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Concentrations of digestible, metabolizable, and net energy in soybean meal produced in different areas of the United States and fed to pigs[1]

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ABSTRACT: An experiment was conducted to determine concentrations of DE, ME, and NE in soybean meal (SBM) produced in different areas of the United States if fed to growing pigs. Twenty-two sources of SBM were procured from crushing facilities located throughout the soybean growing area of the United States. For analysis, crushing plant locations were separated into 4 zones: 1) MI, MN, and SD ($n = 4$); 2) GA, IN, and OH ($n = 6$); 3) IA, MO, and NE ($n = 7$), and 4) IL ($n = 5$). Dietary treatments included a corn-based diet and 22 diets based on a mixture of corn and each source of SBM. Twenty-three growing barrows (initial BW: 26.4 ± 1.8 kg) were allotted to a 23 × 8 Youden square design with 23 diets and 8 periods. Pigs were placed in individual metabolism crates that were equipped with a feeder, a cup waterer, slatted floors, and a urine tray. Feces and urine were collected for 5 d after a 7-d adaptation period. The GE was 4,165, 4,209, 4,162, and 4,198 kcal/kg (as-fed) for SBM from Zones 1, 2, 3, and 4, respectively, and the GE in SBM from Zone 2 tended ($P = 0.08$) to be greater than the GE in SBM from Zones 1 and 3. The apparent total tract digestibility (ATTD) of GE for SBM was not different among zones. The DE and ME were 4,343 and 4,098; 4,319 and 4,117; 4,135 and 3,926; and 4,248 and 4,039 kcal/kg DM for SBM from Zones 1, 2, 3, and 4, respectively. The DE and ME of SBM from Zones 1 and 2 were greater ($P < 0.05$) than the DE and ME of SBM from Zone 3, but the DE and ME of SBM from Zone 4 were not different from that of the other zones. Net energy was calculated for each source of SBM using a published prediction equation based on DE, ether extract, starch, CP, and ADF. The NE of SBM from Zones 1 and 2 (2,534 and 2,497 kcal/kg DM) was greater ($P < 0.05$) than the NE of SBM from Zone 3 (2391 kcal/kg DM), but the NE of SBM from Zone 4 (2448 kcal/kg DM) was not different from the NE of SBM from the other zones. Regardless of growing area, values for DE, ME, and NE of SBM determined in this experiment are greater than values published by NRC (2012) and indicate that DE, ME, and NE values for SBM may be underestimated by NRC (2012). In conclusion, regardless of growing area, GE, DE, ME, and NE were not different for SBM from the northern or eastern growing area or from Illinois, but DE, ME, and NE were less in SBM from the western growing area.

Key words: digestible energy, metabolizable energy, net energy, pigs, soybean meal

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INTRODUCTION

Soybean meal (**SBM**) is the most used AA source in swine diets in the United States (Shelton et al., 2001), and pigs consume approximately 26% of all SBM produced in the United States (Stein et al., 2008; ASA, 2014). In addition to providing AA to the diets, SBM also provides energy and values for DE, ME, and NE of SBM in published feed composition tables are approximately 4,000, 3,600, and 2,300 kcal/kg DM, respectively (Sauvant et al., 2004; de Blas et al., 2010; Rostagno et al., 2011; NRC, 2012). However, in 10 different experiments conducted at the University of Illinois in recent years, values for DE and ME in SBM have consistently been 200 to 400 kcal/kg DM greater than values from feed composition tables (Baker and Stein, 2009; Goebel and Stein, 2011; Sulabo et al., 2013; Rojas and Stein, 2013a, b; Yoon and Stein,

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2013; Rodriguez et al., 2013; Baker et al., 2014; Rojas et al., 2014; Kim et al., 2014). In most of the experiments conducted at the University of Illinois, SBM that was sourced from IL was used. It has been reported that the chemical composition of soybeans and SBM varies depending on where in the United States the beans were grown because CP concentration in soybeans grown in the northern United States is less than in beans grown farther south (Grieshop et al., 2003; Karr-Lilienthal et al., 2004). There is, however, limited data on how differences in the chemical composition of soybeans influence the concentrations of DE, ME, and NE in SBM. It is, therefore, possible that the greater DE and ME for SBM obtained at the University of Illinois may be explained by a better nutritional value of SBM produced in IL compared with SBM produced elsewhere, but this hypothesis has not been experimentally verified. Therefore, the objective of this experiment was to test the hypothesis that SBM produced in IL has different DE, ME, and NE than SBM produced in other states.

MATERIALS AND METHODS

Soybean Meals, Animals, and Experimental Design

Twenty-two sources of SBM were procured from 22 different crushing facilities in different regions of the United States (Tables 1 and 2). Approximately 500 kg of each source was collected from crushing plants in GA, IL, IN, IA, MI, MN, MO, NE, OH, and SD and then subsampled, labeled, and stored. For analysis, the crushing plant locations were separated into 4 zones: 1) MI, MN, and SD (4 samples); 2) GA, IN, and OH (6 samples); 3) IA, MO, and NE (7 samples), and 4) IL (5 samples). The average growing degree days are 1,553, 2,246, 2,097, and 1,931, respectively, for Zones 1, 2, 3, and 4. Twenty-three growing barrows (initial BW: 26.4 ± 1.8 kg) were allotted to a 23 × 8 Youden square design with 23 diets and 8 periods. Pigs were placed individually in metabolism crates that were equipped with a feeder, a nipple waterer, slatted floors, and a urine tray to allow for the total, but separate, collection of urine and fecal materials.

Diets, Feeding, and Sample Collection

Dietary treatments included a corn-based diet and 22 diets based on a mixture of corn and each source of SBM (Tables 3 and 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 and all corn-SBM diets were formulated to contain approximately 19% CP. Feed consumption was recorded daily, and pigs were weighed at the beginning of each period to determine feed allowance for the following period. A single batch of corn was used to mix all diets, and a sample of each diet was collected at the time of mixing. Pigs were limit-fed to 3 times their maintenance requirement for ME (197 kcal ME/kg$^{0.60}$; NRC, 2012), which was divided into 2 daily meals that were fed at 0700 and 1600 h. Pigs had access to water on an ad libitum basis throughout the experiment. The experiment had 8 periods, with each period lasting 14 d. The initial 7 d were considered the adaptation period to the diet, whereas urine and fecal materials were collected for 5 d according to standard procedures using the marker to marker approach with the first marker (chromic oxide) being fed in the morning meal on d 8, and the second marker (ferric oxide) being fed in the morning of d 13 (Adeola, 2001). Urine was collected in urine buckets over a preservative of 50 mL of 3*N* HCl from d 8 to d 13. Fecal samples and 20% of the collected urine were stored at -20°C immediately after collection.

Table 1. Location of the crushing plants where the 22 sources of soybean meal were produced

State	Zone	No. of samples
Michigan	1	1
Minnesota	1	2
South Dakota	1	1
Georgia	2	1
Indiana	2	3
Ohio	2	2
Iowa	3	3
Missouri	3	2
Nebraska	3	2
Illinois	4	5
Total	4	22

Chemical Analyses

At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a subsample was lyophilized (Kim et al., 2009). Fecal samples were thawed and mixed within pig and diet, and a subsample was lyophilized and finely ground before analysis. Duplicate samples of fecal, urine, diet, and ingredient samples were analyzed for GE using bomb calorimetry (Model 6300; Parr Instruments, Moline, IL). Duplicate samples of diets, corn, and each source of SBM were analyzed for DM (Method 930.15; AOAC, 2007), CP (Method 990.03; AOAC, 2007), ash (Method 942.05; AOAC, 2007), ADF (Method 973.18; AOAC, 2007), NDF (Holst, 1973), and lignin (Method 973.18 (A-D); AOAC, 2007). Single samples of corn and SBM were analyzed for AA (Method 982.30 E [a, b, c]; AOAC, 2007). Duplicate samples of corn and SBM were also analyzed for acid hydrolyzed ether extract (Method 2003.06; AOAC, 2007), ether extract

Table 2. Composition of corn and soybean meal (as-fed basis)

		Zone[1]						
Item, %	Corn	1	2	3	4	Average[2]	SEM	*P*-value[3]
GE, kcal/kg	3965	4165	4209	4162	4198	4184	19.99	0.08
DM	89.49	88.60	88.71	88.30	89.03	88.66	0.39	0.58
CP	9.52	46.64	48.44	46.50	48.06	47.41	0.65	0.09
AEE[4]	1.84	1.11[ab]	0.86[ab]	1.37[a]	0.69[b]	1.01	0.18	0.05
Ether extract	0.54	0.75	0.64	0.81	0.44	0.66	0.14	0.29
ADF	2.55	4.81	4.76	4.89	4.76	4.80	0.22	0.96
NDF	12.54	7.78	7.53	8.21	8.94	8.11	0.47	0.22
Lignin	0.66	0.60	0.59	0.58	0.63	0.60	0.03	0.68
Ash	1.36	7.01	6.59	7.10	6.96	6.91	0.25	0.47
Ca	0.01	0.34	0.36	0.47	0.42	0.40	0.07	0.49
P	0.23	0.63	0.65	0.67	0.64	0.65	0.01	0.28
TIU,[5] units/mg	–	3.73	3.45	3.26	2.52	3.24	0.46	0.36
Carbohydrates								
Starch	57.48	0.90	1.01	0.89	ND[6]	0.45	0.44	0.27
Maltose	0.00	0.62	0.60	0.60	0.63	0.61	0.02	0.73
Sucrose	0.57	7.73	7.36	7.07	6.62	7.20	0.29	0.12
Stachyose	ND	4.46	4.48	4.50	4.25	4.42	0.13	0.51
Raffinose	ND	0.90	0.83	1.02	1.03	0.94	0.07	0.14
Indispensable, AA %								
Arg	0.39	3.36	3.46	3.37	3.44	3.41	0.05	0.36
His	0.23	1.18	1.22	1.19	1.23	1.21	0.02	0.21
Ile	0.28	2.05	2.15	2.11	2.17	2.12	0.06	0.51
Leu	0.92	3.58	3.66	3.56	3.69	3.62	0.05	0.12
Lys	0.28	3.00	3.09	2.99	3.05	3.03	0.05	0.39
Met	0.16	0.64	0.63	0.62	0.64	0.63	0.01	0.51
Phe	0.37	2.26	2.33	2.26	2.34	2.30	0.04	0.22
Thr	0.27	1.75[ab]	1.80[a]	1.73[b]	1.81[a]	1.77	0.02	0.02
Trp	0.06	0.70	0.71	0.69	0.71	0.70	0.01	0.35
Val	0.39	2.17	2.28	2.24	2.30	2.25	0.06	0.58
Dispensable, AA %								
Ala	0.56	1.96	2.00	1.96	2.02	1.99	0.02	0.08
Asp	0.51	5.09	5.21	5.07	5.21	5.14	0.06	0.23
Cys	0.19	0.62	0.63	0.61	0.64	0.63	0.01	0.48
Glu	1.34	7.71	7.82	7.68	7.79	7.75	0.12	0.79
Gly	0.32	1.89[c]	1.96[ab]	1.91[bc]	1.97[a]	1.93	0.02	0.03
Pro	0.68	2.25	2.27	2.23	2.30	2.26	0.02	0.21
Ser	0.33	2.15	2.17	2.08	2.17	2.14	0.04	0.28
Tyr	0.24	1.65[b]	1.70[ab]	1.66[b]	1.73[a]	1.68	0.02	0.02
Total AA	7.60	44.18	45.29	44.13	45.39	44.72	0.51	0.20
Lys:CP ratio[7]	–	6.42	6.33	6.43	6.34	6.38	0.07	0.54

[a-c]Means within a row lacking a common superscript are different ($P < 0.05$).

[1]Zone 1 = MI, MN, and SD; Zone 2 = GA, IN, and OH; Zone 3 = IA, MO, and NE; and Zone 4 = IL.

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

[3]*P*-values for the comparison of soybean meal from the 4 zones.

[4]AEE = acid hydrolyzed ether extract.

[5]TIU = trypsin inhibitor units.

[6]ND = not detected.

[7]Lys:CP ratio was calculated by expressing the concentration of Lys in source of soybean meal as a percentage of the concentration of CP (Stein et al., 2009).

Table 3. Ingredient composition of experimental diets (as-fed basis)

	Diet	
Ingredient, %	Corn diet	Soybean meal diets[1]
Ground corn	96.78	71.25
Soybean meal	–	26.00
Ground limestone	1.02	1.00
Monocalcium phosphate	1.50	1.05
Sodium chloride	0.40	0.40
Vitamin-mineral premix[2]	0.30	0.30

[1]Twenty-two corn-SBM diets were formulated using 22 different sources of soybean meal. These diets were formulated to contain 19% CP.

[2]The vitamin-micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate

(Method 920.39; AOAC, 2007), Ca (Method 985.01 A, B, and C; AOAC, 2007), P (Method 985.01 A, B, and C; AOAC, 2007), and starch (Method 979.10; AOAC, 2007). Each source of SBM was analyzed for glucose, sucrose, maltose, fructose, stachyose, and raffinose as described by Cervantes-Pahm and Stein (2010), and each source of SBM was also analyzed for trypsin inhibitors (Method Ba 12–75; AOCS, 2006).

Calculations and Statistical Analysis

Following analysis, the apparent total tract digestibility (**ATTD**) of energy was calculated in all diets using the direct procedure (Adeola, 2001). The DE and ME for the corn diet were divided by 0.9678 to calculate DE and ME for corn. This value was then used to calculate the contribution of corn to the DE and ME of the corn-SBM diets, and the DE and ME in SBM were then calculated by difference (Adeola, 2001). The NE of SBM was calculated using the following equation: NE = (0.700 × DE) + (1.61 × EE) + (0.48 × starch) − (0.91 × CP) − (0.87 × ADF), which was adapted from Noblet et al. (1994). The ATTD of GE in all diets was calculated using the direct procedure and the ATTD of GE in all sources of SBM was calculated by the difference as outlined for DE and ME values (Adeola, 2001).

Data were analyzed using the pig as the experimental unit. Analysis of variance was used with the PROC MIXED function in SAS (SAS Inst. Inc., Cary, NC). Outliers were identified using the UNIVARIATE procedure. The zone in which the SBM was produced was the fixed effect, and pig and replicate were random effects. Means were calculated using an LS means statement and were separated using the PDIFF option with the Tukey adjustment. The nutrient composition, DE, ME, NE, and ATTD of GE for SBM were compared among zones. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

RESULTS

Chemical Characteristics of Ingredients

The SBM from Zone 2 tended ($P = 0.08$) to have greater GE than SBM from Zones 1 and 3, but DM was not different among zones. The concentration of CP in SBM from Zones 2 and 4 tended ($P = 0.09$) to be greater than the CP for SBM from Zones 1 and 3 and the concentration of AEE in SBM from Zone 3 was greater ($P = 0.05$) than in SBM from Zone 4. Concentrations of ADF, NDF, lignin, ash, Ca, and P were not different among SBM from Zones 1, 2, 3, and 4. Likewise, concentrations of trypsin inhibitors and starch were not different among zones and the same was the case for maltose, sucrose, stachyose, and raffinose. There was a greater concentration ($P < 0.05$) of Thr in SBM from Zones 2 and 4 compared with SBM from Zone 3, and SBM from Zone 4 also contained more ($P < 0.05$) Tyr than SBM

Table 4. Analyzed nutrient composition of experimental diets containing corn or corn and soybean meal from Zones 1, 2, 3, and 4 (as-fed basis)

		Soybean meal[1]					
Item, %	Corn diet	Zone 1	Zone 2	Zone 3	Zone 4	Average[2]	SEM
GE, kcal/kg	3841	3923	3923	3899	3922	3917	12.82
DM	89.90	89.17	89.23	88.93	89.27	89.15	0.17
CP	8.26	18.83	19.12	18.72	19.07	18.93	0.52
ADF	2.66	3.35	3.22	3.34	3.24	3.29	0.17
NDF	10.61	10.65	10.12	10.33	10.82	10.48	0.34
Lignin	0.43	0.48	0.50	0.49	0.49	0.49	0.03
Ash	4.40	5.80	5.29	5.54	5.70	5.58	0.23

[1]Zone 1 = MI, MN, and SD; Zone 2 = GA, IN, and OH; Zone 3 = IA, MO, and NE; and Zone 4 = IL.

[2]Average is for the 22 corn-soybean meal diets.

Table 5. Intake and output of energy, apparent total tract digestibility (ATTD) of energy, and concentration of DE and ME in experimental diets containing corn or corn and soybean meal obtained from Zones 1, 2, 3, and 4

		Zone[1]						
Item	Corn	1	2	3	4	Average[2]	SEM	*P*-value[3]
GE intake, kcal/d	8145	8346	8357	8311	8312	8332	794.91	0.86
GE fecal, kcal/d	1047	975	978	1024	992	992	91.95	0.32
GE urine, kcal/d	205	12	10	10	10	11	1.37	0.24
ATTD of GE, %	86.99	88.14	88.11	87.53	87.70	87.87	0.74	0.29
DE, kcal/kg DM	3712	3882[a]	3875[a]	3835[b]	3858[ab]	3863	32	0.04
ME, kcal/kg DM	3593	3732	3736	3694	3718	3720	36	0.11

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

[1]Zone 1 = MI, MN, and SD; Zone 2 = GA, IN, and OH; Zone 3 = IA, MO, and NE; and Zone 4 = IL.

[2]Average is for the 22 corn-soybean meal diets.

[3]*P*-values for the comparison of data for the 4 zones.

from Zones 1 and 3. Likewise, SBM from Zone 4 had a greater ($P < 0.05$) concentration of Gly than SBM from Zones 1 and 3, and SBM from Zone 2 also contained more ($P < 0.05$) Gly than SBM from Zone 1.

Energy Digestibility and Concentrations of DE, ME, and NE

Gross energy intake, fecal excretion of GE, urine excretion of GE, and ATTD of GE were not different among diets containing SBM from the 4 zones (Table 5). The DE for diets containing SBM from Zones 1 and 2 was greater ($P < 0.05$) than the DE for diets containing SBM from Zone 3, but no differences in the ME of diets containing SBM from the different zones were observed.

The ATTD of GE of SBM was not different among the 4 zones (Table 6). However, the DE of SBM from Zones 1 and 2 was greater ($P < 0.05$) than the DE of SBM from Zone 3, but the DE of SBM from Zone 4 was not different from that of SBM from the other zones. The ME of SBM from Zone 2 and the NE of SBM from Zone 3 were also greater ($P < 0.05$) than for SBM from Zone 3, but SBM from Zone 4 had ME and NE values that were not different from any of the other zones.

DISCUSSION

In the 2013–2014 crop year, 284 million t of soybeans were produced in the world, with approximately 90 million t being harvested in the United States. (USDA, 2015). Thus, U.S. production accounted for 31.7% of the global soybean production, making the United States the top soybean producer in the world (ASA, 2014). Approximately 51% of the soybeans harvested in the United States in 2013 were crushed domestically, which resulted in production of approximately 37 million t of SBM (USDA, 2015). Of the total SBM production in the United States, 73% (27 million t) was fed to livestock, and the majority of the remaining 27% was exported (ASA, 2014). The total usage of SBM in pig diets in the United States is estimated at 26% or almost 7 million t per year (Stein et al., 2008), and SBM is, therefore, a major contributor of energy in diets fed to pigs. Consequently, having a correct energy value for SBM is important.

The 22 sources of SBM that were used in this experiment were divided among 4 arbitrarily chosen zones, but whereas the SBM was sourced from crushing plants located in those zones, the growing locations of the soybeans were unknown. It is possible that some crushing facilities sourced soybeans from a state locat-

Table 6. Apparent total tract digestibility of energy (ATTD) and concentration of DE, ME, and NE in soybean meal obtained from each of the 4 zones

	Zone[1]						
	1	2	3	4	Average[2]	SEM	*P*-value[3]
ATTD of GE, %	91.76	91.68	89.36	90.82	90.91	4.08	0.29
DE, kcal/kg DM	4343[a]	4319[a]	4136[b]	4247[ab]	4261	125	< 0.01
ME, kcal/kg DM	4096[ab]	4117[a]	3926[b]	4038[ab]	4044	140	0.04
NE, kcal/kg DM[4]	2534[a]	2497[ab]	2391[b]	2448[ab]	2467	88	0.02

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

[1]Zone 1 = MI, MN, and SD; Zone 2 = GA, IN, and OH; Zone 3 = IA, MO, and NE; and Zone 4 = IL.

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

[3]*P*-values for the comparison of soybean meal obtained from the 4 zones.

[4]NE, kcal/kg DM calculated according to Noblet et al. (1994): NE = (0.70 × DE) + (1.61 × ether extract) + (0.48 × starch) – (0.91 × CP) – (0.87 × ADF).

Table 7. Comparison of DE, ME, NE, and ratios of NE:DE in soybean meal

Item	DE, kcal/kg DM	ME, kcal/kg DM	NE, kcal/kg DM[1]	NE, kcal/kg DM[2]	NE:DE, %
NRC (1998)	4140	3797	2322	2244	56
NRC (2012)	4022	3661	2319	2319	58
Sauvant et al. (2004)	3955	3607	2262	2204	57
de Blas et al. (2010)	3848	3706	2183	2299	57
Rostagno et al. (2011)	3970	3614	2210	2268	56
University of Illinois[3]	4413	3973	2592	–	59
This experiment	4261	4044	2467	–	58

[1]NE (kcal/DM) calculated according to Noblet et al. (1994): NE = (0.700 × DE) + (1.61 × ether extract) + (0.48 × starch) – (0.91 × CP) – (0.87 × ADF).

[2]NE (kcal/kg DM) as indicated in reference publication.

[3]Values are averages from experiments conducted at the University of Illinois at Urbana-Champaign from 2009 to 2014 (Baker and Stein, 2009; Goebel and Stein, 2011; Sulabo et al., 2013; Rojas and Stein, 2013a; Yoon and Stein, 2013; Rojas and Stein, 2013b; Rodriguez et al. 2013; Baker et al., 2014; Rojas et al., 2014; Kim et al., 2014).

ed in a different zone, but it is expected that most crushing plants sourced soybeans from the local area and it is, therefore, believed that differences observed among the zones are reflective of not only crushing plant locations, but also growing locations. The observation that the concentration of CP was less in SBM from Zones 1 and 3 compared with SBM from Zones 2 and 4 supports this hypothesis because a similar observation has been previously reported (Grieshop et al., 2003).

Variability in the nutrient composition among sources of SBM exists depending on differences in growing areas, soil type, variety of soybeans, or processing conditions (Grieshop et al., 2003; Karr-Lilienthal et al., 2004). The tendency for increased total AA and CP in SBM from Zones 2 and 4 compared with SBM from Zones 1 and 3 was mainly a result of increased concentrations of Thr, Leu, and some dispensable AA. This observation is in agreement with previous data (Dudley-Cash, 1999; Grieshop et al., 2003). The decrease in growing days and h of sunlight in the northern growing area compared with growing areas farther south allows less time for N fixation, which may result in less protein synthesis in soybeans grown in the northern United States. (Hurburgh et al., 1987, 1990). Differences in CP also were reported among sources of SBM from different regions of Brazil, with greater CP for SBM produced in Goiás and Mato Grosso do Sol compared with other Brazilian states (Goldflus et al., 2006).

Trypsin inhibitors may reduce protein digestibility in SBM by decreasing the activity of trypsin, chymotrypsin, and other proteases, but the concentrations of trypsin inhibitors is reduced by heat treatment (Yen et al., 1974). The trypsin inhibitor units in SBM used in this experiment was less than 4 regardless of growing area, which indicates that all sources of the SBM were adequately processed (Chang et al., 1987; Monari, 1993; Lallès, 2000). The Lys:CP ratio for all sources of SBM was greater than 6.0, which indicates that these sources of SBM were not heat damaged or overprocessed (González-Vega et al., 2011).

Stachyose and raffinose are poorly digested oligosaccharides that decrease energy utilization and increase flatulence, but the concentrations of oligosaccharides was not influenced by the zones in which the SBM was produced, which is in agreement with previous data (Rackis et al., 1970; Leske et al., 1995). Unlike other antinutritional factors, oligosaccharides cannot be removed using heat treatment.

To reduce the concentration of CP in SBM, soy hulls are sometimes added to the defatted meal (Stein et al., 2008). Concentrations of ADF and NDF were not different in SBM from the 4 zones, which indicates that the SBM contained similar amounts of soy hulls regardless of the zone in which it was produced. A similar observation was reported by Grieshop et al. (2003). The concentrations of ADF and NDF that were determined in this experiment are also in agreement with values from NRC (2012).

Corn was used in the basal diet because pigs tolerate corn well and readily consume diets containing corn. The concentration of CP and NDF in corn was greater than indicated in NRC (2012), but the concentration of AEE in the corn used in this experiment was only 1.84%, whereas the NRC (2012) value for corn is 3.68%. The differences in AEE, CP, and NDF concentrations were likely the reason for the lower values for DE and ME of corn that were determined in this experiment, compared with NRC (2012), but these values are within the range of published values (Widmer et al., 2007; Stein et al., 2009; Baker and Stein, 2009; Liu et al., 2012).

Studies have been conducted to determine the ATTD of GE and concentrations of DE and ME in SBM compared with other protein sources (Goebel and Stein, 2011; Rojas and Stein, 2013b; Sulabo et al., 2013; Yoon and Stein, 2013; Baker et al., 2014; however, these studies did not use SBM from different growing regions in the same experiment. To our knowledge, DE, ME, and NE concentrations have never been reported for sources of SBM obtained from different areas of the

United States, but the observation that the DE, ME, and NE in SBM produced in Zone 3 are less than for SBM produced in Zones 1 or 2 indicates that production region may impact the energy value of SBM.

The average concentrations of GE in the 22 sources of SBM are in agreement with data reported by Sauvant et al. (2004), Rostagno et al. (2011), and NRC (2012). In contrast, the DE and ME of SBM obtained in this experiment (Table 7) are greater than several book values (NRC, 1998; Sauvant et al., 2004; de Blas et al., 2010; Rostagno et al., 2011; NRC, 2012), but are in agreement with results obtained in recent experiments conducted at the University of Illinois (Baker and Stein, 2009; Goebel and Stein, 2011; Sulabo et al., 2013; Rojas and Stein, 2013a,b; Yoon and Stein, 2013; Rodriguez et al., 2013; Baker et al., 2014; Rojas et al., 2014; Kim et al., 2014). The observation that the DE and ME in SBM from IL was not different from the DE and ME in SBM produced in other areas of the United States indicates that it is not only the SBM from IL that has a greater DE and ME than values published in feed composition tables. It therefore appears that regardless of the production zone, SBM produced in the United States contains 200 to 400 kcal/kg DM more DE and ME than values published in many feed composition tables.

The NE value calculated for SBM in this experiment was 150 to 250 kcal/kg DM greater than published book values, but this was expected because the NE in this experiment was calculated using an equation that included DE and the chemical composition of SBM. This particular equation was used because this is the equation that was used to calculate NE values in NRC (2012). The observation that the NE:DE ratio for SBM obtained in this experiment and in previous experiments conducted at the University of Illinois is close to the value that can be calculated from feed composition tables further indicates that the main reason for the increased NE observed in this experiment is a greater ATTD of GE in SBM, and therefore, an increased value for DE. The reduced concentrations of ADF and NDF that was observed in the SBM used in the present experiment as compared with values published by Sauvant et al. (2004) and Rostagno et al. (2011) may be one of the reasons for the greater DE in SBM observed in this experiment. However, regardless of the way the energy value of SBM is expressed, results of the current experiment indicate that SBM produced in the United States contains more DE, ME, and NE than what is currently included in published feed ingredient composition tables. It is possible that one reason for this observation is that values in feed ingredient composition tables typically are averages of values obtained from around the world. For broiler chickens, it has been demonstrated that soybean meal produced in the United States has greater ME values than soybean meal produced in Argentina (Ravindran et al., 2014). It is, therefore, possible that the reason for the lower NE values in feed composition tables than those obtained for SBM from the United States is that SBM produced outside the United States has reduced DE, ME, and NE compared with SBM produced in the United States. However, to our knowledge, no studies in which the DE, ME, or NE of SBM produced in different countries and fed to pigs were compared have been conducted.

Conclusion

Values for GE, DE, ME, and NE were not different for SBM from Zones 1, 2, and 4, but DE was less for SBM from Zone 3 compared with SBM from Zones 1 and 2, and ME and NE in SBM from Zone 3 was less than SBM produced in Zone 2 and Zone 1, respectively. However, Values for DE, ME, and NE in SBM produced in IL is not greater than in SBM produced in other areas of the United States. However, all sources of SBM used in this experiment have DE, ME, and NE values that are greater than values published in several feed composition tables, but values obtained in this experiment are in agreement with values obtained in a number of recent experiments conducted at the University of Illinois. It is, therefore, possible that current feed composition tables underestimate DE, ME, and NE values for SBM produced in the United States, which may have implications for formulation of practical diets fed to pigs.

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