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Chemical composition and amino acid digestibility of soybean meal produced in the United States, China, Argentina, Brazil, or India[1]

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ABSTRACT: An experiment was conducted to compare nutritional composition of soybean meal (SBM) produced in China, Argentina, Brazil, the U.S., or India and the apparent ileal digestibility (AID) and the standardized ileal digestibility (SID) of CP and AA in these SBM when fed to growing pigs. Five sources of SBM from China, Argentina, Brazil, and the U.S., and 4 sources from India were collected for a total of 24 sources of SBM. All samples were analyzed for energy, DM, and nutrients, and each source was included in a cornstarch based diet in which SBM was the only AA contributing ingredient. An N-free diet was also formulated. Twenty-five barrows (initial BW: 30.53 ± 1.73 kg) were equipped with a T-cannula in the distal ileum and randomly allotted to a 25 × 8 Youden square design with 25 diets and 8 periods. Results indicate that the concentration of CP was greater ($P < 0.05$) in SBM from Brazil and India (49.3 and 49.5%, respectively) than in SBM from China, Argentina, or the U.S. (45.1, 46.7, and 47.3%, respectively, as-fed basis). The concentration of most indispensable AA followed the same pattern as CP with the exception that SBM from the U.S. contained more ($P < 0.05$) indispensable AA than SBM from China or Argentina. However, SBM from India contained more ($P < 0.05$) trypsin inhibitors than SBM from the other countries. A greater ($P < 0.05$) AID and SID of CP and most AA was observed in SBM from the U.S. compared with SBM from Brazil, Argentina, and India, but there were no differences between SBM from the U.S. and SBM from China. However, because of the lower concentration of AA in SBM from China, the concentration of standardized ileal digestible AA in SBM from China was less ($P < 0.05$) than in SBM from the U.S. Soybean meal from the U.S. or Brazil had less ($P < 0.05$) variability in SID values than SBM from Argentina, China, or India. In conclusion, the SID of CP and AA is dependent on the country where the SBM is produced. This difference and the variability within each country should be evaluated when formulating diets for pigs.

Key words: amino acid digestibility, pigs, soybean meal, soybean origin

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INTRODUCTION

Soybean meal (**SBM**) is the premiere source of AA for growing, finishing, and reproducing pigs (Stein et al., 2008), but as is the case with all feed ingredients, variability in the nutritional value has been demonstrated among different sources of SBM (Ravindran et al., 2014; García-Rebollar et al., 2016). Differences in growing area, soil type, and climatic conditions and also differences among varieties of soybeans, or in processing conditions, may contribute to variability in the nutritional value of SBM (Grieshop and Fahey, 2001; Karr-Lilienthal et al., 2004a; García-Rebollar et al., 2016). Soybean meal produced in the U.S. sometimes contains more CP and less trypsin inhibitor activity and fewer oligosaccharides than SBM produced in Argentina or Brazil, which results in greater apparent ileal digestibility (**AID**) of N and GE and increased apparent ME in broilers (de Coca-Sinova et al., 2008; Ravindran et al., 2014). These variations cause some concern in industries where SBM of different origins are used to formulate diets for pigs because variability in concentrations of digestible nutrients and energy results in difficulties in accurately predicting the amount of energy and nutrients in a given diet.

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Soybean meal produced in the U.S. has a greater concentration of total AA compared with SBM from other countries (Karr-Lilienthal et al., 2004a), and the standardized ileal digestibility (**SID)** of CP and most AA in SBM from the U.S. is greater than in SBM from Argentina when fed to pigs or broilers (Frikha et al., 2012; Goerke et al., 2012). Whereas research has been conducted to determine the SID of AA in SBM produced in different areas of the U.S. (Sotak-Peper et al., 2017), limited research has been conducted to determine the concentration of digestible AA in sources of SBM from other countries. Therefore, the objective of this research was to test the hypothesis that the AID and SID of AA in SBM is independent of the country in which the SBM was produced.

MATERIALS AND METHODS

The experiment was conducted following a protocol that was reviewed and approval by the Institutional Animal Care and Use Committee at the University of Illinois. Pigs used in the experiment were the offspring of Line 359 boars mated to C-46 females (Pig Improvement Company, Hendersonville, TN).

Soybean Meals, Animals, and Experimental Design

A total of 24 samples of SBM were used. Five samples were from the U.S. and selected from crushing plants located in SD, IA, IL, IN, and OH. Nineteen additional samples were selected from crushing plants located in Brazil, Argentina, India, or China. Five samples of SBM were collected from each country, except from India where only 4 samples were collected. The SBM from China and India was collected from feed mills or crushing plants located in those countries, but SBM from Argentina and Brazil were collected from feed mills in South Korea, the Philippines, Spain, and Denmark. Approximately 300 kg of each source of SBM were shipped to the University of Illinois at Urbana-Champaign and labeled, subsampled, and stored.

Twenty-five growing barrows (initial BW: 30.53 ± 1.73 kg) were equipped with a T-cannula in the distal ileum and allotted to a 25 × 8 Youden square design with 25 diets and 8 periods. Therefore, there were 8 replications per diet. Pigs were housed in individual pens (1.2 × 1.5 m) that were equipped with a feeder, a nipple waterer, and a tri-bar floor in an environmentally controlled room.

Twenty-five cornstarch-based diets were prepared, with 24 diets based on a mixture of corn-starch and each source of SBM and 1 diet being an N-free diet that was used to estimate the basal ileal endogenous losses of CP and AA (Table 1). Vitamins and minerals were included in all diets to meet or exceed estimated nutrient requirements (NRC, 2012). All diets contained 0.4% chromic oxide as an indigestible marker.

Table 1. Composition of experimental diets (as-fed basis)

	Diets	
Ingredient, %	Soybean meal diets[1]	N-free diet
Soybean meal	40.00	–
Soybean oil	3.00	4.00
Solka floc	–	4.00
Monocalcium phosphate	1.30	2.40
Limestone	1.30	0.50
Sucrose	20.00	20.00
Chromic oxide	0.40	0.40
Cornstarch	33.30	67.50
Magnesium oxide	–	0.10
Potassium carbonate	–	0.40
Sodium chloride	0.40	0.40
Vitamin micromineral premix[2]	0.30	0.30
Total	100	100

[1]Twenty four diets were formulated using 24 different sources of soybean meal.

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2208 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 B12, 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.

Feeding and Sample Collection

All pigs were provided feed in an amount equivalent to 3 times their estimated ME requirement for maintenance (i.e., 197 kcal ME/kg$^{0.60}$; NRC, 2012). Feed was provided every day at 0700 h, and pigs had access to water at all times. Each period lasted 7 d with the initial 5 d being the adaptation period to the diet, whereas ileal digesta were collected for 8 h on d 6 and 7. A 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 of digesta, and replaced with a new bag. Digesta were stored at –20°C to prevent bacterial degradation of the AA in the digesta. All diets were fed in meal form. Pigs were weighed at the beginning of each period to determine feed allowance during the following week and the BW of each pig was also recorded at the conclusion of the experiment.

Chemical Analyses

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a subsample was collected for chemical analysis. A sample of each diet was collected at the time of diet mixing. Digesta samples were lyophilized and finely ground prior to chemical analysis. Samples of diets, ingredients, and ileal digesta were analyzed for DM (Method 930.15; AOAC, 2007), CP (Method 990.03; AOAC, 2007), and AA [Method 982.30 E (a, b, c); AOAC, 2007], and diets and digesta were also analyzed for chromium (Method 990.08; AOAC, 2007). All samples of SBM were also analyzed for GE using bomb calorimetry (Model 6300; Parr Instruments, Moline, IL), ADF and NDF using Ankom Technology method 12 and 13, respectively (Ankom 2000 Fiber Analyzer, Ankom Technology, Macedon, NY), and ADL using Ankom Technology method 9 (Ankom Daisy^{II} Incubator, Ankom Technology, Macedon, NY). Acid hydrolyzed ether extract (**AEE**; Method 2003.06; AOAC, 2007), and ash (Method 942.05; AOAC, 2007) were also determined in all sources of SBM. These samples were also analyzed for Ca, P, Mg, K, Na, S, Cu, Fe, Mn, Mo, and Zn using inductively coupled plasma–optical emission spectroscopy (Method 985.01 A, B, C, and D; AOAC, 2007) after wet ash preparation (Method 975.03; AOAC, 2007). Each source of SBM was also analyzed for sucrose, raffinose, and stachyose (Method HPLC 977.2; AOAC, 2007), phytic acid (Ellis et al., 1977), and trypsin inhibitor units (**TIU**; Method Ba 12–75; AOCS, 2006).

Calculations and Statistical Analysis

Values for AID, endogenous losses, and SID of CP and AA were calculated in all diets containing SBM and endogenous losses were calculated from pigs fed the N-free diet (Stein et al., 2007). The concentration of standardized ileal digestible CP and AA was calculated by multiplying the concentration of CP and AA in each source by the SID value for that source (Cervantes-Pahm et al., 2014). Phytate-bound P was calculated as 28.2% of the analyzed phytate concentration (Tran and Sauvant, 2004) and non-phytate bound P was calculated by subtracting phytate-bound P from total P. The Lys:CP ratio in each source of SBM was calculated by expressing the concentration of Lys as a percentage of the concentration of CP (Stein et al., 2009).

For nutrient composition, data were analyzed using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with the experimental unit being the source of SBM and the model included country as the fixed effect. Data for AID and SID of CP and AA, as well as for the concentration of standardized ileal digestible CP and AA were also analyzed using the PROC MIXED procedure of SAS with the experimental unit being the pig. Therefore, an ANOVA was conducted with country as the fixed effect, and pig and period as random effects. A second ANOVA was conducted to determine if differences in SID of CP and AA within each country exist, and in this analysis, source was the fixed effect, and pig and period were random effects. Least squares means were calculated using the LS Means option and means were separated using the PDIFF option in SAS. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

RESULTS

Chemical Characteristics of Soybean Meals

Soybean meal from China contained more ($P < 0.05$) DM than SBM from Brazil, the U.S., and India, and SBM from Brazil had a greater ($P < 0.05$) GE than SBM from the other countries, but the concentration of ash, AEE, and ADL was not different among countries (Table 2). Soybean meal from the U.S. and Argentina contained less ($P < 0.05$) ADF than SBM from China and India, and the concentration of NDF in SBM from India tended ($P < 0.10$) to be greater than in SBM from Argentina and the U.S. Argentinian SBM contained more ($P < 0.05$) sucrose than Brazilian and Indian SBM, but less ($P < 0.05$) than Chinese SBM. There was a greater ($P < 0.05$) concentration of raffinose in SBM from India compared with SBM from the other countries and SBM from the U.S. contained more ($P < 0.05$) stachyose than SBM from the other countries. Soybean meal from India also had a greater ($P < 0.05$) concentration of TIU than SBM from China, Argentina, and the U.S.

Brazilian and Indian SBM had a greater ($P < 0.05$) concentration of CP than SBM from Argentina, China, and the U.S., and SBM from the U.S. and Argentina contained more ($P < 0.05$) CP than SBM from China. For most indispensable AA, there was a greater ($P < 0.05$) concentration in SBM from Brazil, the U.S., and India compared with SBM from China and Argentina, and SBM from the U.S. had a greater ($P < 0.05$) concentration of all indispensable AA than SBM from China. Likewise, for most dispensable AA, the concentration in SBM from China was less ($P < 0.05$) than in SBM from the other countries. However, no differences were observed in the concentration of Cys among countries. The Lys:CP ratio in SBM from the U.S. was greater ($P < 0.05$) than in SBM from China, Argentina, and Brazil.

There was a greater ($P < 0.05$) concentration of Ca and Mg in SBM from Brazil, the U.S., and India

Table 2. Concentration of energy, DM, and nutrients in soybean meal from China, Argentina, Brazil, the U.S., and India[1,2]

	Country						
Item	China	Argentina	Brazil	U.S.	India	SEM	*P*-value
GE, kcal/kg	4126^{b}	4149^{b}	4214^{a}	4123^{b}	4140^{b}	19.3	0.018
DM, %	89.5^{a}	89.1^{ab}	88.4^{b}	88.5^{b}	88.3^{b}	0.30	0.038
CP, %	45.1^{c}	46.7^{b}	49.3^{a}	47.3^{b}	49.5^{a}	0.54	< 0.001
Ash, %	6.34	6.89	6.66	6.71	6.88	0.27	0.616
AEE,[3]%	1.25	1.67	1.70	1.66	1.19	0.28	0.540
ADF, %	5.60^{a}	3.69^{b}	4.95^{ab}	3.69^{b}	6.41^{a}	0.52	0.007
NDF, %	9.46	7.18	8.46	7.25	9.96	0.81	0.089
ADL, %	0.19	0.49	0.32	0.20	0.26	0.11	0.318
Sucrose, %	8.91^{a}	7.56^{b}	5.52^{c}	8.59^{ab}	4.69^{c}	0.42	< 0.001
Raffinose, %	1.18^{c}	1.47^{bc}	1.54^{b}	1.45^{bc}	1.98^{a}	0.12	0.003
Stachyose, %	5.55^{b}	5.23^{bc}	4.47^{c}	6.47^{a}	5.09^{bc}	0.28	0.001
TIU/mg[4]	2.92^{bc}	1.99^{c}	3.46^{ab}	2.69^{bc}	4.10^{a}	0.35	0.006
Indispensable AA, %							
Arg	3.27^{b}	3.27^{b}	3.41^{ab}	3.42^{a}	3.53^{a}	0.05	0.088
His	1.25^{c}	1.33^{b}	1.36^{b}	1.37^{ab}	1.41^{a}	0.02	< 0.001
Ile	2.07^{d}	2.16^{cd}	2.34^{a}	2.24^{bc}	2.31^{ab}	0.03	< 0.001
Leu	3.33^{c}	3.57^{b}	3.76^{a}	3.66^{ab}	3.75^{a}	0.05	< 0.001
Lys	2.85^{c}	2.96^{bc}	3.05^{ab}	3.07^{ab}	3.12^{a}	0.04	0.001
Met	0.61^{b}	0.63^{ab}	0.64^{a}	0.65^{a}	0.66^{a}	0.01	0.049
Phe	2.20^{c}	2.38^{b}	2.52^{a}	2.42^{ab}	2.49^{ab}	0.04	< 0.001
Thr	1.62^{b}	1.77^{a}	1.80^{a}	1.78^{a}	1.82^{a}	0.03	< 0.001
Trp	0.65^{b}	0.69^{a}	0.69^{a}	0.70^{a}	0.67^{ab}	0.01	0.016
Val	2.14^{c}	2.25^{b}	2.40^{a}	2.33^{ab}	2.39^{a}	0.03	< 0.001
Total	20.0^{c}	21.0^{b}	22.0^{a}	21.6^{ab}	22.21^{a}	0.29	< 0.001
Dispensable AA, %							
Ala	1.84^{c}	2.00^{b}	2. 09^{a}	2.03^{ab}	2.06^{ab}	0.03	< 0.001
Asp	4.82^{c}	5.03^{b}	5.33^{a}	5.22^{ab}	5.42^{a}	0.07	< 0.001
Cys	0.63	0.60	0.62	0.63	0.63	0.01	0.138
Glu	7.79^{c}	8.08^{bc}	8.58^{a}	8.43^{ab}	8.70^{a}	0.13	< 0.001
Gly	1.81^{d}	1.93^{c}	2.04^{ab}	1.98^{bc}	2.06^{a}	0.02	< 0.001
Pro	2.07^{c}	2.20^{b}	2.32^{a}	2.28^{ab}	2.39^{a}	0.04	< 0.001
Ser	1.93^{b}	2.09^{a}	2.17^{a}	2.08^{a}	2.18^{a}	0.04	0.003
Tyr	1.49^{b}	1.68^{a}	1.73^{a}	1.68^{a}	1.71^{a}	0.04	0.002
Total	22.4^{c}	23.6^{b}	24.9^{a}	24.3^{ab}	25.1^{a}	0.34	< 0.001
All AA	42.8^{c}	45.1^{b}	47.5^{a}	46.5^{ab}	47.8^{a}	0.62	< 0.001
Lys:CP ratio[5]	6.22^{b}	6.25^{b}	6.15^{b}	6.45^{a}	6.29^{ab}	0.04	0.014

$^{a–d}$Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Five sources of soybean meal from China, Argentina, Brazil, and the U.S. and 4 sources of soybean meal from India were used.

[2]All values were adjusted to 88% DM.

[3]AEE = acid hydrolyzed ether extract.

[4]TIU = trypsin inhibitor units.

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

compared with Chinese SBM (Table 3). A greater ($P < 0.05$) concentration of K was observed in the Argentinian SBM compared with SBM from the other countries, but the Chinese and Indian SBM had the least ($P < 0.05$) concentrations of K. Soybean meal

Table 3. Concentration of phytate and minerals in soybean meal from China, Argentina, Brazil, the U.S., and India[1,2]

	Country						
Item	China	Argentina	Brazil	U.S.	India	SEM	*P*-value
Macro minerals							
Ca, %	0.18^{c}	0.25^{bc}	0.30^{ab}	0.37^{a}	0.41^{a}	0.04	0.002
P, %	0.68^{a}	0.67^{ab}	0.62^{bc}	0.66^{ab}	0.59^{c}	0.10	0.039
Total phytate, %	1.88^{a}	1.77^{a}	1.57^{b}	1.64^{b}	1.51^{b}	0.04	< 0.001
P in phytate,[3]%	0.53^{a}	0.50^{a}	0.44^{b}	0.46^{b}	0.43^{b}	0.01	< 0.001
Non-phytate P,[4]%	0.15	0.17	0.18	0.20	0.17	0.01	0.097
Mg, %	0.24^{c}	0.29^{bc}	0.31^{ab}	0.30^{ab}	0.33^{a}	0.02	0.006
K, %	2.05^{c}	2.26^{a}	2.15^{b}	2.15^{b}	2.02^{c}	0.02	< 0.001
Na, mg/kg	5.52	27.9	14.8	109.3	13.8	34.8	0.218
S, %	0.42	0.41	0.42	0.44	0.41	0.01	0.106
Micro minerals							
Cu, mg/kg	7.5	11.2	9.0	18.7	15.5	3.03	0.087
Fe, mg/kg	109.4^{b}	92.9^{b}	150.9^{b}	157.4^{b}	598.0^{a}	38.9	< 0.001
Mn, mg/kg	31.0^{c}	40.7^{bc}	29.7^{c}	45.9^{ab}	56.3^{a}	4.96	0.009
Mo, mg/kg	2.58^{bc}	8.12^{a}	3.93^{bc}	4.92^{b}	1.85^{c}	0.86	< 0.001
Zn, mg/kg	43.7	41.4	50.5	77.0	57.1	10.2	0.127

$^{a–c}$Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Five sources of soybean meal from China, Argentina, Brazil, and the U.S. and 4 sources of soybean meal from India were used.

[2]All values were adjusted to 88% DM.

[3]P in phytate was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[4]Non-phytate P was calculated as the difference between total P and phytate-bound P.

from China and Argentina contained more ($P < 0.05$) phytate and P bound to phytate than SBM from Brazil, the U.S., and India. However, the concentration of non-phytate P was not different among countries. Likewise, concentrations of S, Cu, and Zn were not different among countries. There was greater ($P < 0.05$) concentration of Mn and Fe in SBM from India compared with SBM from China, Argentina, and Brazil, and Argentinian SBM contained more ($P < 0.05$) Mo than SBM from the other countries.

Amino Acid Digestibility

The AID of CP and most AA in SBM from the U.S. was greater ($P < 0.05$) than for SBM from Argentina, Brazil, and India, with SBM from China having AID for most AA that was not different from the SBM from Brazil and India (Table 4). However, for most AA, the AID in SBM from Argentina was less than in SBM from China ($P < 0.05$). The SID of CP and AA followed the same pattern as the AID values (Table 5).

Table 4. Apparent ileal digestibility of CP and AA in soybean meal from China, Argentina, Brazil, the U.S., and India[1]

Item	Country					SEM	*P*-value
	China	Argentina	Brazil	U.S.	India		
CP, %	82.5[bc]	82.8[bc]	82.9[b]	85.6[a]	81.2[c]	0.85	< 0.001
Indispensable AA, %							
Arg	92.8[a]	91.1[b]	91.7[b]	92.7[a]	92.1[ab]	0.49	0.001
His	90.1[ab]	88.7[c]	88.9[c]	90.4[a]	89.2[bc]	0.62	0.004
Ile	88.4[ab]	87.6[b]	88.0[b]	89.5[a]	87.9[b]	0.60	0.013
Leu	88.5[ab]	87.1[c]	87.8[bc]	89.2[a]	87.6[bc]	0.62	0.004
Lys	88.7[ab]	86.5[c]	87.3[bc]	89.6[a]	87.7[bc]	0.80	0.003
Met	89.7[a]	88.5[b]	98.0[ab]	90.0[a]	88.2[b]	0.55	0.009
Phe	88.8[ab]	87.2[c]	88.4[ab]	89.4[a]	88.1[bc]	0.60	0.003
Thr	82.4[ab]	80.6[c]	81.3[bc]	83.2[a]	81.1[bc]	0.84	0.020
Trp	89.4[ab]	88.8[b]	88.6[bc]	90.3[a]	87.6[c]	0.56	< 0.001
Val	84.7[ab]	83.5[b]	83.8[b]	85.8[a]	83.7[b]	0.75	0.012
Mean	88.5[ab]	87.0[c]	87.6[bc]	89.1[a]	87.6[bc]	0.61	0.003
Dispensable AA, %							
Ala	83.8[ab]	82.1[c]	82.7[bc]	84.8[a]	82.4[bc]	0.92	0.011
Asp	86.2[ab]	84.4[c]	85.0[bc]	87.1[a]	86.2[ab]	0.82	0.004
Cys	79.1[a]	73.6[b]	74.1[b]	78.6[a]	76.4[ab]	1.49	< 0.001
Glu	87.7[ab]	85.4[c]	86.5[bc]	88.5[a]	88.1[ab]	0.92	0.001
Gly	73.7[ab]	71.7[b]	71.8[b]	76.4[a]	73.9[ab]	1.68	0.036
Ser	87.5[ab]	85.8[c]	86.4[bc]	87.9[a]	86.4[bc]	0.63	0.014
Tyr	87.3[ab]	86.3[b]	87.3[ab]	88.3[a]	86.9[b]	0.56	0.026
Mean	85.4[ab]	83.4[c]	84.2[bc]	86.4[a]	85.3[ab]	0.34	0.004
All AA	86.9[ab]	85.2[c]	85.9[bc]	87.8[a]	86.4[abc]	22.7	0.004

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

[1]Five sources of soybean meal from China, Argentina, Brazil, and the U.S. and 4 sources of soybean meal from India were used.

Table 5. Standardized ileal digestibility of CP and AA in soybean meal from China, Argentina, Brazil, the U.S., and India[1,2]

Item	Country					SEM	*P*-value
	China	Argentina	Brazil	U.S.	India		
CP, %	91.9[b]	91.1[bc]	90.9[bc]	93.8[a]	89.9[c]	0.84	< 0.001
Indispensable AA, %							
Arg	96.8[ab]	95.6[c]	95.6[c]	96.9[a]	95.9[bc]	0.49	0.003
His	93.5[a]	92.1[b]	92.1[b]	93.8[a]	92.3[b]	0.61	0.002
Ile	92.6[ab]	91.6[b]	91.7[b]	93.4[a]	91.5[b]	0.59	0.004
Leu	92.3[ab]	91.0[c]	91.2[bc]	92.9[a]	90.9[c]	0.61	0.001
Lys	92.1[ab]	90.0[c]	90.6[bc]	92.9[a]	90.8[bc]	0.79	0.002
Met	94.4[ab]	93.5[bc]	93.6[abc]	94.7[a]	92.7[c]	0.54	0.007
Phe	92.5[ab]	90.9[c]	91.6[bc]	93.0[a]	91.4[bc]	0.59	0.001
Thr	90.2[a]	88.5[b]	88.4[b]	90.8[a]	88.2[b]	0.82	0.004
Trp	93.7[ab]	93.0[b]	92.6[bc]	94.3[a]	91.7[c]	0.56	< 0.001
Val	90.6[ab]	89.3[bc]	89.0[c]	91.4[a]	88.9[c]	0.74	0.002
Mean	92.9[a]	91.4[b]	91.6[b]	93.4[a]	91.5[b]	0.62	0.001
Dispensable AA, %							
Ala	91.7[a]	89.9[b]	89.9[b]	92.5[a]	89.5[b]	0.91	0.002
Asp	90.2[a]	88.6[b]	88.7[b]	91.1[a]	89.8[ab]	0.81	0.003
Cys	86.3[a]	81.5[b]	81.6[b]	86.2[a]	83.6[ab]	1.47	< 0.001
Glu	90.9[ab]	88.7[c]	89.4[bc]	91.7[a]	90.9[ab]	0.91	0.002
Gly	93.8[ab]	92.3[bc]	90.5[c]	96.1[a]	91.9[bc]	1.66	0.012
Ser	93.8[ab]	92.5[b]	91.0[c]	94.2[a]	92.3[bc]	0.64	< 0.001
Tyr	92.0[ab]	91.0[bc]	90.5[c]	92.8[a]	91.1[bc]	0.57	0.003
Mean	97.0[ab]	95.3[c]	94.8[c]	97.7[a]	95.6[bc]	0.34	0.002
All AA	94.9[ab]	93.4[c]	93.3[c]	95.6[a]	93.6[bc]	22.7	0.002

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

[1]Five sources of soybean meal from China, Argentina, Brazil, and the U.S. and 4 sources of soybean meal from India were used.

[2]Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of DMI) as CP, 17.38; Arg, 0.59; His, 0.19; Ile, 0.37; Leu, 0.57; Lys, 0.43; Met, 0.12; Phe, 0.36; Thr, 0.57; Trp, 0.12; Val, 0.54; Ala, 0.66; Asp, 0.87; Cys, 0.20; Glu, 1.12; Gly, 1.64; Ser, 0.57; and Tyr, 0.29.

A greater ($P < 0.05$) SID of CP and most AA was observed in SBM from the U.S. compared with SBM from Brazil, Argentina, and India, but there were no differences between SBM from the U.S. and SBM from China. For most AA, the SID was not different among Argentina, Brazil, and India.

The concentration of standardized ileal digestible CP and AA in SBM from the U.S. was greater ($P < 0.05$) than in SBM from China, but no differences were observed between Indian SBM and U.S. SBM (Table 6). Soybean meal from Argentina had reduced ($P < 0.05$) concentration of standardized ileal digestible CP compared with SBM from the U.S., but greater ($P < 0.05$) concentration than in SBM from China, and there were no differences among SBM from the U.S., Brazil, and India. For most AA, the concentration of standardized ileal digestible AA in Brazilian SBM was greater ($P < 0.05$) than in Argentinian SBM, but less ($P < 0.05$) than in SBM from India.

Amino Acid Digestibility in SBM within Countries

No differences in the SID of CP and most AA were detected among the 5 sources of SBM from China with the exception that the SID of Val in source 05 was greater ($P = 0.05$) than in the other 4 sources (Table 7). There was also a tendency ($P \leq 0.10$) for an increase in the SID of Ile, Leu, Lys, Phe, Cys, and Tyr in source 05 compared with the other sources of Chinese SBM.

In the case of Argentinian SBM (Table 8), the SID of CP and some AA was less ($P < 0.05$) in source 01 than in sources 02, 03, and 04 and the SID of His, Ile, Phe, Val, and Ser tended ($P < 0.10$) to also be less in source 01 than in sources 02, 03, and 04. The SID of CP, indispensable AA and most dispensable AA was not different among the 5 sources of SBM from Brazil (Table 9). No differences in the SID of CP and AA were detected among the 5 sources of SBM from the

Table 6. Concentration of standardized ileal digestible CP and AA in soybean meal from China, Argentina, Brazil, the U.S., and India[1]

	Country						
Item	China	Argentina	Brazil	U.S.	India	SEM	*P*-value
CP, g/kg	414.2^{c}	426.2^{b}	447.8^{a}	443.1^{a}	445.2^{a}	4.28	< 0.001
Indispensable AA, g/kg							
Arg	31.7^{c}	31.3^{c}	32.6^{b}	33.04^{b}	33.9^{a}	0.21	< 0.001
His	11.7^{d}	12.3^{c}	12.5^{b}	12.9^{a}	13.0^{a}	0.09	< 0.001
Ile	19.1^{d}	19.8^{c}	21.4^{a}	20.9^{b}	21.1^{ab}	0.16	< 0.001
Leu	30.7^{c}	32.6^{b}	34.3^{a}	34.0^{a}	34.1^{a}	0.26	< 0.001
Lys	26.3^{c}	26.7^{c}	27.6^{b}	28.4^{a}	28.4^{a}	0.25	< 0.001
Met	5.7^{c}	5.9^{c}	6.0^{b}	6.2^{a}	6.1^{ab}	0.04	< 0.001
Phe	20.4^{d}	21.7^{c}	23.1^{a}	22.5^{b}	22.7^{ab}	0.18	< 0.001
Thr	14.6^{c}	15.7^{b}	15.9^{ab}	16.2^{a}	16.0^{ab}	0.16	< 0.001
Trp	6.0^{c}	6.4^{b}	6.4^{b}	6.6^{a}	6.2^{c}	0.05	< 0.001
Val	19.3^{c}	20.1^{b}	21.4^{a}	21.2^{a}	21.2^{a}	0.19	< 0.001
Mean	185.5^{c}	192.4^{b}	201.1^{a}	201.8^{a}	202.7^{a}	1.49	< 0.001
Dispensable AA, g/kg							
Ala	16.9^{c}	17.9^{b}	18.7^{a}	18.7^{a}	18.5^{a}	0.20	< 0.001
Asp	43.5^{d}	44.7^{c}	47.2^{b}	47.4^{b}	48.6^{a}	0.45	< 0.001
Cys	5.4^{a}	4.9^{c}	5.1^{bc}	5.4^{a}	5.3^{ab}	0.09	< 0.001
Glu	70.8^{c}	71.9^{c}	76.7^{b}	77.2^{ab}	79.0^{a}	0.82	< 0.001
Gly	17.0^{c}	17.8^{b}	18.4^{ab}	19.0^{a}	18.9^{a}	0.33	< 0.001
Ser	18.1^{c}	19.4^{b}	19.8^{b}	19.6^{b}	20.1^{a}	0.18	< 0.001
Tyr	13.7^{b}	15.4^{a}	15.6^{a}	15.5^{a}	15.5^{a}	0.15	< 0.001
Mean	217.0^{c}	225.5^{b}	235.5^{a}	237.3^{a}	240.4^{a}	2.23	< 0.001
All AA	406.2^{c}	422.2^{b}	442.7^{a}	443.6^{a}	447.4^{a}	3.70	< 0.001

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

[1]Five sources of soybean meal from China, Argentina, Brazil, and the U.S. and 4 sources of soybean meal from India were used.

Table 7. Standardized ileal digestibility of CP and AA in soybean meal from China

	Soybean meal						
Item	Source 01	Source 02	Source 03	Source 04	Source 05	SEM	*P*-value
CP, %	91.6	91.3	90.2	90.7	94.1	1.33	0.203
Indispensable AA, %							
Arg	97.2	96.3	96.2	95.8	97.7	0.83	0.259
His	93.2	93.2	92.9	91.9	94.7	0.83	0.137
Ile	92.2	92.1	91.8	91.3	94.5	0.86	0.065
Leu	92.0	91.9	91.8	90.9	94.0	0.83	0.084
Lys	91.7	92.3	91.5	89.9	94.0	1.03	0.064
Met	93.7	93.7	93.6	93.6	95.7	0.84	0.200
Phe	92.4	91.9	91.9	91.2	94.1	0.82	0.096
Thr	89.9	89.9	89.1	88.7	92.1	1.14	0.212
Trp	93.3	93.3	93.6	92.8	94.6	0.81	0.608
Val	90.0	90.2	89.8	88.8	92.9	0.99	0.051
Mean	92.6	92.5	92.2	91.4	94.5	0.87	0.104
Dispensable AA, %							
Ala	91.0	91.2	91.1	89.4	94.3	1.26	0.109
Asp	90.7	90.2	89.3	88.2	91.7	1.21	0.161
Cys	86.6	87.0	84.5	83.9	89.1	1.58	0.104
Glu	91.7	90.7	90.5	88.2	92.6	1.33	0.109
Gly	93.5	93.5	92.9	90.2	97.4	2.80	0.504
Ser	93.5	93.5	92.7	93.2	95.2	0.84	0.210
Tyr	91.6	91.9	91.4	90.4	93.8	0.82	0.072
Mean	97.0	96.2	96.5	95.0	98.9	1.25	0.221
All AA	94.9	94.4	94.4	93.2	96.8	1.05	0.167

U.S., with the exception that the SID of Lys was greater ($P < 0.05$) in source 04 than in sources 01, 02, and 05 (Table 10). A tendency ($P \leq 0.10$) for the SID of Ile, Thr, Asp, Cys, and Glu in source 04 to be greater than in sources 02 and 05 was also observed. For Indian SBM, source 01 had a reduced ($P < 0.05$) SID of CP compared with sources 03 and 04, and for most AA, the SID in source 01 was less ($P < 0.05$) than in the other 3 sources (Table 11).

DISCUSSION

Chemical Characteristics of Ingredients

The proximate analysis of the SBM from China, Argentina, Brazil, the U.S., and India was within the range of values reported in the literature (Karr-Lilienthal et al., 2004a; de Coca-Sinova et al., 2008; Ravindran et al., 2014; Sotak-Peper et al., 2015; García-Rebollar et al., 2016). The carbohydrates and macromineral composition was in agreement with values reported by Goerke et al. (2012) and Sotak-Peper et al. (2016), respectively. Likewise, the composition of CP and AA of the SBM used in this experiment was within expected values (Thakur and Hurburgh, 2007; de Coca-Sinova et al., 2008; Goerke et al., 2012; Sotak-Peper et al., 2015).

The observation that SBM from Brazil contains more CP than SBM from other countries, is consistent with values reported by Thakur and Hurburgh (2007), Goerke et al. (2012), and Ravindran et al. (2014). The observation that the concentration of most indispensable AA in SBM from Brazil, India, and the U.S. was greater than in SBM from China and Argentina is in agreement with data indicating that the concentration of AA in SBM from Argentina is less than in SBM from Brazil or the U.S. (Karr-Lilienthal et al., 2004a; Goerke et al., 2012; Ravindran et al., 2014; García-Rebollar et al., 2016). These differences in the nutritional value of SBM may be a result of differences among varieties, geographical location, and processing of the beans (Wang and Johnson, 2001; Goldflus et al., 2006; Mateos et al., 2011; Stein et al., 2016). Rotundo and Westgate (2009) reported that water

Table 8. Standardized ileal digestibility of CP and AA in soybean meal from Argentina

	Soybean meal						
Item	Source 01	Source 02	Source 03	Source 04	Source 05	SEM	*P*-value
CP, %	88.4[b]	93.5[a]	92.5[a]	92.9[a]	90.6[ab]	1.28	0.044
Indispensable AA, %							
Arg	93.8[b]	97.2[a]	96.8[a]	97.0[a]	94.6[ab]	0.86	0.025
His	89.8	93.8	93.4	93.5	92.0	1.08	0.067
Ile	89.6	93.2	92.8	92.7	91.4	0.94	0.064
Leu	88.7[b]	92.8[a]	92.1[a]	92.1[a]	90.9[ab]	0.99	0.054
Lys	86.7[b]	92.7[a]	92.2[a]	92.5[a]	88.3[b]	1.31	0.005
Met	90.9[b]	94.8[a]	94.7[a]	94.0[a]	94.7[a]	0.93	0.021
Phe	88.7	92.5	92.1	92.1	90.9	0.99	0.063
Thr	85.5[b]	90.4[a]	90.0[a]	90.2[a]	88.2[ab]	1.27	0.028
Trp	91.4[c]	95.1[a]	93.9[ab]	93.7[abc]	92.3[bc]	0.87	0.048
Val	86.8	91.0	90.8	90.4	89.1	1.20	0.073
Mean	89.0[b]	93.3[a]	92.8[a]	92.8[a]	91.0[ab]	0.99	0.016
Dispensable AA, %							
Ala	87.1[b]	92.3[a]	91.8[a]	91.0[a]	90.0[ab]	1.48	0.026
Asp	86.0[c]	91.1[a]	90.2[ab]	90.7[ab]	87.5[bc]	1.21	0.015
Cys	75.0[c]	86.3[a]	84.5[ab]	86.5[a]	78.7[bc]	2.46	0.006
Glu	85.4[c]	92.2[a]	90.5[ab]	92.5[a]	86.5[bc]	1.59	0.009
Gly	87.5[c]	97.4[a]	96.1[ab]	97.3[a]	88.7[bc]	2.82	0.047
Ser	90.1	93.8	93.8	93.7	91.7	1.06	0.058
Tyr	88.9	92.4	91.9	92.3	90.7	1.02	0.110
Mean	92.1[c]	98.8[a]	96.7[ab]	97.8[ab]	93.8[bc]	1.44	0.016
All AA	90.6[c]	96.0[a]	94.8[ab]	95.3[ab]	92.4[bc]	1.21	0.020

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

Table 9. Standardized ileal digestibility of CP and AA in soybean meal from Brazil

	Soybean meal						
Item	Source 01	Source 02	Source 03	Source 04	Source 05	SEM	*P*-value
CP, %	92.1	91.0	93.2	88.6	89.2	1.89	0.222
Indispensable AA, %							
Arg	96.1	96.0	96.7	95.0	93.9	0.88	0.097
His	92.7	92.1	93.4	91.6	90.0	1.10	0.117
Ile	92.8	91.3	92.7	90.1	91.2	1.17	0.216
Leu	92.3	90.8	92.4	98.8	90.3	1.19	0.224
Lys	92.4	91.1	92.3	87.1	89.5	2.15	0.219
Met	94.9	93.6	94.7	92.1	92.4	1.10	0.121
Phe	92.7	91.1	92.5	90.5	90.8	1.14	0.290
Thr	90.1	87.8	90.4	85.9	87.1	1.79	0.166
Trp	92.8	92.7	92.3	92.1	91.6	1.07	0.755
Val	90.4	88.3	90.5	86.9	88.6	1.50	0.194
Mean	92.7	91.4	92.9	90.0	90.6	1.29	0.197
Dispensable AA, %							
Ala	91.6	89.8	91.8	86.8	88.8	2.04	0.199
Asp	91.0[a]	88.4[ab]	90.4[ab]	87.0[b]	86.7[ab]	1.79	0.054
Cys	86.3	80.0	85.2	76.6	80.2	3.99	0.258
Glu	92.0	88.1	90.8	88.8	87.6	1.83	0.075
Gly	90.7	90.8	94.3	86.5	89.4	4.11	0.629
Ser	93.8[a]	86.2[c]	93.5[ab]	90.7[b]	90.7[ab]	1.39	< 0.001
Tyr	92.1[a]	86.9[b]	92.4[a]	90.2[a]	90.7[a]	1.13	0.003
Mean	96.9	94.5	96.2	93.3	92.9	1.92	0.180
All AA	94.9	93.0	94.8	91.7	91.8	1.59	0.166

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

stress and growth at high temperature reduce the protein concentration in soybeans. The greater concentration of ADF observed in SBM from India and China and the tendency for SBM from India to have greater concentration of NDF than SBM from Argentina and the U.S. is in agreement with reported data (Thakur and Hurburgh, 2007; Ravindran et al., 2014), which indicates that there may be a greater concentration of hulls added back to the SBM from India and China compared with SBM from other countries.

The concentration of carbohydrates in soybeans is influenced by variety and growing conditions, including soil type, fertilization application, and the climate in which the soybeans were grown (Hollung et al., 2005). It has also been suggested that more sucrose will be synthesized in soybeans grown in colder locations than in warmer climates (Kumar et al., 2010; Frikha et al., 2012), which may explain the greater concentrations of sucrose in SBM from Argentina and the U.S. than in SBM from Brazil. A similar observation was reported by Mateos et al. (2011), Frikha et al. (2012), and Ravindran et al. (2014), whereas Goerke et al. (2012) reported that SBM from Brazil contains more sucrose than SBM from Argentina. The observation that the concentration of stachyose is less in SBM from Brazil than in SBM from the U.S. is also in agreement with reported values (Frikha et al., 2012; Goerke et al., 2012; García-Rebollar et al., 2016). However, the concentration of raffinose was not different among SBM from Argentina, Brazil, and the U.S.

The values for the concentration of TIU in SBM from different countries reported in previous studies (Goerke et al., 2012; Ravindran et al., 2014; García-Rebollar et al., 2016), and including this experiment are not consistent. This is likely a consequence of the fact that residual TIU in SBM is a result of the degree of heat processing applied to SBM during the toasting process in the crushing plants (Stein et al., 2016) and it is, therefore, likely that the concentration of TIU in SBM is a result of processing applied to each source of SBM and not a result of origin of the meal. The fact that the TIU in SBM from China, Argentina, Brazil, and the U.S. was less than 4 indicates that the SBM from these countries was not under-processed (Sotak-Peper et al., 2015). In contrast, the observation that the average TIU value for the SBM from India was slightly above 4 may indicate that some of the Indian sources of SBM was not properly processed. The Lys:CP ratio for SBM used in this experiment was greater than 6 regardless of the country of origin, which

Table 10. Standardized ileal digestibility of CP and AA in soybean meal from the U.S.

Item	Soybean meal Source 01	Source 02	Source 03	Source 04	Source 05	SEM	*P*-value
CP, %	92.5	91.5	95.1	95.7	92.7	1.39	0.193
Indispensable AA, %							
Arg	96.2	95.8	97.0	98.4	96.1	0.92	0.289
His	93.2	92.4	94.2	95.7	92.5	1.08	0.216
Ile	92.7	92.1	93.8	95.6	91.8	1.06	0.101
Leu	92.1	91.3	93.1	95.2	91.4	1.12	0.137
Lys	91.5[b]	91.0[b]	93.2[ab]	95.4[a]	91.5[b]	1.07	0.037
Met	93.6	93.6	95.2	96.5	93.0	1.12	0.193
Phe	92.4	91.5	93.2	95.2	91.5	1.08	0.110
Thr	89.8	88.6	92.0	93.7	89.1	1.43	0.087
Trp	93.5	93.6	94.8	96.2	92.9	1.10	0.274
Val	90.8	89.5	91.9	93.9	89.5	1.35	0.143
Mean	92.5	91.9	93.8	95.7	92.0	1.06	0.085
Dispensable AA, %							
Ala	91.5	90.3	93.7	94.7	90.5	1.48	0.159
Asp	90.6	89.3	91.4	93.8	89.1	1.29	0.092
Cys	84.4	82.8	87.6	89.5	84.6	1.95	0.104
Glu	90.8	89.0	92.5	94.4	89.6	1.43	0.068
Gly	93.5	92.4	98.9	100.1	93.2	2.94	0.243
Ser	93.7	92.8	95.0	96.2	93.1	1.10	0.181
Tyr	92.2	91.4	93.0	95.1	91.6	1.09	0.132
Mean	96.5	95.5	98.5	100.3	96.3	1.40	0.131
All AA	94.5	93.7	96.2	98.0	94.2	1.22	0.106

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

Table 11. Standardized ileal digestibility of CP and AA in soybean meal from India

Item	Soybean meal Source 01	Source 02	Source 03	Source 04	SEM	*P*-value
CP, %	87.3[b]	88.6[ab]	90.5[a]	91.3[a]	1.60	0.050
Indispensable AA, %						
Arg	93.7[b]	96.5[a]	95.5[a]	96.2[a]	0.77	0.008
His	89.5[b]	93.1[a]	92.4[a]	92.6[a]	1.01	0.006
Ile	88.3[b]	91.6[a]	92.3[a]	92.0[a]	1.14	0.008
Leu	87.8[b]	91.3[a]	91.4[a]	91.3[a]	1.17	0.012
Lys	87.9	91.5	91.2	90.8	1.33	0.056
Met	90.1	92.4	93.6	92.2	1.30	0.072
Phe	88.2[b]	91.9[a]	91.9[a]	91.6[a]	1.14	0.011
Thr	84.2[b]	88.4[a]	89.2[a]	88.8[a]	1.53	0.018
Trp	88.7[b]	92.0[a]	92.5[a]	92.7[a]	0.97	0.009
Val	85.4[b]	88.8[ab]	89.4[a]	89.8[a]	1.41	0.020
Mean	88.5[b]	91.9[a]	91.9[a]	91.9[a]	1.11	0.012
Dispensable AA, %						
Ala	86.3	89.1	90.4	90.1	1.67	0.057
Asp	87.5[b]	89.5[ab]	90.4[a]	90.4[a]	1.06	0.041
Cys	80.3	83.2	83.5	84.1	2.40	0.444
Glu	88.3	90.9	91.2	90.8	1.29	0.114
Gly	89.5	89.6	92.6	94.3	2.53	0.116
Ser	89.5[b]	92.1[ab]	93.1[a]	93.4[a]	1.08	0.010
Tyr	88.0[b]	91.0[a]	93.3[a]	91.0[a]	0.90	0.001
Mean	93.2[b]	95.3[ab]	96.0[a]	96.3[a]	1.19	0.045
All AA	90.9[b]	93.6[b]	94.0[a]	94.1[a]	1.13	0.021

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

indicates that the SBM was not heat damaged or overprocessed (González-Vega et al., 2011).

The content of Ca in SBM from the U.S. was greater than values reported by NRC (2012) and by Stein et al. (2016), but in agreement with values reported by Sotak-Peper et al. (2016). The observation that SBM from the U.S. and India has a greater concentration of Ca than SBM from other countries is consistent with reported data (Karr-Lilienthal et al., 2004a; Ravindran et al., 2014; García-Rebollar et al., 2016). This high concentration of Ca may be a result of limestone sometimes being added to SBM as a flow agent (Walk et al., 2012; Ravindran et al., 2014; García-Rebollar et al., 2016). The average concentration of P in SBM is approximately 0.70% (Stein et al., 2016), but SBM from India had a lower concentration of P. This observation agrees with data reported by Ravindran et al. (2014), indicating that Indian SBM has the least concentration of P compared with SBM from Argentina, Brazil, and the U.S. Likewise, the greater concentration of P in SBM from China compared with SBM from Brazil and India is consistent with values reported by Karr-Lilienthal et al. (2004a). The content of P in SBM from the U.S. observed in this experiment is in agreement with values reported by Batal et al. (2010) and Sotak-Peper et al. (2016). However, the content of P bound to phytate observed in this experiment is greater than values reported by NRC (2012) and by Sotak-Peper et al. (2016) for SBM from the U.S.

Argentinian SBM has the greatest concentration of K compared with all other countries, which is in agreement with data previously published (Karr-Lilienthal et al., 2004a; Ravindran et al., 2014; García-Rebollar et al., 2016) and the observation that Chinese SBM has a greater concentration of Mg than SBM from other countries is consistent with values reported by Karr-Lilienthal et al. (2004a). The variation in the concentration of minerals in SBM is likely a result of differences in the concentration of minerals in the soil where the soybeans were grown (Karr-Lilienthal et al., 2004a; Roriz et al., 2014; García-Rebollar et al., 2016). The observation that Indian SBM has a greater concentration of Fe than SBM from all other countries agrees with values reported by Karr-Lilienthal et al. (2004a) and Ravindran et al. (2014) and is likely a result of high iron in the soil in the soybean producing areas of India. High iron and the low concentration of P in SBM from India, may also be a result of low pH of the soil (Huerta and Martin, 2002). However, a high concentration of Fe in SBM may also be a result of contamination during processing (Karr-Lilienthal et al., 2004a).

Amino Acid Digestibility in SBM from Different Countries

The AID of CP and AA of SBM were within expected values (NRC, 2012) and the values for the AID and SID of CP and AA were in agreement with values reported by Berrocoso et al. (2015). However, the SID of CP and AA was greater in this study compared with values reported by NRC (2012) and Stein et al. (2016).

Different studies have evaluated the digestibility of CP and AA using SBM from different countries when fed to broiler chickens (de Coca-Sinova et al., 2008; Frikha et al., 2012; Ravindran et al., 2014), piglets (Eklund et al., 2012; Goerke et al., 2012), and growing pigs (Karr-Lilienthal et al., 2004b). However, to the best of our knowledge, this is the first time that SBM from the 5 major soybean-producing countries are compared. The observation that the SID of most AA is greater in SBM from the U.S. than in SBM from Argentina and India agrees with data reported in previous studies with the exception of Eklund et al. (2012) and Ravindran et al. (2014) who did not observe differences in the digestibility of SBM from the U.S., Argentina, and Brazil. Likewise, the observation that there are no differences in the SID of AA between SBM from the U.S. and China concurs with data reported by Karr-Lilienthal et al. (2004b), who compared the SID of AA in 1 source of SBM from the U.S. with 3 sources of SBM from China.

The SID of CP and AA of the SBM from Argentina, Brazil, and the U.S. were greater than values reported in piglets (Eklund et al., 2012; Goerke et al., 2012). These differences may be due to the limited capacity of CP and AA absorption in young pigs (Li et al., 1993; Pedersen et al., 2016). Likewise, the SID of CP and AA reported in this experiment were greater than values reported by Karr-Lilienthal et al. (2004b). The reason for these differences may be the methodology used to collect and process ileal digesta samples. In this experiment there was no correlation between the AID and SID of CP and AA and the CP concentration in SBM. This observation concurs with data reported by Goerke et al. (2012) and Ravindran et al. (2014), but is in disagreement with de Coca-Sinova et al. (2008) and Frikha et al. (2012), who reported that the ileal AA digestibility in SBM was directly correlated with the concentration of CP.

Trypsin inhibitors reduce nutrient digestibility and have been demonstrated to decrease SID values in piglets (Goebel and Stein, 2011). Oligosaccharides in SBM are not digested by pigs, and may also reduce the SID of AA in pigs (Smiricky et al., 2002; Hollung et al., 2005). Therefore, the observation that the SID of CP and most AA is greater in SBM from the U.S. than in SBM from India may be a consequence of the greater concentration of raffinose and TIU in SBM from India. However, SBM from the U.S. had the greatest concentration of stachyose and also the greatest SID of most AA so there does not appear to be a negative influence of stachyose on SID of AA.

Despite the lack of differences in the SID of AA between SBM from the U.S. and SBM from China, the concentration of standardized ileal digestible AA in SBM from China was the least among SBM from all countries, which is result of the reduced AA concentration in SBM from China compared with SBM from the U.S. Likewise, SBM from India having low SID of AA, had greater concentration of standardized ileal digestible CP and most AA than SBM from China and Argentina, which is a result of the greater concentration of CP and AA in the SBM from India. This observation agrees with Ravindran et al. (2014) who reported that there were no differences in the SID of CP and most AA between SBM from the U.S. and Argentina when fed to broiler chickens, but differences in the concentration of standardized digestible CP and most AA were observed because of reduced concentration of AA in the SBM from Argentina. These observations illustrate that neither AA concentrations nor SID values alone indicate the protein value of SBM, but if these values are multiplied to calculate the concentration of standardized ileal digestible CP and AA, a better estimate of the protein value is obtained.

Variability in Amino Acid Digestibility in SBM within Countries

The observation that there are no differences in the SID of CP and most AA among the 5 sources of SBM from the U.S. and Brazil is in agreement with values reported by Karr-Lilienthal et al. (2004b) and Goerke et al. (2012) who also concluded that the SID of AA in different sources of SBM does not differ. Likewise, van Kempen et al. (2002) reported that the variation in AA digestibility among 4 sources of SBM from the U.S. was very small and Sotak-Peper et al. (2017) concluded that the concentration of digestible AA is constant among sources of SBM obtained from different areas of the U.S. However, the differences in the SID of AA that were observed among sources of SBM from Argentina is consistent with data reported by Goerke et al. (2012). The differences among sources of SBM from Argentina may also be explained by the environment where soybeans were grown and the conditions of SBM processing. Nevertheless, these data indicate that the likelihood of receiving a consistent product in terms of standardized ileal digestible AA is greater in SBM from Brazil or the U.S. than in SBM from Argentina.

Conclusions

The SBM from China, Argentina, Brazil, the U.S., and India that was used in this experiment differed in nutrient composition. Soybean meal from Brazil and India had the greatest concentrations of CP and AA and SBM from China had the least concentrations. However, differences in the AID and SID among countries were observed, with greater values in SBM from the U.S. and China than in SBM from Argentina, Brazil, and India. The concentration of standardized ileal digestible CP and AA, however, was less in SBM from China than in SBM from the other countries, and SBM from the U.S. and India had greater concentrations of digestible AA than SBM from Argentina, whereas SBM from Brazil was intermediate. Soybean meal from the U.S., China, and Brazil also had less variability among sources compared with SBM from Argentina and China. Therefore, the differences in the SID of CP and AA across and within countries should be taken in account when diets for growing pigs are formulated.

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