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# Chemical Composition and Protein Quality Comparisons of Soybeans and Soybean Meals from Five Leading Soybean-Producing Countries

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Soybeans (SBs) were obtained from five leading SB-producing countries (Argentina, Brazil, China, India, and the United States), imported to the United States, and processed into soybean meal (SBM) under uniform conditions in the United States. SBs from China had the highest crude protein (CP) content while SBs and the resultant SBM from Argentina had the lowest. Additional differences in the quality of the SB and resultant SBM samples collected were noted. An additional set of SBM produced in these five countries and subjectively evaluated to be of low, intermediate, and high quality also were obtained and evaluated. Overall, SBM quality affected amino acid and mineral concentrations with differences existing both among and within countries. SBM produced in the United States had a higher CP content than SBM produced in other countries. Amino acid concentrations generally increased, and antinutritional factors decreased with increasing subjective quality assessment.

**KEYWORDS: International; soybeans; soybean meals; protein quality**

## INTRODUCTION

Soybean meal (SBM) accounts for approximately 62% of the proteinaceous ingredients used in diets of all food-producing animals and is the primary protein source used in swine diets worldwide (*1*). In 2001, the world soybean (SB) crop was valued at $12.3 billion, with about 42% of the world's crop being raised in the United States (*1*). SB production in other countries has increased in recent years. After the United States, Brazil had the next highest SB production (24% of the world's crop), followed by Argentina (16%), China (8%), and India (3%; *1*). Even though the United States is the leading SB producer, it is third in SBM export, contributing 16% toward the world's supply, behind Argentina (35%) and Brazil (25%; *1*).

Because of differences in environmental conditions, genetic varieties, and processing conditions, SBM chemical composition differs among geographic regions and affects the nutritional value of these meals (*2*, *3*). SB processing conditions, such as moisture, drying time, and toasting or drying temperature, can contribute to the differences observed in SBM quality. Over- and underprocessing due to improper heating conditions can result in the production of poor quality SBM. If SBM is underprocessed, high concentrations of antinutritional factors such as trypsin inhibitors and saponins remain and potentially decrease the quality of SBM, particularly for nonruminants (*4*). Overprocessing of SBM results in a portion of the lysine being rendered unavailable for poultry and swine because of the Maillard reaction (*4*).

On the basis of increased global competition and variation in processing methodologies being employed, it is important to determine if differences in SBM quality occur both among and within countries. The objective of this research was to determine the compositional and quality differences among select SB and SBM samples from five different geographic regions of the world.

## MATERIALS AND METHODS

**Sources of SBs and SBMs.** One 450 kg sample of whole SB was collected from each of five countries (Argentina, Brazil, China, India, and the United States) by an American Soybean Association representative within each country. One sample of high quality SBs was obtained from each country, but both a low and a high quality SB sample were obtained from India. The low quality SB was produced in a year with higher than normal rainfall and was potentially exposed to flooding. These SBs were processed into SBM within the United States under standardized processing conditions at the Texas A & M University pilot processing plant. Initially, the SBs were cracked using the Ferrel Ross Cracking Rolls (Ferrel Ross, Oklahoma City, OK) with a gap setting of 0.13 cm. Then, the cracked SBs were dehulled using the Kice Aspirator (Kice Industries, Wichita, KS), whereupon they were screened (Smico Vibratory screener, Simco Manufacturing Co., LLC, Oklahoma City, OK) to remove whole beans and large hull particles. After this, the SBs were heated to 65.6−76.7 °C in a French stack cooker and flaked using Bauer flaking rolls. Then, the flakes were extracted using a Crown model 2 extractor using hexane as the solvent at ambient

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temperature. Next, the hexane solvent was removed and toasting was completed in the Crown desolventizer/toaster (DT; Crown Iron Works Co., Minneapolis, MN) that contained three different trays (top, middle, and bottom), which were at the same bed depth for each SB. Efforts were made to maintain similar temperatures across batches in the Crown DT.

In addition to the SB samples described above, an additional set of three different samples of at least 250 kg of SBM from the same five countries were collected by an American Soybean Association representative located in that country who subjectively evaluated the SBM to be of high, intermediate, or low quality. Indicators used to determine quality included SBM color, protein content, and (or) processor history. No data were available on processing conditions used to prepare the meals or the genetic varieties of the SB sources. As a control, a high quality SBM obtained from a U.S. processor was purchased on the open market and used as a standard for comparison with the other SBMs.

**Laboratory Analysis.** Prior to analysis, all SBs and SBMs were ground through a 2 mm screen using a Wiley Mill, model 4 (Thomas-Wiley, Swedesboro, NJ). Whole SBs were ground with dry ice to avoid loss of oil. A subsample of SB and SBM was further ground through a 0.5 mm screen prior to potassium hydroxide (KOH) protein solubility analysis. Samples of SB were stored at −20 °C, and the SBM was stored at room temperature until later analyses. SBs and all SBMs were analyzed for dry matter (DM), organic matter (OM; *5*), and crude protein (CP) by the Kjeldahl method (*5*). SBMs were analyzed for total dietary fiber (TDF; *6*) while SBs were analyzed for neutral detergent fiber (NDF; *7*). The fat content of the samples was determined by acid hydrolysis (*8*) followed by ether extraction according to Budde (*9*). Analysis of amino acid concentrations was conducted at the University of Missouri Experiment Station Chemical Laboratories using a Beckman 6300 amino acid analyzer (Beckman Coulter, Inc., Fullerton, CA) according to AOAC (*5*) procedures. The urease activity (*10*), KOH protein solubility (*4*), and protein dispersability index (*10*) were determined on all SB and SBM samples. The SBM samples were analyzed for mineral content according to AOAC (*5*) using inductively coupled plasma (ICP) spectroscopy (model 137, Applied Research Laboratories, Valencia, CA) at Star Labs [Ohio Agricultural Research and Development Center (OARDC), Wooster, OH].

The particle size was determined on all SBM samples according to the American Society of Agriculture Engineers (ASAE; *11*) using a Ro-tap style shaker (W. S. Tyler, Mentor, OH). Nine sieves ranged in size from 105 to 2000 $\mu$m with the geometric mean calculated according to ASAE (*11*).

Because only one sample was collected for each category of SB or SBM, statistical analysis could not be completed. However, to maintain quality control during chemical analysis, the error between duplicate samples was determined. If the error between duplicates of a sample was greater than 5%, the assay was repeated, with the exception of acid-hydrolyzed fat where a variation of less than 10% was accepted.

## RESULTS AND DISCUSSION

**Composition of Whole SB Samples.** The chemical composition of whole SBs obtained from each country is presented in **Table 1**. All SBs had similar DM and OM contents (ranges: 90.1−93.2 and 93.8−95.1%, respectively). The SB sample from China had the highest CP concentration (44.9%) while SBs from Argentina had the lowest CP concentration (32.6%). Different CP contents of the SB would likely result in different CP contents of the resultant SBM. While the environmental conditions under which these SB were grown are not known, several environmental factors, including rainfall (*12*), temperature (*13*), and photoperiod (*14*), can result in differences in protein and oil accretion in SB. Grieshop and Fahey (*2*) previously reported lower CP values for Brazilian SB (40.9% of DM) as compared to Chinese (42.1%) or U.S. SBs (41.6%). However, the current Brazilian SB sample had a slightly higher CP content than did the U.S. SB. The Grieshop and Fahey (*2*) data are more robust as multiple samples from individual countries were collected and evaluated as compared to the single sample analysis reported here. Additionally, CP concentrations ranging from 40.1 to 4.2.2% of DM were noted by Grieshop et al. (*15*), higher than the sample analyzed in the current study.

**Table 1.** Chemical Composition of an Individual Sample of SBs from Five Geographic Locations

| | SB source | | | | | |
|---|---|---|---|---|---|---|
| | | | | India[a] | | United |
| item | Argentina | Brazil | China | low | high | States |
| DM (%) | 91.0 | 90.5 | 90.6 | 93.2 | 91.9 | 90.1 |
| | %, DM basis | | | | | |
| OM | 94.4 | 95.1 | 93.8 | 94.5 | 94.8 | 94.9 |
| CP | 32.6 | 39.3 | 44.9 | 37.5 | 39.6 | 37.1 |
| acid-hydrolyzed fat | 14.1 | 13.6 | 12.9 | 13.1 | 12.8 | 15.1 |
| NDF | 23.3 | 22.6 | 23.4 | 24.9 | 22.4 | 22.4 |
| | essential amino acids | | | | | |
| arginine | 2.24 | 2.82 | 3.42 | 2.64 | 2.88 | 2.79 |
| histidine | 0.90 | 1.05 | 1.19 | 1.03 | 1.08 | 1.03 |
| isoleucine | 1.51 | 1.66 | 2.06 | 1.68 | 1.84 | 1.80 |
| leucine | 2.47 | 3.04 | 3.41 | 2.80 | 3.09 | 2.94 |
| lysine | 2.07 | 2.41 | 2.69 | 2.38 | 2.48 | 2.37 |
| methionine | 0.48 | 0.54 | 0.64 | 0.54 | 0.54 | 0.53 |
| phenylalanine | 1.63 | 2.08 | 2.33 | 1.91 | 2.03 | 1.95 |
| threonine | 1.25 | 1.48 | 1.62 | 1.44 | 1.47 | 1.40 |
| tryptophan | 0.55 | 0.36 | 0.53 | 0.58 | 0.49 | 0.44 |
| valine | 1.70 | 1.80 | 2.20 | 1.74 | 1.98 | 1.95 |
| | nonessential amino acids | | | | | |
| alanine | 1.46 | 1.70 | 1.90 | 1.58 | 1.71 | 1.64 |
| aspartate | 3.44 | 4.27 | 5.00 | 4.13 | 4.36 | 4.10 |
| cystine | 0.59 | 0.57 | 0.72 | 0.62 | 0.57 | 0.63 |
| glutamate | 5.35 | 6.86 | 7.86 | 6.72 | 7.28 | 6.64 |
| glycine | 1.48 | 1.70 | 1.88 | 1.55 | 1.76 | 1.68 |
| proline | 1.31 | 1.70 | 1.95 | 1.72 | 1.75 | 1.67 |
| serine | 1.31 | 1.75 | 1.81 | 1.65 | 1.75 | 1.54 |
| tyrosine | 1.15 | 1.46 | 1.56 | 1.39 | 1.42 | 1.35 |
| TEAA | 14.8 | 17.2 | 20.1 | 16.7 | 17.9 | 17.2 |
| TNEAA | 16.1 | 20.0 | 22.7 | 19.4 | 20.6 | 19.3 |
| TAA | 30.9 | 37.3 | 42.8 | 37.5 | 38.5 | 36.5 |

[a] Low = low quality SB; high = high quality SB.

The acid-hydrolyzed fat content was highest for the SB sample from the United States, but the range for all samples was from 12.9 to 15.1%. Acid-hydrolyzed fat concentrations for SBs reported in other studies were higher than those found in the current study. Grieshop and Fahey (*2*) reported that SBs from the United States and Brazil had fat values of approximately 18.7% and SBs from China had concentrations of 17.3%, and Grieshop et al. (*15*) reported concentrations of 17.4−20.1% for U.S. SB samples. The NDF concentration was similar for SBs from all countries averaging approximately 23% of DM. This concentration was much higher than that reported in other studies with a range of 13.4−13.9% reported for Brazilian, Chinese, and U.S. SBs (*2*) and a range of 11.1−12.2% reported for U.S. SB (*15*).

The amino acid concentrations followed the same trend as CP analysis. The SB sample from China had the highest concentration of CP, total essential, and total nonessential amino acids (TNEAA), with the Argentinian SB sample having the lowest concentrations of these components. The amino acid concentrations for Indian, Brazilian, and U.S. SBs had similar concentrations for each of the amino acids. Lysine, which often is the first limiting amino acid in swine diets when SBM is the protein source, was highest in the SBs from China and lowest in SBs from Argentina.

Both KOH protein solubility and PDI were used to assess protein quality of the SB. KOH solubility measures the

**Table 2.** Protein Quality Characteristics of Individual Samples of SBs from Five Geographic Locations

| | SB source | | | | | |
|---|---|---|---|---|---|---|
| | | | | India[a] | | |
| item | Argentina | Brazil | China | low | high | United States |
| KOH protein solubility, % of CP | 79.1 | 81.8 | 79.1 | 83.2 | 73.3 | 84.1 |
| protein dispersibility index, % of CP | 80.4 | 71.8 | 52.5 | 58.9 | 85.8 | 78.5 |
| urease activity, pH units | 1.89 | 0.65 | 1.07 | 1.04 | 0.52 | 1.24 |

[a] Low = low quality SB; high = high quality SB.

percentage of the protein soluble in KOH, while PDI measures the percentage of protein soluble in water. The SBs from the United States and Brazil and the low quality SBs obtained from India had the highest protein solubility in KOH (84.1, 81.8, and 83.2%, respectively) of all samples collected, suggesting that they have a higher nutritional value. The lowest value found occurred in the high quality Indian SB sample (73.3%; **Table 2**). These protein solubility values were much higher than those found by Grieshop and Fahey (*2*) for SBs from Brazil (67.7% of CP), China (69.3%), and the United States (74.1%). However, these KOH values were similar to those noted by Grieshop et al. (*15*) for U.S. SBs (range: 70.7−83.8%). The PDI values for the SB were quite variable between sources. The SBs from China and the low quality SBs from India had much lower PDI values than did any of the other SBs. The highest PDI values were noted for the Argentinean and high quality Indian SBs. The PDI values for these two SBs were similar to those noted by Grieshop et al. (*15*) for U.S. SBs (range: 81.7−86.3%). A large variation existed in the urease values among countries. By measuring urease activity, an estimate of the trypsin inhibitor activity is given. A higher urease activity also indicates a higher trypsin inhibitor activity. A higher trypsin inhibitor activity can lead to a decrease in animal growth rate. Fortunately, heat processing, such as toasting during the production of SBM, can inactivate the trypsin inhibitor and prevent a decrease in animal performance. The SBs from Argentina had the highest urease value, indicating the highest trypsin inhibitor activity. SBs from the United States, China, and India (low quality) had urease values with pH changes greater than 1. SBs from Brazil and India (high quality) had the lowest urease values. The urease activities found in the current study were slightly lower than those found for U.S. SBs (range: 1.93−2.22 pH units; *15*).

**Comparison of SBMs Produced from SBs Obtained from Five Countries and Processed under Uniform Conditions.** All SB samples were processed into SBM at one location in the United States. While every effort was made to use uniform processing conditions when producing the SBM, some differences occurred in processing temperatures. During the extraction phase of SBM production, the United States and Brazilian SBs were exposed to slightly lower temperatures (37 and 36 °C, respectively) than the other SBMs, while the low quality Indian, Argentinean, and Chinese SBs were exposed to a temperature of 39 °C. The high quality Indian SB was extracted at the highest temperature (43.3 °C). Because the SB flakes were extracted at ambient temperature, it was not possible to control the variation in temperature.

During the desolventizing and toasting processes, temperatures in the three trays in the DT also varied. The tray temperatures were lowest overall for the Brazilian SBM with temperatures of 52.2 and 93.3 °C for the top and bottom trays, respectively. The SBM produced from Argentinean, Chinese, and Indian SBs all were dried at 57.2° in the top tray. There was more variation in temperature in the middle and bottom trays, with the SBM dried at temperatures ranging from 65.5 (China) to 84.4 °C (Argentina) for the middle tray. For the bottom tray, the temperatures, with the exception of the Brazilian SBM, ranged from 110 (high quality Indian SBM) to 117.7 °C (Argentinean SBM).

**Table 3.** Chemical Composition of SBMs Prepared from SBs Produced in Different Geographic Regions of the World but Processed under Uniform Conditions in the United States

| | SB source | | | | | |
|---|---|---|---|---|---|---|
| | | | | India[a] | | |
| item | Argentina | Brazil | China | low | high | United States |
| DM (%) | 95.4 | 95.8 | 96.1 | 96.9 | 96.3 | 96.1 |
| | %, DM basis | | | | | |
| OM | 92.3 | 93.3 | 92.8 | 92.3 | 92.9 | 92.9 |
| CP | 47.4 | 57.0 | 58.5 | 54.6 | 57.8 | 53.2 |
| acid-hydrolyzed fat | 4.4 | 4.4 | 4.6 | 5.6 | 2.9 | 4.1 |
| TDF | 23.7 | 19.7 | 20.1 | 20.7 | 18.6 | 24.1 |
| | essential amino acids | | | | | |
| arginine | 3.29 | 4.10 | 4.33 | 3.87 | 4.24 | 3.96 |
| histidine | 1.32 | 1.51 | 1.53 | 1.48 | 1.57 | 1.46 |
| isoleucine | 2.15 | 2.41 | 2.48 | 2.40 | 2.60 | 2.46 |
| leucine | 3.62 | 4.41 | 4.35 | 4.22 | 4.51 | 4.14 |
| lysine | 2.97 | 3.38 | 3.39 | 3.33 | 3.55 | 3.25 |
| methionine | 0.72 | 0.75 | 0.81 | 0.78 | 0.77 | 0.77 |
| phenylalanine | 2.39 | 2.91 | 2.93 | 2.81 | 3.03 | 2.80 |
| threonine | 1.88 | 2.13 | 2.12 | 0.80 | 2.15 | 1.97 |
| tryptophan | 0.75 | 0.85 | 0.83 | 2.08 | 0.85 | 0.76 |
| valine | 2.37 | 2.54 | 2.59 | 2.55 | 2.75 | 2.71 |
| | nonessential amino acids | | | | | |
| alanine | 2.18 | 2.45 | 2.45 | 2.41 | 2.48 | 2.39 |
| aspartate | 5.18 | 6.27 | 6.50 | 6.07 | 6.49 | 5.88 |
| cystine | 0.86 | 0.81 | 0.92 | 0.84 | 0.80 | 0.88 |
| glutamate | 8.05 | 10.26 | 10.40 | 9.95 | 10.67 | 9.53 |
| glycine | 2.02 | 2.25 | 2.30 | 2.21 | 2.32 | 2.21 |
| proline | 2.32 | 2.81 | 2.84 | 2.69 | 2.86 | 2.67 |
| serine | 1.97 | 2.39 | 2.45 | 2.30 | 2.43 | 2.11 |
| tyrosine | 1.68 | 2.01 | 2.00 | 1.96 | 2.07 | 1.89 |
| TEAA | 21.5 | 25.0 | 25.4 | 24.3 | 23.9 | 24.3 |
| TNEAA | 24.3 | 29.3 | 29.8 | 28.4 | 30.1 | 27.6 |
| TAA | 45.7 | 54.3 | 55.2 | 52.8 | 54.0 | 51.8 |

[a] Low = low quality SB; high = high quality SB.

Differences in processing conditions of a particular feedstuff can result in differences in nutrient digestibilities (*16*). The heating process is designed to denature any remaining antinutritional factors present in SB. If temperatures are too low, some antinutritional factors may not be completely destroyed (*4*). However, if the drying temperatures used are too high, nutrient damage (i.e., lysine) may occur (*4*).

All SBMs had similar DM (95.4−96.9%) and OM (92.3−93.3%) contents (**Table 3**). All SBMs except that from Argentina (47.4%) had greater than 53% CP. The lower CP content in the SBM produced from the Argentinean SB perhaps is a direct result of the lower CP content in the Argentinean SB itself. The CP concentration increased approximately 12% age units for SBM produced from Argentinean and Chinese SBs as compared with the concentration found in the SB itself, and 14% age units for SBMs produced from Indian, Brazilian, and U.S. SBs. This is to be expected, as protein is concentrated as the hull and oil are removed from the SB during processing.

Amino acid concentrations followed the same trends as CP concentrations. The amino acid concentrations in the Argentinean SBM also were much lower than in any of the other SBM. The SBM produced from Argentinean SBs had lower concentrations of many essential amino acids than were reported in the NRC for SBM (*17*). All other SBMs had lysine concentrations similar to the 3.36% value (DM basis) reported by NRC

**Table 4.** Mineral Composition (DM Basis) of SBMs Prepared from SBs Produced in Different Geographic Regions of the World but Produced under Uniform Conditions in the United States

| | SB source | | | | | |
|---|---|---|---|---|---|---|
| | | | | India[a] | | United |
| item | Argentina | Brazil | China | low | high | States |
| | | | macrominerals (%)[b] | | | |
| calcium | 0.27 | 0.24 | 0.23 | 0.35 | 0.32 | 0.31 |
| phosphorus | 0.71 | 0.65 | 0.76 | 0.72 | 0.71 | 0.72 |
| potassium | 2.71 | 2.46 | 2.12 | 2.62 | 2.35 | 2.07 |
| magnesium | 0.35 | 0.28 | 0.27 | 0.43 | 0.42 | 0.29 |
| sulfur | 0.40 | 0.39 | 0.41 | 0.42 | 0.36 | 0.41 |
| sodium | 0.01 | 0.01 | 0.01 | ND | 0.01 | ND |
| chloride | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| | | | microminerals ($\mu$g/g) | | | |
| aluminum | 52.4 | 40.7 | 67.6 | 40.7 | 93.5 | 17.7 |
| barium | 11.5 | 3.1 | 5.2 | 3.1 | 1.0 | 6.2 |
| boron | 47.2 | 50.1 | 42.7 | 46.4 | 58.2 | 38.5 |
| cobalt | 0.7 | ND | ND | 0.9 | ND | ND |
| chromium | 0.3 | 0.6 | 1.2 | 1.4 | 0.7 | 0.7 |
| copper | 29.4 | 14.6 | 18.7 | 23.7 | 20.8 | 16.6 |
| iron | 148.8 | 90.8 | 213.3 | 388.0 | 199.4 | 125.9 |
| manganese | 39.8 | 31.3 | 44.7 | 46.4 | 39.9 | 51.0 |
| molybdenum | 13.5 | 12.9 | 2.6 | 0.8 | 2.9 | 6.6 |
| nickel | 6.3 | 1.7 | 11.9 | 4.6 | 4.0 | 5.9 |
| selenium | 0.45 | 0.01 | 0.14 | 0.14 | 0.30 | 0.31 |
| zinc | 61.8 | 53.2 | 58.3 | 56.8 | 59.2 | 53.1 |

[a] Low = low quality SB; high = high quality SB. [b] ND = values below detection levels.

**Table 5.** Protein Quality Characteristics of SBMs Prepared from SBs Produced in Different Geographic Regions of the World but Produced under Uniform Conditions in the United States

| | SB source | | | | | |
|---|---|---|---|---|---|---|
| | | | | India[a] | | United |
| item | Argentina | Brazil | China | low | high | States |
| KOH protein solubility, % of CP | 74.0 | 84.9 | 87.0 | 88.5 | 93.9 | 82.3 |
| protein dispersibility index, % of CP | 27.3 | 37.1 | 31.3 | 40.3 | 57.4 | 23.9 |
| urease activity, pH units | 0.20 | 0.13 | 0.13 | 0.20 | 0.25 | 0.04 |

[a] Low = low quality SB; high = high quality SB.

(*17*) for dehulled SBM. The SBM produced from the high quality Indian SB had approximately 30% less acid-hydrolyzed fat than the other SBM. This could be due to more complete extraction of the fat during SBM processing than occurred for other SBM samples.

Most minerals are incorporated into grains based on the seed genetics and indirectly by the available mineral concentration found in the soil. The calcium and phosphorus values for all of the SBMs in this experiment were relatively similar but slightly lower than NRC values (*17*) for dehulled SBM (**Table 4**). Calcium concentrations for the SBM produced from Indian SB were slightly higher than for the other countries. Concentrations of other macrominerals found in the SBM were similar to NRC (*17*) values. However, there were higher magnesium concentrations in both SBM samples produced from Indian SB. The amount of calcium, phosphorus, and magnesium bound to phytate is not known. If present in the bound form, their bioavailability would be compromised (*18*).

There was a greater difference between countries in the micro- or trace minerals found in the SBM. The differences in these mineral concentrations are perhaps due to differences in soil mineral content and (or) their availability to plant tissue. Only the SBM produced from Argentinean and the low quality Indian SBs had detectable amounts of cobalt, whereas the other samples were below the detection limit of the ICP equiptment. The Brazilian (90.8 $\mu$g/g), Argentinean (148.8 $\mu$g/g), and U.S. (125.9 $\mu$g/g) SBM had iron concentrations below the NRC (*17*) value of 195.6 $\mu$g/g. The selenium content of the SB is directly related to the selenium content found in the soil and its availability to the plant since the plant has no requirement for selenium. It is notable that almost no selenium was found in the SBM produced from Brazilian SBs. The SBM produced from Chinese SBs and low quality Indian SBs also had low selenium contents. However, the selenium content of the SBM produced from high quality Indian SBs was twice as high as that from its low quality counterpart. The results indicate that there may have been a substantial difference in the selenium content in the soils between and within countries. A large difference was found in the aluminum content of the SBM, ranging from 17.7 $\mu$g/g for U.S. to 93.9 $\mu$g/g for the SBM produced from high quality Indian SBs.

SBM protein quality data are presented in **Table 5**. In chick growth studies, a growth depression has been reported when animals consumed SBM that was underprocessed and had a protein solubility in KOH greater than 85% (*19*) and when chicks consumed SBM that was overprocessed and had a protein solubility less than 70% (*4*). On the basis of these data, none of the SBM produced in the United States were overprocessed. However, SBM except those produced from Argentinean and Brazilian SBs had protein solubilities in KOH greater than 85%, suggesting that the resultant SBM may have been underprocessed. The protein dispersibility index is another commonly used indicator of proper processing of SBM. In this experiment, SBM PDI values ranged from 24 to 40% except for the sample produced from high quality Indian SBs. Batal at el. (*20*) showed that when SB flakes were autoclaved, the PDI value dropped to 45% and was associated with increased growth of chicks as compared to SB flakes that were not autoclaved and had a PDI value of 63%. The SBM prepared from high quality Indian SBs had a PDI value of 57% and, thus, may have been underprocessed.

The acceptable range of change in pH units to assess urease activity is 0.05−0.20 (*21*), with urease values greater than 0.2 reflecting underprocessed SBM and incomplete inactivation of trypsin inhibitor activity. The SBMs produced from Indian and Argentinean SBs were at or above 0.2 pH unit changes, potentially indicating a higher urease activity or underprocessing. The SBs from Argentina had the highest urease activity initially, so a longer heating time may have been needed to completely destroy the urease and trypsin inhibitor activity in these SBs. The value of 0.04 for the U.S. SBs implies that it may have been overheated. However, SBMs with zero urease activity do not necessarily have a lowered nutritional value (*22*). Cecectomized roosters fed SBM with zero urease activity had lysine digestibilities greater than 90% (*21*). This indicates that the SBM from the United States with low urease activity may not have been overheated during processing.

The laboratory protein quality assessments of these SBMs indicate that processing conditions may not have been optimized for all SBMs, resulting in certain meals being underprocessed as indicated by KOH solubility and PDI values. According to Batal et al. (*20*), who observed fluctuations in KOH solubility with increased heating times, PDI analysis may be more accurate than KOH in quantifying underprocessed SBM. The PDI results indicate that only the SBM produced from high quality Indian SBs was underprocessed, having been processed at an intermediate temperature in the DT trays. The Brazilian SBs were processed at lower temperatures than the high quality Indian

**Table 6.** Chemical Composition of SBMs of Various Qualities (Low, Intermediate, and High) Obtained from Five Geographic Locations

| | SBM source[a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Argentina | | | Brazil | | | China | | | India | | | United States | | |
| item | control | low | inter. | high | low | inter. | high | low | inter. | high | low | inter. | high | low | inter. | high |
| DM (%) | 91.0 | 89.2 | 88.1 | 88.1 | 89.8 | 89.1 | 89.8 | 90.1 | 88.1 | 88.5 | 89.5 | 89.2 | 90.3 | 89.2 | 89.4 | 89.3 |
| | | | | | | | %, DM basis | | | | | | | | | |
| OM | 92.5 | 92.6 | 92.3 | 92.8 | 93.0 | 93.2 | 93.4 | 93.5 | 93.9 | 93.5 | 90.8 | 91.0 | 92.6 | 92.9 | 91.8 | 92.6 |
| CP | 53.1 | 50.1 | 50.8 | 51.3 | 51.8 | 52.7 | 52.3 | 48.8 | 50.7 | 52.9 | 51.7 | 51.6 | 59.5 | 54.2 | 51.1 | 55.4 |
| acid-hydrolyzed fat | 4.1 | 5.9 | 4.6 | 4.7 | 4.5 | 4.5 | 4.7 | 3.9 | 3.4 | 3.5 | 3.9 | 3.3 | 3.6 | 3.2 | 5.3 | 3.7 |
| TDF | 21.2 | 22.5 | 24.8 | 19.0 | 23.8 | 23.3 | 22.4 | 24.2 | 21.0 | 19.4 | 23.4 | 21.6 | 17.0 | 18.4 | 18.4 | 17.5 |
| | | | | | | | essential amino acids | | | | | | | | | |
| arginine | 4.01 | 3.75 | 3.76 | 3.93 | 3.89 | 3.82 | 3.97 | 3.59 | 3.87 | 3.95 | 3.77 | 3.66 | 4.49 | 3.83 | 3.91 | 4.25 |
| histidine | 1.43 | 1.37 | 1.40 | 1.43 | 1.40 | 1.41 | 1.45 | 1.33 | 1.35 | 1.62 | 1.44 | 1.37 | 1.63 | 1.42 | 1.45 | 1.51 |
| isoleucine | 2.35 | 2.24 | 2.28 | 2.36 | 2.28 | 2.29 | 2.38 | 2.12 | 2.16 | 2.28 | 2.74 | 2.11 | 2.68 | 2.37 | 2.36 | 2.53 |
| leucine | 4.03 | 3.94 | 4.02 | 4.13 | 4.12 | 4.02 | 4.14 | 3.81 | 3.85 | 4.07 | 4.09 | 3.89 | 4.72 | 4.08 | 4.01 | 4.27 |
| lysine | 3.44 | 3.13 | 3.20 | 3.28 | 3.17 | 3.27 | 3.33 | 3.08 | 3.10 | 3.67 | 3.34 | 3.15 | 3.69 | 3.32 | 3.34 | 3.47 |
| methionine | 0.79 | 0.71 | 0.74 | 0.73 | 0.71 | 0.75 | 0.72 | 0.72 | 0.70 | 0.79 | 0.75 | 0.71 | 0.81 | 0.76 | 0.77 | 0.81 |
| phenylalanine | 2.68 | 2.60 | 2.66 | 2.72 | 2.76 | 2.68 | 2.79 | 2.40 | 2.57 | 2.76 | 2.73 | 2.58 | 3.19 | 2.72 | 2.69 | 2.81 |
| threonine | 2.03 | 1.90 | 1.95 | 2.01 | 1.99 | 1.95 | 2.02 | 1.87 | 1.87 | 2.08 | 2.00 | 1.93 | 2.24 | 1.97 | 1.99 | 2.06 |
| tryptophan | 0.78 | 0.75 | 0.79 | 0.82 | 0.80 | 0.82 | 0.79 | 0.77 | 0.76 | 0.86 | 0.85 | 0.76 | 0.86 | 0.82 | 0.79 | 0.85 |
| valine | 2.69 | 2.43 | 2.46 | 2.57 | 2.42 | 2.44 | 2.53 | 2.29 | 2.34 | 2.92 | 2.47 | 2.29 | 2.80 | 2.57 | 2.56 | 2.79 |
| | | | | | | | nonessential amino acids | | | | | | | | | |
| alanine | 2.44 | 2.28 | 2.27 | 2.38 | 2.36 | 2.35 | 2.36 | 2.20 | 2.21 | 2.59 | 2.39 | 2.23 | 2.59 | 2.40 | 2.37 | 2.52 |
| aspartic acid | 6.03 | 5.57 | 5.70 | 5.86 | 5.96 | 5.84 | 5.97 | 5.50 | 5.60 | 6.28 | 5.97 | 5.62 | 6.83 | 5.80 | 5.85 | 6.19 |
| cysteine | 0.86 | 0.73 | 0.79 | 0.77 | 0.76 | 0.80 | 0.79 | 0.79 | 0.77 | 0.87 | 0.78 | 0.72 | 0.85 | 0.86 | 0.92 | 0.87 |
| glutamic acid | 9.76 | 9.05 | 9.18 | 9.51 | 9.52 | 9.36 | 9.73 | 8.87 | 9.22 | 9.88 | 9.65 | 9.25 | 11.21 | 9.40 | 9.47 | 10.22 |
| glycine | 2.27 | 2.13 | 2.17 | 2.19 | 2.22 | 2.19 | 2.23 | 2.03 | 2.08 | 2.36 | 2.21 | 2.07 | 2.40 | 2.15 | 2.19 | 2.32 |
| proline | 2.43 | 2.48 | 2.53 | 2.60 | 2.62 | 2.56 | 2.65 | 2.41 | 2.50 | 2.33 | 2.57 | 2.48 | 3.05 | 2.59 | 2.63 | 2.77 |
| serine | 2.34 | 2.14 | 2.18 | 2.26 | 2.28 | 2.26 | 2.28 | 2.14 | 2.11 | 2.51 | 2.32 | 2.19 | 2.54 | 2.16 | 2.19 | 2.23 |
| tyrosine | 1.86 | 1.83 | 1.87 | 1.88 | 1.93 | 1.87 | 1.94 | 1.72 | 1.75 | 1.92 | 1.88 | 1.83 | 2.17 | 1.89 | 1.86 | 1.94 |
| TEAA | 24.2 | 22.8 | 23.3 | 24.0 | 23.6 | 23.5 | 24.1 | 22.0 | 22.6 | 25.0 | 24.2 | 22.4 | 27.1 | 23.9 | 23.9 | 25.4 |
| TNEAA | 28.0 | 26.2 | 26.7 | 27.5 | 27.7 | 27.2 | 28.0 | 25.7 | 26.2 | 28.7 | 27.8 | 26.4 | 31.6 | 27.3 | 27.5 | 29.1 |
| TAA | 52.2 | 49.0 | 50.0 | 51.4 | 51.2 | 50.7 | 52.1 | 47.6 | 48.8 | 53.7 | 52.0 | 48.8 | 58.7 | 51.1 | 51.4 | 54.4 |

[a] Low = low quality SBM; intermediate = intermediate quality SBM; and high = high quality SBM.

SBs and were not underprocessed as indicated by the laboratory quality measures. This may indicate that different SBs need to be processed under different conditions depending on the genetics and composition of the SB. Within each geographic location, processing conditions need to be determined so as to produce the highest quality SBM for swine and poultry.

**Comparison of High, Intermediate, and Low Quality SBMs Processed within Each Country.** DM and OM values were similar for all SBMs (**Table 6**). All SBMs contained greater than 50% CP, except the low quality SBM from China (48.8%). CP concentrations of SBM samples in the current study were generally higher than those previously reported for SBM from the United States (48.3%), Brazil (49.0%), Argentina (44.2%), and India (46.5%) by Baize (*3*). Except for Brazil, the high quality SBM also had the highest CP concentration within each country. The high quality SBM from India had the highest CP concentration (59.5%) as compared to all other SBM samples analyzed. The control SBM from the United States and the low and high quality U.S. SBMs also had higher CP concentrations than the remainder of the SBM samples studied. SBMs with lower CP concentrations tended to have higher acid-hydrolyzed fat concentrations, corroborating the negative correlation found between oil and protein concentrations of SBs (*23*). TDF concentrations were lowest for SBM produced in the United States as compared with SBM produced in other countries, indicating a potential higher digestibility for the SBM produced in the United States. In general, within each country, TDF concentrations decreased as quality indicators increased.

As regards amino acid concentrations, only the high quality SBMs from China, the United States, and India, as well as the control SBM, had higher lysine concentrations than reported in the NRC (*17*). For all countries, lysine concentrations were directly proportional to other indices of SBM quality. The largest difference in lysine content occurred for samples from China (3.08−3.67%). With lysine generally being the first limiting amino acid in swine diets, a higher lysine concentration in an ingredient is desirable. The intermediate quality SBM from China had the lowest concentration of total essential amino acids (TEAA), while the high quality SBM from India had the highest concentrations of these amino acids. Within each country, the high quality SBM had the highest total essential amino acid concentrations.

The mineral concentrations of the SBM produced in the five countries are presented in **Table 7**. The SBM from China had calcium concentrations much lower (0.19−0.23%) than those reported in the NRC (*17*) for SBM (0.38% on a DM basis). There also was considerable variation in the calcium content of the SBM from the United States (0.26−0.60%). Because the majority of the calcium in SBM is bound to phytate, increased calcium concentrations do not necessarily correspond to increased bioavailable calcium (*18*). It is possible that calcium carbonate was added to the SBM as a flow agent. All other macrominerals were found in the SBM at concentrations slightly above NRC (*17*) reported values and were within normal ranges.

As regards microminerals, SBM from India had detectable concentrations of cobalt, supporting the observation that cobalt was detectable in the SBM prepared in the United States from the Indian SBs. The only other SBMs with detectable concentrations of cobalt were the intermediate quality SBM from Brazil and the United States. A large variation was found in the iron content of the samples possibly because of potential contamination from processing equipment. The SBM processed in India

**Table 7.** Mineral Composition (DM Basis) of SBMs of Various Qualities (Low, Intermediate, and High) from Five Geographic Locations

| | SBM source[a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Argentina | | | Brazil | | | China | | | India | | | United States | | |
| item | control | low | inter. | high | low | inter. | high | low | inter. | high | low | inter. | high | low | inter. | high |
| | | | | | | | macrominerals (%)[b] | | | | | | | | | |
| calcium | 0.25 | 0.25 | 0.30 | 0.24 | 0.30 | 0.31 | 0.28 | 0.23 | 0.19 | 0.21 | 0.51 | 0.50 | 0.43 | 0.26 | 0.31 | 0.60 |
| phosphorus | 0.70 | 0.67 | 0.67 | 0.68 | 0.60 | 0.67 | 0.65 | 0.72 | 0.70 | 0.72 | 0.64 | 0.62 | 0.72 | 0.82 | 0.78 | 0.77 |
| potassium | 2.21 | 2.32 | 2.36 | 2.32 | 2.31 | 2.44 | 2.36 | 2.51 | 2.43 | 2.34 | 2.32 | 2.33 | 2.48 | 2.57 | 2.55 | 2.34 |
| magnesium | 0.29 | 0.27 | 0.28 | 0.26 | 0.32 | 0.29 | 0.28 | 0.30 | 0.27 | 0.26 | 0.40 | 0.39 | 0.41 | 0.34 | 0.31 | 0.30 |
| sulfur | 0.37 | 0.31 | 0.32 | 0.33 | 0.33 | 0.36 | 0.36 | 0.41 | 0.42 | 0.37 | 0.34 | 0.34 | 0.43 | 0.44 | 0.44 | 0.44 |
| sodium | 0.01 | ND | ND | 0.01 | ND | ND | 0.01 | ND | ND | ND | ND | ND | ND | ND | ND | 0.01 |
| cloride | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 | 0.05 | 0.04 | 0.04 | 0.04 | 0.02 | 0.03 | 0.04 |
| | | | | | | | microminerals ($\mu$g/g) | | | | | | | | | |
| aluminum | 151.6 | 132.3 | 114.6 | 69.2 | 250.6 | 113.4 | 154.9 | 82.2 | 103.3 | 96.0 | 1295.1 | 1244.5 | 47.6 | 39.2 | 674.9 | 40.3 |
| barium | 3.3 | 6.7 | 7.9 | 5.7 | 3.3 | 11.2 | 7.8 | 6.7 | 4.5 | 5.6 | 5.6 | 5.6 | 2.2 | 6.7 | 9.0 | 5.6 |
| boron | 47.3 | 44.9 | 49.9 | 46.5 | 32.3 | 33.7 | 36.8 | 27.8 | 34.1 | 31.6 | 46.9 | 46.0 | 50.9 | 40.4 | 40.3 | 39.2 |
| cobalt | ND | ND | ND | ND | ND | 0.9 | ND | ND | ND | ND | 1.6 | 1.7 | 1.0 | ND | 0.6 | ND |
| chromium | 0.7 | 0.5 | 0.5 | 0.4 | 0.7 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 2.5 | 2.4 | 0.5 | 0.5 | 2.0 | 0.4 |
| copper | 18.7 | 19.1 | 19.3 | 19.3 | 14.5 | 18.0 | 16.7 | 14.4 | 13.6 | 14.7 | 23.5 | 22.4 | 22.2 | 14.6 | 19.0 | 20.2 |
| iron | 191.2 | 241.1 | 213.4 | 152.1 | 264.0 | 222.3 | 183.8 | 156.6 | 183.9 | 161.6 | 1129.7 | 1177.3 | 118.5 | 122.2 | 455.5 | 108.7 |
| manganese | 33.0 | 41.5 | 42.0 | 39.7 | 31.2 | 41.5 | 33.4 | 33.3 | 32.9 | 33.9 | 71.5 | 72.9 | 44.3 | 50.5 | 50.4 | 40.3 |
| molybdenum | 8.8 | 7.9 | 7.9 | 10.2 | 5.6 | 1.1 | 4.5 | 2.2 | 2.3 | 2.3 | 1.1 | 2.2 | 3.3 | 2.2 | 4.5 | 3.4 |
| nickel | 5.5 | 3.4 | 3.4 | 3.4 | 1.1 | 1.1 | 2.2 | 12.2 | 7.9 | 11.3 | 5.6 | 5.6 | 4.4 | 2.2 | 12.3 | 5.6 |
| selenium | 0.13 | 0.35 | 0.32 | 0.35 | 0.01 | 0.02 | 0.01 | 0.02 | 0.02 | 0.03 | 0.20 | 0.20 | 0.39 | 0.10 | 0.92 | 0.16 |
| zinc | 57.1 | 44.9 | 47.7 | 36.3 | 56.8 | 56.1 | 56.8 | 50.0 | 45.4 | 46.3 | 58.1 | 58.3 | 58.7 | 66.2 | 66.0 | 58.3 |

[a] Low = low quality SBM; intermediate = intermediate quality SBM; and high = high quality SBM. [b] ND = values below detection levels.

**Table 8.** Particle Size and Protein Quality Characteristics of SBMs of Various Qualities (Low, Intermediate, and High) Obtained from Five Geographic Locations

| | SBM source[a] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Argentina | | | Brazil | | | China | | | India | | | United States | | |
| item | low | inter. | high | low | inter. | high | low | inter. | high | low | inter. | high | low | inter. | high |
| particle size ($\mu$m) | 514 | 649 | 590 | 649 | 647 | 700 | 537 | 631 | 802 | 596 | 700 | 638 | 517 | 504 | 485 |
| KOH protein solubility, % of CP | 76.6 | 76.2 | 74.9 | 75.5 | 82.8 | 84.5 | 73.6 | 74.3 | 80.4 | 80.0 | 81.9 | 81.2 | 81.0 | 84.8 | 86.2 |
| protein dispersibility index, % of CP | 22.2 | 25.2 | 24.4 | 17.1 | 19.8 | 15.8 | 17.1 | 16.5 | 28.5 | 35.7 | 35.8 | 29.4 | 36.8 | 52.1 | 48.2 |
| urease activity, pH units | 0.01 | 0.05 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 | 0.06 | 0.03 | 0.04 | 0.06 | 0.05 | 0.04 | 0.03 |

[a] Low = low quality SBM; intermediate = intermediate quality SBM; and high = high quality SBM.

had extremely high concentrations of iron (greater than 1100 $\mu$g/g for the low and intermediate quality SBM). However, the high quality SBM from India had a concentration of only 118.5 $\mu$g/g, indicating either large variations in the quantities of iron found in the soil within countries or iron contamination of the SBM at the processing site. Selenium was not detectable in the SBM from Brazil and China. Both of these countries have areas that are historically low soil selenium concentrations. There was a large difference in the selenium content of the SBM from the United States that could reflect the large differences regionally in soil content of selenium within the United States.

Laboratory protein quality measures as well as mean particle size of the SBM processed within each country are reported in **Table 8**. The high quality SBM from China had the largest particle size (802 $\mu$m). This could lead to a slightly lower digestibility as Fastinger and Mahan (*24*) reported that true ileal amino acid digestibility increased in grower−finisher pigs with decreasing SBM particle size, particularly when the particle size decreased from 900 to 600 $\mu$m. Lawrence et al. (*25*) found that decreasing particle size from 1226 to 444 $\mu$m did not affect average daily gain or feed efficiency in a nursery pig study.

Protein solubility as measured in KOH was lowest for the low and intermediate quality SBM from China. The KOH solubility values also were low for Argentinean SBM. These values were lower than those reported by Baize (*3*) for Argentinean SBM (78%). All KOH protein solubility values were between 70 and 85%, suggesting that none of the samples were overprocessed or underprocessed (*19*). For all countries except Argentina, the protein solubility in KOH increased with an increase in subjective quality measures.

Protein dispersibility index values also suggest that none of the samples were underprocessed. The highest PDI value was found for the intermediate quality SBM from the United States (52%). This value is comparable to the highest PDI value (47%) found for autoclaved SB flakes reported by Batal et al. (*20*) that led to increased growth of chicks as compared to uncooked SB flakes. The SBM from Brazil had very low PDI values (15.8−19.8%). Batal et al. (*20*), however, failed to note a depression in growth with PDI values as low as 14%. The protein dispersibility index and KOH solubility values did not follow similar patterns for the various SBM samples. For example, for the U.S. SBM samples, the high quality SBM had the highest KOH solubility while the intermediate quality SBM had the highest PDI value.

Urease activity, in pH units, was 0.06 or below for all SBM samples. Although values were slightly below the acceptable range (0.05−0.20), they do not necessarily predict a lowered digestibility. Once the trypsin inhibitor activity is destroyed, the urease value can no longer decrease; therefore, a zero urease activity or one less than 0.05 may simply indicate that the trypsin inhibitor activity was no longer present in the SBM. The laboratory protein quality assessments of the SBM detected no

clear signs of differences in protein quality. These measures may imply that the SBMs were properly processed within each country. While laboratory assays are useful tools, in vivo measures of protein quality will provide a more accurate indication of amino acid availability to swine.

Differences in the chemical composition of SBM occurred both among and within countries. This can be due to differences in both the variety of SB used to produce the SBM and the differences in processing conditions during the production of the SBM. Grieshop et al. (*15*) analyzed SBs and the resultant SBMs from 10 commercial processing plants in the United States. While no differences existed in individual or total amino acids (TAA) concentrations of the SB, significant differences in these nutrients were noted in the SBM. This is due to differences in the stability of amino acids when exposed to heating. In that same study, SBM samples were collected from 55 different U.S. processing plants. Differences were noted in CP, TDF, and acid-hydrolyzed fat concentrations among SBM based on the region of the United States in which the SBs were grown and processed. While no similar survey for other countries has been published, it is safe to assume that similar or perhaps greater variations exist in the SBMs produced in these countries as well. Differences in SBM composition and quality will impact swine diet formulation practices, and the more accurate the compositional analysis, the more precise the dietary formulation and the better growth and feed efficiency response one might expect from swine. Some idea of the differences in composition can be obtained by subjective analyses of the SBM in question. For example, in the current study, SBM tended to be higher in nutrient concentrations and lower in antinutritional factors such as TDF with increases in subjective quality measures.

In conclusion, the composition of SB and SBM varied depending on the country of origin and where they were processed. When SBMs subjectively deemed to be of low, intermediate, and high qualities were evaluated, amino acid concentrations and protein solubility in KOH tended to improve as subjective quality increased. Chemical and biological assays of ingredient quality are useful in predicting the nutritive value of that ingredient for the animal itself, but in vivo ileal digestibility assays must be the standard to more accurately determine the bioavailability of amino acids in SBMs for pigs.

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