to the University of Illinois for analysis. Samples from individual plants were not pooled, but were analyzed individually to provide replication for statistical analysis. All samples were collected while the plant was running normally, and no processing information was collected. The SBMs were not dehulled at these plants. Plants were located in Iowa (two), Michigan (one), Nebraska (two), North Carolina (one), and South Dakota (one). Each plant was labeled 1−7, and plant owners and company names were kept confidential. Plant 4 sent two SBM samples, labeled 4A and 4B, which were coarse and fine ground,

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Table 1. Chemical Composition and Protein Quality Indices of Soybeans Collected from Seven Commercial Extruder/Expeller Processing Plants

	soybean source[a] (plant no.)							
item[b]	1	2	3	4	5	6	7	SD
dry matter, %	93.3d	91.1b	91.9c	90.2a	92.7cd	92.4c	92.3c	0.27
	%, dry matter basis							
organic matter	93.9	93.9	93.9	94.0	94.1	93.9	94.4	0.15
crude protein	38.3	39.1	39.4	39.6	40.3	39.9	39.5	0.54
acid-hydrolyzed fat	21.4cd	21.9d	19.8ab	21.5cd	20.0bc	18.8a	21.4cd	0.41
crude fat	20.4bc	21.4d	19.7b	20.5bcd	20.1bc	18.3a	20.8cd	0.34
protein quality indices								
protein dispersability index, % of CP	76.4	76.4	81.2	76.4	80.8	80.5	81.2	3.93
KOH solubility, % of CP	69.7	79.0	72.0	67.1	70.6	71.4	74.4	5.85
urease activity, pH units	2.12b	2.11b	2.07b	1.94a	2.09b	1.93a	2.05b	0.030

[a] Means within a row with uncommon letters differ ($P < 0.05$). [b] $N = 3$.

respectively, but only one SB sample. No information was provided as to whether there were other differences in processing conditions.

Experiment 2 was conducted to determine the effects of altering the temperature during extruder/expeller processing on amino acid digestibilities by cecectomized roosters. One batch of SBs (Seed Beans, Adams County, IL) was processed at the Texas A&M University pilot processing plant (College Station, TX). All conditions during extruder/expeller processing were held constant except for the temperature used during extrusion, which was set at 121, 135, 150, or 160 °C to produce four different lots of SBM. These SBMs were sent to the University of Illinois for analysis and use in the cecectomized rooster assay (see below).

Chemical Analysis. Prior to analysis, SBs and SBMs were ground through a 2-mm screen using a Wiley mill, model 4 (Thomas-Wiley, Swedesboro, NJ). Soybean samples were ground with dry ice to avoid fat loss and stored frozen at −20 °C. A subsample of each SB and SBM was further ground through a 0.5-mm screen prior to potassium hydroxide (KOH) protein solubility and urease activity assays. Soybean and SBM samples were analyzed for dry matter (DM; method 920.36) and organic matter (OM; method 924.05) according to AOAC methods (*4*). Crude protein (CP) was determined according to AOAC method 990.03 (*4*) using a Leco nitrogen/protein determinator (model FP-2000, Leco Corp., St. Joseph, MI). Acid-hydrolyzed fat content of the samples was determined by acid hydrolysis (*5*) followed by ether extraction according to the method of Budde (*6*), whereas crude fat concentrations were determined according to AOAC method 920.39 (*4*). Urease activity (*7*), KOH protein solubility (*8*), and protein dispersability index (*7*) were determined on SB and SBM samples. Analysis of amino acid concentrations was conducted at the University of Missouri Experiment Station Chemical Laboratories using a Beckman 6300 amino acid analyzer (Beckman Coulter, Inc., Fullerton, CA) according to AOAC (*4*) procedures (method 994.12 for sulfur and regular amino acids and method 988.15 for tryptophan).

Only SBM samples produced at the pilot plant (experiment 2) were analyzed for phosphorus (P) concentrations. These SBMs were analyzed for total P (*4*) and phytate-bound P. Phytate-bound P was determined by quantifying the phytic acid concentrations using the methods of Talamond et al. (*9*, *10*) and quantified via HPLC with a Dionex DX300 gradient pump system using an ASRS suppressor, an OmniPac PAX-100 anion exchange column, and a conductivity meter with suppression as the detector. Non-phytate P was determined as the difference between total P and phytate-bound P.

All procedures were performed in duplicate except for amino acids, for which only one analysis/sample was conducted. To maintain quality control during chemical analysis, the error between duplicate samples was determined and, if >5%, the assay was repeated.

Amino Acid Digestibilities. To determine the true digestibility of amino acids in the SBM samples produced in the pilot plant (experiment 2), the precision-fed rooster assay of Sibbald (*11*) was used. Twenty single-comb White Leghorn roosters that had been previously cecetomized (*12*) were used. All surgical and animal care procedures were approved by the University of Illinois Institutional Animal Care and Use Committee. The roosters were housed in individual cages with raised wire floors in an environmentally controlled room. Feed was withdrawn from the roosters for 24 h prior to the experiment to remove any residual feed from the gastrointestinal tract. After the 24 h withdrawal, four roosters were crop intubated with 30 g of each SBM sample, and excreta were collected for 48 h after intubation. To correct for endogenous amino acid excretion, excreta were collected from four cecetomized roosters that had been deprived of feed for 48 h. All excreta samples were lyophilized, weighed, ground, and analyzed for amino acid concentrations, and true amino acid digestibilities calculated. True amino acid digestibilities were calculated by subtracting amino acid output (less average amount of that amino acid excreted by fasted roosters) from amino acid intake and dividing that sum by amino acid intake.

Statistical Analysis. In experiment 1, compositional data were analyzed as a completely randomized design. The model included the fixed effect of processing plant. Least-squares means were compared using a Fisher protected least significant difference test. An α level of 0.05 was used to determine statistical significance.

For experiment 2, amino acid digestibility data were analyzed as a completely randomized design using the mixed models procedure of the SAS (SAS Institute, Cary, NC). The model included the fixed effect of SBM fed. Data were compared using the Fisher protected least significant difference test. An α level of 0.05 was used to determine statistical significance.

RESULTS

Experiment 1. Minimal differences existed in the composition of SBs used in the extruder/expeller processing plants (**Table 1**). Dry matter concentrations ranged from 90.2 to 93.3%, with SBs from plants 2 and 4 having lower ($P < 0.05$) DM concentrations than those from the other plants. No differences were noted in OM or CP concentrations among SBs arriving at these plants.

Both crude and acid-hydrolyzed fat concentrations were lowest in SBs arriving at plant 6 and highest in those arriving at plant 2. Acid-hydrolyzed fat concentrations ranged from 18.8 to 21.9%, whereas crude fat concentrations ranged from 18.3 to 21.4%. Overall, crude fat concentrations were 0.51 of a percentage unit lower than acid-hydrolyzed fat concentrations.

Protein dispersibility index (PDI), KOH solubility, and urease activity were measured as indicators of protein quality. No differences were noted in PDI or KOH solubility values. Urease activity was lower ($P < 0.05$) in SBs arriving at plants 4 and 6.

Little variation existed in lysine (2.59−2.75%), total essential (17.8−18.8%), total nonessential (20.5−22.0%), or total amino acids (38.3−40.8%) among SB samples (**Table 2**). The only amino acids for which significant differences were noted were the sulfur-containing amino acids. Methionine concentrations

Table 2. Amino Acid Composition (Percent, Dry Matter Basis) of Soybeans Collected from Seven Commercial Extruder/Expeller Processing Plants

	soybean source[a] (plant no.)							
item[b]	1	2	3	4	5	6	7	SD
essential amino acids								
arginine	2.85	2.84	2.94	3.06	2.92	2.97	2.98	0.082
histidine	1.05	1.06	1.09	1.09	1.06	1.08	1.08	0.024
isoleucine	1.87	1.86	1.90	1.93	1.84	1.85	1.93	0.046
leucine	3.04	3.04	3.10	3.18	3.05	3.07	3.14	0.075
lysine	2.60	2.62	2.63	2.75	2.59	2.61	2.72	0.059
methionine	0.52a	0.53ab	0.56b	0.57b	0.52a	0.50a	0.55b	0.012
phenylalanine	1.96	1.96	2.01	2.06	1.97	2.02	2.04	0.051
threonine	1.48	1.50	1.52	1.61	1.51	1.51	1.54	0.040
tryptophan	0.40	0.45	0.49	0.47	0.43	0.39	0.46	0.034
valine	2.01	1.99	2.03	2.07	1.96	1.98	2.04	0.047
nonessential amino acids								
alanine	1.71	1.70	1.74	1.79	1.71	1.72	1.77	0.036
aspartate	4.45	4.45	4.55	4.73	4.48	4.47	4.64	0.119
cysteine	0.61ab	0.64abc	0.59a	0.65bc	0.60a	0.60a	0.66c	0.016
glutamate	6.76	6.59	7.01	7.28	6.93	6.87	6.92	0.203
glycine	1.70	1.74	1.73	1.81	1.73	1.73	1.79	0.033
proline	1.95	1.92	2.01	2.05	1.99	1.96	1.97	0.046
serine	1.78	1.81	1.92	2.07	1.93	1.90	1.87	0.077
taurine	0.06	0.07	0.07	0.07	0.08	0.07	0.07	0.008
tyrosine	1.40	1.41	1.42	1.46	1.40	1.42	1.48	0.037
total essential amino acids	17.8	17.9	18.3	18.8	17.9	18.0	18.5	0.45
total nonessential amino acids	20.5	20.5	21.1	22.0	20.9	20.8	21.4	0.51
total amino acids	38.3	38.3	39.4	40.8	38.8	38.8	39.9	0.94

[a] Means within a row with uncommon letters differ ($P < 0.05$). [b] $N = 3$.

Table 3. Chemical Composition and Protein Quality Indices of Soybean Meals Collected from Seven Commercial Extruder/Expeller Processing Plants

	soybean meal source[a] (plant no.)								
item[b]	1	2	3	4A	4B	5	6	7	SD
dry matter, %	95.4bc	96.2bcd	96.2bcd	95.1b	96.5d	89.2a	96.3cd	88.6a	0.37
	%, dry matter basis								
organic matter	93.2	93.2	93.4	93.3	93.3	93.3	93.3	93.0	0.14
crude protein	45.1a	46.6ab	47.5ab	50.4bc	48.9bc	48.4bc	50.7cd	52.6d	0.87
acid-hydrolyzed fat	10.1c	10.2cd	10.4cd	9.8c	11.3d	8.6b	9.9c	4.9a	0.37
crude fat	7.9bcd	9.0d	8.1bcd	7.4b	9.0cd	7.5bc	7.9bcd	4.1a	0.50
protein quality indices									
protein dispersability index, % of CP	9.4a	11.5ab	10.3a	23.6cd	17.8bc	6.6a	18.8cd	25.7d	2.39
KOH solubility, % of CP	74.5bc	70.4b	72.0b	80.6b	79.4b	54.3a	78.5b	72.5b	4.36
urease activity, pH units	0.01	0.06	0.03	0.10	0.06	0.01	0.01	0.05	0.035

[a] Means within a row with uncommon letters differ ($P < 0.05$). [b] $N = 3$.

were lowest ($P < 0.05$) in SBs arriving at plants 1, 5, and 6 versus plants 3, 4, and 7, with plant 2 samples being intermediate. Cysteine concentrations were lowest in SBs arriving at plants 3, 5, and 6 versus plants 4 and 7, with samples from plants 1 and 2 being intermediate.

More differences were detected in the resultant SBMs than were noted in the SBs (**Table 3**). Dry matter concentrations ranged from 88.6 to 96.5%. Soybean meal produced at plants 5 and 7 had the lowest DM concentration, perhaps due to differences in drying methods. Differences existed between SBM 4A and 4B, which are the coarse and fine ground samples, respectively, from the same plant. A wide range (45.1−52.6%) was noted in CP concentrations of the SBM samples. Crude and acid-hydrolyzed fat concentrations followed similar patterns. Soybean meal produced at plant 7 had the lowest fat concentrations, indicating a more efficient removal of the SB oil. Sample 4A had a lower fat concentration than sample 4B.

Differences were noted in protein quality indices among SBMs as well. The PDI values ranged from 6.6 to 25.7%. SBMs produced at plants 1, 3, and 5 had lower PDI values than those produced at plants 4, 6, and 7. Protein solubility in KOH resulted in few differences among treatments. SBM produced at plant 5 was less soluble in KOH (54.3%) than all other SBMs (70.4−80.6%). Urease activities of all SBMs were between 0.01 and 0.10, with no differences noted among SBMs.

With regard to amino acid composition, SBMs from plants 1 and 2 had lower total essential, total nonessential, and total amino acid concentrations than did SBMs produced at plants 4−7 (**Table 4**). Plant 7 had higher concentrations of total essential and total amino acids than plants 3−5. No differences were detected in total amino acid concentrations of the SBs arriving at the plant. In general, individual amino acids followed the same pattern. Soybean meal produced at plant 1 consistently had the lowest concentration of individual amino acids, with the exception of cysteine. Amino acid concentrations of SBMs from plants 2 and 3 generally were similar to those of SBMs produced at plant 1, whereas SBMs produced at plants 6 and 7 usually contained the highest concentrations of individual amino

Table 4. Amino Acid Composition (Percent, Dry Matter Basis) of Soybean Meals Collected from Seven Commercial Extruder/Expeller Processing Plants

	soybean meal source[a] (plant no.)								
item[b]	1	2	3	4A	4B	5	6	7	SD
essential amino acids									
arginine	3.11a	3.21a	3.37ab	3.69cd	3.58bcd	3.52bc	3.77d	3.80d	0.078
histidine	1.21a	1.26ab	1.30bc	1.36cd	1.33c	1.35cd	1.41d	1.48e	0.024
isoleucine	2.09a	2.11a	2.19ab	2.34bcd	2.24ab	2.32bc	2.41cd	2.48d	0.053
leucine	3.42a	3.48ab	3.56ab	3.83c	3.70bc	3.81c	3.89cd	4.06d	0.074
lysine	2.78a	2.87a	2.93ab	3.19cd	3.08bc	2.81a	3.18cd	3.33d	0.056
methionine	0.55a	0.61b	0.61bc	0.63bcd	0.62bcd	0.60b	0.65b	0.66d	0.013
phenylalanine	2.26a	2.33ab	2.36abc	2.56d	2.46bcd	2.52cd	2.64e	2.74e	0.053
threonine	1.72a	1.78a	1.83ab	1.97cd	1.91bc	1.93bc	1.95cd	2.04d	0.039
tryptophan	0.65a	0.72cd	0.68ab	0.75de	0.73cd	0.74cd	0.70bc	0.79e	0.013
valine	2.14a	2.13a	2.27ab	2.40bc	2.30b	2.36bc	2.49c	2.49c	0.054
nonessential amino acids									
alanine	1.95a	2.02ab	2.01ab	2.16c	2.09bc	2.18c	2.19c	2.38d	0.040
aspartate	4.69a	4.84ab	4.98ab	5.33cd	5.17bc	5.25bc	5.40cd	5.62d	0.110
cysteine	0.65ab	0.68abc	0.68bcd	0.70cde	0.72cde	0.63a	0.74e	0.73de	0.017
glutamate	7.48a	7.75ab	8.12bc	8.85d	8.51cd	8.52cd	8.85d	8.95d	0.206
glycine	1.88	1.93	1.99	2.10	2.04	2.10	2.10	2.19	0.038
proline	2.29a	2.34ab	2.39ab	2.57c	2.48bc	2.57c	2.61cd	2.76d	0.050
serine	2.02a	2.07ab	2.29bc	2.48c	2.37c	2.49c	2.38c	2.43c	0.076
taurine	0.05	0.04	0.05	0.05	0.04	0.05	0.05	0.05	0.004
tyrosine	1.59a	1.64ab	1.68abc	1.80d	1.72bcd	1.77cd	1.81de	1.91e	0.033
total essential amino acids	19.9a	20.5a	21.1ab	22.7cd	22.0bc	22.0bc	23.1cd	23.9d	0.43
total nonessential amino acids	22.7a	23.5a	24.5ab	26.2bc	25.3b	25.7bc	25.8bc	27.1c	0.60
total amino acids	42.7a	44.0a	45.6ab	48.9cd	47.2bc	47.7bc	48.8cd	51.0d	0.99

[a] Means within a row with uncommon letters differ ($P < 0.05$). [b] $N = 3$.

Table 5. Chemical Composition and Protein Quality Indices of Soybean Meals Produced at Various Temperatures during Extruder/Expeller Processing[a]

	processing temperature			
item	121 °C	135 °C	150 °C	160 °C
dry matter, %	93.80	94.63	95.40	95.90
	%, dry matter basis			
organic matter	93.55	92.28	93.27	93.18
crude protein	48.53	48.61	49.48	49.77
total phosphorus	0.69	0.68	0.69	0.69
phytate phosphorus	0.54	0.54	0.55	0.42
non-phytate phosphorus	0.15	0.14	0.14	0.27
protein quality indices				
protein dispersability index, % of CP	55.66	43.53	20.49	10.09
KOH solubility, % of CP	82.57	78.03	72.94	61.64
urease activity, pH units	2.11	1.91	0.06	0.02

[a] No statistical comparisons were made on chemical analysis due to lack of replication of data.

acids. Soybean meals produced at plants 4 and 5 were intermediate in amino acid concentrations. Both SBMs produced at plant 4 were similar in concentrations of all amino acids as would be expected.

Experiment 2. The chemical compositions of the SBMs produced in the pilot extruder/expeller processing plant were similar (**Table 5**). This was expected as all SBMs were produced from the same batch of SBs. The phytate-bound phosphorus was decreased when the SB were heated to 160 °C.

Both PDI and KOH solubility followed the expected pattern of decreased solubility with increased heat processing. Protein dispersibility index and KOH solubility values ranged from 10.09 to 55.66% and from 61.64 to 82.57% of CP, respectively. Urease activity was very high for SBMs prepared at 121 and 135 °C.

Table 6. Amino Acid Composition of Soybean Meals Produced at Different Temperatures during Extruder/Expeller Processing[a]

	processing temperature			
item	121 °C	135 °C	150 °C	160 °C
essential amino acids				
arginine	3.28	3.27	3.45	3.41
histidine	1.22	1.23	1.31	1.31
isoleucine	2.08	2.11	2.23	2.18
leucine	3.47	3.49	3.69	3.65
lysine	2.87	2.86	3.03	3.01
methionine	0.62	0.62	0.65	0.64
phenylalanine	2.28	2.28	2.45	2.42
threonine	1.73	1.70	1.80	1.81
tryptophan	0.67	0.53	0.68	0.64
valine	2.20	2.27	2.38	2.32
nonessential amino acids				
alanine	1.90	1.91	2.02	2.00
aspartate	5.04	5.05	5.30	5.25
cystine	0.82	0.83	0.84	0.77
glutamate	8.40	8.32	8.54	8.44
glycine	1.87	1.90	1.99	1.96
proline	2.26	2.22	2.37	2.36
serine	2.06	1.96	1.95	1.97
tyrosine	1.60	1.60	1.69	1.67
total essential amino acids	20.42	20.36	21.67	21.39
total nonessential amino acids	23.95	23.79	24.70	24.42
total amino acids	44.37	44.15	46.37	45.81

[a] No statistical comparisons were made on chemical analysis due to lack of replication of data.

Amino acid compositions also were similar among treatments (**Table 6**). True digestibilities of amino acids were lower when roosters were fed SBMs prepared at 121 or 135 °C compared to when SBMs prepared at 150 or 160 °C were fed (**Table 7**). In fact, total amino acid digestibilities were approximately 20% lower for SBMs prepared at the lower temperatures compared to the higher temperatures. Average digestibilities were very low for lysine (74.3%), methionine (69.2%), and cysteine

Table 7. True Amino Acid Digestibilities of Soybean Meals Produced at Different Temperatures during Extruder/Expeller Processing

	processing temperature[a]				
item[b]	121 °C	135 °C	150 °C	160 °C	SD
essential amino acids					
arginine	81.9a	79.3a	91.9b	93.6b	2.69
histidine	76.5a	72.3a	85.4b	88.3b	2.47
isoleucine	72.4a	67.9a	86.4b	89.7b	3.45
leucine	74.4a	69.3a	87.2b	90.2b	3.46
lysine	75.0a	73.5a	87.1b	89.3b	2.94
methionine	72.3ab	66.1a	87.1bc	90.1c	4.45
phenylalanine	76.5a	71.9a	89.5b	91.9b	3.14
threonine	69.4a	63.6a	83.6b	85.7b	4.05
tryptophan	76.5b	67.4a	89.8c	92.6c	1.60
valine	70.9a	65.7a	85.5b	88.4b	4.17
nonessential amino acids					
alanine	70.7ab	62.6a	81.7bc	84.5c	4.27
aspartate	77.3a	73.6a	88.8b	90.7b	2.64
cystine	69.7ab	63.0a	81.4b	83.5b	4.44
glutamate	83.4a	80.1a	91.4b	93.4b	2.21
glycine	36.0ab	9.8a	43.5b	37.5b	7.92
proline	77.1a	71.4a	88.4b	90.9b	2.84
serine	73.5a	66.5a	86.0b	88.1b	3.49
tyrosine	75.5a	71.5a	89.5b	92.2b	3.40
total essential amino acids	74.6a	69.7a	87.3b	90.0b	3.05
total nonessential amino acids	70.4a	62.3a	81.3b	82.6b	3.34
total amino acids	65.9a	60.3a	76.8b	78.6b	2.82

[a] Means within a row with uncommon letters differ ($P < 0.05$). [b] $N = 4$.

(66.4%) in the SBMs prepared at 121 and 135 °C compared to the average of those prepared at 150 and 160 °C (88.2, 82.4, and 88.6%, respectively).

DISCUSSION

Experiment 1. Although the composition of the SB may be affected by cultivar used and growing conditions, limited differences were noted in composition of the SB utilized at the commercial extruder/expeller processing plants surveyed. This may be due in part to the fact that most processing plants were located in a similar geographic region [Nebraska (two plants), Iowa (two plants), and South Dakota]. However, two plants were located outside this area in Michigan and North Carolina, but the compositions of these two SBs were still similar to the others.

Minimal differences were noted in the composition of SB arriving at the processing plants. Dry matter, OM, and CP concentrations were similar to those reported in previous papers (mean = 41%; *2*, *13*). In addition, crude fat concentrations were similar to those found in other studies. Grieshop and Fahey (*13*) reported SBs from the United States contain approximately 18.7% and Grieshop et al. (*2*) reported concentrations of 17.4−20.1% for U.S. SB samples. Crude and acid-hydrolyzed fat analyses were both conducted on the SBs. Crude fat is the standard for fat measurement in the feed industry. However, crude fat analysis does not quantify phospholipids or sphingolipids. Acid-hydrolyzed fat analysis allows for measurement of all lipids.

Whereas few differences were noted in SB composition, more differences existed in SBM composition. Crude fat concentrations were 0.8−2.3 percentage units less than acid-hydrolyzed fat concentrations. Gums and soapstocks found in SBMs contain fat in the forms of soaps, triglycerides, and phosphatide, and, therefore, a large percentage of the fat in these additives is not quantified by the crude fat procedure (*14*). However, the fat from these sources is partially available to meet the animal's energy needs.

When protein quality indices were compared, some differences were noted among SBMs. Batal et al. (*15*) showed that when SB flakes were autoclaved, the PDI value dropped to 45% and was associated with increased growth of chicks compared to SB flakes that were not autoclaved (underprocessed) and with a PDI value of 63%. All PDI values were <45%, indicating that none were underprocessed. However, SBMs produced at plants 1, 3, and 5 had lower PDI values than those produced at plants 4, 6, and 7 and may have been overprocessed. There is currently no single PDI value that indicates overprocessing. Chung et al. (*16*) noted a value of 7.3% to be representative of rumen bypass protein. If so, the SBM produced at plant 5 would likely be overprocessed.

Another indicator of protein quality is protein solubility in KOH. In chick studies, a growth depression was reported when animals consumed SBM that was underprocessed and had a protein solubility in KOH of >85% (*17*) and when chicks consumed SBM that was overprocessed and had a protein solubility of <70% (*8*). On the basis of these data, only the SBM produced at plant 5 was overprocessed.

Urease activity is an indicator of trypsin inhibitor activity. Trypsin inhibitors can cause pancreatic hypertrophy in poultry if present at too high of a level in the diet (*18*). The optimal range of urease activity values for SBM is 0.05−0.20 pH unit change (*18*). Although some values were below the optimal range, a low urease value alone is not indicative of overprocessing and may not result in a decrease in digestibility (*19*). Once the trypsin inhibitor activity is destroyed, the urease value can no longer decrease; therefore, a zero urease activity or one of <0.05 may simply indicate that the trypsin inhibitor activity was no longer present in the SBM. Taking the three protein quality tests together, it appears that SBM produced at plant 5 was overprocessed, whereas SBMs produced at plants 1 and 3 are on the edge of the acceptable range and may have been slightly overprocessed. All other plants produced SBM of optimal quality on the basisof laboratory analyses.

Even though amino acid concentrations were similar among SBs, much larger differences were noted among SBMs. This indicates that differences in processing conditions among plants had a significant effect on SBM composition, more so than environmental conditions affected SB composition. Grieshop et al. (*2*) found similar results when comparing SBs and the resultant SBMs from nine commercial solvent extraction and one mechanical extraction (extruder/expeller) processing plant in the United States. Although no differences existed in individual or total amino acid concentrations of the SBs, significant differences in amino acid profiles were noted in the SBMs. These differences are likely due to differences in the amount of fat removed, as well as possible alterations in amino acids during processing.

One example of this is that whereas plant 5 generally had high concentrations of the other amino acids, the SBM produced at that site was one of the lowest in concentrations of lysine and cysteine. These two amino acids are susceptible to Maillard browning and may be modified or destroyed due to overprocessing. This is in agreement with the PDI and KOH solubility data. Soybeans arriving at plant 5 had lower concentrations of sulfur-containing amino acids than did SBs arriving at the other plants, but the concentration of methionine in SBM from plant 5 was intermediate compared to that of the other SBMs tested. Low concentrations of amino acids noted for SBM produced at plant 1, along with PDI solubility data, indicate potential overprocessing.

As has been noted with solvent-extracted SBM (*2*), processing conditions in commercial extruder/expeller processing plants vary, resulting in differences in composition of the resultant

SBM. It is important that the optimal processing conditions be determined to prevent overprocessing (as was noted in this experiment) as well as underprocessing. In extruder/expeller processing, variables such as temperature and length of time in the extruder can have a substantial impact on the nutritional value of the resultant SBM. Other factors such as efficiency of oil removal and hull removal may affect the SBM value as an animal feed. Although increased oil removal may be optimal for the processing plant, it will result in a decreased amount of available energy for the animal. Increased concentrations of SB hulls will result in increased fiber concentrations and potentially decreased digestibility of some SBM amino acids (*20*). As in vivo studies are conducted to test the efficiency of selected processing conditions, the results determined should affect how commercial SBM is prepared.

Experiment 2. The composition of the SBM produced at the pilot plant was similar as expected. One interesting difference was that phytate-bound phosphorus concentrations were lower in SBM heated to higher temperatures. This resulted in higher non-phytate phosphorus that may be more available to the animal. Previous research in our laboratory has shown the analytical non-phytate phosphorus concentration to be similar to available phosphorus concentrations determined in vivo (*21*).

Protein quality indices indicate that some of the samples may have been under- or overprocessed. According to Batal et al. (*15*), a PDI value of ≤45% for SBM is indicative of adequate heat processing and good growth performance of chicks. The SBM prepared at 121 °C had a PDI value of 55.7%, indicative of inadequate heat processing, whereas all other vlaues were below 45%. In addition, Chang et al. (*16*) indicated that a PDI value of 7.3% is indicative of rumen escape protein due to overprocessing. The SBM produced at 160 °C had a PDI value of 10.1%, suggesting that it may have been overprocessed. With regard to KOH solubility, a growth depression was reported when chicks consumed SBM that was underprocessed [with a protein solubility in KOH of >85% (*17*)] and when chicks consumed SBM that was overprocessed [with a protein solubility of <70% (*8*)]. On the basis of these data, SBM prepared at 160 °C was overprocessed, whereas all others were adequately processed. However, Parsons et al. (*22*) noted a value of 59% KOH solubility as the threshold to indicate overprocessing based on a broken-line model fitted to the gain/feed ratio of chicks. On the basis of this value, the SBMs produced at 160 °C were not overprocessed. The acceptable range of change in pH units for urease activity is generally 0.05−0.20 (*18*), with urease values of >0.2 reflecting underprocessed SBM and insufficient inactivation of trypsin inhibitor activity. The values for the SBMs prepared at low temperatures were well outside this acceptable range.

The amino acids most affected by heat processing due to destruction resulting from the Maillard reaction are lysine, histidine, and cysteine (*23*, *24*). No numeric decrease was noted in the concentration of these amino acids, except for cysteine at 160 °C. This may indicate little to no destruction during processing. Total essential (20.4−21.7%), total nonessential (23.8−24.7%), and total (44.2−46.4%) amino acid concentrations were similar among SBMs. In fact, lower digestibilities were noted with SBMs processed at lower temperatures. Amino acid digestibility data, along with urease activity data (and PDI data for the SBM extruded at 121 °C), suggest that the SBMs prepared at lower temperatures were underprocessed. Feeding cecectomized roosters undercooked SBM resulted in a true cysteine digestibility of 67%, whereas feeding roosters properly cooked SBM resulted in a cysteine digestibility of 82% (*23*). However, the low PDI and KOH values noted for SBMs extruded at 160 °C did not correlate to a decrease in amino acid digestibility. This may indicate that the lower threshold for KOH solubility is closer to the 59% value proposed by Parsons et al. (*22*). These data suggest that no single protein quality index alone is reflective of proper processing conditions. It is important that urease or trypsin inhibitor activity be analyzed in conjunction with protein solubility to obtain an accurate assessment of processing adequacy.

When the data from the current study are compared with previous studies utilizing extruder/expeller-produced SBM, the ideal temperature range for processing can be narrowed. Perrilla et al. (*25*) noted decreased body weights of broilers fed SBM extruded at 118 and 120 °C compared to those of broilers fed SBM extruded at 122, 126, or 140 °C. Additionally, the lowest pancreas weight was noted at 140 °C, which indicated an absence of pancreatic hypertrophy in these animals. Growth performance of chicks was lower when SBMs extruded at 104 or 121 °C were fed compared to when SBMs extruded at 138 or 154 °C were fed (*26*). A linear increase in amino acid digestibilities also was noted. When nursery pigs were fed SBMs extruded at 143.3, 148.9, 154.4, 160.0, or 165.6 °C, no differences were noted in average daily gain or average daily feed intake over a 20 day period (*27*). A quadratic increase was noted for the gain/feed ratio with the highest value obtained at 154.4 °C. However, the ratio ranged only from 0.56 to 0.60. Extrusion at 135 °C did not result in adequately processed SBM in the current study. From these data, it appears that a temperature of at least 138 °C should be reached when using extruder/expeller processing to ensure adequate inactivation of antinutritional factors, such as trypsin inhibitor. Additionally, temperatures as high as 165 °C do not appear to have a negative effect on nutrient digestibility and growth performance.

Although not compared to solvent-extracted SBM in the current study, amino acid digestibilities for SBMs extruded at 150 and 160 °C were similar to those reported in other studies (*21*, *26*). Zhang et al. (*26*) noted similar feed efficiency values when chicks were fed SBM extruded at 138 or 154 °C compared to solvent-extracted SBM. Higher CP digestibilities were noted for pigs fed diets containing extruded/expelled SBM with (86.2%) or without (85.4%) hulls compared to solvent-extracted SBM without hulls (83.2%; *28*). In addition, pigs fed the extruded/expelled SBM had higher digestibilities of arginine, isoleucine, leucine, lysine, phenylalanine, and valine than did those fed the solvent-extracted SBM. This indicates that there is a potential, if properly processed, for extruder/expeller-produced SBM to be of equal or greater value in poultry diets as solvent-extracted SBM.

In summary, as the use of extruder/expeller processing to produce SBM increases, it becomes increasingly important to understand how this processing technology affects nutrient composition and quality of the resultant SBM. Knowledge regarding the effects of this type of processing is limited in comparison to that regarding the effects of solvent extraction. Current data clearly demonstrate a substantial effect of differences in processing conditions used in commercial extruder/expeller processing plants. Also, a wide range of quality characteristics occur in the available SBMs produced using this method. Using amino acid digestibility data, optimal extrusion temperatures should be in excess of 135 °C, and temperatures as high as 165 °C still result in adequately processed SBM.

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