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Amino acid digestibility in soybean meal sourced from different regions of the United States and fed to pigs[1]

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ABSTRACT: An experiment was conducted to determine the apparent ileal digestibility (AID) and the standardized ileal digestibility (SID) by growing pigs of AA in soybean meal (SBM) produced in different regions of the United States. Twenty-two growing barrows (25.5 ± 1.73 kg) were fitted with a T-cannula near the distal ileum and allotted to a 22 × 8 Youden square design. Twenty-two sources of SBM were procured from soybean crushing plants located throughout the United States. For analysis, the crushing plant locations were separated into the following 3 zones: 1) Michigan, Minnesota, and South Dakota (n = 4); 2) Georgia, Illinois, Indiana, and Ohio (n = 11); and 3) Iowa, Missouri, and Nebraska (n = 7). Dietary treatments included 22 diets based on a mixture of cornstarch, sucrose, and each source of SBM as the sole source of CP. Results indicated that the concentration of most indispensable and dispensable AA in SBM were not different among zones. However, SBM from zone 2 had a greater (P < 0.05) concentration of Thr than SBM from zone 3 and a greater (P < 0.05) concentration of Gly than SBM from zone 1. The concentration of Tyr in SBM from zone 2 was also greater (P < 0.05) than in SBM from zones 1 and 3. However, if concentrations of AA were calculated as a percent of CP, there were no differences in the concentrations of indispensable and dispensable AA among SBM from the 3 zones. Likewise, the AID of CP and the AID of indispensable and dispensable AA were not different among SBM from the 3 zones. The SID of CP and most AA was also not different among SBM from the 3 zones. However, SBM from zone 3 had a greater (P < 0.05) SID of His, Asp, and Cys than SBM from zone 2, and SBM from zone 1 had a greater (P < 0.05) SID of Lys than SBM from zone 2. There was also a tendency (P < 0.10) for SBM from zone 3 to have a greater SID of Ile, Leu, Phe, Val, Ala, and Tyr than SBM from zone 2. If the concentrations of SID CP and AA were calculated as grams per kilogram, SBM among the 3 zones were not different with the exception that there was a tendency (P = 0.07) for SBM from zone 2 to contain more SID Thr and SID Tyr than SBM from zone 3. In conclusion, only a few differences in concentrations and digestibility of CP and AA exist among sources of SBM from different zones in the United States. These observations indicate that the protein value is not different among SBM produced in the United States regardless of the location of the crushing plants.

Key words: amino acids, apparent ileal digestibility, pigs, soybean meal, standardized ileal digestibility

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INTRODUCTION

In the 2014-2015 crop year, the United States, Brazil, Argentina, China, Paraguay, and India were the major global producers of soybeans, accounting for 92% of total world production and producing a total of 293.3 million t of soybeans (ASA, 2015). The United States is the top soybean producer in the world, with a total production of 107 million t of soybeans in 2015. In the United States, soybean meal (**SBM**) is the most commonly used protein source

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in swine diets (Shelton et al., 2001) and accounts for 26% of total SBM consumption (Stein et al., 2008).

Soybeans grown in the northern United States have a decreased CP concentration compared with soybeans grown further south because of fewer growing days and fewer hours of sunlight (Dudley-Cash, 1999). A decrease in growing days and hours of sunlight allows the soybean plant less time for N fixation and, therefore, reduced protein synthesis. Because traditional CP assays measure N content, these samples tend to have decreased CP values compared with SBM from other parts of the United States. However, the protein in SBM produced in the northern United States may sometimes have greater concentrations of indispensable AA (Grieshop et al., 2003), but this is not always the case. Research has been conducted to compare the nutritional value of SBM produced in different parts of the world (Karr-Lilienthal et al., 2004; Wang et al., 2011; Ravindran et al., 2014); however, no research has been conducted to compare the digestibility of AA among SBM produced in different regions of the United States. Therefore, the objective of this experiment was to test the hypothesis that known differences in CP in soybeans grown in different areas of the United States will also result in differences in the quantities of digestible AA that are present in SBM produced from crushing plants located in different regions of the United States.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for the experiment. Twenty-two growing barrows (initial BW, 25.5 ± 1.73 kg) were fitted with a T-cannula near the distal ileum and allotted to a 22 × 8 Youden square design with 22 pigs and 8 periods. Pigs were placed in individual pens (1.2 by 1.5 m) that were equipped with a self-feeder, a nipple waterer, and a slatted tri-bar floor.

Twenty-two sources of SBM were procured from crushing facilities in different regions of the United States (Tables 1, 2, and 3; Appendix Table A1) in the spring and summer of 2012. The dietary treatments included 22 diets based on a mixture of cornstarch, sucrose, and each source of SBM, with SBM as the only source of AA in the diets (Table 4). Vitamins and minerals were included in all diets to meet or exceed the estimated nutrient requirements for growing pigs (NRC, 2012). All diets were fed in meal form. Feed consumption was recorded daily, and individual pig weights were recorded at the beginning of each period to determine feed allowance during the period. Pigs were limit fed to 3 times their estimated energy requirement for maintenance (i.e., 197 kcal of ME/kg$^{0.60}$; NRC, 2012), but

Table 1. Locations of the crushing plants for the 22 sources of soybean meal used in the experiment

State	Zone	No. of samples
Michigan	1	1
Minnesota	1	2
South Dakota	1	1
Georgia	2	1
Illinois	2	5
Indiana	2	3
Ohio	2	2
Iowa	3	3
Missouri	3	2
Nebraska	3	2
Total	3	22

throughout the experiment, pigs had ad libitum access to water. The experiment had a total of 8 periods, with each period lasting 7 d. The first 5 d of each period were considered the adaptation period to the diet, whereas ileal digesta were collected for 8 h on d 6 and 7 of each period. A 225-mL plastic bag was attached to the cannula barrel using a cable tie and digesta flowing into the bag were collected. Bags were removed every 30 min, or whenever full, and replaced with a new bag. Digesta were stored at −20°C immediately after collection.

At the conclusion of the experiment, ileal digesta were thawed and mixed within animal and diet, and a subsample was collected for analysis. Samples of the diets and of each source of SBM were also collected. Ileal digesta were lyophilized and finely ground before analysis. Samples of diets, digesta, and SBM were analyzed for CP (method 990.03; AOAC International, 2007) and DM (method 930.15; AOAC International, 2007). These samples were also analyzed for AA (method 982.30 E [a, b, c]; AOAC International, 2007) at the Experiment Station Chemical Laboratories (University of Missouri, Columbus, MO), and diets and digesta samples were analyzed for chromium (method 990.08; AOAC International, 2007) at the same laboratory. Samples of SBM were analyzed for trypsin inhibitor concentration (method Ba 12–75; AOCS, 2006).

Values for apparent ileal digestibility (**AID**) for CP and all AA in each diet were calculated according to Stein et al. (2007). By correcting AID values for basal endogenous losses, values for the standardized ileal digestibility (**SID**) of CP and AA were calculated (Stein et al., 2007). Values for the basal endogenous losses of CP and AA were calculated as the average from 22 experiments conducted at the University of Illinois between 2007 and 2014. The concentrations of digestible AA were calculated by multiplying the concentration of each AA in each source of SBM by the SID of that AA and multiplied by 10 to be expressed in grams per kilogram.

Table 2. Analyzed nutrient composition of soybean meal (as-fed basis)

Item	Zone[1] 1	2	3	Average[2]	Pooled SEM	*P*-value
CP[3], %	46.64[xy]	48.27[x]	46.50[y]	47.41	0.65	0.039
DM, %	88.60	88.85	88.30	88.63	0.35	0.444
NDF, %	7.78	7.54	8.21	7.84	0.81	0.794
ADF, %	4.81	5.00	4.89	4.90	0.29	0.890
Indispensable, AA %						
Arg	3.36	3.45	3.37	3.41	0.04	0.203
His	1.18	1.22	1.19	1.21	0.01	0.106
Ile	2.05	2.17	2.11	2.13	0.05	0.262
Leu	3.58	3.67	3.56	3.62	0.04	0.057
Lys	3.00	3.06	2.99	3.03	0.04	0.249
Met	0.64	0.64	0.62	0.63	0.01	0.375
Phe	2.26	2.33	2.26	2.30	0.03	0.098
Thr	1.75[ab]	1.80[a]	1.73[b]	1.77	0.02	0.010
Trp	0.70	0.71	0.69	0.70	0.01	0.322
Val	2.17	2.29	2.24	2.26	0.05	0.319
Dispensable, AA %						
Ala[3]	1.96[y]	2.01[x]	1.96[y]	1.98	0.02	0.048
Asp	5.09	5.20	5.07	5.14	0.05	0.108
Cys	0.62	0.63	0.61	0.62	0.01	0.318
Glu	7.71	7.79	7.68	7.74	0.10	0.635
Gly	1.89[b]	1.96[a]	1.91[ab]	1.93	0.02	0.018
Pro	2.25	2.28	2.23	2.26	0.02	0.164
Ser	2.15	2.16	2.08	2.13	0.03	0.188
Tyr	1.65[b]	1.71[a]	1.66[b]	1.68	0.02	0.016
Total AA	44.00	45.09	43.97	44.54	0.47	0.107
TIU[4], units/mg	3.73	3.03	3.26	3.29	0.44	0.553

[a,b]Means within a row lacking a common superscript letter are different (*P* < 0.05).

[1]Zone 1 = Michigan, Minnesota, and South Dakota; zone 2 = Georgia, Illinois, Indiana, and Ohio; zone 3 = Iowa, Missouri, and Nebraska. A total of 4, 11, and 7 sources of soybean meal were collected from zone 1, zone 2, and zone 3, respectively.

[2]Th average is for the 22 sources of soybean meal.

[3]Means were separated with Tukey adjustment and means within a row lacking a common superscript letter (x,y) tend to be different (*P* < 0.10).

[4]TIU = trypsin inhibitor units.

Table 3. Concentrations of AA in soybean meal expressed as a percent of CP

Item, %	Zone[1] 1	2	3	Average[2]	Pooled SEM	*P*-value
Indispensable AA						
Arg	7.21	7.14	7.25	7.19	0.06	0.344
His	2.54	2.54	2.56	2.54	0.03	0.635
Ile	4.38	4.49	4.54	4.48	0.10	0.588
Leu	7.66	7.61	7.65	7.64	0.07	0.841
Lys	6.42	6.35	6.43	6.39	0.06	0.453
Met	1.37	1.32	1.34	1.34	0.02	0.203
Phe	4.85	4.84	4.86	4.85	0.05	0.957
Thr	3.76	3.73	3.73	3.73	0.03	0.841
Trp	1.50	1.47	1.49	1.48	0.02	0.253
Val	4.65	4.76	4.83	4.76	0.11	0.588
Mean	44.33	44.25	44.68	44.40	0.45	0.723
Dispensable AA						
Ala	4.21	4.16	4.21	4.19	0.04	0.637
Asp	10.92	10.79	10.90	10.85	0.10	0.549
Cys	1.34	1.31	1.32	1.32	0.02	0.752
Glu	16.54	16.15	16.51	16.34	0.25	0.388
Gly	4.06	4.07	4.11	4.08	0.04	0.629
Pro	4.82	4.72	4.79	4.76	0.05	0.255
Ser	4.62	4.47	4.48	4.50	0.07	0.342
Tyr	3.54	3.54	3.57	3.55	0.03	0.828
Mean	50.03	49.22	49.89	49.58	0.50	0.414
Total AA	94.36	93.47	94.57	93.98	0.89	0.553

[1]Zone 1 = Michigan, Minnesota, and South Dakota; zone 2 = Georgia, Illinois, Indiana, and Ohio; zone 3 = Iowa, Missouri, and Nebraska. A total of 4, 11, and 7 sources of soybean meal were collected from zone 1, zone 2, and zone 3, respectively.

[2]The average is for the 22 sources of soybean meal.

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The normality of residuals and outliers were tested using the UNIVARIATE procedure of SAS. Means that deviated from the treatment mean by more than 3 times the interquartile range were considered outliers and removed. Data for the analyzed nutrient and AA composition, concentration of AA as percent of CP, and concentration of digestible AA in SBM were analyzed using a model that included zone as a fixed effect. Data for the AID and SID of AA were analyzed using a model that included the fixed effect of zone and period and the random effect of pig. Least squares means for each zone were calculated using the LSMeans procedure in SAS, and if significant differences were detected, means were separated using the PDIFF option with the Tukey adjustment and pooled SEM were calculated. Results were considered significant at a *P* value of ≤0.05 and a trend at a *P* value of ≤0.10.

RESULTS

The concentration of CP in SBM from zone 2 tended to be greater (*P* = 0.051) than that in SBM from zone 3 (Table 2). The concentration of DM, NDF, and ADF were not different among the 3 zones. The concentrations of most indispensable AA in SBM were not different among zones, but SBM from zone 2 had a greater (*P* < 0.05) concentration of Thr than SBM from zone 3; this value was not different from SBM from zone 1. Likewise, there was a tendency (*P* = 0.067) for an increase in the concentration of Leu in SBM from zone 2 compared with SBM from zone 3. Concentrations of most dispensable AA in SBM were not different among zones, but SBM from zone 2 had a greater (*P* < 0.05) concentration of Gly than SBM from zone 1; however, this value was not different from SBM from zone 3. Soybean meal from zone 2 had a greater (*P* < 0.05) concentration of Tyr compared with

Table 4. Ingredient composition (as-fed basis) of experimental diets containing soybean meal[1]

Ingredient, %	Soybean meal diet
Soybean meal	35.00
Soybean oil	2.00
Cornstarch	49.72
Sucrose	10.00
Ground limestone	0.75
Monocalcium phosphate	1.55
Chromic oxide	0.40
Sodium chloride	0.40
Vitamin-mineral premix[2]	0.18
Total	100.00

[1]A total of 22 cornstarch-soybean meal diets were formulated using 22 different sources of soybean meal. Diets were formulated to contain 16.5% CP.

[2]The vitamin-micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A as retinyl acetate, 6,682 IU; vitamin D_3 as cholecalciferol, 1,325 IU; vitamin E as DL-alpha tocopheryl acetate, 40 IU; vitamin K as menadione dimethylprimidinol bisulfite, 0.85 mg; thiamin as thiamine mononitrate, 0.14 mg; riboflavin, 3.95 mg; pyridoxine as pyridoxine hydrochloride, 0.14 mg; vitamin B_{12}, 0.02 mg; D-pantothenic acid as D-calcium pantothenate, 14.1 mg; niacin, 26.46 mg; folic acid, 0.95 mg; biotin, 0.26 mg; Cu as copper sulfate and copper chloride, 12 mg; Fe as ferrous sulfate, 75.6 mg; I as ethylenediamine dihydriodide, 0.76 mg; Mn as manganese sulfate, 36.12 mg; Se as sodium selenite and selenium yeast, 0.18 mg; and Zn as zinc sulfate, 75.06 mg.

SBM from zones 1 and 3. The concentration of Ala in SBM from zone 2 tended to be greater ($P = 0.063$) than in SBM from zone 3. However, if concentrations of AA were calculated as a percent of CP, there were no differences in the indispensable and dispensable AA among SBM from the 3 zones (Table 3).

The outlier test identified 2 pigs that were outliers—1 pig was fed SBM from zone 2 in period 7 and 1 pig was fed SBM from zone 3 in period 1. These pigs were disregarded in data analyses and summary.

The AID of CP and the AID of indispensable and dispensable AA were not different among SBM from the 3 zones (Table 5). Likewise, the SID of CP and the SID of Arg, Met, Thr, Trp, Glu, and Ser were not different among SBM from the 3 zones (Table 6). However, SBM from zone 3 had a greater ($P < 0.05$) SID of His, Asp, and Cys than SBM from zone 2, but these values were not different from SBM from zone 1. Likewise, there was a tendency ($P < 0.10$) for a greater SID of Ile, Leu, Phe, Val, Ala, Tyr, mean of indispensable AA, mean of dispensable AA, and total AA in SBM from zone 3 than in SBM from zone 2. The SID of Lys in SBM from zone 1 also tended to be greater ($P = 0.077$) than in SBM from zone 2. There was an effect of period only for the AID of Trp, Val, Ala, Cys, and Glu and for the SID of Thr, Trp, and Glu, but no interactions were observed.

If the concentrations of SID CP and AA were calculated as grams per kilogram, no differences among the 3 zones were observed (Table 7). There was, however, a tendency ($P = 0.075$) for an increase in the concentration of SID Thr from SBM from zone 2 compared with SBM from zone 3. Likewise, the concentration of SID Tyr in SBM from zone 2 tended to be greater ($P = 0.071$) than in SBM from zone 1.

Table 5. Apparent ileal digestibility (%) of CP and AA in soybean meal by growing pigs[1]

	Zones				Pooled	
Item, %	1	2	3	Average[2]	SEM	*P*-value
CP	85.12	84.06	84.62	84.46	0.61	0.360
Indispensable AA						
Arg	92.40	92.48	92.93	92.61	0.31	0.343
His	90.39	89.88	90.62	90.21	0.36	0.197
Ile	89.03	88.47	89.13	88.79	0.40	0.260
Leu	89.14	88.53	89.18	88.85	0.41	0.221
Lys	89.08	88.21	88.80	88.55	0.46	0.254
Met	90.17	90.17	90.39	90.25	0.41	0.871
Phe	89.56	88.89	89.47	89.21	0.40	0.260
Thr	83.13	82.67	83.22	82.93	0.64	0.648
Trp	91.29	90.48	90.82	90.75	0.44	0.307
Val	86.65	86.13	86.92	86.48	0.53	0.329
Mean	88.94	88.55	89.16	88.89	0.39	0.364
Dispensable AA						
Ala	83.97	83.43	84.43	83.86	0.66	0.321
Asp	87.95	87.08	88.01	87.54	0.49	0.147
Cys	81.63	80.26	81.83	81.03	0.77	0.114
Glu	89.81	89.41	89.78	89.62	0.59	0.729
Gly	75.51	74.14	75.64	74.95	1.28	0.422
Pro	68.13	63.78	63.28	64.62	3.31	0.191
Ser	88.02	87.74	88.07	87.90	0.43	0.747
Tyr	88.66	88.07	88.78	88.53	0.42	0.378
Mean	83.14	81.14	82.50	82.26	1.00	0.237
All AA	86.38	85.39	86.22	86.00	0.55	0.242

[1]Zone 1 = Michigan, Minnesota, and South Dakota; zone 2 = Georgia, Illinois, Indiana, and Ohio; zone 3 = Iowa, Missouri, and Nebraska. A total of 4, 11, and 7 sources of soybean meal were collected from zone 1, zone 2, and zone 3, respectively. Each source of soybean meal was fed to 8 pigs, but 1 pig from zone 2, period 7, and 1 pig from zone 3, period 1, were identified as outliers and removed. Therefore, data are least squared means of 32, 87, and 55 observations for zone, 1, zone 2, and zone 3, respectively.

[2]The average is for the 22 sources of soybean meal.

DISCUSSION

The 22 sources of SBM that were used in this experiment were divided among 3 zones. Soybean meal was sourced from crushing plants located within those zones, but the growing locations of the soybeans that were used by the crushing plants were unknown. It is possible that some crushing facilities sourced soybeans from a state located in a different zone, but it is expected that the majority of crushing plants sourced soybeans from the local area; therefore, the differences observed among the zones are believed to be reflective of both growing area

Table 6. Standardized ileal digestibility (%) of CP and AA in soybean meal by growing pigs[1,2]

Item, %	Zones 1	Zones 2	Zones 3	Average[3]	Pooled SEM	*P*-value
CP	95.66	94.28	94.94	94.78	0.58	0.120
Indispensable AA						
Arg	98.17	97.98	98.27	98.06	0.29	0.676
His	94.88[ab]	94.12[b]	94.99[a]	94.59	0.33	0.049
Ile	93.79	93.12	93.92	93.52	0.37	0.090
Leu	93.50	92.80	93.62	93.22	0.39	0.074
Lys	93.57[a]	92.39[b]	93.18[ab]	92.97	0.44	0.049
Met	95.07	94.76	95.38	94.96	0.37	0.348
Phe	93.79	93.06	93.85	93.48	0.36	0.078
Thr	92.58	91.56	92.50	92.10	0.60	0.144
Trp	95.97	95.25	95.88	95.56	0.40	0.172
Val	93.54	92.63	93.69	93.16	0.48	0.060
Mean	94.47	93.73	94.50	94.23	0.36	0.086
Dispensable AA						
Ala	93.21	92.16	93.43	92.80	0.61	0.076
Asp	92.38[ab]	91.23[b]	92.41[a]	91.83	0.47	0.023
Cys	91.16[ab]	89.44[b]	91.30[a]	90.40	0.70	0.021
Glu	93.36	92.88	93.46	93.27	0.55	0.514
Ser	96.01	95.40	96.01	94.95	0.40	0.221
Tyr	93.47	92.77	93.53	93.17	0.38	0.098
Mean	93.23	92.26	93.34	92.95	0.46	0.069
All AA	94.00	93.17	94.06	93.75	0.39	0.073

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

[1]Basal endogenous losses (g/kg DMI): CP = 19.55; Arg = 0.68; His = 0.21; Ile = 0.37; Leu = 0.60; Lys = 0.48; Met = 0.11; Phe = 0.38; Thr = 0.62; Trp = 0.13; Val = 0.55; Ala = 0.69; Asp = 0.85; Cys = 0.22; Glu = 1.11; Ser = 0.63; Tyr = 0.28.

[2]Zone 1 = Michigan, Minnesota, and South Dakota; zone 2 = Georgia, Illinois, Indiana, and Ohio; zone 3 = Iowa, Missouri, and Nebraska. A total of 4, 11, and 7 sources of soybean meal were collected from zone 1, zone 2, and zone 3, respectively. Each source of soybean meal was fed to 8 pigs, but 1 pig from zone 2, period 7, and 1 pig from zone 3, period 1, were identified as outliers and removed. Therefore, data are least squared means of 32, 87, and 55 observations for zone 1, zone 2, and zone 3, respectively.

[3]The average is for the 22 sources of soybean meal.

Table 7. Concentrations (g/kg) of standardized ileal digestible CP and AA in soybean meal[1]

Item, g/kg	Zones 1	Zones 2	Zones 3	Average[2]	Pooled SEM	*P*-value
CP	445.85	455.44	441.71	449.33	5.51	0.128
Indispensable AA						
Arg	32.97	33.73	33.09	33.39	0.39	0.269
His	11.22	11.51	11.32	11.40	0.14	0.292
Ile	19.17	20.17	19.81	19.87	0.47	0.364
Leu	33.42	34.09	33.32	33.72	0.37	0.194
Lys	28.00	28.32	27.84	28.11	0.37	0.553
Met	6.06	6.04	5.95	6.01	0.08	0.542
Phe	21.21	21.75	21.23	21.49	0.29	0.252
Thr	16.18	16.49	16.05	16.29	0.16	0.075
Trp	6.69	6.74	6.66	6.70	0.07	0.615
Val	20.30	21.26	21.04	21.02	0.51	0.445
Total	195.20	200.10	196.29	197.99	2.52	0.302
Dispensable AA						
Ala	18.26	18.52	18.28	18.40	0.17	0.394
Asp	47.00	47.49	46.82	47.19	0.50	0.513
Cys	5.67	5.66	5.61	5.64	0.09	0.868
Glu	71.98	72.41	71.70	72.10	0.97	0.828
Ser	20.63	20.58	19.99	20.40	0.33	0.286
Tyr	15.41	15.86	15.51	15.67	0.15	0.071
Total	178.94	180.52	177.90	179.39	1.73	0.458
All AA	374.14	380.61	374.19	377.39	4.02	0.341

[1]Zone 1 = Michigan, Minnesota, and South Dakota; zone 2 = Georgia, Illinois, Indiana, and Ohio; zone 3 = Iowa, Missouri, and Nebraska. A total of 4, 11, and 7 sources of soybean meal were collected from zone 1, zone 2, and zone 3, respectively. Each source of soybean meal was fed to 8 pigs, but 1 pig from zone 2, period 7, and 1 pig from zone 3, period 1, were identified as outliers and removed. Therefore, data are least squared means of 32, 87, and 55 observations for zone, 1, zone 2, and zone 3, respectively.

[2]The average is for the 22 sources of soybean meal.

and crushing plant locations. Thus, we used the same approach as any purchasers of commercial SBM would use by knowing the location of the crushing plant but not knowing the exact location where the beans were grown.

The concentrations of most AA in the SBM used in this experiment are in agreement with previous data (Cromwell et al., 1999; de Blas et al., 2010; Rostagno et al., 2011; NRC, 2012). The concentration of total AA for SBM from zone 2 was not different from values previously reported, but the concentration of total AA was less for SBM from zones 1 and 3 compared with previous values (Karr-Lilienthal et al., 2004). However, Grieshop et al. (2003) analyzed the chemical composition of SBM from 10 processing plants from different regions of the United States. Nine of the 10 processing plants had greater concentrations of AA in SBM compared with the values reported in this experiment, but 1 processing plant in the northern United States produced SBM with an AA concentration that was less than the values analyzed in this experiment. The lack of variability in the AA concentration in SBM collected among the 3 zones is in agreement with data indicating that the variability in AA concentration among sources is less than the variability among laboratories in analyzed values for AA (Cromwell et al., 1999).

The concentrations of most AA as a percent of CP are within the range of values reported by de Blas et al. (2010), Rostagno et al. (2011), and NRC (2012). The observation that SBM from all 3 zones had a Lys to CP ratio that was greater than 6.0% indicates that, regardless of zone, SBM was not overprocessed (González-Vega et al., 2011). However, the fact that trypsin inhibitor values for all zones were less than 4 indicates that the SBM used in this experiment were also not underprocessed (Chang et al., 1987; Monari, 1993; Lallès, 2000). Thus, it appears that crushing plants in the United States, regardless of where they are located, do an excellent job of processing soybeans to produce SBM with a high protein value providing adequate processing to inactivate trypsin inhibitors but without overheating the SBM.

The greater concentration of CP in SBM from zone 2 compared with the concentration of CP for SBM from zone 3 is mainly the result of greater concentrations of a few indispensable and dispensable AA. Soy hulls may be added to the SBM after processing, resulting in a reduction in CP (Stein et al., 2008); however, the reduction in CP observed in this experiment for SBM from zones 1 and 3 is most likely due to environmental conditions because values for ADF and NDF were not different among zones. Grieshop et al. (2003) observed reduced concentrations of CP for SBM from the northern United States compared with SBM from the midwestern and southern United States, and Hurburgh et al. (1990) reported that SBM from the northern and western United States tended to have concentrations of CP approximately 1% less than that of SBM produced in other regions. Thus, the observation in this experiment that CP in the SBM produced in zone 1 or zone 3 is less than that in SBM produced in zone 2 is in agreement with previous reports. The reduction in CP in SBM from the northern United States may be the result of fewer hours of sunlight and a shorter growing season, which results in less N fixation by the plant (Dudley-Cash, 1999).

The AID of AA obtained in this experiment were in agreement with reported values (de Blas et al., 2010; González-Vega et al., 2011; NRC, 2012), but values for the SID of many AA were greater than some previously reported values (de Blas et al., 2010; González-Vega et al., 2011; NRC, 2012). The reason for this difference is most likely that a greater endogenous loss of AA was used to calculate SID values in this experiment compared with some previous values.

Whereas SBM from the northern United States contains less CP than SBM from other regions in the United States, it may contain more indispensable AA, which would make it a better quality source of protein (Grieshop et al., 2003). However, we were unable to verify this hypothesis, and there were no differences in the AID of AA among SBM from the 3 zones. In contrast, the observed differences in the SID of a few AA among zones indicate that the source of SBM may affect digestibility of some AA, but differences were generally small. However, it appears that the location in which the crushing plant is located, and therefore also the location in which the soybeans were grown, may have a small impact on the SID of some AA, with greater values observed for soybeans grown in the northern or western growing areas compared with those of soybeans grown further to the south and east. However, when the SID of the AA were multiplied by the concentration of AA in each source of SBM to calculate the concentrations of SID AA per kilogram of SBM, which is the most important nutritional value, no differences among the 3 zones were observed, with the exception that there was a tendency for SBM from zone 2 to have a greater concentration of SID Thr than SBM from zone 3 and a greater concentration of SID Tyr than SBM from zone 1. Thus, because the concentrations of digestible AA were not different among zones, no rankings can be assigned to SBM from the 3 zones. These observations indicate that neither the quality of protein nor the quantity of digestible AA is different among zones. Pigs that are fed SBM from the different zones will, therefore, receive comparable concentrations of digestible AA regardless of where in the United States the SBM is produced.

Conclusions

The results of this experiment indicate that differences in concentrations of CP and some AA in SBM sources from different areas of the United States exist because a reduction in the concentration of CP and some AA was observed in SBM from zones 1 and 3 compared with SBM from zone 2. Minor differences in the SID of AA were observed, but no differences in the average SID of indispensable, dispensable, and total AA were detected. There were no differences among SBM from the 3 zones in terms of concentration (g/kg) of SID indispensable AA, SID dispensable AA, or SID total AA, although there was a tendency for SBM from zone 2 to have a greater concentration of SID Thr and SID Tyr than SBM from zones 3 and 1, respectively. Overall, although minor differences in the concentrations and digestibility of CP and AA among sources of SBM obtained from different areas of the United States were observed, concentrations of digestible AA were largely constant among sources of SBM regardless of where it was produced. It is, therefore, concluded that the protein value of SBM produced in the United States is not influenced by the geographical location of the soybean crushing plant.

APPENDIX Table A1. Analyzed concentrations (%) of DM, CP, ADF, NDF, and AA in the 22 sources of soybean meal (as-fed basis)

	Source of soybean meal																						
Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Mean
DM	89.7	89.9	87.5	87.2	88.7	89.1	87.6	87.5	88.2	89.3	88.1	89.4	89.2	90.3	89.0	89.5	88.2	88.4	88.6	88.9	88.0	87.6	88.6
CP	48.9	48.1	48.4	46.6	45.9	46.7	45.6	46.4	46.2	48.1	48.2	49.1	47.1	50.9	50.8	46.0	44.2	46.2	47.3	48.7	46.9	46.7	47.4
ADF	4.4	4.4	4.9	4.5	5.2	4.5	4.4	4.8	4.7	5.2	4.5	4.5	4.4	4.8	4.8	5.6	6.0	5.2	4.6	4.5	5.3	4.6	4.8
NDF	7.2	10.7	9.0	8.3	8.4	7.7	8.3	7.3	7.6	8.3	7.7	9.1	7.1	7.4	7.8	9.2	10.9	7.2	7.4	6.8	7.6	7.4	8.1
Indispensable AA																							
Arg	3.52	3.41	3.55	3.42	3.28	3.39	3.21	3.35	3.33	3.50	3.41	3.44	3.41	3.47	3.53	3.26	3.20	3.44	3.40	3.56	3.46	3.40	3.41
His	1.23	1.23	1.27	1.22	1.17	1.20	1.11	1.17	1.17	1.22	1.19	1.20	1.21	1.25	1.25	1.17	1.14	1.22	1.22	1.26	1.22	1.20	1.21
Ile	2.24	2.25	2.33	2.20	2.08	2.15	1.73	2.10	1.98	2.13	2.05	2.08	2.09	2.17	2.21	1.96	2.03	2.13	2.17	2.25	2.23	2.20	2.13
Leu	3.72	3.72	3.82	3.65	3.51	3.60	3.40	3.54	3.50	3.61	3.61	3.66	3.61	3.73	3.71	3.50	3.41	3.67	3.60	3.77	3.65	3.62	3.62
Lys	3.13	3.00	3.16	2.97	2.91	3.07	2.85	2.94	2.91	3.08	3.03	2.99	2.98	3.18	3.17	2.91	2.88	3.09	3.07	3.17	3.07	3.04	3.03
Met	0.63	0.66	0.65	0.64	0.62	0.65	0.66	0.59	0.62	0.63	0.61	0.63	0.63	0.66	0.64	0.62	0.59	0.64	0.65	0.65	0.63	0.63	0.63
Phe	2.38	2.38	2.43	2.34	2.25	2.28	2.09	2.26	2.22	2.29	2.28	2.31	2.32	2.36	2.37	2.20	2.15	2.33	2.29	2.40	2.34	2.31	2.30
Thr	1.76	1.80	1.81	1.73	1.70	1.75	1.74	1.72	1.76	1.79	1.80	1.81	1.78	1.88	1.83	1.79	1.65	1.80	1.73	1.84	1.73	1.74	1.77
Trp	0.71	0.73	0.70	0.68	0.69	0.70	0.68	0.71	0.70	0.69	0.73	0.70	0.70	0.72	0.71	0.68	0.67	0.71	0.71	0.74	0.69	0.68	0.70
Val	2.38	2.40	2.46	2.35	2.22	2.29	1.84	2.22	2.09	2.27	2.16	2.19	2.22	2.30	2.34	2.07	2.18	2.25	2.31	2.38	2.40	2.32	2.26
Dispensable AA																							
Ala	1.98	2.07	2.08	2.00	1.94	1.98	1.92	1.92	1.97	1.96	1.95	1.98	2.00	2.05	2.03	1.93	1.88	2.00	1.98	2.05	1.99	1.97	1.98
Asp	5.19	5.27	5.39	5.19	5.04	5.12	4.92	4.97	5.05	5.17	5.05	5.11	5.19	5.32	5.30	4.95	4.81	5.21	5.16	5.33	5.19	5.14	5.14
Cys	0.61	0.63	0.64	0.61	0.62	0.65	0.64	0.57	0.60	0.62	0.60	0.60	0.63	0.65	0.64	0.65	0.59	0.62	0.66	0.66	0.63	0.62	0.62
Glu	7.73	8.28	7.96	7.99	7.79	7.72	7.46	7.53	7.85	7.56	7.38	7.54	7.99	7.86	7.91	7.30	7.29	7.86	7.79	7.89	7.94	7.66	7.74
Gly	1.92	2.02	2.01	1.95	1.89	1.93	1.82	1.88	1.91	1.94	1.89	1.93	1.94	2.00	2.00	1.90	1.85	1.94	1.93	2.00	1.97	1.94	1.93
Pro	2.27	2.32	2.35	2.27	2.20	2.27	2.19	2.20	2.21	2.26	2.21	2.28	2.27	2.30	2.32	2.21	2.13	2.33	2.26	2.32	2.24	2.24	2.26
Ser	2.08	2.10	2.14	1.99	2.03	2.13	2.26	2.07	2.14	2.16	2.18	2.20	2.13	2.30	2.22	2.18	1.99	2.23	2.09	2.22	2.00	2.06	2.13
Tyr	1.67	1.73	1.78	1.68	1.64	1.69	1.59	1.66	1.64	1.69	1.67	1.70	1.69	1.74	1.72	1.67	1.58	1.70	1.66	1.75	1.69	1.66	1.68
All AA	45.29	46.20	46.70	45.05	43.82	44.69	42.28	43.56	43.81	44.75	43.96	44.50	45.04	46.11	46.11	43.17	42.22	45.34	44.82	46.40	45.21	44.58	44.71

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