

EFFECTS OF ORIGIN ON THE NUTRITIONAL VALUE OF SOYBEAN MEAL

BY

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DISSERTATION

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ABSTRACT: To determine the effect of origin on the nutritional value of soybean meal (**SBM**) fed to growing pigs or broilers, 6 experiments were conducted. The sources of SBM used in Exp. 1, 2, and 3 were the same and were procured from crushing facilities throughout the U.S. For analysis, crushing plant locations were separated into 4 zones: 1) northern growing area (MI, MN, and SD), 2) eastern growing area (GA, IN, and OH), 3) western growing area (IA, MO, and NE), and 4) IL. The objective of Exp. 1 was to determine concentrations of DE, ME, and NE in SBM produced in different areas of the United States when fed to growing pigs. Results indicated that the SBM from Zone 2 had a tendency ($P < 0.10$) to have greater GE than SBM from Zones 1 and 3, and there was also a tendency ($P < 0.10$) for a greater concentration of ether extract in SBM from Zone 3 compared with the concentration of ether extract in SBM from Zone 4, but there were no differences among SBM from Zones 1, 2, and 3. The DE, ME, and NE were 4,343, 4,098, and 2,534 kcal/kg DM; 4,319, 4,117, and 2,497 kcal/kg DM; 4,135, 3,926, and 2,391 kcal/kg DM; and 4,248, 4,039, and 2,448 kcal/kg DM for SBM from Zones 1, 2, 3, and 4, respectively. The apparent total tract digestibility of GE were not different among diets containing SBM from the 4 zones. Regardless of growing area, GE, DE, ME, and NE were not different for SBM from the northern or eastern growing areas or from Illinois, but DE, ME, and NE were less ($P < 0.05$) in SBM from the western growing area. The objective of Exp. 2 was to determine the apparent ileal digestibility (**AID**) and standardized ileal digestibility (**SID**) of AA in SBM produced in different regions of the United States when fed to growing pigs. Results indicated there was a tendency ($P < 0.10$) for a reduction in the concentration of dispensable AA for SBM from Zone 2 compared with SBM from Zone 3. The concentration of CP in SBM from Zone 2 and 4 were greater ($P < 0.05$) than the CP for SBM from Zone 3, but not different from the CP of SBM from Zone 1. Soybean meal from Zone 4 had the least ($P < 0.05$) AID and SID

of CP compared with SBM from the other zones. There was also a tendency ($P < 0.10$) for SBM from Zone 3 to have a greater mean SID for all indispensable AA than SBM from the Zones 2 and 4. The average SID of dispensable AA and of total AA was also greater ($P < 0.05$) for SBM from Zone 3 compared with SBM from Zone 2. However, if calculated as g digestible AA per kg of SBM, very few differences were observed, indicating that the protein value is not different for SBM sourced from different regions of the U.S. The objective of Exp. 3 was 1) to determine if the area in which soybeans are grown influence the concentration of P, phytate, and macro- and micro-minerals in the SBM produced from the beans, and therefore, also influence the apparent total tract digestibility (**ATTD**) and standardized total tract digestibility (**STTD**) of P in SBM, and 2) to test the hypothesis that inclusion of microbial phytase will increase the ATTD and STTD of P in SBM. Results indicated that the total concentration of P was 0.63, 0.65, 0.67, and 0.64% for SBM from Zones 1, 2, 3, and 4, respectively, and there was a tendency ($P < 0.10$) for a reduced concentration of P in SBM from Zone 1 compared with SBM from Zone 3. There was an increase ($P < 0.05$) for ATTD and STTD of P when phytase was included in the diets, and there was also a tendency ($P < 0.10$) for SBM from Zone 3 to have values for ATTD and STTD of P that were less than SBM from Zone 4. The ATTD of Ca for SBM from Zone 2 was less ($P < 0.05$) compared with SBM from Zones 1 and 4, but was not different from that of SBM from Zone 3. The objective of Exp. 4 was to determine the AID and SID of AA by weanling pigs in 4 sources of fermented SBM (FSBM A, B, C, and D) and to compare these values to the digestibility of AA in conventional SBM, fishmeal, and poultry by-product meal (**PBM**). The CP in conventional SBM was 49.94% and ranged from 51.70 to 59.04% in the 4 sources of fermented SBM. The AID and SID of CP was greater ($P < 0.05$) in fermented SBM B compared with the other ingredients; however, conventional SBM and fermented SBM C and D had greater

($P < 0.05$) AID of CP compared with FSBM A, PBM, or fishmeal. The average AID and SID of indispensable AA, dispensable AA, and total AA in SBM and fermented SBM B and C were greater ($P < 0.05$) than in fermented SBM A and D, PBM, and fishmeal. It was concluded that concentrations of CP and AA are greater in fermented SBM than in conventional SBM, and AID and SID values may be greater in fermented SBM than in PBM and fishmeal. However, differences among sources of fermented SBM exist, which is likely a result of differences in processing conditions among sources of fermented SBM. Eight sources of SBM were used in Exp. 5 and 6, and these sources were procured from Argentina (2 sources; ARG1 and ARG2), Brazil (1 source), China (1 source), Thailand (1 source), and the United States (3 sources; US1, US2, and US3). The objectives of Exp. 5 and 6 were to determine the concentrations of nitrogen-corrected apparent metabolizable energy (**AMEn**) as well as AA digestibility in the 8 sources of SBM when fed to broiler chicks. Concentration of GE was 4,156, 4,154, 4,154, 4,123, 4,125, 4,190, 4,206, and 4,094 kcal/kg (as fed basis) for SBM from ARG1, ARG2, Brazil, China, Thailand, US1, US2, and US3, respectively. The concentrations of CP and total AA were 45.28 and 44.50%; 45.35 and 44.22%; 47.73 and 45.91%; 48.67 and 47.69%; 47.66 and 45.49%; 46.66 and 45.24%; 47.20 and 44.72%; and 47.18 and 46.22% for SBM from ARG1, ARG2, Brazil, China, Thailand, US1, US2, and US3, respectively. The AMEn was less ($P \leq 0.05$) in ARG1 and ARG2 compared with SBM from China, Thailand, US1, and US2. However, no differences in AMEn among SBM from China, Thailand, or the U.S. were observed. Soybean meal US3 had greater ($P < 0.05$) SID of total AA compared with SBM from US2 and Thailand, but the SID of total AA in the other 5 SBM sources was not different from that of US3. In conclusion, energy concentration was less for SBM produced in the western U.S. compared with SBM from other zones of the U.S., but the quantity and quality of protein in SBM was largely

unaffected by the zone in which the SBM was produced. Likewise, the zone in which SBM was produced did not impact concentrations of P or phytate and only minor differences in digestibility of P and Ca were observed. However, regardless of production area, the digestibility of P in SBM was increased if microbial phytase was included in the diet. Differences in AMEn and SID of AA were also observed from SBM sourced from different countries, with SBM from Argentina having the lowest digestibility of GE and AA among sources. In conclusion, origin of SBM may affect its nutritional value when fed to growing pigs or broilers.

Key words: broilers, composition, digestibility, pigs, soybean meal

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CHAPTER ONE: INTRODUCTION

Soybeans grown in different countries or different areas of the U.S. have different composition because of differences in environmental conditions or in soybean genetics. These differences impact the CP and total AA concentrations of soybean meal (**SBM**), but it is not known if the digestibility of GE, AA, and P is also influenced by the location where the soybeans were grown (Grieshop and Fahey, 2001; Karr-Lilienthal et al., 2004).

Differences in AA, CP, and lipid concentrations were observed in soybeans among and within Brazil, China, and the U.S. (Grieshop and Fahey, 2001). Ravindran et al. (2014) also reported differences in CP, lipids, and fiber concentrations among SBM from Argentina, Brazil, India, and the U.S., with SBM from Brazil having greater concentrations of CP than SBM from the U.S. or Argentina. The concentration of CP was less for SBM from the northern U.S. compared with SBM from the southern U.S., and the concentration of fat was greater for SBM from the southern U.S. compared with SBM from the northern U.S. (Grieshop et al., 2003). Frikha et al. (2012) reported that Brazilian SBM had greater concentrations of CP compared with American and Argentinian SBM, with the American SBM having intermediate concentrations of CP. Differences in CP were also reported among sources of SBM from different regions of Brazil, with greater CP for SBM produced in Goiás and Mato Grosso do Sul compared with other Brazilian states (Goldflus et al., 2006). However, Eklund et al. (2012) observed no differences in chemical concentrations or standardized ileal digestibility (**SID**) of AA among SBM from Argentina, Brazil, or the U.S.

Likewise, the SID of AA from SBM from China, India, and U.S. fed to pigs was not different, but the SID of AA for SBM from Argentina and Brazil was less than in the other sources (Karr-Lilienthal et al., 2004). Pigs fed SBM from the U.S. had improved G:F as well as

greater ADG compared with pigs fed SBM from Brazil or India, but no differences in ADG or G:F were observed for pigs fed SBM from Brazil or India (Wang et al., 2011). Pigs fed SBM from the U.S. also had greater apparent total tract digestibility of DM and N compared with pigs fed SBM from Brazil or India (Wang et al., 2011). Ravindran et al. (2014) observed a reduction in SID of AA for broilers fed SBM from India compared with broilers fed SBM from the U.S., Brazil, or Argentina, but there were no differences in the SID of most AA among SBM from the U.S., Brazil, or Argentina. The apparent metabolizable energy was less ($P < 0.05$) for broilers fed SBM from India compared with broilers fed SBM from the U.S. or Brazil (Ravindran et al., 2014).

Conventional SBM, or solvent-extracted dehulled SBM, is produced when fat is extracted from soy flour using a solvent and is also the premiere source of protein used in diets fed to growing, finishing, or reproducing pigs. Because of the presence of anti-nutritional factors (e.g., trypsin inhibitors, lignin, antigenic proteins, and oligosaccharides) in SBM, it is not tolerated well by weanling pigs, and causes a decrease in growth performance (Li et al., 1990, 1991; Friesen et al., 1993; Qin et al., 1996). A temporary reduction in growth performance may be a result of decreased nutrient digestibility caused by a transient hypersensitivity reaction to the oligosaccharides and antigenic proteins in SBM (Li et al., 1990). This transient hypersensitivity reaction causes villus atrophy in the small intestine (Li et al., 1990). In broiler chicks, differences in stachyose, raffinose, or fiber concentrations may also affect growth performance, with broilers fed SBM containing greater concentrations of these components experiencing lower digestibility compared with broilers fed SBM containing lower levels (Perryman et al., 2013). This may be due to indigestibility of these components, a reduction in gut transit time because of the larger fiber load (Perryman et al., 2013), or the inability of the young chick's immature

digestive tract being unable to handle the digestion of these components (Choct and Annison, 1990). Fermentation of SBM removes some antinutritional factors, such as oligosaccharides and antigenic proteins, allowing weanling pigs to better tolerate fermented SBM than conventional SBM (Min et al., 2004; Kim et al., 2007; Cervantes-Pahm and Stein, 2010; Rojas and Stein, 2013). Broiler chicks have also been reported to benefit from the inclusion of fermented SBM in the diet at the expense of conventional SBM during early stages of development (Hirabayashi et al., 1998; Wang et al., 2012).

While large amounts of data are available on the differences among sources of SBM, few studies have been conducted in vivo to determine the effect of origin on the nutritional value of SBM fed to pigs or poultry. Therefore, it is important to determine the effects of variation among growing zones and countries on energy and nutrient digestibility in SBM. The objective of this dissertation, therefore, is to determine effects of growing zones on the energy concentrations and digestibility, apparent ileal digestibility of CP and AA, **SID** of CP and AA, and standardized total tract digestibility of P in SBM fed to growing pigs. The second objective of this dissertation is to determine the effects of country on the nitrogen-corrected apparent metabolizable energy and the SID of AA of SBM fed to broilers.

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CHAPTER 2: NUTRITIONAL VALUE OF SOYBEAN MEAL: REVIEW OF LITERATURE

Soybeans (*Glycine max*) were domesticated by Chinese farmers during the Zhou Dynasty (1125 to 256 BCE) and have since spread throughout the world (Hymowitz, 1970). In 1765, the first soybean seeds were planted in the United States on a Georgia farm by Samuel Bowen (Hymowitz, 1970). These first soybean seeds were used to manufacture soy sauce, vermicelli, and sago powder substitute (Hymowitz, 1990). In 1851, soybeans were planted on farms in Illinois and later spread through the other Corn Belt states. During this time, soybeans were introduced as a feedstuff in poultry and swine feed. Scientific evaluations of the crop, however, did not begin until the late 19th century. During and after World War II, soybean production increased because soybean oil was used to replace imported fats and oils and to produce glycerin. The remaining soybean meal (**SBM**) was incorporated in livestock feed as a protein source. Following the war, the Marshall Plan, a program implemented by the United States after World War II to provide aid to Europe, used soybeans to feed the people of Europe during food shortages (DeConde et al., 2002).

Over the last 26 years, United States soybean production has increased from 52.9 million t to 83.2 million t (ASA, 2012). Currently, the United States, Brazil, Argentina, China, and India are the top ranked producers of soybeans in the world accounting for 90% of the world's soybean production (Table 2.1; ASA, 2012). In 2011, 63% of SBM produced in the United States was allocated to livestock feed (ASA, 2012). Today in the United States, SBM is the most commonly used protein source in swine diets (Shelton et al., 2001), which accounts for 25% of SBM usage in the United States (Table 2.2; Stein et al., 2008; ASA, 2012). Due to the large use

of SBM in livestock diets, SBM is the standard that all other sources of protein are measured against.

While SBM is the gold standard for sources of protein in livestock diets, it can be processed in several ways. Conventional SBM, which is solvent-extracted dehulled SBM, is produced when fat is extracted from the soy flour using a solvent (Stein et al., 2013). This solvent is usually hexane. To deactivate antinutritional factors, conventional SBM must be toasted prior to dietary inclusion. Expelled SBM is produced when soybean oil is expelled from extruded dehulled soybeans (Stein et al., 2013). Because the mechanical separation of fat from the soybeans is less effective than solvent extraction, expelled SBM contains more fat compared with conventional SBM. A relatively new product in the United States, enzyme-treated SBM, is produced when conventional SBM is treated with an enzyme blend to decrease the concentrations of oligosaccharides and antigenic proteins (Stein et al., 2013). The end result is a SBM that may be fed to weanling pigs. Fermented SBM is produced when conventional SBM is treated with the bacterium *Aspergillus oryzae* or other microbes to deactivate antinutritional factors (Stein et al., 2013). Because the antinutritional factors are deactivated, enzyme treated SBM and fermented SBM may be fed as a replacement for animal proteins to weanling pigs without negatively affecting growth.

ANTINUTRITIONAL FACTORS IN SOYBEAN MEAL

Soybeans contain several antinutritional factors that may decrease pig growth performance, such as trypsin inhibitors, lectins, antigenic proteins, and oligosaccharides (Cromwell, 2000). Trypsin is a pancreatic enzyme that aides in the digestion of dietary proteins. Trypsin inhibitors decrease protein digestibility by decreasing the activity of trypsin,

chymotrypsin, and other enzymes (Yen et al., 1977). The 2 trypsin inhibitors in soybeans are Kunitz Trypsin inhibitors (**KTI**) and Bowman-Birk inhibitors (**BBI**; Rackis, 1972), with KTI responsible for 83% to 91% of trypsin inhibitor activity in soybeans (Johnson et al., 1980). The BBI has a molecular weight (**MW**) of 7,900 with 7 disulfide bonds, and KTI has a MW of 21,500 with 2 disulfide bonds (Wolf, 1977). The BBI is more heat treatment resistant than KTI because the large disulfide bond to MW ratio stabilizes its protein conformation, and KTI is heat labile because of the decrease in the disulfide bond to MW ratio (Clemente et al., 2007). To inactivate BBI, the temperature must be greater than 100°C (Webster et al., 2003). When SBM is extruded, the temperature ranges between 143°C and 166°C, which inactivates KTI and BBI. When these trypsin inhibitors are inactivated, the apparent ileal digestibility (**AID**) of AA increases 15 percentage units (Herkelman et al., 1992). While KTI was identified in the late 1940's (Kunitz, 1947), the first low Kunitz soybean cultivar was not produced until the late 1960's (Singh et al., 1969). The low Kunitz soybean cultivar was superior to raw soybeans in growing pig diets and improved growth performance (Yen et al., 1974). In 1986, KTI was successfully eliminated from commercial soybean cultivars. Two trials were conducted to compare growth performance of pigs fed diets containing low KTI SBM with performance of pigs fed either high KTI SBM or conventional SBM (Cook et al., 1988). Growing pigs fed corn-based diets with low KTI SBM had increased ($P < 0.01$) ADG and G:F compared with pigs fed corn-based diets with high KTI SBM. However, these pigs had decreased ($P < 0.01$) ADG and G:F compared with pigs fed conventional SBM. Finishing pigs fed the corn-based diet with low KTI SBM also had increased ($P < 0.05$) ADG compared with pigs fed high KTI SBM and decreased ($P < 0.05$) ADG compared with pigs fed conventional SBM. However, the finishing pigs fed the low KTI SBM had G:F that was not different from that of pigs fed the high KTI

SBM. The difference among growing and finishing pigs may indicate that the response to KTI is age dependent. Results of further research has indicated that pigs fed low temperature-processed low-KTI soybeans had improved standardized ileal digestibility (**SID**) for CP and all AA except Trp and Pro, compared with pigs fed low temperature-processed conventional soybeans (Goebel and Stein, 2011a). However, pigs fed high temperature processed low KTI or high temperature-processed conventional soybeans have improved SID for CP and AA compared with pigs fed low temperature-processed low-KTI soybeans or low temperature-processed conventional soybeans, but no differences were observed for SID of CP and AA between pigs fed the 2 sources of high temperature soybeans. The decrease in ADG that was observed in the growth trials (Cook, et al., 1988) and the decrease in SID for CP and AA (Goebel and Stein, 2011a) indicate that other heat-labile antinutritional factors are present in soybeans that decrease pig growth and nutrient digestibility. As a consequence, low KTI SBM has not been incorporated into commercial diet formulations. It has, however, not been possible to eliminate these other factors from soybeans, and heat treatment is still necessary to maximize growth performance of pigs.

Several methods currently exist to test SBM for trypsin inhibitors. The direct analysis for total trypsin inhibitors is a good indicator for the presence of trypsin inhibitors in under-heated or raw SBM; however, when trypsin inhibitor levels are low or zero, it does not indicate if the SBM is overheated (Parsons, 2000). Trypsin inhibitor analyses are not generally used because they are time consuming, and 3 methods (i.e., AACC, 1969; Kakade et al., 1974; Hamerstrand et al., 1981) produce different results (Parsons, 2000). The standard AACC method (AACC 71-10; 1969) uses the synthetic substrate, benzoyl-DL-arginine-*p*-nitroanilide (**BAPA**) hydrochloride to determine the trypsin inhibitor activity of soy products. Kakade et al. (1974) also used BAPA to

determine trypsin inhibitor activity of soy products. This method used heated (37°C) BAPA mixed with the soy product extract. Expression of trypsin activity was determined to be an increase of 0.01 absorbance units at 410 nm per 10mL of BAPA mixed. Results were compared with a reagent blank that consisted of 30% acetic acid, trypsin, and water, but did not contain BAPA. Hamerstrand et al. (1981) used the Kakade et al. (1974) procedure; however, the equation to determine the concentration of trypsin inhibitors in the sample was modified due to concerns over erroneous values using the original mathematical method. Using the Hamerstrand et al. (1981) method resulted in a 20% increase in trypsin inhibitor activity compared with the Kakade et al. (1974) method.

Because trypsin inhibitor analyses are time consuming and produce inconsistent results, urease activity is sometimes used to determine SBM quality. Urease activity is measured using a urease assay (AOCS, 1973) or SOYCHEK (LSB Products, Memphis, TN). The urease assay (AOCS, 1973) indirectly determines urease activity by measuring the increase in pH from the release of ammonia from the urease enzyme (Parsons, 2000). The SOYCHEK is a simpler method than the AOCS (1973) method. SOYCHEK is a pH-sensitive-color indicator in liquid form used to determine the presence of urease (Parsons, 2000). If urease is present, the SBM sample turns red. When the liquid is poured over the SBM sample, the rate and intensity of color change indicates urease activity in under-heated or raw SBM. However, SOYCHEK is not a good indicator of overheated SBM, similar to the drawback of the analysis for total trypsin inhibitors.

Lectins, also known as hemagglutinins, adhere to red blood cells and mucosal cells of the intestine because they have a strong affinity for the carbohydrates on the cell surfaces (Wang, 2008). Once adhered to the mucosal cells of the intestine, lectins destroy the organization of

cells, reducing nutrient absorption and utilization capabilities. However, like trypsin inhibitors in soybeans, lectins can be denatured by heat during processing. The first variety of lectin-free soybeans was developed at the University of Illinois in the Department of Crop Sciences (Bernard and Nelson, 1996). The first feeding study was conducted in chicks and compared the nutritional value of raw lectin-free soybeans with raw KTI-free soybeans, raw conventional soybeans, and commercial heat processed SBM (Douglas et al., 1999). The chicks fed the raw lectin-free soybean diet had improved ADG and G:F compared with chicks fed the raw conventional soybeans. However, these chicks had poorer ADG and G:F compared with chicks fed the raw KTI-free soybean diet or the SBM diet. In research with pigs, it was observed that pigs fed lectin-free soybeans performed similarly to pigs fed KTI-free soybeans; however, they had reduced growth performance compared with pigs fed dehulled SBM, conventional soybeans, and lectin and KTI-free soybeans (Palacios et al., 2004). While pigs fed the lectin and KTI-free soybeans had improved growth performance compared with pigs fed lectin-free soybeans, KTI-free soybeans, or conventional soybeans, they had poorer growth performance than pigs fed the dehulled SBM. These studies indicate the presence of other antinutritional factors in soybeans that decrease pig growth and nutrient digestibility.

Antigenic proteins, such as β -conglycinin and glycinin, cause immune responses within the intestinal lumen of weanling pigs (Newby et al., 1984; Stokes et al., 1987; Li et al., 1990). The antigenic proteins present in soybeans can be reduced through fermentation or enzyme-treatment of the soybeans (Sissons, 1982). Fermented SBM is conventional SBM that has been inoculated with bacteria, such as *Aspergillus oryzae* or other microbes. The fermentation process deactivates antinutritional factors that negatively affect pig growth and health. Pigs fed increasing levels of fermented SBM (3.75% to 7.50%) have similar ADG and ADFI compared

with pigs fed increasing levels of select menhaden fish meal (3% to 6%) and pigs fed dehulled SBM; however, pigs fed increasing levels of fermented SBM had improved G:F (Jones et al., 2010; Kim et al., 2010). Pigs fed dried porcine solubles had increased ($P < 0.05$) ADG compared with pigs fed dehulled SBM or select menhaden fish meal (Jones et al., 2010), which was expected because animal proteins are more digestible than plant proteins and stimulate ADFI, and therefore, ADG.

A decrease in growth performance from d 0 to 14 was observed for weanling pigs fed diets containing dehulled SBM compared with those fed diets containing milk proteins (Friesen et al. 1993). Transient hypersensitivity in the intestine causing villus atrophy may be the main reason for the decrease in pig growth performance from d 0 to 14 if they are fed diets containing large quantities of SBM (Li et al., 1990). However, pigs fed the diets containing SBM had decreased ADFI, which will also reduce growth performance (Friesen et al., 1993). A few weeks after the introduction of antigenic proteins from soybeans in the diet, young pigs become acclimated to these proteins and are no longer negatively affected by them (Lallès, 2000).

Oligosaccharides, primarily stachyose and raffinose, are poorly digested carbohydrates that decrease energy utilization and increase flatulence in poultry and pigs (Rackis, et al., 1970; Leske et al., 1995). Unlike other antinutritional factors, oligosaccharides cannot be decreased or removed using heat treatment. However, low-oligosaccharide soybean varieties, with an 87% decrease in stachyose and raffinose concentrations, have been produced (Parsons et al., 2000). Broiler chicks fed corn-SBM-based diets containing low-oligosaccharide SBM, high-protein SBM, or conventional SBM had growth performance and nutrient digestibility that was not different (Baker et al., 2011). Pigs fed conventional soybeans had increased AID and SID for CP compared with pigs fed SBM (Baker et al., 2010). However, no differences were observed in

AID and SID for CP among pigs fed low oligosaccharide soybeans or high-protein soybeans compared with pigs fed conventional soybeans or SBM. The AID of AA, except Trp, was not different between conventional soybeans and low oligosaccharide soybeans. No differences were observed for AID of AA, except Lys, Phe, and Asp, for pigs fed conventional soybeans compared with pigs fed SBM. Furthermore, no differences in AID, except Cys, were observed for pigs fed high protein soybeans compared with pigs fed low oligosaccharide pigs. The SID of Met, Trp, and Cys was greater ($P < 0.05$) in pigs fed conventional soybeans compared with pigs fed either low oligosaccharide soybeans or high protein soybeans. The SID of AA in pigs fed high-protein soybeans was not different compared with pigs fed low oligosaccharide soybeans.

While heat treating SBM removes antinutritional factors, overheating of SBM causes a decrease in AA concentration and digestibility due to Maillard reactions (Ford, 1973; Qin et al., 1998; Gonzalez-Vega et al., 2011). Maillard reactions are non-enzymatic reactions catalyzed by heat treatment that causes the condensation of the NH_2 group of an AA with a reducing sugar (Grummer and Rabelo, 2000; Pahm et al., 2008). To determine if SBM is overheated, the Lys:CP ratio can be calculated or reactive Lys can be determined. The SBM is not heat damaged if Lys:CP is greater than or equal to 6%; however, SBM is heat damaged if the ratio is below 6% (Almeida, 2013). The protein solubility test (**KOH**) determines the amount of total N that is soluble in soybeans, and it is used to determine the level of heat damage that has occurred due to toasting (Paulsen, 2008). If heat damage has not occurred, the protein solubility index should be 73% or higher when 0.2% KOH is used (NOPA, 2007). The protein dispersibility index (**PDI**; American Oil Chemists Society, 1980) measures the solubility of protein in water to determine the optimum level of heat processing in soy products (Batal et al., 2000). The effectiveness of PDI was evaluated by comparing it with the effectiveness of the KOH solubility and urease tests

(Batal et al., 2000). Diets contained dehulled, solvent extracted soy flakes, which were autoclaved at 6 min intervals from 0 to 36 min at 121°C and a pressure of 105 kPa. The KOH solubility and urease tests did not have consistent responses, especially for the shorter autoclave times; however, the PDI tests were consistent regardless of the autoclave time and may be a better indicator of the minimum heating needed. The inconsistency in the KOH solubility and urease tests could be the main cause of inconsistency in the results for determining the maximum acceptable amounts of urease, or pH change, in soybean meal. However, typical pH change ranges from 0.05 to 0.2 (Balloun, 1980; Waldroup et al., 1985). Overall if a SBM had a PDI of 45% or less, it was found to be adequately heated (Batal et al., 2000). This value, however, is greater than the National Soybean Processors Association recommendation of a PDI between 15 and 30%. Autoclaving of SBM at 125°C for 15 to 30 min results in a decrease in Arg, Lys, and Cys concentrations and AID and SID of all AA compared with non-autoclaved or oven dried SBM (González-Vega et al., 2011). In heat treated SBM, color measurements using Minolta spectrophotometers may also be used to predict the digestibility of Lys. Oven drying the SBM at 125°C for 30 min resulted in a minimal decrease in AA concentration and digestibility (González-Vega et al., 2011). However, samples of SBM autoclaved for 15 min or 30 min were darker than samples of SBM that were oven dried at 125°C or not heated (González-Vega et al., 2011). The L* values in the SBM that was untreated, autoclaved for 15 min, or autoclaved for 30 min were 77.7, 61.8, and 52.5, respectively, and the a* values in the SBM that was untreated, autoclaved for 15 min, and autoclaved for 30 min were 3.4, 10.0, and 12.5, respectively. The decreased L* value and increased a* value indicate that the SBM became darker as time in the autoclave increased due to the increased occurrence of Maillard reactions. Results of other experiments have also indicated a linear decrease in the total Lys concentration and decreased

Cys and Arg concentrations in SBM when autoclaved at 125°C in 3 min intervals for 3 min to 30 min (Fontaine et al., 2007). The concentration of other indispensable AA remained unchanged when autoclaved at 125°C for up to 30 min. As the SBM was autoclaved for longer periods of time, the sample became browner, indicating the presence of Maillard reaction products (Fontaine et al., 2007). As Maillard reactions increased, the AA digestibility of the SBM, specifically of Lys, decreased (Chang et al., 1987; Fontaine et al., 2007; Boucher et al., 2009). This indicates that the pressure, moisture, and high temperature associated with autoclaving decreases the AID and SID of AA, whereas the high temperature and dry conditions associated with oven drying does not decrease AID and SID of all AA.

ENERGY AND NUTRIENT COMPOSITION

Currently, SBM is the most commonly used protein source in livestock feed (Stein et al., 2008). The nutrient and AA compositions of SBM complement the nutrient and AA compositions of corn (Tables 2.3 and 2.4; Baker, 2000). Soybean meal is rich in Lys and Trp and deficient in sulfur AA; however, corn is rich in sulfur AA and deficient in Lys and Trp (Baker, 2000).

Due to a decrease in growing days and hours of sunlight, soybeans produced in the Northern United States have a in N fixing within the soybean plant; therefore, causing a decrease in CP concentration compared with soybeans grown further south (Dudley-Cash, 1999). Traditional CP assays measure the N content of the sample; therefore, samples from the Northern United States contain less CP compared with samples from other parts of the United States. However, the CP of SBM produced in the Northern United States may contain more indispensable AA, making it a higher quality protein (Grieshop et al., 2003).

Soybean meal from the United States and Europe has a greater concentration of CP and decreased concentration of crude fiber compared with SBM from other countries (Park and Hurburgh, 2002). Pigs fed SBM from the United States had improved G:F as well as increased ADG and final BW compared with pigs fed SBM from Brazil or India; however, there were no differences in ADG, final BW, and G:F for pigs fed SBM from Brazil or India (Wang et al., 2011). Pigs fed SBM from the United States had greater ($P < 0.01$) ATTD of DM and N compared with pigs fed SBM from Brazil or India; however, no differences were observed in ATTD of DM and N for pigs fed SBM from Brazil or India. The SBM from the United States had a greater KOH protein solubility and decreased concentration of crude fiber and ether extract compared with SBM from Brazil and China. The increase in crude fiber of the SBM from Brazil and China may explain the decrease in ATTD and growth performance (Karr-Lilienthal et al., 2004). Pigs fed SBM from India had decreased true digestibility of CP, which may cause a decreases in the concentration of AA available to the pigs and; therefore, result in decreased growth performance (Wang et al., 2011).

AMINO ACID DIGESTIBILITY

The SID of Lys and Trp in SBM is greater compared with canola meal and corn DDGS, and the digestibility of sulfur AA is greater in SBM than in canola meal and corn DDGS (Gonzalez-Vega et al., 2012; NRC, 2012). Soybean meal contains more CP (47.7%) compared with canola meal and corn DDGS (37.5% and 27.4%, respectively; Table 2.5). Soybean meal contains less ether extract than canola meal and corn DDGS; however, it also contains less crude fiber. Therefore, SBM supplies more energy to pigs compared with canola meal and corn DDGS because the energy is more digestible.

The SID of indispensable AA in SBM ranges from 85.4% for Thr to 95.2% for Arg (Table 2.6). Variation in SID of AA among sources of SBM may be due to antinutritional factors, heat damage, concentration of fiber, or differences in voluntary feed intake (Almeida and Stein, 2012). However, the variation in SID values for AA is less among sources of SBM than among sources of most other protein ingredients (NRC, 2012).

Because full-fat soybeans contain more lipids, it is expected to have a greater digestibility of AA compared with SBM (Cromwell, 2000; Zarkadas and Wiseman, 2005). However, the AA digestibility in full-fat soybeans can be affected by the type of soybeans used and the concentration of protein present, especially with the introduction of high protein soybeans (Cervantes-Pahm and Stein, 2008). The effect of adding soybean oil to SBM fed to pigs on the SID of CP and AA has been reported (Cervantes-Pahm and Stein, 2008). Pigs fed SBM with soybean oil had greater ($P < 0.05$) SID of CP and most AA compared with pigs fed SBM without soybean oil, which may be a result of the fat causing a decrease in the rate of gastric emptying, as well as a decrease in the rate of passage in the small intestine (Valaja and Siligander-Rasi, 2001). This allows for greater absorption of the AA and peptides from the SBM (Zhao et al., 2000).

As particle size decreases, digestibility of a feed ingredient increases because of an increase in surface area and an improvement in feed efficiency (Owsley et al., 1981; Wondra et al., 1995a, b, c, d). The average particle size of SBM is 800 to 900 μm (Fastinger and Mahan, 2003). Growing-finishing pigs were fed dietary treatments containing SBM at 4 different particle sizes (185, 329, 600, or 949 μm) to determine the digestibility of AA and energy using ileal digestibility techniques (Fastinger and Mahan, 2003). As particle size decreased, the AID of Ile, Met, Phe, and Val increased ($P < 0.05$); however, there was only a tendency for an

increase ($P < 0.10$) in AID for all dispensable AA and the remaining indispensable AA.

However, the greatest improvement in AA digestibility occurred when particle size decreased from 949 to 600 μm . The digestibility of energy in SBM was not different among the different particle sizes, with only a 1.0% increase in the digestibility of energy as particle size decreased.

With the addition of soy hulls to SBM, a decrease in digestibility of DM, CP, and GE is expected because soy hulls contain insoluble non-starch polysaccharides, which are primarily made up of cellulose (Kornegay, 1978; Lo, 1989). The decrease in digestibility is observed at inclusion levels of soy hulls as low as 15% (Mitaru et al., 1984). Growing pigs were fed diets containing dehulled SBM with increasing levels of soy hulls (0, 3, 6, or 9%) to determine the effects of soy hulls on the ileal digestibility of N and AA of SBM (Dilger et al., 2004). The AID of N was similar among all dietary treatments; however, the AID of DM and GE decreased (linear, $P < 0.05$) as the level of soy hulls increased. The increase in soy hulls also caused a decrease (linear, $P < 0.05$) in AID for Arg, His, Lys, Phe, Asn, Ser, and Tyr. Increased concentrations of soy hulls also caused a decrease in AID for Ile (quadratic, $P < 0.05$). On average, a 1% increase in soy hulls caused a 0.18% decrease in the AID for Arg, His, Ile, Lys, Phe, and Trp. Pigs fed FSBM had AID of DM, CP and all indispensable AA, except Lys, that was not different from values obtained from pigs fed SBM or ESBM (Cervantes-Pahm and Stein, 2010). Pigs fed FSBM or SBM had decreased ($P < 0.05$) SID of CP compared with pigs fed ESBM. Pigs fed FSBM had decreased SID of Lys compared with pigs fed SBM or ESBM. The decrease in Lys digestibility may be from heat damage during processing.

The AA profile and CP quality of soybeans are dependent on processing conditions; however, the conditions of the soil, location, and environment during growing and harvesting also play a part in the AA profile and CP quality of the soybeans (Goldflus et al., 2006; Thakur

and Hurburgh, 2007). Broilers were fed diets containing SBM from the United States, Brazil, or Argentina to determine the influence of origin on the digestibility of AA and CP in 22 samples of SBM (Frikha et al., 2012). Broilers fed SBM from the United States had increased ADFI and improved G:F ($P < 0.05$) compared with broilers fed SBM from Brazil or Argentina. Broilers fed SBM from the United States or Brazil had similar AID and SID for several indispensable AA; however, broilers fed SBM from the United States or Brazil had increased ($P < 0.05$) AID and SID for several indispensable AA when compared with broilers fed SBM from Argentina. Growing-finishing pigs were fed diets containing SBM from the United States, Brazil, and India to determine the influence of origin on growth performance and nutrient digestibility (Wang et al., 2011). Pigs fed SBM from the United States had increased ($P < 0.05$) ADG and G:F compared with pigs fed SBM from Brazil or India; however, ADFI was not different among sources. Pigs fed SBM from Brazil had ADG, ADFI, and G:F that were not different from that of pigs fed SBM from India. Pigs fed SBM from the United States had an increase ($P < 0.01$) in AID of DM and N compared with pigs fed SBM from Brazil or India. The increase in growth performance and nutrient digestibility for pigs and poultry fed SBM from the United States may be due to an increase in the concentration of CP and a decrease in the concentration of crude fiber in SBM from the United States compared with SBM from other countries (Park and Hurburgh, 2002).

The SID of CP of SBM from the United States was greater compared with SBM from Argentina (Goerke et al., 2012). The SID of CP of SBM from Brazil was intermediate to the SID of CP of SBM from the United States or Argentina. The SID of indispensable AA, except Trp, of SBM from Brazil or the United States was not different, and with the exception of Arg, Phe, and Trp, the SID of indispensable AA in SBM from Argentina and the United States was

not different. The SID of all dispensable AA, except Asp and Gly, of SBM from Brazil or the United States was not different, and with the exception of Asp, Gly, and Ser, the SID of dispensable AA was not different in SBM from Argentina and the United States.

ENERGY DIGESTIBILITY

The average concentration of GE in SBM is 4,212 kcal/kg (Table 2.7), and the average concentrations of DE, ME, and NE are 3,588 kcal/kg, 3,285 kcal/kg, and 2,021 kcal/kg, respectively. The GE in SBM is greater than the GE in corn, which is 3,933 kcal/kg; however, values for DE and ME in SBM (3,588 kcal/kg and 3,285 kcal/kg, respectively) are close to the values for corn (3,451 kcal/kg and 3,395 kcal/kg, respectively; NRC, 2012). The NE of corn (2,672 kcal/kg) is greater than the NE of SBM (2,021 kcal/kg; NRC, 2012). The apparent total tract digestibility (**ATTD**) of energy in corn is approximately 90.4%, whereas the ATTD of energy in SBM is approximately 87.9% (Pedersen et al., 2007).

PHOSPHORUS DIGESTIBILITY

Phosphorus provides skeletal support and is also important in lipid transport and metabolism, and cell-membrane structure (Pond et al., 2005). The total P concentration is the sum of phytate bound P, inorganic P, and other P in the SBM. Phytate, or phytic acid, is a cyclic compound with 6 P groups attached to a central 6-carbon ring that is nutritionally unavailable to pigs and poultry because they produce little phytase in their gastrointestinal tracts (Paulsen, 2008). An increase in phytate bound P in soybeans decreases the concentration of inorganic P, therefore, decreasing the absorption of P in the small intestine and ultimately, decreasing its digestibility (Erdman, 1979). Because of the decrease in P absorption, greater amounts of

phytate-bound P will result in an increase in the concentration of P in the feces. Phytate-bound P also binds to Zn, Ca, Mg, Mn, K, and Fe, which renders these minerals nutritionally unavailable to pigs and increases their concentrations in the feces (Paulsen, 2008). Soybeans contain 1 to 2% phytic acid (Deak and Johnson, 2007), which results in approximately two-thirds of the P in soybeans being bound to phytate (Table 2.3; Paulsen, 2008). As a consequence, the digestibility of P by pigs is relatively low.

Phytase is an enzyme that converts phytic acid to orthophosphate, inositol, and other phosphorus-inositol intermediates to increase the amount of P available to the pig (Swick and Ivy, 1992). Addition of microbial phytase decreases the concentration of fecal P by 35% (Simons et al., 1990), and increases ATTD and standardized total tract digestibility (**STTD**) of P (Almeida and Stein, 2010). Because phytase increases P digestibility, supplementation of dietary P can be reduced, therefore, decreasing the amount of P excreted in the feces by 30% to 60% (Nasi, 1990; Jongbloed et al., 1992; Lei et al., 1993a).

The concentration of P in SBM ranges from 0.6 to 0.7% and the ATTD of P in SBM ranges between 38.0 and 41.6% (Table 2.3). These values are greater than those for corn (Bohlke et al., 2005; Rostagno et al., 2011; NRC, 2012). Of the total P in SBM, approximately 0.40% is bound to phytate and 0.2 to 0.3% P is non-phytate P. Increasing levels of dietary phytase results in a quadratic increase in apparent digestibility of P with the greatest improvement in digestibility occurring when 500 units/kg of phytase is added to the diets (Traylor et al., 2001). However, it has also been reported that ATTD of P increased linearly when diets were supplemented with increasing levels of phytase between 0 units/kg and 1,000 units/kg (Akinmusire and Adeola, 2009). An increase ($P < 0.001$) in ATTD of P was also

observed for pigs fed diets supplemented with phytase compared with those fed diets without phytase (Goebel and Stein, 2011b; Rojas and Stein, 2012).

Weanling pigs may be fed ESBM or FSBM because of the low concentration of antinutritional factors in these sources of SBM. The ADFI, DMI, and ATTD of DM are not different between ESBM and SBM; however, the P output in feces is decreased in pigs fed ESBM (Goebel and Stein, 2011). The ATTD of P is also greater ($P < 0.01$) in pigs fed ESBM compared with pigs fed SBM. The total concentration of P is greater in FSBM than SBM; however, the concentration of phytate is decreased in FSBM (Rojas and Stein, 2012). This caused a decrease in the concentration of P bound to phytate in FSBM, and therefore, an increase ($P < 0.01$) in the ATTD and STTD of P without and with microbial phytase in the diet. However, phytase increased the ATTD and STTD of P more in pigs fed SBM compared with those fed FSBM.

Because the large intestine does not absorb P or have endogenous losses of P, AID values of P are not different from values for the ATTD of P (Fan et al., 2001; Bohlke et al., 2005; Dilger and Adeola, 2006). Due to the reduced cost and difficulty of determining total tract digestibility of P, ATTD values are determined more frequently than AID values (Almeida and Stein, 2010).

The ATTD of P is dependent on the concentration of P in the diet (Fan et al., 2001). The 2 types of endogenous losses that can be observed are diet specific endogenous losses and basal endogenous losses, and total endogenous losses consist of the sum of these 2 sources (Stein, 2011). Basal endogenous losses represent the total P that is lost from the pig without regard to diet; however, it is affected by the DMI of the diet (Stein et al., 2007) with an average value of 200 mg/kg DMI in pigs (Stein, 2011). Because the values for ATTD of P are affected by the

concentration of dietary P (Fan et al., 2001), the values for ATTD of P are corrected for basal endogenous P to calculate STTD of P. Unlike values for ATTD, values for STTD of P are additive in mixed diets. Basal endogenous losses are relatively constant among experiments and do not have to be determined in each experiment to calculate values for STTD. Instead, values for ATTD can be corrected using the average basal endogenous losses (200 mg/kg of DMI) to estimate STTD of P.

CALCIUM DIGESTIBILITY

Metabolism of Ca is closely linked to that of P, and regulated by parathyroid hormone, vitamin D, and calcitonin. Calcium plays an important role in skeletal support with 99% of Ca stored in the bones and teeth (Pond et al., 2005). Calcium also functions in regulating cellular metabolism. A decrease in Ca concentration increases nerve and muscle excitability, and an increase in Ca concentration decreases nerve and muscle excitability.

Dehulled SBM contains an average of 0.33% Ca, making the Ca level in SBM greater than in corn (Bohlke et al., 2005; Rostagno et al., 2011; NRC, 2012). Like P, the large intestine does not absorb or have endogenous losses of Ca, which means that AID and ATTD values are not different (Partridge, 1978; Bohlke et al., 2005). The concentration of Ca in SBM ranges from 0.20% to 0.70%, and the ATTD of Ca in SBM is 46.7% (Table 2.3; Bohlke et al., 2005). One mol of phytic acid binds to 3 to 6 mol of Ca, rendering it unavailable to the pig (Kornegay, 1996); however, adding phytase to the diet increases Ca digestibility because it hydrolyzes the phytic acid complexes that bind the Ca (Nasi, 1990; Lei et al., 1993b). This indicates that the concentration of Ca bound to the phytic acid in SBM is released by phytase. Adding phytase to diets containing SBM increases Ca absorption more than adding phytase to diets containing

FSBM (Rojas and Stein, 2012). The ATTD of Ca is decreased ($P < 0.05$) in pigs fed FSBM compared with pigs fed SBM; however, ATTD of Ca was increased ($P < 0.05$) when phytase was added to the diets. The ATTD of Ca in pigs fed ESBM is decreased ($P < 0.05$) compared to pigs fed SBM (Goebel and Stein, 2011). The Ca absorption increased when phytase was added to both diets.

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TABLES

Table 2.1. Top 5 soybean producing countries 2008-2013^{1, 2}

Item	2008	2009	2010	2011	2012	2013
United States	72.9 (33%)	80.7 (38%)	90.6 (35%)	83.2 (33%)	82.0 (31%)	89.5 (32%)
Brazil	61.0 (28%)	57.0 (27%)	70.0 (27%)	72.0 (29%)	83.5 (31%)	87.5 (31%)
Argentina	46.2 (21%)	32.0 (15%)	49.5 (19%)	48.0 (19%)	51.5 (19%)	54.0 (19%)
China	14.0 (6%)	15.5 (7%)	15.2 (6%)	13.5 (5%)	12.8 (5%)	12.2 (4%)
India	9.3 (4%)	9.1 (4%)	9.6 (4%)	11.0 (4%)	11.5 (4%)	11.0 (4%)
Total	203.4 (92%)	194.3 (91%)	234.9 (91%)	227.7 (90%)	238.6 (90%)	254.2 (90%)

¹American Soybean Association Soy Stats 2009-2014; Soyatech (2014).

²Units are expressed as million t (percent of world soybean production).

Table 2.2. Soybean meal (million t) fed to livestock in the United States 2008-2013^{1,2}

Item	2008	2009	2010	2011	2012	2013
Poultry	13.8 (48%)	11.6 (48%)	11.6 (49%)	11.9 (48%)	13.2 (49%)	13.3 (50%)
Swine	7.5 (26%)	6.3 (26%)	6.1 (25%)	6.3 (25%)	7.0 (26%)	6.9 (26%)
Beef	3.6 (12%)	3.0 (12%)	3.0 (12%)	3.0 (12%)	3.1 (11%)	2.9 (11%)
Dairy	2.5 (9%)	2.1 (9%)	2.0 (8%)	2.1 (9%)	2.3 (9%)	2.1 (8%)
Pet food	0.7 (2%)	0.6 (2%)	0.6 (3%)	0.6 (3%)	0.6 (2%)	0.7 (2%)
Other	0.9 (3%)	0.8 (3%)	0.8 (3%)	0.8 (3%)	0.7 (3%)	0.6 (3%)
Total	29.0 (100%)	24.4 (100%)	24.1 (100%)	24.7 (100%)	27.1 (100%)	26.5 (100%)

¹American Soybean Association Soy Stats 2009-2014.

²Units are expressed as million t (% of US SBM used by livestock species).

Table 2.3. Concentration of DM and macronutrients and digestibility of P in dehulled soybean meal¹

Item, %	Average	Least value	Greatest value	SD
DM	88.71	87.32	89.98	1.06
CP	47.91	47.22	48.36	0.44
Crude fiber	4.04	3.89	4.19	0.21
Fat	1.24	0.83	1.52	0.32
Ash	6.00	5.70	6.30	0.33
NDF	8.73	6.14	14.93	3.56
ADF	6.05	3.87	12.28	3.52
Ca	0.37	0.23	0.56	0.11
Total P	0.66	0.60	0.72	0.05
Phytate P	0.40	0.38	0.43	0.02
Non-phytate P ²	0.25	0.20	0.33	0.06
ATTD ³ P	39.53	38.00	41.60	1.86
STTD ³ P	47.05	46.10	48.00	1.34

¹Data from Bohlke et al., 2005; Baker and Stein, 2009; Rostagno et al., 2011; Goebel and Stein, 2011b; Rojas and Stein, 2012; NRC, 2012.

²Non-phytate P = total P - phytate P (Rojas and Stein, 2012).

³ATTD = Apparent total tract digestibility; STTD = standardized total tract digestibility.

Table 2.4. Amino acid composition of dehulled soybean meal¹

Item, %	Average	Least value	Greatest value	SD
Indispensable AA				
Arg	3.50	3.22	3.63	0.14
His	1.26	1.13	1.32	0.06
Ile	2.20	1.92	2.36	0.13
Leu	3.68	3.36	3.88	0.16
Lys	3.03	2.91	3.20	0.11
Met	0.68	0.63	0.76	0.04
Phe	2.34	1.56	2.51	0.32
Thr	1.89	1.73	2.08	0.10
Trp	0.68	0.65	0.73	0.03
Val	2.30	1.92	2.45	0.16
Dispensable AA				
Ala	2.58	1.95	5.20	1.28
Asp	5.37	5.16	5.65	0.18
Cys	0.67	0.52	0.73	0.07
Glu	8.58	8.39	8.85	0.16
Gly	2.00	1.93	2.06	0.06
Pro	2.45	2.38	2.55	0.08
Ser	2.26	1.92	2.69	0.27
Tyr	1.68	1.58	1.78	0.08

Table 2.4 (Cont.)

¹Data from Stein et al., 2001; Traylor et al., 2001; Bohlke et al., 2005; Baker and Stein, 2009; Goebel and Stein, 2011b; Rostagno et al., 2011; Rojas and Stein, 2012; NRC, 2012.

Table 2.5. Concentration of dry matter, macronutrients, and amino acids in canola meal, corn distillers dried grains with solubles (DDGS), soybean meal, and dehulled sunflower meal¹

Item, %	Canola meal	Corn DDGS	Soybean meal	Sunflower meal
DM	91.33 ± 2.40	89.35 ± 1.55	89.98 ± 2.62	90.40 ± 0.14
CP	37.50 ± 3.01	27.36 ± 2.00	47.73 ± 2.30	39.86 ± 4.78
Crude fiber	10.50 ± 1.59	8.92 ± 1.38	3.89 ± 1.60	18.44 ± 2.53
Ether Extract	3.22 ± 1.23	8.71 ± 0.46	2.86 ± 0.91	2.90 ²
Ash	6.89 ± 0.84	4.04 ± 1.00	6.27 ± 0.51	6.06 ± 0.89
Ca	0.69 ± 0.10	0.08 ± 0.07	0.33 ± 0.10	0.39
P	1.08 ± 0.07	0.60 ± 0.20	0.71 ± 0.09	1.16
Amino Acids				
Arg	2.28 ± 0.57	1.23 ± 0.16	3.45 ± 0.26	3.32 ± 0.27
His	1.07 ± 0.25	0.74 ± 0.08	1.28 ± 0.10	0.93 ± 0.10
Ile	1.42 ± 0.14	1.06 ± 0.09	2.14 ± 0.18	1.54 ± 0.18
Leu	2.45 ± 0.27	3.25 ± 0.44	3.62 ± 0.27	2.47 ± 0.11
Lys	2.07 ± 0.33	0.90 ± 0.13	2.96 ± 0.19	1.45 ± 0.10
Met	0.71 ± 0.18	0.57 ± 0.11	0.66 ± 0.08	0.78 ± 0.17
Phe	1.48 ± 0.24	1.37 ± 0.16	2.40 ± 0.19	1.63 ± 0.23
Thr	1.55 ± 0.38	0.99 ± 0.06	1.86 ± 0.11	1.37 ± 0.06
Trp	0.43 ± 0.10	0.20 ± 0.03	0.66 ± 0.08	0.48 ± 0.04
Val	1.78 ± 0.21	1.39 ± 0.12	2.23 ± 0.19	1.76 ± 0.21
Ala	1.61 ± 0.22	2.13 ± 0.30	2.06 ± 0.16	1.63 ± 0.09
Asp	2.56 ± 0.22	2.01 ± 0.26	5.41 ± 0.46	3.55 ± 0.21

Table 2.5 (Cont.)

Item, %	Canola meal	Corn DDGS	Soybean meal	Sunflower meal
Cys	0.86 ± 0.12	0.44 ± 0.06	0.70 ± 0.08	0.48 ± 0.21
Glu	6.35 ± 0.94	5.35 ± 0.83	8.54 ± 1.19	8.25 ± 0.74
Gly	1.80 ± 0.25	1.13 ± 0.09	1.99 ± 0.20	2.09 ± 0.13
Pro	2.02 ± 0.78	2.36 ± 0.31	2.53 ± 0.41	2.01 ± 0.61
Ser	1.49 ± 0.24	1.40 ± 0.20	2.36 ± 0.23	1.66 ± 0.10
Tyr	1.06 ± 0.22	1.22 ± 0.16	1.59 ± 0.20	0.81 ± 0.17

¹Data from NRC, 2012.

²Values without standard deviations were single means.

Table 2.6. Standardized ileal digestibility (SID) of crude protein and amino acids in dehulled soybean meal

Item, %	Average	Least value	Greatest value	SD
CP	88.05	87.00	90.40	1.58
Indispensable AA				
Arg	95.20	94.00	96.20	1.03
His	91.20	90.00	92.70	1.17
Ile	88.43	88.00	89.00	0.42
Leu	88.13	87.50	88.90	0.58
Lys	90.28	89.00	91.90	1.20
Met	89.03	86.10	90.70	2.03
Phe	88.53	88.00	89.30	0.57
Thr	85.38	83.60	87.40	1.57
Trp	92.00	91.00	93.80	1.56
Val	86.03	83.40	87.00	1.75
Dispensable AA				
Ala	84.85	83.40	86.00	1.08
Asp	87.05	86.00	87.90	0.79
Cys	84.25	92.20	87.80	2.48
Glu	89.14	87.70	90.40	1.12
Gly	86.43	84.00	88.20	1.92
Pro	114.48	107.80	122.70	6.17
Ser	89.25	87.60	91.40	1.58

Table 2.6 (Cont.)

Item, %	Average	Least value	Greatest value	SD
Tyr	88.88	88.00	90.00	0.83

¹Data from Bohlke et al., 2005; Stein et al., 2005; Baker and Stein, 2009; NRC, 2012.

Table 2.7. Concentration and digestibility of energy (kcal/kg) in dehulled soybean meal¹

Item	Average	Least value	Greatest value	SD
GE, kcal/kg	4,212	4,132	4,313	71.3
DE, kcal/kg	3,588	3,418	3,779	126.3
ME, kcal/kg	3,285	3,201	3,410	69.5
NE, kcal/kg	2,021	1,935	2,087	78.1
ATTD of energy, % ²	87.9	87.2	88.5	0.9

¹Data from Woodworth et al., 2001; Bontems et al., 2004; Baker and Stein, 2009;

Goebel and Stein, 2011b; Rostagno et al., 2011; Rojas and Stein, 2012; NRC, 2012.

²ATTD = apparent total tract digestibility.

CHAPTER 3: CONCENTRATION OF DIGESTIBLE, METABOLIZABLE, AND NET ENERGY IN SOYBEAN MEAL PRODUCED IN DIFFERENT AREAS OF THE UNITED STATES AND FED TO PIGS

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 U.S. For analysis, crushing plant locations were separated into 4 zones: 1) northern growing area (MI, MN, and SD), 2) eastern growing area (GA, IN, and OH), 3) western growing area (IA, MO, and NE), and 4) IL. 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 was 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 (2,391 kcal/kg DM), but the NE of SBM from Zone 4 (2,448 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

INTRODUCTION

Soybean meal (**SBM**) is the most used AA source in swine diets in the U.S. (Shelton et al., 2001) and pigs consume approximately 26% of all SBM produced in the U.S. (Stein et al., 2008; ASA, 2014). In addition to providing AA to the diets, SBM also provides energy to the diets 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, 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 is recognized that the chemical composition of soybeans and SBM varies depending on where in

the U.S. the beans were grown because CP concentration in soybeans grown in the northern U.S. is less than in beans grown further 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 from soybeans grown in different areas of the U.S. have different concentrations of DE, ME, and NE.

MATERIALS AND METHODS

Soybean Meals, Animals, and Experimental Design

Twenty-two sources of SBM were procured from crushing facilities in different regions of the U.S. (Tables 3.1 and 3.2). 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 sub-sampled, labeled, and stored. For analysis, the crushing plant locations were separated into 4 zones: 1) northern growing area (MI, MN, and SD; 4 samples), 2) eastern growing area (GA, IN, and OH; 6 samples), 3) western growing area (IA, MO, and NE; 7 samples), and 4) IL (5 samples). 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 3.3 and 3.4). 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. Corn-SBM diets were formulated to 18% 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 ($197 \text{ kcal ME/kg}^{0.60}$; 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 being fed in the morning meal on d 8, and the second marker being fed in the morning of d 13 (Adeola, 2001). Urine was collected in urine buckets over a preservative of 50 mL of 3N HCl from d 8 to d 13. Fecal samples and 20% of the collected urine were stored at -20°C immediately after collection.

Chemical Analyses

At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a sub-sample was lyophilized (Kim et al., 2009). Fecal samples were thawed and mixed within pig and diet and a subsample was lyophilized and finely ground prior to 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 Int., 2007), CP (Method 990.03; AOAC Int., 2007), ash (Method 942.05; AOAC Int., 2007), ADF (Method 973.18; AOAC Int., 2007), NDF (Holst, 1973), and lignin (Method 973.18 (A-D); AOAC Int., 2007). Single samples of corn and SBM were analyzed for AA [Method 982.30 E (a, b, c); AOAC Int., 2007]. Duplicate samples of corn and SBM were also analyzed acid hydrolyzed ether extract (Method 2003.06; AOAC Int., 2007), ether extract (Method 920.39; AOAC Int., 2007), Ca (Method 985.01 A, B, and C; AOAC Int., 2007), P (Method 985.01 A, B, and C; AOAC Int., 2007), and starch (Method 979.10; AOAC Int., 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: $NE = (0.700 \times DE) + (1.61 \times EE) + (0.48 \times \text{starch}) - (0.91 \times CP) - (0.87 \times ADF)$, 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 difference as outlined for DE and ME values (Adeola, 2001).

Data were analyzed using pig as the experimental unit. Analysis of variance was used with the PROC MIXED function in SAS (SAS Institute 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. 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 GE concentration of corn was 3,965 kcal/kg (as-fed basis), and the GE was 4,165, 4,209, 4,162, and 4,198 kcal/kg (as-fed basis) for SBM from Zones 1, 2, 3, and 4, respectively. The SBM from Zone 2 had a tendency ($P = 0.08$) to have greater GE than SBM from Zones 1 and 3, but DM was not different among zones. The concentration of CP in corn was 9.52% (as-fed basis), and the average concentration of CP in SBM was 47.41% (as-fed basis). The concentration of CP in SBM from Zones 2 and 4 were greater ($P < 0.05$) than the CP for SBM from Zone 3, but not different from the CP of SBM from Zone 1. The concentration of acid hydrolyzed ether extract in SBM from Zone 3 was greater ($P < 0.05$) than the concentration in SBM from Zones 2 and 4, but not different from that in SBM from Zone 1. There was a tendency ($P < 0.10$) for a greater concentration of ether extract in SBM from Zone 3 compared with the concentration of ether extract in SBM from Zone 4, but there were no differences among SBM from Zones 1, 2, and 3. Concentrations of ADF, NDF, and lignin were not different among SBM from Zones 1, 2, 3, and 4, but the ash content was less ($P < 0.05$) in SBM from Zone 2 than in SBM from the other zones. The concentrations of Ca and P in SBM from Zone 3 tended ($P = 0.06$) to be greater than Ca and P in SBM from Zone 1, but concentrations of trypsin

inhibitors and starch were not different among zones. No glucose or fructose was detected in the SBM, and the concentration of maltose was not different among SBM from the 4 zones. Sucrose concentration was greater ($P < 0.05$) in SBM from Zone 1 compared with the concentration of sucrose in SBM from Zone 4, but not different from the SBM from the other zones. A tendency ($P = 0.06$) for an increase in raffinose concentration was observed for SBM from Zones 3 and 4 compared with from Zone 1, but there were no differences among SBM in the concentration of stachyose.

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 3.5). 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. The ME for diets containing SBM from Zone 2 was also greater ($P < 0.05$) than for diets containing SBM from Zone 3, but the ME of diets containing SBM from Zones 1 and 4 were not different from the ME of the other diets.

There was a tendency ($P = 0.09$) for ATTD of GE in SBM from Zone 1 to be greater than the ATTD of GE for SBM from Zone 3, but ATTD of GE in SBM from Zone 4 was not different from that of SBM from the other zones (Table 3.6). The DE, ME, and NE of SBM from Zones 1 and 2 were greater ($P < 0.05$) than the DE, ME, and NE of SBM from Zone 3, but the DE, ME, and NE in SBM from Zone 4 was not different from that of SBM from 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 U.S. (USDA, 2015). Thus, U.S. production accounted for 31.7% of the global soybean production, making the U.S. the top soybean producer in the world (ASA, 2014). Approximately 51% of the soybeans harvested in the U.S. 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 U.S., 73% (27 million t) was fed to livestock, and most of the remaining 27% was exported (ASA, 2014). The total usage of SBM in pig diets in the U.S. 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. As a consequence, having a correct energy value for SBM is important.

The 22 sources of SBM that were used in this experiment were divided among 4 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 located 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 growing location as well as crushing plant location.

Variability in the nutrient composition among sources of SBM exists depending on different environmental conditions, such as 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 further south allows less time for N fixation, which may result in less protein synthesis in soybeans grown in the northern U.S. (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., 1977). 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., 1984; 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 over processed (Gonzalez-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; however, further processing (e.g., fermentation) may decrease concentrations of oligosaccharides (Cervantes-Pahm and Stein, 2010; Rojas and Stein, 2013b).

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), but were less than values reported by Sauvant et al. (2004) and Rostagno et al. (2011).

Soybean crushing facilities may add limestone to SBM to improve flowability (Chiba, 2001), and this may be the reason for the tendency for an increase in Ca concentration of SBM from Zone 3 compared with SBM from Zones 1 and 2. The average concentration of Ca in the SBM used in this experiment was greater than the value reported by NRC (2012), which further indicates that some crushing plants may have added limestone to the meal.

Corn was used in the basal diet because pigs tolerate corn well and readily consume diets containing corn. The concentration of 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 and NDF concentrations were likely the reason for the lower values for GE, 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 and Stein, 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 U.S., but the observation that the DE, ME, and NE in SBM

produced in the western growing area are less than for SBM produced further north or east indicates that growing region may impact the energy value of SBM.

The average concentrations of GE and the ATTD of GE in the 22 sources of SBM are in agreement with data reported by Sauvant et al. (2004), Rostagno et al. (2011), NRC (2012), and Rojas and Stein (2013). In contrast, the calculated DE and ME of SBM were greater than several book values (Table 3.7; NRC, 1998; Sauvant et al., 2004; de Blas et al., 2010; Rostagno et al., 2011; NRC, 2012), but 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 U.S. 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 U.S. 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. 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 U.S. 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 U.S. 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 U.S. is that SBM produced outside the U.S. has reduced DE, ME, and NE compared with SBM produced in the U.S. 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.

CONCLUSIONS

Results of this experiment indicate that SBM from different regions of the U.S. have concentrations of most nutrients and antinutritional factors (e.g., trypsin inhibitors and oligosaccharides) that are not different. The exception, however, is that SBM from the northern and western U.S. contains less CP than SBM produced in other areas. Overall, regardless of growing region, GE, DE, ME, and NE were not different for SBM from Zones 1, 2, and 4, but DE, ME, and NE were less for SBM from Zone 3 compared with SBM from the other zones. 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 of SBM produced in the U.S.

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TABLES

Table 3.1. Locations of the crushing plants
for the 22 sources of soybean meal used in the
experiment

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

Table 3.2. Composition of corn and soybean meal (as-fed basis)

Item, %	Corn	Zone ¹				Average ²	SEM	P-value ³
		1	2	3	4			
GE, kcal/kg	3,965	4,165	4,209	4,162	4,198	4,184	19.99	0.08
DM	89.49	88.60	88.71	88.30	89.03	88.66	0.39	0.18
CP	9.52	46.64 ^{ab}	48.44 ^a	46.50 ^b	48.06 ^a	47.41	0.65	0.03
AEE ⁴	1.84	1.11 ^{ab}	0.86 ^b	1.37 ^a	0.69 ^b	1.01	0.18	0.04
Ether extract	0.54	0.75	0.64	0.81	0.44	0.66	0.14	0.07
ADF	2.55	4.81	5.20	4.89	4.76	4.91	0.32	0.34
NDF	12.54	7.78	7.53	8.21	8.94	8.11	0.47	0.13
Lignin	0.66	0.60	0.59	0.58	0.63	0.58	0.06	0.13
Ash	1.36	7.01 ^a	6.31 ^b	7.10 ^a	6.96 ^a	6.91	0.25	0.05
Ca	0.01	0.34	0.30	0.47	0.42	0.38	0.06	0.06
P	0.23	0.63	0.65	0.67	0.64	0.65	0.01	0.07
TIU ⁵ , units/mg	-	3.73	3.64	3.26	2.52	3.29	0.55	0.11
Carbohydrates								
Starch	57.48	0.90	1.01	0.89	ND ⁶	0.70	0.71	0.14
Glucose	1.03	ND	ND	ND	ND	ND	-	-
Maltose	0.00	0.62	0.60	0.60	0.63	0.61	0.02	0.33
Fructose	0.71	ND	ND	ND	ND	ND	-	-
Sucrose	0.57	7.73 ^a	7.36 ^{ab}	7.07 ^{ab}	6.62 ^b	7.20	0.29	0.02
Stachyose	ND	4.46	4.48	4.50	4.25	4.42	0.13	0.17

Table 3.2. (Cont.)

Item, %	Corn	Zone ¹				Average ²	SEM	P-value ³
		1	2	3	4			
Raffinose	ND	0.90	0.83	1.02	1.03	0.94	0.07	0.06
Indispensable, AA %								
Arg	0.39	3.36	3.46	3.37	3.44	3.41	0.26	0.17
His	0.23	1.18	1.22	1.19	1.23	1.21	0.02	0.11
Ile	0.28	2.05	2.15	2.11	2.17	2.12	0.06	0.16
Leu	0.92	3.58 ^{ab}	3.66 ^{ab}	3.56 ^b	3.69 ^a	3.62	0.05	0.04
Lys	0.28	3.00	3.09	2.99	3.05	3.03	0.05	0.12
Met	0.16	0.64	0.63	0.62	0.64	0.63	0.01	0.16
Phe	0.37	2.26	2.33	2.26	2.34	2.30	0.04	0.10
Thr	0.27	1.75 ^{bc}	1.80 ^{ab}	1.73 ^c	1.81 ^a	1.78	0.03	0.05
Trp	0.06	0.70	0.71	0.70	0.71	0.70	0.01	0.15
Val	0.39	2.17	2.28	2.24	2.30	2.25	0.06	0.20
Dispensable, AA %								
Ala	0.56	1.96 ^b	2.00 ^{ab}	1.96 ^b	2.02 ^a	1.99	0.02	0.03
Asp	0.51	5.09	5.21	5.07	5.21	5.03	0.33	0.10
Cys	0.19	0.62	0.63	0.61	0.64	0.63	0.01	0.15
Glu	1.34	7.71	7.82	7.68	7.79	7.75	0.12	0.39
Gly	0.32	1.89 ^c	1.96 ^{ab}	1.91 ^{bc}	1.97 ^a	1.93	0.02	0.04
Pro	0.68	2.25 ^{ab}	2.27 ^{ab}	2.23 ^b	2.30 ^a	2.26	0.02	0.05
Ser	0.33	2.15	2.16	2.08	2.17	2.14	0.04	0.10

Table 3.2. (Cont.)

Item, %	Corn	Zone ¹				Average ²	SEM	P-value ³
		1	2	3	4			
Tyr	0.24	1.65 ^b	1.70 ^{ab}	1.66 ^b	1.73 ^a	1.68	0.02	0.01
Total AA	7.60	44.18	45.29	44.13	45.39	44.75	0.54	0.09
Lys:CP ratio ⁷	-	6.42	6.33	6.43	6.34	6.38	0.07	0.25

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

¹Zone 1 = northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = IL.

² Average is for the 22 sources of soybean meal.

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

⁴AEE = acid hydrolyzed ether extract.

⁵TIU = trypsin inhibitor units.

⁶ND = Not detected.

⁷Lys: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 3.3. Ingredient composition of experimental diets (as-fed basis)

Ingredients, %	Diets	
	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
Total	100	100

¹Twenty-two corn-SBM diets were formulated using 22 different sources of soybean meal. These diets were formulated to 18% CP.

²The 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 D₃ 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 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.

Table 3.4. Analyzed nutrient composition of experimental diets containing corn or corn and soybean meal from Zones 1, 2, 3, and 4 (as-fed basis)

Item, %	Corn diet	Soybean meal ¹				Average ²	SEM
		Zone 1	Zone 2	Zone 3	Zone 4		
GE, kcal/kg	3,841	3,923	3,923	3,899	3,922	3,917	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

¹Zone 1 = northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = Illinois.

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

Table 3.5. 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

Item	Corn	Zone ¹				Average ²	SEM	P-value ³
		1	2	3	4			
GE intake, kcal/d	8,145	8,346	8,357	8,311	8,312	8,332	794.91	0.47
GE fecal, kcal/d	1,047	975	978	1,024	992	992	91.95	0.14
GE urine, kcal/d	205	12	10	10	10	11	1.37	0.11
ATTD of GE, %	86.99	88.14	88.11	87.53	87.70	87.87	0.74	0.11
DE, kcal/kg DM	3,712	3,882 ^a	3,875 ^a	3,835 ^b	3,858 ^{ab}	3,863	32	0.02
ME, kcal/kg DM	3,593	3,732 ^{ab}	3,736 ^a	3,694 ^b	3,718 ^{ab}	3,720	36	0.02

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

¹Zone 1 = northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = IL.

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

Table 3.5 (Cont.)

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

Table 3.6. 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				Average ²	SEM	P-value ³
	1	2	3	4			
ATTD of GE, %	91.76	91.63	89.36	90.82	90.89	4.08	0.09
DE, kcal/kg DM	4,343 ^a	4,319 ^a	4,136 ^b	4,247 ^{ab}	4,261	125	0.01
ME, kcal/kg DM	4,096 ^a	4,117 ^a	3,926 ^{bc}	4,038 ^{ab}	4,044	140	0.04
NE, kcal/kg DM ⁴	2,534 ^a	2,497 ^a	2,391 ^b	2,448 ^{ab}	2,467	88	0.02

^{a-b}Means within a row lacking a common superscript are different ($P < 0.05$).

¹Zone 1 = northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = IL.

²Average is for the 22 sources of soybean meal.

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

⁴NE, kcal/kg DM calculated according to Noblet et al. (1994): $NE = (0.70 \times DE) + (1.61 \times \text{ether extract}) + (0.48 \times \text{starch}) - (0.91 \times CP) - (0.87 \times ADF)$.

Table 3.7. 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	4,140	3,797	2,322	2,244	56
NRC, 2012	4,022	3,661	2,319	2,319	58
Sauvant et al., 2004	3,955	3,607	2,262	2,204	57
De Blas et al., 2010	3,848	3,706	2,183	2,299	57
Rostagno et al., 2011	3,970	3,614	2,210	2,268	56
University of Illinois ³	4,413	3,973	2,592	-	59
This experiment	4,261	4,044	2,467	-	58

¹NE kcal/DM calculated according to Noblet et al. (1994): $NE = (0.700 \times DE) + (1.61 \times \text{ether extract}) + (0.48 \times \text{starch}) - (0.91 \times CP) - (0.87 \times ADF)$.

²NE kcal/kg DM as indicated in reference publication.

³Values are averages from all experiments conducted at the University of Illinois at Urbana-Champaign from 2009-2014 (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).

CHAPTER 4: DETERMINATION OF AMINO ACID DIGESTIBILITY IN SOYBEAN MEAL FROM DIFFERENT REGIONS OF THE UNITED STATES AND FED TO PIGS

ABSTRACT: An experiment was conducted to determine the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of AA in SBM produced in different regions of the United States when fed to growing pigs. Twenty-two growing barrows (25.5 ± 1.73 kg) were fitted with a T-cannula near the distal ileum and allotted to a 22×8 Youden Square design with 22 pigs and 8 periods. Twenty-two sources of SBM were procured from crushing facilities throughout the U.S. For analysis, the crushing plant locations were separated into 4 zones: 1) northern U.S., 2) eastern U.S., 3) western U.S., and 4) IL. The dietary treatments included 22 diets based on a mixture of cornstarch, sucrose, and each source of SBM as the sole source of CP. Pigs were fed each diet during a 7 d period with ileal digesta being collected during the last 2 d of each period. Average values for basal endogenous losses of AA were used to calculate SID of CP and AA. Soybean meal from Zones 2 and 4 contained more ($P < 0.05$) CP than SBM from Zone 3. Soybean meal from Zone 4 also contained more ($P < 0.05$) Leu than SBM from Zone 3 and more ($P < 0.05$) Thr than SBM from Zones 1 and 3. Soybean meal from Zone 2 also had greater ($P < 0.05$) concentration of Thr than SBM from Zone 3. There were no differences in concentrations of indispensable AA, dispensable AA, or total AA as a percent of CP among SBM from the 4 zones, except a tendency ($P < 0.10$) for SBM from Zone 1 to have greater concentrations of Met, Trp, and Phe than SBM from Zone 2. The SBM from Zone 4 had reduced ($P < 0.05$) AID and SID of CP compared with SBM from the other 3 zones, and SBM from Zone 2 had less ($P < 0.05$) AID of CP than SBM from Zone 3. Soybean meal from Zone 3 had greater ($P < 0.05$) SID of His, Ile, Phe, and Val than SBM from Zone 2 and also greater ($P <$

0.05) SID of His, Leu, Lys, and Val than SBM from Zone 4. There was also a tendency ($P < 0.10$) for SBM from Zone 3 to have a greater mean SID for indispensable AA than SBM from Zones 2 and 4. The SID of the mean of dispensable AA and the mean of all AA was also greater ($P < 0.05$) for SBM from Zone 3 compared with SBM from Zone 2. However, if calculated as g/kg, SBM from Zone 3 contained less ($P < 0.05$) SID CP compared with SBM from Zone 2, and less ($P < 0.05$) SID Thr than SBM from Zone 4, but there were no other differences in the SID of indispensable, dispensable, or total AA among SBM from all zones. In conclusion, minor differences in concentrations and digestibility of CP and AA exist among sources of SBM from different zones of the U.S., but, except for Thr, no differences in concentration of digestible AA were observed among SBM sourced from 4 different growing areas of the U.S., indicating that the protein value is not different among SBM produced in the U.S. regardless of growing area of the soybeans.

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

INTRODUCTION

In 2013, the United States, Brazil, Argentina, China, and India were the major global producers of soybeans, accounting for 90% of world production and producing a total of 254.2 million t of soybeans (ASA, 2014). The United States is the top soybean producer in the world, with total production of 89.5 million t of soybeans in 2013. In the United States, SBM is the most commonly used protein source in swine diets (Shelton et al., 2001), accounting for 26% of total SBM consumption (Stein et al., 2008; ASA, 2014).

Soybeans grown in the northern United States have a decreased CP concentration compared with soybeans grown further south because of fewer growing days and fewer h of sunlight (Dudley-Cash, 1999). A decrease in growing days and h of sunlight allow the soybean plant less time for N-fixation, and therefore, reduced protein synthesis. Because traditional CP assays measure N content, these samples tend to have decreased CP values compared with SBM from other parts of the United States. However, the protein in SBM produced in the northern United States may sometimes have greater concentrations of indispensable AA, (Grieshop et al., 2003), but this is not always the case. Research has been conducted to compare the nutritional value of SBM produced in different parts of the world (Karr-Lilienthal et al., 2004; Wang et al., 2011; Ravindran et al., 2014); however, no research has been conducted to compare the digestibility of AA among SBM produced in different regions of the United States. Therefore, the objective of this experiment was to test the hypothesis that the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of AA in SBM fed to growing pigs are influenced by the region within the United States where the SBM is produced.

MATERIALS AND METHODS

Twenty two growing barrows (initial BW: 25.5 ± 1.73 kg) were fitted with a T-cannula near the distal ileum and allotted to a 22×8 Youden Square design with 22 pigs and 8 periods. Pigs were placed in individual pens (1.2×1.5 m) that were equipped with a self-feeder, a nipple waterer, and a slatted tri-bar floor.

Twenty-two sources of SBM were procured from crushing facilities in different regions of the United States (Tables 4.1 and 4.2). The dietary treatments included 22 diets based on a

mixture of cornstarch, sucrose, and each source of SBM, with SBM as the only source of AA in the diets (Table 4.4). 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. Average basal endogenous loss values from a total of 22 experiments conducted at the University of Illinois from 2007 to 2014 were used to calculate SID of CP and AA. Feed consumption was recorded daily, and pigs were weighed at the beginning of each period to determine feed allowance during the period. Pigs were limit fed to 3 times their estimated energy requirement for maintenance ($197 \text{ kcal of ME/kg}^{0.60}$; NRC, 2012). Feed was provided in 1 daily meal at 0700 h. Throughout the experiment, pigs had ad libitum access to water. The experiment had a total of 8 periods, with each period lasting 7 d. The first 5 d of each period was considered the adaptation period to the diet, whereas ileal digesta were collected for 8 h on d 6 and 7 of each period. A 225 mL plastic bag was attached to the cannula barrel using a cable tie and digesta flowing into the bag were collected. Bags were removed every 30 min, or whenever full, and replaced with a new bag. Digesta were stored at -20°C immediately after collection.

At the conclusion of the experiment, ileal digesta were thawed and mixed within animal and diet, and a sub-sample was collected for analysis. Samples of the diets and of each source of SBM were also collected. Ileal digesta were lyophilized and finely ground before analysis. Samples of diets, digesta, and SBM were analyzed in duplicate for CP (Method 990.03; AOAC Int., 2007) and DM (Method 930.15; AOAC Int., 2007). Single samples of diets, digesta, and SBM were analyzed for AA [Method 982.30 E (a, b, c); AOAC Int., 2007], and diets and digesta were also analyzed in duplicate for chromium (Method 990.08; AOAC Int., 2007).

The AID values for AA in each diet were calculated using equation [1] (Stein et al., 2007):

$$\text{AID (\%)} = [1 - (\text{AA}_d/\text{AA}_f) \times (\text{Cr}_f/\text{Cr}_d)] \times 100 \quad [1]$$

where AID is the apparent ileal digestibility value of an AA (%), AA_d is the concentration of the AA in the feed DM, AA_f is the concentration of the AA in the fecal DM, Cr_f is the concentration of chromium in the feed DM, and Cr_d is the concentration of chromium in the ileal digesta DM.

The AID of CP was also calculated using this equation.

The basal endogenous flow to the distal ileum of each AA was determined using equation [2] (Stein et al., 2007):

$$\text{IAA}_{\text{end}} = \text{AA}_d \times (\text{Cr}_f/\text{Cr}_d) \quad [2]$$

where IAA_{end} is the basal endogenous loss of the AA (mg/kg DMI). The basal endogenous loss of CP was also determined using this equation.

By correcting AID values for each AA for the IAA_{end} of the AA, SID for the AA was calculated using equation [3] (Stein et al., 2007):

$$\text{SID (\%)} = \text{AID} + [(\text{IAA}_{\text{end}}/\text{AA}_f) \times 100] \quad [3]$$

where SID is the standardized ileal digestibility (%).

Data were analyzed by ANOVA using the PROC MIXED procedure in SAS (SAS Institute Inc., Cary, NC). Normality of data was confirmed using the UNIVARIATE procedure in PROC MIXED. Zone was the fixed effect and pig was the random effect. Least squares means were calculated using the LS Means option and means were separated using the PDIFF statement in PROC MIXED. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

RESULTS

The concentrations of most indispensable AA in SBM were not different among zones, but SBM from Zone 4 had a greater ($P < 0.05$) concentration of Leu than SBM from Zone 3, but this value was not different from SBM from Zones 1 or 2. The SBM from Zone 4 also had a greater ($P < 0.05$) concentration of Thr than SBM from Zones 1 and 3, and SBM from Zone 2 contained more Thr than SBM from Zone 3. The concentrations of most dispensable AA in SBM were not different among zones, but SBM from Zone 4 had greater ($P < 0.05$) concentrations of Ala and Tyr than SBM from Zones 1 and 3. The SBM from Zones 2 and 4 had greater ($P < 0.05$) concentrations of Gly than SBM from Zone 1, and the concentration of Gly in SBM from Zone 4 was also greater ($P < 0.05$) than in SBM from Zone 3. Soybean meal from Zone 4 had greater ($P < 0.05$) concentration of Pro compared with SBM from Zone 3. The concentrations of total AA in SBM from Zone 4 tended ($P = 0.09$) to be greater than in SBM from Zones 1 and 3.

However, if concentrations of AA were calculated as a percent of CP, there were no differences in the majority of indispensable and dispensable AA among SBM from the 4 zones (Table 4.3). There was a tendency ($P < 0.10$) for a reduction in Met for SBM from Zone 2 compared with SBM from Zone 1, with SBM from Zones 3 and 4 having intermediate concentrations of Met. There was also a tendency for a reduction in Pro for SBM from Zone 2 compared with SBM from Zones 1 or 3, and there was a tendency ($P < 0.10$) for a reduction in Tyr for SBM from Zone 2 compared with SBM from Zone 4.

Soybean meal from Zone 4 had the least ($P < 0.05$) AID of CP compared with SBM from the other zones (Table 4.5), but there were no differences among zones for AID of indispensable AA. There were also no differences in AID for Ala, Glu, Ser, or Tyr among zones. However,

there was a tendency ($P < 0.10$) for a reduction in AID of Asp for SBM from Zone 4 compared with SBM from zones 1 and 3, and there was also a tendency ($P < 0.10$) for a reduction in AID of Cys for SBM from Zone 4 compared with SBM from Zone 3.

Soybean meal from Zone 4 had the least ($P < 0.05$) SID of CP compared with SBM from Zones 1 and 3, but there were no differences in the SID of Arg and Met among zones (Table 4.6). However, SBM from Zone 3 had greater ($P < 0.05$) SID of His, Ile, Phe, and Val compared with SBM from Zone 2, and SBM from Zone 3 also had greater ($P < 0.05$) SID of His, Leu, Lys, and Val than SBM from Zone 4. Soybean meal from Zone 1 had greater ($P < 0.05$) SID of Lys compared with SBM from Zones 2 and 4. There was a tendency ($P < 0.10$) for SBM from Zone 3 to have greater SID of Thr compared with SBM from Zone 2, and there was also a tendency ($P < 0.10$) for SBM from Zone 1 to have greater SID of Trp than SBM from Zone 4. There was a tendency ($P < 0.10$) for SBM from Zone 3 to have greater SID for the average of indispensable AA than SBM from Zones 2 or 4. Soybean meal from Zone 3 had greater ($P < 0.05$) SID of Ala and Tyr than SBM from Zone 2, and the SID of Asp and Cys was greater ($P < 0.05$) for SBM from Zone 3 than for SBM from Zone 4. The SID for the average of dispensable AA and for the average of all AA was also greater ($P < 0.05$) for SBM from Zone 3 compared with SBM from Zone 2.

If the concentrations of SID CP and AA were calculated as g per kg, SBM from Zone 2 contained more ($P < 0.05$) SID CP than SBM from Zone 3, but this value was not different from the SID of CP for SBM from Zones 1 and 4 (Table 4.7). Soybean meal from Zone 4 contained more ($P < 0.05$) SID Thr than SBM from Zone 3, but for other indispensable AA, no differences among SBM were observed. There were also no differences in concentrations of the sum of SID indispensable AA, SID dispensable AA, and SID total AA.

DISCUSSION

The 22 sources of SBM that were used in this experiment were divided among 4 zones. Soybean meal was sourced from crushing plants located within those zones, but the growing locations of the soybeans that were used by the crushing plants were unknown. It is possible that some crushing facilities sourced soybeans from a state located in a different zone, but it is expected that the majority of crushing plants sourced soybeans from the local area, and therefore, the differences observed among the zones are believed to be reflective of both growing area and crushing plant locations. Thus, we used the same approach as any purchasers of commercial SBM will use by knowing the location of the crushing plant but not knowing the exact location where the beans were grown.

Amino acids are the building blocks of protein and are considered indispensable or dispensable, depending on whether or not the AA can be synthesized *de novo*. Soybean meal is currently the most common protein source fed to pigs (Stein et al., 2008) because its nutrient and AA composition is complementary to that of corn (Baker, 2000). Corn is rich in sulfur-containing AA, such as Met, but is deficient in Lys and Trp; however, SBM is the opposite of corn and is rich in Lys and Trp, but deficient in the sulfur-containing AA (Baker, 2000). Along with a complementary nutrient profile, SBM contains more AA and less fiber compared with other protein sources, such as canola meal, sunflower meal, and dried distiller's grains with solubles (NRC, 2012), making it the gold standard for protein sources.

The concentrations of most AA in the SBM used in this experiment are in agreement with previous research (de Blas et al., 2010; Rostagno et al., 2011; NRC, 2012). The concentration of total AA for SBM from Zones 2 and 4 was not different from values previously reported, but the

concentration of total AA was less for SBM from Zones 1 and 3 compared with previous values (Karr-Lilienthal et al., 2004). However, Grieshop et al. (2003) analyzed the chemical composition of SBM from 10 processing plants from different regions of the U.S. Nine of the 10 processing plants had greater concentrations of AA in SBM compared with values reported in this experiment, but 1 processing plant in the northern U.S. produced SBM with an AA concentration that was less than values analyzed in this experiment.

The concentrations of most AA as a percent of CP are also in agreement with values reported by Rostagno et al. (2011) and NRC (2012), but the majority of these values are less than those reported by de Blas et al. (2010). The concentrations of Lys and Met as a percent of CP were 6.24% and 1.39% for SBM, respectively, whereas values for corn are 3.03% and 2.18%, respectively (NRC, 2012).

The observation that SBM from all 4 zones had Lys:CP ratio that were greater than 6.0% indicates that regardless of zone, SBM was not over-processed (Gonzalez-Vega et al., 2011). However, the fact that trypsin inhibitor values for all zones were less than 4 indicates that the SBM used in this experiment were also not under-processed (Chang et al., 1987; Monari, 1993; Lallès, 2000).

The greater concentration of CP in SBM from Zone 2 compared with the concentration of CP for SBM from Zones 1 and 3 is mainly the result of greater concentrations of Leu, Thr, and a few dispensable AA. Soy hulls may be added to the SBM after processing, resulting in a reduction of CP (Stein et al., 2008); however, the reduction in CP observed in this experiment is most likely due to environmental conditions because values for ADF and NDF (data not shown) were not different among zones. Grieshop et al. (2003) observed reduced concentrations of CP

for SBM from the northern U.S. compared with SBM from the midwestern and southern U.S., and Hurburgh et al. (1990) reported that SBM from the northern and western U.S. tended to have concentrations of CP approximately 1% less than SBM produced in other regions. Thus the observation in this experiment that CP in the SBM produced in the northern or western regions is less than in SBM produced further east or south is in agreement with previous reports. The reduction in CP in SBM from the northern U.S. may be the result of fewer h of sunlight and a shorter growing season, which results in less N fixation by the plant (Dudley-Cash, 1999).

The AID and SID of CP and most AA observed in this experiment are greater than values reported by NRC (2012), and values from this experiment are also greater than true ileal digestibility values reported by de Blas et al. (2010) and Rostagno et al. (2011). The AID and SID of CP and AA may be elevated in this experiment because the SBM had been processed without causing any heat damage, but with adequate inactivation of trypsin inhibitors as indicated by the Lys:CP ratio being above 6.0% and the concentration of trypsin inhibitors being under 4. It has been reported that whereas SBM from the northern U.S. contains less CP than SBM from other regions in the U.S., it may contain more indispensable AA, which would make it a better quality source of protein (Grieshop et al., 2003). However, we were unable to verify this hypothesis and there were no differences in AID of AA, with the exception of a few dispensable AA, among SBM from the 4 zones. In contrast, the observed differences in the SID of AA among zones indicate that source of SBM may affect AA digestibility.

Because the concentrations of digestible AA were not different among zones, no rankings can be assigned to SBM from the 4 zones. These observations indicate that neither the quality of protein nor the quantity of digestible AA is different among zones. Pigs that are fed SBM from

the different zones will, therefore, receive comparable concentrations of digestible AA regardless of where in the U.S. the SBM is produced.

CONCLUSIONS

Results of this experiment indicate that differences in concentrations of CP and AA among zones of the U.S. exist. A reduction in the concentrations of CP and some AA was observed in SBM from the northern or western U.S. compared with values from the eastern U.S. or IL. Soybean meal from IL had the least ($P < 0.05$) AID and SID of CP compared with SBM from the other zones, but no differences in AID of AA, with the exception of a few dispensable AA, were observed among SBM from all 4 zones. Minor differences in SID of AA were observed, but no differences in the average SID of indispensable AA or total AA were detected. There were no differences among SBM from the 4 zones in terms of concentration (g/kg) of SID indispensable AA, SID dispensable AA, or SID total AA. Overall, although minor differences in concentrations and digestibility of CP and AA among sources of SBM obtained from different zones of the U.S. were observed, concentrations of digestible AA was largely constant among sources of SBM regardless of where it was produced. It is, therefore, concluded that the protein value of U.S. SBM is not influenced by the geographical location of the soy crushing plant.

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TABLES

Table 4.1. Locations of the crushing plants for the 22 sources of soybean meal used in the experiment

State	Zone ¹	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

Table 4.2. Analyzed nutrient composition of soybean meal (as-fed basis)

Item	Zone ¹				Average ²	SEM	<i>P</i> -value
	1	2	3	4			
CP, %	46.64 ^{ab}	48.44 ^a	46.50 ^b	48.06 ^a	47.41	0.65	0.03
DM, %	88.60	88.71	88.30	89.03	88.66	0.39	0.18
Indispensable, AA %							
Arg	3.36	3.46	3.37	3.44	3.41	0.26	0.17
His	1.18	1.22	1.19	1.23	1.21	0.02	0.11
Ile	2.05	2.15	2.11	2.17	2.12	0.06	0.16
Leu	3.58 ^{ab}	3.66 ^{ab}	3.56 ^b	3.69 ^a	3.62	0.05	0.04
Lys	3.00	3.09	2.99	3.05	3.03	0.05	0.12
Met	0.64	0.63	0.62	0.64	0.63	0.01	0.16
Phe	2.26	2.33	2.26	2.34	2.30	0.04	0.10
Thr	1.75 ^{bc}	1.80 ^{ab}	1.73 ^c	1.81 ^a	1.78	0.03	0.05
Trp	0.70	0.71	0.70	0.71	0.70	0.01	0.15
Val	2.17	2.28	2.24	2.30	2.25	0.06	0.20
Dispensable, AA %							
Ala	1.96 ^b	2.00 ^{ab}	1.96 ^b	2.02 ^a	1.99	0.02	0.03
Asp	5.09	5.21	5.07	5.21	5.03	0.33	0.10
Cys	0.62	0.63	0.61	0.64	0.63	0.01	0.15
Glu	7.71	7.82	7.68	7.79	7.75	0.12	0.39
Gly	1.89 ^c	1.96 ^{ab}	1.91 ^{bc}	1.97 ^a	1.93	0.02	0.04

Table 4.2. (Cont.)

Item	Zone ¹				Average ²	SEM	<i>P</i> -value
	1	2	3	4			
Pro	2.25 ^{ab}	2.27 ^{ab}	2.23 ^b	2.30 ^a	2.26	0.02	0.05
Ser	2.15	2.16	2.08	2.17	2.14	0.04	0.10
Tyr	1.65 ^b	1.70 ^{ab}	1.66 ^b	1.73 ^a	1.68	0.02	0.01
Total AA	44.18	45.29	44.13	45.39	44.75	0.54	0.09
TIU ³ , units/mg	3.73	3.64	3.26	2.52	3.29	0.55	0.11

¹Zone = 1: northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = Illinois.

²Average is for the 22 sources of soybean meal.

³TIU = trypsin inhibitor units.

Table 4.3. Concentrations of AA in soybean meal expressed as a percent of CP

	Zone ¹				Average ²	SEM	P-value
Item, %	1	2	3	4			
Indispensable AA							
Arg	7.21	7.12	7.25	7.16	7.18	0.07	0.16
His	2.54	2.52	2.56	2.55	2.54	0.03	0.25
Ile	4.38	4.46	4.54	4.52	4.47	0.11	0.32
Leu	7.66	7.55	7.65	7.69	7.64	0.07	0.22
Lys	6.42	6.36	6.43	6.34	6.39	0.07	0.30
Met	1.37	1.31	1.34	1.34	1.34	0.02	0.06
Phe	4.85	4.82	4.86	4.88	4.85	0.06	0.48
Thr	3.76	3.70	3.73	3.77	3.74	0.03	0.19
Trp	1.50	1.46	1.49	1.48	1.48	0.02	0.09
Val	4.65	4.73	4.83	4.79	4.75	0.12	0.32
Mean	44.33	44.03	44.68	44.51	44.39	0.50	0.32
Dispensable AA							
Ala	4.21	4.13	4.21	4.21	4.19	0.04	0.18
Asp	10.92	10.74	10.90	10.84	10.85	0.10	0.12
Cys	1.34	1.30	1.32	1.32	1.32	0.03	0.35
Glu	16.54	16.10	16.51	16.22	16.34	0.27	0.25
Gly	4.06	4.05	4.11	4.11	4.08	0.05	0.24
Pro	4.82	4.68	4.79	4.78	4.77	0.05	0.07
Ser	4.62	4.43	4.48	4.51	4.51	0.08	0.12

Table 4.3 (Cont.)

Item, %	Zone ¹				Average ²	SEM	P-value
	1	2	3	4			
Tyr	3.54	3.50	3.57	3.59	3.55	0.03	0.07
Mean	50.03	48.92	49.89	49.58	49.61	0.55	0.19
Total AA	94.36	92.95	95.57	94.09	93.99	0.97	0.21

^{a-b}Means within a row lacking a common superscript letter are different

($P < 0.05$).

¹Zone = 1: northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = Illinois.

²Average is for the 22 sources of soybean meal.

Table 4.4. Ingredient composition (as-fed basis) of experimental diets containing soybean meal (SBM)¹

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

¹A total of 22 cornstarch-SBM diets were formulated using 22 different sources of SBM. Diets were formulated to 16.5% CP.

²The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 6,682 IU; vitamin D₃ as cholecalciferol, 1,325 IU; vitamin E as DL-alpha tocopheryl acetate, 40 IU; vitamin K as menadione dimethylprimidinol bisulfite, 0.85 mg; thiamin as thiamine mononitrate, 0.14 mg; riboflavin, 3.95 mg; pyridoxine as pyridoxine hydrochloride, 0.14 mg; vitamin B₁₂, 0.02 mg; D-pantothenic acid as D-calcium pantothenate, 14.1 mg; niacin, 26.46 mg; folic acid, 0.95 mg; biotin, 0.26 mg; Cu, 12 mg as copper sulfate and copper chloride; Fe, 75.6 mg as ferrous sulfate;

Table 4.4 (Cont.)

I, 0.76 mg as ethylenediamine dihydriodide; Mn, 36.12 mg as manganese sulfate; Se, 0.18 mg as sodium selenite and selenium yeast; and Zn, 75.06 mg as zinc sulfate.

Table 4.5. Apparent ileal digestibility (%) of CP and AA in soybean meal by growing pigs¹

Item, %	Zones ²				Average ³	SEM	P-value
	1	2	3	4			
CP	84.81 ^{ab}	85.92 ^a	84.25 ^b	82.35 ^c	84.33	0.77	0.02
Indispensable AA							
Arg	92.40	92.56	92.78	92.45	92.55	0.36	0.40
His	90.38	89.82	90.51	89.93	90.16	0.42	0.16
Ile	88.98	88.29	89.04	88.64	88.74	0.44	0.16
Leu	89.10	88.40	89.09	88.80	88.85	0.46	0.19
Lys	89.03	88.32	88.77	88.08	88.55	0.54	0.18
Met	89.96	90.22	90.38	90.04	90.15	0.44	0.47
Phe	89.52	88.75	89.48	89.11	89.22	0.45	0.16
Thr	83.06	82.37	83.18	82.75	82.84	0.71	0.31
Trp	90.99	90.48	90.70	90.18	90.59	0.49	0.21
Val	86.63	86.03	86.67	86.22	86.39	0.59	0.30
Mean	89.04	88.65	89.08	88.67	88.86	0.45	0.42
Dispensable AA							
Ala	83.94	82.98	84.25	93.86	83.76	0.72	0.11
Asp	87.95	87.27	87.93	86.73	87.47	0.55	0.06
Cys	81.39	80.25	81.57	79.63	80.71	0.91	0.07
Glu	89.45	89.14	89.69	89.42	89.43	0.66	0.41
Gly	75.10	73.52	74.71	74.80	74.53	1.51	0.36
Pro	66.29	65.52	62.71	61.88	64.35	3.63	0.15

Table 4.5 (Cont.)

Item, %	Zones ²				Average ³	SEM	P-value
	1	2	3	4			
Ser	87.98	87.64	87.94	87.67	87.81	0.49	0.59
Tyr	88.66	88.07	88.78	88.34	88.46	0.45	0.19
Mean	88.01	87.36	88.16	87.58	87.78	0.57	0.21
All AA	88.54	88.01	88.63	88.14	88.33	0.46	0.28

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

¹Data are least square means of 8 observations.

²Zone = 1: northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = Illinois.

³Average is for the 22 sources of soybean meal.

Table 4.6. Standardized ileal digestibility (%) of CP and AA in soybean meal by growing pigs^{1,2}

Item, %	Zones ³				Average ⁴	SEM	P-value
	1	2	3	4			
CP	95.69 ^a	94.85 ^{ab}	94.98 ^a	93.59 ^b	94.78	0.60	0.04
Indispensable AA							
Arg	98.17	97.98	98.27	97.83	98.06	0.31	0.22
His	95.02 ^{ab}	94.10 ^b	95.09 ^a	94.14 ^b	94.59	0.36	0.04
Ile	93.77 ^{ab}	93.07 ^b	94.05 ^a	93.18 ^{ab}	93.52	0.39	0.03
Leu	93.49 ^{ab}	92.66 ^{ab}	93.74 ^a	92.97 ^b	93.22	0.40	0.02
Lys	93.75 ^a	92.51 ^{bc}	93.36 ^{ab}	92.27 ^c	92.97	0.45	0.03
Met	95.07	94.76	95.38	94.65	94.96	0.39	0.12
Phe	93.79 ^{ab}	92.91 ^b	93.98 ^a	93.23 ^{ab}	93.48	0.38	0.01
Thr	92.58	91.37	92.67	91.78	92.10	0.62	0.06
Trp	95.95	95.36	95.88	95.07	95.56	0.43	0.10
Val	93.54 ^{ab}	92.62 ^b	93.83 ^a	92.65 ^b	93.16	0.51	0.04
Mean	89.76	89.18	90.06	89.21	89.55	0.41	0.08
Dispensable AA							
Ala	93.21 ^{ab}	91.90 ^b	93.62 ^a	92.45 ^{ab}	92.80	0.65	0.02
Asp	92.39 ^a	91.58 ^{ab}	92.52 ^a	90.83 ^b	91.83	0.50	0.02
Cys	91.17 ^a	89.79 ^{ab}	91.48 ^a	89.15 ^b	90.40	0.75	0.05
Glu	93.65	92.79	93.63	92.99	93.27	0.59	0.18
Ser	96.01	95.39	96.01	95.40	94.95	0.43	0.20

Table 4.6 (Cont.)

Item, %	Zones ³				Average ⁴	SEM	P-value
	1	2	3	4			
Tyr	93.43 ^{ab}	92.60 ^b	93.68 ^a	92.98 ^{ab}	93.17	0.39	0.02
Mean	90.12 ^{ab}	89.36 ^b	90.58 ^a	89.51 ^{ab}	89.97	0.52	0.04
All AA	89.28 ^{ab}	88.62 ^b	89.69 ^a	88.73 ^{ab}	89.08	0.45	0.05

^{a-e}Means within a row lacking a common superscript letter are different (P < 0.05).

¹Data are least square means of 8 observations.

²Basal endogenous losses: CP = 19.55; Arg = 0.68; His = 0.21; Ile = 0.37; Leu = 0.60; Lys = 0.48; Met = 0.11; Phe = 0.38; Thr = 0.62; Trp = 0.13; Val = 0.55; Ala = 0.69; Asp = 0.85; Cys = 0.22; Glu = 1.11; Ser = 0.63; Tyr = 0.28.

³Zone = 1: northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = Illinois.

⁴Average is for the 22 sources of soybean meal.

Table 4.7. Concentrations (g/kg) of standardized ileal digestible CP and AA in soybean meal¹

Item, g/kg	Zones ²				Average ³	SEM	P-value ⁴
	1	2	3	4			
CP	446.30 ^{ab}	459.47 ^a	441.61 ^b	449.78 ^{ab}	449.30	6.12	0.03
Indispensable AA							
Arg	33.01	33.77	33.12	33.69	33.40	0.43	0.25
His	11.24	11.48	11.33	11.54	11.40	0.15	0.21
Ile	19.17	20.09	19.83	20.26	19.84	0.53	0.20
Leu	33.42	33.87	33.36	34.34	33.75	0.41	0.09
Lys	28.08	28.48	27.90	28.11	28.14	0.41	0.28
Met	6.06	6.00	5.95	6.08	6.02	0.08	0.29
Phe	21.22	21.65	21.25	21.85	21.49	0.32	0.21
Thr	16.20 ^{ab}	16.39 ^{ab}	16.06 ^b	16.61 ^a	16.31	0.17	0.03
Trp	6.69	6.72	6.66	6.75	6.70	0.08	0.51
Val	20.32	21.21	21.06	21.31	20.97	0.57	0.27
Total	195.41	199.66	196.62	200.54	198.02	2.67	0.22
Dispensable AA							
Ala	18.27	18.37	18.31	18.69	18.41	0.19	0.14
Asp	47.03	47.61	46.88	47.32	47.21	0.56	0.32
Cys	5.67	5.65	5.62	5.67	5.65	0.09	0.70
Glu	72.20	72.29	71.87	72.48	72.21	1.06	0.68
Ser	20.64	20.50	19.99	20.68	20.45	0.36	0.17

Table 4.7 (Cont.)

Item, g/kg	Zones ²				Average ³	SEM	<i>P</i> -value ⁴
	1	2	3	4			
Tyr	15.42 ^b	15.70 ^{ab}	15.52 ^b	16.05 ^a	15.67	0.16	0.02
Total	179.23	180.12	178.19	180.89	179.61	2.22	0.30
All AA	374.64	379.78	374.81	381.43	377.63	4.62	0.26

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

¹Data are least square means of 8 observations.

²Zone = 1: northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = Illinois.

³Average is for the 22 sources of soybean meal.

**CHAPTER 5: EFFECTS OF PRODUCTION AREA AND MICROBIAL
PHYTASE ON THE APPARENT AND STANDARDIZED TOTAL TRACT
DIGESTIBILITY OF PHOSPHORUS BY GROWING PIGS**

ABSTRACT: An experiment was conducted to determine if the area in which soybeans are grown influence the concentration of P, phytate, and macro- and micro-minerals in the soybean meal (**SBM**) produced from the beans, and therefore, also influence the apparent total tract digestibility (**ATTD**) and standardized total tract digestibility (**STTD**) of P in SBM. The second objective was to test the hypothesis that inclusion of microbial phytase will increase the ATTD and STTD of P in SBM. Two hundred growing barrows (initial BW: 16.90 ± 1.79 kg) were placed in metabolism crates and allotted to a randomized complete block design with 40 diets and 5 replicate pigs per treatment. Twenty sources of SBM were procured from crushing facilities located in different regions of the U.S. The crushing plant locations were separated into 4 zones: 1) northern growing area (MI, MN, and SD; 4 samples), 2) eastern growing area (GA, IN, and OH; 5 samples), 3) western growing area (IA, MO, and NE; 6 samples), and 4) IL (5 samples). Dietary treatments included 40 diets. For each source of SBM, 2 diets based on cornstarch and SBM were formulated. One of these diets contained no microbial phytase and the other diet contained 500 units/kg of microbial phytase. Pigs were placed in individual metabolism crates that were equipped with a feeder, a nipple waterer, and a slatted floor. Feces were collected for 4 d after a 4 d adaptation period using the marker to marker procedure. Soybean meal from Zone 3 contained more ($P < 0.05$) Ca than

SBM from Zone 2, but concentrations of P or phytate in the SBM was not affected by zone where the SBM was produced. However, the percentage of P that was bound to phytate was greater ($P < 0.05$) for SBM from Zone 2 than from SBM from Zone 3, and the concentration of non-phytate P was less ($P < 0.05$) for SBM from Zone 2 than for SBM from Zone 3. Concentrations of all other minerals were not affected by zone with the exception that SBM from Zones 3 and 4 contained less ($P < 0.05$) Mb than SBM from Zone 2. Output of Ca and P decreased ($P < 0.05$) when microbial phytase was added to the diet. An increase ($P < 0.05$) was observed for ATTD and STTD of P when phytase was included in the diets, and there was a tendency ($P < 0.10$) for SBM from Zone 3 to having less ($P < 0.05$) ATTD and STTD of P than SBM from Zone 4. Overall, only minor differences in ATTD and STTD of P exist among SBM produced in different areas of the U.S., but microbial phytase will increase digestibility of Ca and P in SBM.

Key words: apparent total tract digestibility, microbial phytase, phosphorus, standardized total tract digestibility, soybean meal

INTRODUCTION

Of the P in cereal grains, oilseed meals, and many grain by-products, 60% to 75% of the P is unavailable to pigs because it is bound to phytate (Taylor, 1965; Jongbloed and Kemme, 1990; NRC, 2012). Soybeans contain 1 to 2% phytic acid; therefore, approximately two-thirds of P in soybeans is bound to phytate (Deak and Johnson, 2007; Paulsen, 2008; Rojas and Stein, 2012). To increase digestibility of P,

microbial phytase may be included in the diets (Swick and Ivy, 1992). Increasing dietary levels of phytase resulted in a quadratic increase in apparent digestibility of P in soybean meal (**SBM**), with the greatest improvement observed when 500 units/kg of phytase were added to diets (Traylor et al., 2001).

The chemical composition of SBM is somewhat dependent on the area in which soybeans are grown (Grieshop et al., 2003), but it is not known if there are differences in the concentration of phytate among sources of SBM. The apparent total tract digestibility (**ATTD**) of P in dried distiller's grains with solubles is highly variable among sources (Pedersen et al., 2007), but limited data are available on how differences in the chemical composition of different sources of SBM influence the digestibility of P. Therefore, the objective of this experiment was to test the hypothesis that the area in which soybeans are grown may influence the concentration of P, phytate, and macro- and micro-minerals in the SBM produced from the beans, and therefore, also influence the ATTD and standardized total tract digestibility (**STTD**) of P in SBM. The second objective was to test the hypothesis that inclusion of microbial phytase will increase the ATTD and STTD of P in SBM.

MATERIALS AND METHODS

Soybean Meals, Animals, and Experimental Design

Twenty sources of SBM were procured from crushing facilities located in different regions of the U.S. (Table 5.1). 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 sub-sampled, labeled, and stored. For analysis, the crushing plant locations were

separated into 4 zones: 1) northern growing area (MI, MN, and SD; 4 samples), 2) eastern growing area (GA, IN, and OH; 5 samples), 3) western growing area (IA, MO, and NE; 6 samples), and 4) IL (5 samples). Two hundred growing barrows (initial BW: 16.90 ± 1.79 kg) divided into 5 blocks with 40 pigs per block. Within each block, pigs were randomly allotted to 40 diets. Thus, there were 5 replicate pigs per diet. Pigs were placed in individual metabolism crates that were equipped with a feeder, a nipple waterer, and a slatted floor.

Diets, Feeding, and Sample Collection

Diets were based on a mixture of cornstarch, sucrose, soybean oil, and SBM, with SBM being the only source of P in the diets (Table 5.3). For each source of SBM, 2 diets were formulated; one of these diets contained no microbial phytase and the other diet contained 500 units/kg of microbial phytase (Quantum blue G, AB Vista Feed Ingredients, Marlborough, UK). Vitamins and all minerals, except P, were included in all diets to meet or exceed the estimated nutrient requirements for growing pigs (NRC, 2012). All diets were fed in a meal form. Feed consumption was recorded daily, and pigs were weighed at the beginning of the feeding period to determine the pigs' feed allowance. Pigs were limit fed to 3 times their estimated energy requirement for maintenance (i.e., $197 \text{ kcal of ME/kg}^{0.60}$; NRC, 2012). Feed was provided in 2 daily meals that were fed at 0700 and 1600 h. Throughout the experiment, pigs had ad libitum access to water. Pigs were fed experimental diets for 10 d. The initial 4 d were considered the adaptation period, and feces were collected during the following 4 d according to standard procedures using the marker to marker

approach (Adeola, 2001). Fecal samples were stored at -20°C immediately after collection.

At the conclusion of the experiment, fecal samples were thawed and mixed within pig and diet, and then dried in a 50°C forced air drying oven and finely ground prior to analysis (Model 4, Thomas Scientific, Swedesboro, NJ). Fecal, ingredient, and diet samples were analyzed in duplicate for DM (Method 930.15; AOAC Int., 2007), Ca, and P (Method 985.01 A, B, and C; AOAC Int., 2007). All sources of SBM were also analyzed in duplicate for Mg, K, Na, S, Co, Cr, Cu, Fe, Mb, Mn, Na, Se, and Zn (Method 985.01 A, B, and C; AOAC Int., 2007).

Calculations and Statistical Analysis

Following chemical analysis, ATTD of P was calculated using the direct approach (NRC, 2012). The total tract endogenous loss of P was assumed to be 190 mg/kg DM (NRC, 2012), and this value was used to calculate values for STTD of P (NRC, 2012). Standardized total tract digestibility of P was calculated using the following equation: $STTD (\%) = [(P_{\text{intake}} - (P_{\text{output}} - \text{basal endogenous P loss})) / P_{\text{intake}}] \times 100$ (NRC, 2012). Phytate-bound P was calculated as 28.2% of the analyzed phytate concentration (Tran and Sauvant et al., 2004). Non-phytate bound P was calculated by subtracting the phytate bound P from the total P concentration in the SBM.

Data were analyzed as a randomized complete block design. The zone and the level of phytase (0 or 500 units) and the zone $\times$ phytase interaction were the main effects. Analysis of variance was used with the PROC MIXED function of SAS (SAS Institute, Inc., Cary, NC). Outliers were determined using the UNIVARIATE

procedure. Least squares means for each zone were calculated using the LS Means statement and if significant differences were detected, means were separated using the PDIFF option. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

RESULTS

Concentration of Ca in Zones 1, 2, 3, and 4 was 0.37, 0.30, 0.50, and 0.42%, respectively. Soybean meal from Zone 3 had a greater ($P < 0.05$) concentration of Ca compared with SBM from Zone 2 (Table 5.2). The total concentration of P was 0.63, 0.65, 0.67, and 0.64% for SBM from Zones 1, 2, 3, and 4, respectively, and there was a tendency ($P < 0.10$) for a reduced concentration of P in SBM in Zone 1 compared with SBM in Zone 3. The total concentration of phytate was 1.43, 1.53, 1.50, and 1.46% for SBM from Zones 1, 2, 3, and 4, respectively, and these values were not different. The concentration of phytate-bound P was 0.40, 0.43, 0.42, and 0.41% for Zones 1, 2, 3, and 4, respectively, and those values were also not different, but SBM from Zone 2 had greater ($P < 0.05$) percentage of total P bound to phytate compared with SBM from Zone 3. Soybean meal from Zone 3 had greater ($P < 0.05$) concentrations of nonphytate-bound P (0.25%) compared with SBM from Zone 2 (0.22%), but this value was not different from the nonphytate-bound P in SBM from Zones 1 (0.23%) and 4 (0.23%). The SBM from Zone 3 also had greater ($P < 0.05$) percentage of nonphytate-bound P as a percent of total P compared with SBM from Zone 2.

No differences in concentrations of Mg and S were detected among SBM from the different zones. There was a tendency ($P < 0.10$) for a greater concentration of K in SBM from Zone 4 compared with SBM from Zone 1. There was also a tendency ($P < 0.10$) for a reduction in Na for SBM from Zone 2 compared with SBM from Zone 1. There were no differences in concentrations of Cr, Co, Cu, Fe, Mn, Se, and Zn among SBM from the 4 zones, but there was a reduced ($P < 0.05$) concentration of Mb in SBM from Zones 3 and 4 compared with SBM from Zone 2.

No microbial phytase was detected in the non-phytase diets (Table 5.4). The concentrations of phytase in the diets containing microbial phytase were close to the expected value of 500 units per kg.

Feed intake was greater ($P < 0.05$) for pigs fed SBM from Zone 3 compared with pigs fed SBM from Zones 1 or 4, but feed intake was not different compared with pigs fed SBM from Zone 2 (Table 5.5). There was a zone $\times$ phytase interaction ($P < 0.05$) with feed intake increasing when pigs were fed SBM with phytase from Zones 1 or 3, but there was no difference in feed intake for pigs fed SBM without or with phytase from Zones 2 or 4. Intake of P was greater ($P < 0.05$) for pigs fed SBM from Zone 3 compared with pigs fed SBM from Zones 2 or 4. There was a tendency ($P < 0.10$) for greater P intake for pigs fed SBM without phytase compared with pigs fed SBM with phytase. There was a zone $\times$ phytase interaction ($P < 0.05$), which was caused by differences in increases in P intake between pigs fed SBM without or with phytase. Output of P decreased ($P < 0.05$) when microbial phytase was added to diet. There was a tendency ($P < 0.10$) for a reduction in absorbed P in pigs fed SBM from Zones 1 or 4 compared with pigs fed SBM from Zones 2 or 3, but an increase ($P <$

0.05) in absorbed P was observed when phytase was included in the diet. A zone $\times$ phytase interaction was also observed for absorbed P due to larger increases when phytase was added for SBM from Zones 2 or 3 compared with Zones 1 or 4.

There was an increase ($P < 0.05$) for ATTD and STTD of P when phytase was included in the diets, and there was a tendency ($P < 0.10$) for ATTD and STTD for SBM from Zone 3 being less than for SBM from Zone 4 (Table 5.5). There was also a zone $\times$ phytase interaction for both ATTD and STTD of P because the increases ($P < 0.05$ in ATTD and STTD of P caused by phytase was less for SBM from Zone 4 than for SBM from the other zones.

Intake of Ca was less ($P < 0.05$) for pigs fed SBM from Zone 2 compared with pigs fed SBM from Zones 1, 3, or 4, but no differences in Ca intake were detected when phytase was included. Output of Ca increased ($P < 0.05$) for pigs fed SBM from Zone 3 compared with pigs fed SBM from Zones 1, 2, or 4. Output of Ca decreased ($P < 0.05$) when phytase was added to the diets, and the ATTD of Ca for SBM from Zone 2 was less ($P < 0.05$) compared with SBM from Zones 1 and 4, but not different from the ATTD of Ca for SBM from Zone 3. However, the increase in the ATTD of Ca caused by phytase was greater for SBM from Zones 2 and 3 than for SBM from Zones 1 and 4 (zone $\times$ phytase interaction; $P < 0.05$).

DISCUSSION

The sources of SBM used in this study were divided among 4 zones, and the SBM was procured from crushing plants within the zones, but the growing locations

of the soybeans were unknown. It is, therefore, possible that the soybeans that were crushed originate from a state that is from a different zone than the state where they were crushed, but it was expected that the majority of soybeans were from the local area of the crushing plant. Therefore, it is believed that differences among zones is reflective of both growing and crushing plant locations.

The average concentration of P in SBM was less than values reported by NRC (2012), but in agreement with values reported by de Blas et al. (2010), Rostagno et al. (2011), Rojas and Stein (2012), and Baker et al. (2014). Phytate-bound P and phytate-bound P as a percentage of total P were greater in this study compared with values reported by Rodriguez et al. (2013), but these values were not different from values reported by Rojas and Stein (2012). Phytate-bound P was also not different from values reported by de Blas et al. (2010), Rostagno et al. (2011), and NRC (2012), but phytate-bound P as a percentage of total P was greater in this study compared with values reported by NRC (2012). However, all sources of SBM contained high amounts of phytate, which resulted in a reduction in STTD of P. However, the observation that there were no differences in P, phytate, or phytate-bound P among the 4 zones indicates that there is no regional variability in the concentrations of P and phytate. This observation is in agreement with data for canola meal indicating that there is very little effect of growing location on concentrations of P and phytate (Maison, 2013).

Concentrations of Ca in SBM from Zones 1, 2, and 4 were less than values reported by Rojas and Stein (2012), but were in agreement with values reported by NRC (2012). However, the concentration of Ca in SBM from Zone 3 was not

different from the value reported by Rojas and Stein (2012). The differences in concentrations of Ca may be the result of limestone being added to SBM at some crushing plants to improve flowability (Chiba, 2001).

Differences in mineral concentrations in the soil, may impact the concentrations of minerals in soybeans, and therefore SBM (Shacklette and Boergen, 1984; Gustavsson et al., 2001). However, the majority of mineral values in the SBM used in this experiment are in agreement with values reported by NRC (2012). Values for Na and Se are less in this experiment compared with NRC (2012), but values for Cu and Fe are greater. Differences in Na may be observed, especially in different sources of canola meal due to the addition of NaOH during refining (Newkirk, 2009), but no differences in Na concentrations of the SBM were detected in this experiment. Differences in concentrations of Se in corn obtained from different regions of the U.S. were observed by Mahan et al. (2014), but no differences in concentration of Se were observed in SBM used in this experiment. This may be because the samples of SBM used in this experiment did not originate from areas with high soil concentrations of Se, with the exception of the 1 sample of SBM that was obtained from SD. Values for Mn are greater for SBM from Zones 1, 3, and 4 compared with NRC (2012) values, but SBM from Zone 2 had lower Mn values.

The ATTD and STTD of P observed in this experiment for SBM without microbial phytase were slightly greater than values reported by de Blas et al. (2010), Rostagno et al. (2011), and NRC (2012). However, values from this experiment are in good agreement with data from Goebel and Stein (2011) and Rodriguez et al. (2013).

Phytase is an enzyme that converts phytic acid to orthophosphate, inositol, and other phosphorus-inositol intermediates to increase the amount of P available to the pig (Swick and Ivy, 1992). The observed increase in ATTD of P when microbial phytase was added to the diet is in agreement with previous reports (Akinmusire and Adeola, 2009; Rodriguez et al., 2013). Addition of microbial phytase to SBM may increase ATTD and STTD of P by 16 to 27% (Almeida and Stein, 2010; Rojas and Stein, 2012; Rodriguez et al., 2013). In this experiment, the increase in ATTD and STTD of P was less than in previous experiments when microbial phytase was added; however, when microbial phytase was used, values for ATTD of P were not different from most previous values (Akinmusire and Adeola, 2009; Almeida and Stein, 2010; Rojas and Stein, 2012; Rodriguez et al., 2013).

The ATTD of Ca increases 8 to 11% if microbial phytase is included in the diet (Selle et al., 2009; Goebel and Stein, 2011; Rojas and Stein, 2012; Rodriguez et al., 2013). This indicates that the concentration of Ca bound to the phytic acid in SBM is released by phytase. However, the increase in ATTD of Ca in this experiment when microbial phytase was used was less (approximately 6%) compared with previous data, but values for ATTD of Ca are greater compared with these previous values. This may be due to a higher inclusion rate of limestone in the diets used in this experiment.

CONCLUSION

Results of this experiment indicate that SBM from different regions of the U.S. have concentrations of most nutrients and minerals that are not different. The exception, however, is that SBM from western U.S. contains more Ca than SBM

produced in other areas, but the increased concentration of Ca may be due to the addition of limestone in the crushing plant. Concentrations of phytate were not different among zones and only minor differences in ATTD and STTD of P were observed, indicating that growing area of soybeans does not influence the digestibility of P by pigs. The ATTD and STTD of Ca and P increased for SBM from all zones if microbial phytase was included in the diet.

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TABLES

Table 5.1. Locations of the crushing plants
for the 20 sources of soybean meal used in the
experiment

State	Zone ¹	No. of samples
Michigan	1	1
Minnesota	1	2
South Dakota	1	1
Georgia	2	1
Indiana	2	2
Ohio	2	2
Iowa	3	2
Missouri	3	2
Nebraska	3	2
Illinois	4	5
Total	4	20

¹Zones = 1. northern U.S. (MI, MN, and SD); 2. eastern U.S. (GA, IN, and OH); 3. western U.S. (IA, MO, and NE); 4. IL.

Table 5.2. Analyzed nutrient composition of soybean meal (as-fed basis)

Item	Zone ¹				Average ²	SEM	<i>P</i> -value ³
	1	2	3	4			
N	4	5	6	5	-	-	-
DM, %	88.60	88.71	88.30	89.03	88.66	0.39	0.18
Ca, %	0.34 ^{ab}	0.30 ^b	0.50 ^a	0.42 ^{ab}	0.39	0.06	0.03
P, %	0.63	0.65	0.67	0.64	0.65	0.01	0.09
Phytate, %	1.43	1.53	1.50	1.46	1.48	0.04	0.27
Phytate-bound P, % ⁴	0.40	0.43	0.42	0.41	0.42	0.01	0.16
Phytate-bound P, % of total P	63.75 ^{ab}	66.54 ^a	63.43 ^b	64.06 ^{ab}	64.44	1.02	0.04
Nonphytate P, % ⁵	0.23 ^{ab}	0.22 ^b	0.25 ^a	0.23 ^{ab}	0.23	0.01	0.01
Nonphytate-bound P, % of total P	36.26 ^{ab}	33.45 ^b	36.57 ^a	35.94 ^{ab}	35.56	1.02	0.04
Mg, %	0.29	0.30	0.29	0.30	0.29	0.01	0.24
K, %	2.21	2.27	2.23	2.30	2.25	0.04	0.09
Na, %	0.02	ND	0.01	0.01	0.01	0.01	0.10
S, %	0.43	0.44	0.44	0.45	0.44	0.01	0.18
Microminerals, ppm							

Table 5.2 (Cont.)

Item	Zone ¹				Average ²	SEM	<i>P</i> -value ³
	1	2	3	4			
Cr	1.98	1.42	2.30	2.51	2.05	0.55	0.17
Co	0.10	0.17	0.15	0.14	0.14	0.04	0.19
Cu	25.64	36.85	34.32	29.77	31.64	4.75	0.13
Fe	213.13	176.94	209.49	148.41	186.99	35.01	0.21
Mn	41.62	33.60	38.25	37.50	37.99	3.15	0.15
Mb	4.12 ^{ab}	6.19 ^b	2.67 ^a	1.91 ^a	3.72	1.11	0.03
Se	<4	<4	<4	<4	<4	-	-
Zn	45.50	47.66	52.45	47.54	50.69	5.48	0.40

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

¹Zone 1 = northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = IL.

² Average is for the 20 sources of soybean meal.

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

⁴Phytate-bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

Table 5.2 (Cont.)

⁵Nonphytate P = total P - phytate-bound P.

Table 5.3. Ingredient composition of experimental diets (as-fed basis)

Ingredients, %	Diets ¹	
	Without microbial phytase	With microbial phytase
Cornstarch	36.83	35.83
Soybean meal	43.66	43.67
Ground limestone	1.30	1.30
Soybean oil	2.98	2.97
Sodium chloride	0.39	0.39
Vitamin-mineral premix ²	0.29	0.29
Phytase premix ³	-	1.00
Sucrose	14.55	14.55

¹Twenty diets without microbial phytase were formulated by using 20 different sources of soybean meal. Twenty additional diets were formulated using 20 sources of soybean meal and microbial phytase. Diets were formulated to 0.30% P.

²The 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 D₃ 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 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.

Table 5.3 (Cont.)

³ The phytase premix was prepared by mixing 24.75 kg of cornstarch and 250 grams of microbial phytase [Quantum blue 5G (5000 units per gram)]. By including 1.00% of this mixture in the diet, the complete diet was expected to contain 500 units per kg of microbial phytase.

Table 5.4. Analyzed DM, Ca, P, and phytase in experimental diets (as-fed basis)

Item	Zone ¹							
	1		2		3		4	
	0 FTU ² /kg	500 FTU/kg	0 FTU/kg	500 FTU/kg	0 FTU/kg	500 FTU/kg	0 FTU/kg	500 FTU/kg
DM, %	92.99	93.33	92.73	93.11	93.05	92.78	92.81	92.64
Ca, %	0.77	0.72	0.69	0.69	0.72	0.72	0.79	0.73
P, %	0.28	0.28	0.29	0.29	0.29	0.30	0.28	0.30
Phytase, FTU/kg	<70	508	<70	460	<70	582	<70	570

¹Zone 1 = northern growing area (MI, MN, and SD); Zone 2 = eastern growing area (GA, IN, and OH); Zone 3 = western growing area (IA, MO, and NE); Zone 4 = IL.

²FTU = phytase units.

Table 5.5. Effects of phytase on standardized total tract digestibility (STTD) of P in SBM from different zones of the United States

Item	Zones								SEM	<i>P</i> -value		
	1		2		3		4					
	Phytase Units, FTU/kg											
	0	500	0	500	0	500	0	500				
Feed intake, g	770.8	795.5	795.0	781.0	790.3	811.8	760.8	754.3	13.4	0.02	0.48	0.04
DM/d												
P intake, g/d	2.33	2.40	2.49	2.40	2.48	2.53	2.46	2.27	0.05	0.01	0.07	0.04
P output, g/d	1.55	1.18	1.60	1.20	1.58	1.30	1.49	1.36	0.05	0.25	0.01	0.05
Absorbed P, g/d	0.82	1.11	0.85	1.22	0.86	1.23	0.80	1.11	0.05	0.07	0.01	0.01
ATTD of P, %	50.61	65.89	51.42	64.61	49.69	63.58	55.44	64.71	1.76	0.09	0.01	0.01
STTD of P, %	56.96	72.23	57.56	70.81	55.74	69.88	61.29	71.13	1.75	0.08	0.01	0.04
Ca intake, g/d	6.38	6.03	5.88	5.81	6.03	6.34	6.45	6.01	0.15	0.04	0.30	0.04
Ca output, g/d	1.59	1.28	1.82	1.42	1.65	1.43	1.65	1.21	0.10	0.05	0.01	0.03

Table 5.5 (Cont.)

ATTD of Ca, %	74.01	79.44	69.16	76.03	71.60	77.51	74.14	79.96	1.44	0.01	0.01	0.04
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CHAPTER 6: AMINO ACID DIGESTIBILITY IN FERMENTED SOYBEAN MEAL, CONVENTIONAL SOYBEAN MEAL, AND ANIMAL PROTEINS FED TO WEANLING PIGS

ABSTRACT: An experiment was conducted to determine the apparent ileal digestibility (AID) and the standardized ileal digestibility (SID) of AA by weanling pigs in 4 sources of fermented soybean meal (FSBM) and to compare these values to the digestibility of AA in conventional soybean meal (SBM), fishmeal, and poultry by-product meal (PBM). Sixteen weanling barrows (initial BW: 14.1 ± 1.4 kg) were equipped with a T-cannula in the distal ileum and allotted to a replicated 8×5 Youden square design with diet and period as the 2 blocking criteria. Therefore, there were 10 replicate pigs per treatment. The ingredients used in this experiment were conventional SBM, Menhaden Select fishmeal, PBM, and 4 sources of FSBM (FSBM A, FSBM B, FSBM C, and FSBM D). Eight cornstarch-based diets were prepared, with 7 diets using 1 of these ingredients as the sole source of CP and AA. The last diet was a N-free diet that was used to measure basal endogenous losses of CP and AA. The AID of CP was greater ($P < 0.05$) in FSBM B compared with the other ingredients; however, SBM, FSBM C, and FSBM D had greater ($P < 0.05$) AID of CP than FSBM A. The AID of indispensable AA, dispensable AA, and total AA for SBM and FSBM B and C were greater ($P < 0.05$) than in FSBM A, FSBM D, PBM, and fishmeal, but the AID of indispensable AA, dispensable AA, and total AA for FSBM A, FSBM D, and fishmeal were greater ($P < 0.05$) than in PBM. The SID of CP in SBM and FSBM B were greater ($P < 0.05$) than in FSBM A, FSBM D, PBM, and fishmeal, but the SID of CP in SBM was not different from FSBM C. The SID of indispensable AA, for SBM and FSBM B and C were greater ($P < 0.05$) than in FSBM A, FSBM D, PBM, and fishmeal. The SID of

dispensable AA and total AA for SBM and FSBM B and C were greater ($P < 0.05$) than in FSBM A, FSBM D, PBM, and fishmeal. The AID and SID of all AA, except Gly, of PBM were less ($P < 0.05$) than in the other ingredients.

Key words: amino acid digestibility, conventional soybean meal, fermented soybean meal, fishmeal, pigs, poultry by-product meal

INTRODUCTION

Soybean meal (**SBM**) is the premiere source of protein used in diets fed to all phases of pigs. However, because of the presence of anti-nutritional factors (**ANF**) in SBM, it is not tolerated well by weanling pigs (Li et al., 1990, 1991; Friesen et al., 1993; Qin et al., 1996). The poorer growth performance observed in weanling pigs fed diets containing high concentrations of SBM compared with pigs fed animal proteins may be a result of a decrease in feed intake or decrease in nutrient digestibility (Kenworthy, 1976; Li et al., 1990; Friesen et al., 1993). A decrease in nutrient digestibility may be a result of transient hypersensitivity to the protein in SBM causing villus atrophy in the small intestine (Li et al., 1990).

Animal proteins (i.e. fishmeal or poultry by-product meal; **PBM**), are used in weanling pig diets because they lack ANF associated with SBM. Fishmeal is included in weanling pig diets because it improves growth performance, but the degree of improvement varies (Wiseman et al., 1991; Kim and Easter, 2001; Young et al., 2002). The PBM is fed to weanling pigs as an alternative to higher priced animal protein sources. Performance of pigs fed PBM was not different than pigs fed fishmeal, but variability among sources of PBM causes variability in performance (Zier et al., 2004).

Fermentation of SBM removes some ANF, allowing weanling pigs to better tolerate fermented SBM (**FSBM**) than conventional SBM (Min et al., 2004; Kim et al., 2007; Cervantes-Pahm and Stein, 2010; Rojas and Stein, 2013). Currently, however, only limited knowledge about AA digestibility in FSBM is available. To successfully include FSBM in diets fed to weanling pigs, values for digestible AA must be determined. Therefore, the objective of this experiment was to determine the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of AA by weanling pigs in 4 sources of FSBM and to compare these values to the digestibility of AA in conventional SBM, fishmeal, and PBM.

MATERIALS AND METHODS

Sixteen weanling barrows (initial BW: 14.1 ± 1.4 kg) were equipped with a T-cannula in the distal ileum and allotted to a replicated 8×5 Youden square design with diet and period as the 2 blocking criteria. Therefore, there were 10 replicate pigs per treatment. Pigs were housed in individual pens (1.2×1.5 m) that were equipped with a self-feeder, nipple waterer, and slatted tri-bar floors in an environmentally controlled room. All dietary treatments were fed in meal form. Feed consumption was recorded daily, and pigs were weighed at the beginning of each period to determine the pigs' feed allowance.

The ingredients used in this experiment were conventional SBM, Menhaden Select fishmeal (Omega Protein; Houston, TX), PBM (Scoular Company; Minneapolis, MN), and 4 sources of FSBM. Eight cornstarch-based diets were prepared, with 7 diets using 1 of these ingredients as the sole source of CP and AA (Table 6.2). The last diet was a N-free diet that was used to estimate the basal ileal endogenous losses of CP and AA. Vitamins and minerals were

included in all diets to meet or exceed estimated nutrient requirements (NRC, 2012). All diets also contained 0.4% chromic oxide as the indigestible marker.

All pigs were limit fed 3 times their estimated energy requirement for maintenance (i.e., 197 kcal ME/kg^{0.60}; NRC, 2012). Pigs were fed 1 meal daily at 0700 h, and pigs had access to water at all times. The experiment had 5 periods with each period lasting 7 d. The first 5 d of each period were considered an adaptation period to the diet, whereas ileal digesta were collected for 8 h on d 6 and 7 of each period. A 225 mL plastic bag was attached to the cannula barrel using a cable tie and digesta flowing into the bag were collected. Bags were removed every 30 min, or whenever full, and replaced with a new bag. Digesta were stored at -20°C to prevent bacterial degradation of the AA in the digesta.

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a sub-sample was collected for chemical analysis. A sample of each diet and of each ingredient was also collected. Digesta samples were lyophilized and finely ground prior to chemical analysis. Samples of diets, ingredients, and digesta were analyzed in duplicate for DM (Method 930.15; AOAC Int., 2007) and CP (Method 990.03; AOAC Int., 2007). Single samples of diets, ingredients, and digesta were analyzed for AA (Method 982.30 E (a, b, c); AOAC Int., 2007), and diets and digesta were also analyzed in duplicate for chromium (Method 990.08; AOAC Int., 2007). All ingredients were also analyzed for in duplicate for ADF (Method 973.18; AOAC Int., 2007), NDF (Holst, 1973), acid hydrolyzed ether extract (Method 2003.06; AOAC Int., 2007), Ca (Method 985.01 A, B, and C; AOAC Int., 2007), P (Method 985.01 A, B, and C; AOAC Int., 2007), and ash (Method 942.05; AOAC Int., 2007). The SBM and all FSBM were analyzed in duplicate for trypsin inhibitors (Method Ba 12-75; AOCS, 2006) and starch (Method 979.10; AOAC Int., 2007). Each source of SBM and FSBM was also analyzed in duplicate for

glucose, sucrose, maltose, fructose, stachyose, raffinose, and verbascose as described by Cervantes-Pahm and Stein (2010).

The AID for CP and AA in the FSBM, conventional SBM, fishmeal, and PBM were calculated using equation [1] (Stein et al., 2007):

$$\text{AID (\%)} = [1 - [(AA_d/AA_f) \times (Cr_f/Cr_d)] \times 100 \quad [1]$$

where AID is the apparent ileal digestibility value of an AA (%), AA_d is the concentration of that AA in the ileal digesta DM, AA_f is the AA concentration of that AA in the feed DM, Cr_f is the chromium concentration in the feed DM, and Cr_d is the chromium concentration in the ileal digesta DM. The AID for CP was also calculated using this equation.

The basal endogenous flow to the distal ileum of each AA was determined based on the flow obtained after feeding the N-free diet using equation [2] (Stein et al., 2007):

$$IAA_{\text{end}} = [AA_d \times (Cr_f/Cr_d)] \quad [2]$$

where IAA_{end} is the basal endogenous loss of an AA (mg per kg DMI). The basal endogenous loss of CP was determined using the same equation.

By correcting the AID for the IAA_{end} of each AA, standardized ileal AA digestibility values were calculated using equation [3] (Stein et al., 2007):

$$\text{SID (\%)} = \text{AID} + [(IAA_{\text{end}}/AA_f) \times 100] \quad [3]$$

where SID is the standardized ileal digestibility value (%).

Analysis of variance was used with the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC). The experimental unit was the pig, and the main effects were pig, period, and

diet. Outliers were determined using the UNIVARIATE procedure. Diet or ingredient was the fixed effect, and pig and replicate were random effects. Least squares means were calculated using the LS Means option, and means were separated using the PDIF statement in PROC MIXED. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

RESULTS

Chemical Characteristics of Ingredients

The GE was 4,216 kcal/kg (as-fed basis) in SBM and 4,475, 4,484, 4,519, and 4,396 kcal/kg in FSBM A, B, C, and FSBM D, respectively (Table 6.1). The GE was 5,395 kcal/kg in PBM and 4,273 kcal/kg in fishmeal. The CP in SBM was 49.94% and ranged from 51.70 to 59.04% in the 4 sources of FSBM. For PBM and fishmeal, CP was 68.41% and 63.52%, respectively. The concentration of fat in SBM, FSBM A, B, C, and FSBM D, PBM, and fishmeal was 1.82%, 0.90%, 1.24%, 1.42%, 1.00%, 13.07%, and 10.05%, respectively. The concentrations of P and Ca in SBM, FSBM A, B, C, and FSBM D, PBM, and fishmeal were 0.65% and 0.32%, 0.75% and 0.37%, 0.74% and 0.30%, 0.75% and 0.37%, 0.68% and 0.28%, 1.56% and 2.35%, and 3.28% and 6.00%, respectively. Soybean meal contained 5.20 mg/kg of trypsin inhibitors (**TIU**), whereas FSBM A, C, and FSBM D contained less than 1.00 mg/kg and FSBM B contained 2.00 mg/kg of trypsin inhibitors. The concentration of starch in SBM and FSBM A, B, C, and FSBM D were 0.30%, 0.15%, 0.30%, 0.59%, and 0.29%, respectively. The concentration of disaccharides in SBM and FSBM A, B, C, and FSBM D was 8.30%, 2.09%, 2.13%, 2.50%, and 3.64%, respectively. The concentration of oligosaccharides in SBM and FSBM A, B, C, and FSBM D was 4.68%, 0.11%, 0.14%, 0.09%, and 3.27%, respectively.

Apparent Ileal Digestibility

The AID of CP was greater ($P < 0.05$) in FSBM B compared with the other ingredients; however, SBM and FSBM C and FSBM D had greater ($P < 0.05$) AID of CP compared with FSBM A, PBM, or fishmeal (Table 6.4). The AID of Arg in SBM and FSBM B and C were greater compared with FSBM D, PBM, and fishmeal, but the AID of Arg in SBM and FSBM A and C were not different. The AID of His, Ile, Leu, Met, Phe, Thr, and Val in SBM and FSBM B and C were greater ($P < 0.05$) than in the other ingredients. The AID of Lys in SBM and FSBM C was greater ($P < 0.05$) compared with the other ingredients, but the AID of Lys in FSBM C was not different from that in FSBM B. The AID of Trp in PBM was less ($P < 0.05$) than SBM, FSBM A, B, C, and FSBM D, and fishmeal. The AID of Ala, Asp, Cys, and Gly in SBM and FSBM B and C were greater ($P < 0.05$) than in FSBM A, FSBM D, and PBM. The AID of Pro was less ($P < 0.05$) in PBM than in the other ingredients. The AID of Ser in FSBM B was greater ($P < 0.05$) than FSBM A, FSBM D, fishmeal, and PBM, but was not different from SBM or FSBM C. The AID of Tyr in FSBM B and C was greater ($P < 0.05$) than in FSBM A, FSBM D, PBM, and fishmeal, but was not different from SBM. The AID of indispensable AA, dispensable AA, and total AA in SBM and FSBM B and C were greater ($P < 0.05$) than in FSBM A, FSBM D, PBM, and fishmeal.

Standardized Ileal Digestibility

The SID of CP was greater ($P < 0.05$) in FSBM B than in FSBM A, C, and FSBM D, PBM, and fishmeal, but was not different than in SBM (Table 6.5). The SID of His, Ile, Leu, Met, Phe, Thr, and Val in SBM and FSBM B and C were greater ($P < 0.05$) than in the other ingredients. The SID of Arg in FSBM B was greater ($P < 0.05$) than in FSBM A, FSBM D, PBM, and fishmeal, but not different than in SBM or FSBM C. The SID of Lys in SBM was

greater ($P < 0.05$) than in FSBM A, C, and FSBM D, PBM, and fishmeal, but was not different than in FSBM B. The SID of Trp was less ($P < 0.05$) in PBM compared with the other ingredients. The SID of Ala, Asp, Cys, Glu, Gly, Ser, and Tyr in SBM and FSBM B and C were greater ($P < 0.05$) than in the other ingredients. The SID of Pro was less ($P < 0.05$) for PBM compared with the other ingredients. The SID of indispensable AA, dispensable AA, and total AA in SBM and FSBM B and C were greater ($P < 0.05$) than FSBM A and FSBM D, PBM, and fishmeal.

DISCUSSION

Composition and Chemical Characteristics of Ingredients

The values for the nutrient composition of SBM and the 4 sources of FSBM, agree with values reported by NRC (2012). The FSBM had greater concentrations of DM, CP, and Ca compared with SBM, but had less fat than SBM. These results agree with data from Cervantes-Pahm and Stein (2010), but not with data from Zamora and Veum (1979, 1988) or Feng et al. (2007). During the fermentation process to produce FSBM, sucrose, raffinose, and stachyose were removed by α -galactosidase produced by the bacteria (Shankar and Mulimani, 2007). The removal of sucrose and oligosaccharides was the reason the concentration of CP and other nutrients increases in FSBM compared with SBM.

The nutrient composition of PBM agrees with most values reported by NRC (2012) and Rojas and Stein (2013), except that more CP and less ash and fat were analyzed in PBM used in this experiment. However, the GE was in agreement with the GE reported by NRC (2012) and by Rojas and Stein (2013). PBM is produced using rendered poultry carcasses and contains bones

and other byproducts from the poultry processing industry. Because of different properties of these product streams, variation in nutrient concentrations among sources of PBM may be observed. Because of the relatively low concentration of ash and Ca and P in PBM used in this experiment, it is likely that fewer bones were included. Due to greater concentration of Cys in PBM used in this experiment compared with previous values (NRC, 2012; Rojas and Stein, 2013), feathers may have been included in the PBM.

The nutrient composition of fishmeal agrees with most values reported by Cervantes-Pahm and Stein (2010) and NRC (2012); however, the fishmeal used in this experiment has an increased concentration of fat, ash, Ca, and P compared with previous values. Fishmeal is produced from fish and processed fish's bones and offal. The greater concentrations of Ca and P may be due to more fish bones included in the ingredient, which increased the ash content. However, the GE of fishmeal used in this experiment agrees with previous research, and this may be due to the greater fat concentration (NRC, 2012).

Ileal AA Digestibility

Conventional SBM contains several ANF (i.e., trypsin inhibitors, oligosaccharides, and antigenic proteins), which may cause a decrease in performance if included in diets for newly-weaned pigs (Cromwell, 2000). This decrease in performance is caused by a transient hypersensitivity reaction in the newly-weaned pig's intestine that causes more crypt cell production and villus atrophy which results in decreased nutrient absorption (Li et al., 1990). Trypsin inhibitors are removed using heat treatment, but oligosaccharides and antigenic proteins cannot be removed by heat treatment. Through the process of fermentation, SBM is inoculated with other microbes to remove the oligosaccharides and antigenic proteins through the production and use of α -galactosidase. Research has shown that FSBM has a greater

concentration of small peptides than SBM (Hong et al., 2004), and young pigs have an increased ability to absorb small peptides compared with free AA (Gilbert et al., 2008). Therefore, it was expected that FSBM would have increased AID and SID compared with SBM; however, no differences were observed in this experiment. These results agree with research conducted by Cervantes-Pahm and Stein (2010).

The SID of CP and all AA in FSBM A and FSBM D were lower than FSBM B and C, and this may be due to different bacteria used to produce each FSBM source. Fermented SBM A and FSBM D had similar SID for most AA compared with research conducted by Rojas and Stein (2013) and Cervantes-Pahm et al. (2010). The SID of Lys in FSBM A and FSBM D were less than in SBM, which agrees with observations by Cervantes-Pahm et al. (2010). However, unlike the FSBM used by Cervantes-Pahm et al. (2010), the Lys:CP ratio for these 2 sources of FSBM were greater than 6%, indicating that the FSBM used in this experiment were not heat damaged. Fermented SBM B and C had greater SID of CP and AA compared with values reported by Rojas and Stein (2013) and Cervantes-Pahm et al. (2010).

The fishmeal used in this experiment had similar AID and lower SID compared with research conducted by Cervantes-Pahm and Stein (2010). Bone protein is deficient in the majority of indispensable AA and contains large concentrations of collagen, which is not digestible by the pig (Eastoe and Long, 1960). The fishmeal used in this experiment contained a greater concentration of Ca and P than published values; therefore, the greater concentration of bone protein may have decreased the digestibility of the ingredient.

The PBM used in this experiment had lower AID and SID compared with values reported by Rojas and Stein (2013). Due to the reduction in AID and SID, as well as the greater

concentration of Cys in the PBM compared with research and reference values, feathers may have been included in the PBM.

CONCLUSIONS

Results of the present experiment indicate that FSBM from different sources have similar concentrations of CP and AA, but different AID and SID of CP and AA. Results from this experiment also indicate that FSBM has greater concentrations of DM, CP, ADF, and NDF compared with SBM, but lower concentrations of oligosaccharides and AEE. While the concentrations of CP and AA were greater in fishmeal and PBM, FSBM and SBM had greater SID of CP and AA. Because FSBM has greater SID of CP and AA than PBM and fishmeal, FSBM may be able to replace PBM and fishmeal in weanling pig diets without negatively affecting performance.

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TABLES

Table 6.1. Analyzed nutrient composition of soybean meal (SBM), 4 sources of fermented soybean meal, poultry by-product meal (PBM), and fishmeal (as-fed basis)

Item, %	Ingredient						
	Fermented SBM					PBM	Fishmeal
	SBM	A	B	C	D		
DM	88.54	91.87	91.08	93.66	92.61	96.25	91.08
CP	49.94	59.04	57.72	55.57	51.70	68.41	63.52
Ash	6.85	7.69	7.04	7.34	6.83	9.72	22.70
AEE ¹	1.82	0.90	1.24	1.42	1.00	13.07	10.05
NDF	6.99	11.30	34.24	19.80	19.44	-	-
ADF	5.63	8.79	11.73	14.23	11.73	-	-
P	0.65	0.75	0.74	0.75	0.68	1.56	3.28
Ca	0.32	0.37	0.30	0.37	0.28	2.35	6.00
TIU, mg/kg ²	5.20	<1.00	2.00	<1.00	<1.00	-	-
GE, kcal/kg	4,216	4,475	4,484	4,519	4,396	5,395	4,273

Table 6.1 (Cont.)

Item, %	Ingredient						
	Fermented SBM					PBM	Fishmeal
	SBM	A	B	C	D		
Carbohydrates							
Starch	0.30	0.15	0.30	0.59	0.29	-	-
Fructose	0.57	0.69	0.61	1.40	1.24	-	-
Glucose	1.56	1.36	1.44	1.07	0.63	-	-
Sucrose	6.05	0.04	0.05	0.02	1.49	-	-
Maltose	0.12	0.00	0.30	0.01	0.28	-	-
Raffinose	1.19	0.02	0.04	0.02	0.86	-	-
Stachyose	3.40	0.08	0.10	0.07	2.41	-	-
Verbascose	0.09	0.01	0.00	0.00	0.10	-	-
Indispensable AA, %							
Arg	3.72	3.85	4.06	3.70	3.58	4.54	3.85
His	1.42	1.53	1.56	1.46	1.41	1.43	1.50

Table 6.1 (Cont.)

Item, %	Ingredient						
	Fermented SBM					PBM	Fishmeal
	SBM	A	B	C	D		
Ile	2.31	2.77	2.70	2.65	2.39	2.84	2.58
Leu	4.00	4.52	4.50	4.39	4.04	5.03	4.35
Lys	3.25	3.89	3.55	3.37	3.12	3.81	4.74
Met	0.72	0.80	0.76	0.79	0.70	1.22	1.76
Phe	2.57	2.99	2.93	2.81	2.62	2.74	2.47
Thr	1.98	2.13	2.16	2.07	1.96	2.57	2.35
Trp	0.69	0.74	0.74	0.72	0.67	0.46	0.59
Val	2.36	2.85	2.79	2.75	2.45	3.71	2.96
Dispensable AA, %							
Ala	2.21	2.57	2.49	2.45	2.26	4.10	3.80
Asp	5.87	6.58	6.43	6.24	5.87	5.35	5.60
Cys	0.70	0.78	0.76	0.77	0.72	1.16	0.46

Table. 6.1 (Cont.)

Item, %	Ingredient						
	Fermented SBM					PBM	Fishmeal
	SBM	A	B	C	D		
Glu	9.01	9.82	9.60	9.09	8.82	8.07	7.87
Gly	2.11	2.51	2.36	2.41	2.16	5.84	4.48
Pro	2.57	2.88	2.82	2.77	2.45	4.45	2.86
Ser	2.53	2.40	2.45	2.37	2.20	2.93	2.02
Tyr	1.87	2.05	2.07	1.99	1.87	2.19	2.07
Total AA	53.08	55.66	54.73	52.80	49.38	62.44	56.31

¹AEE = acid hydrolyzed ether extract.

²TIU = trypsin inhibitor units.

Table 6.2. Ingredient composition of experimental diets containing one of 4 sources of fermented soybean meal (FSBM), conventional SBM (SBM), fishmeal, or poultry by-product meal (PBM) (as-fed basis)

Ingredient, %	Diet ²							
	Fermented Soybean Meal					PBM	Fishmeal	N-free
	SBM	A	B	C	D			
Fermented SBM A	-	37.00	-	-	-	-	-	-
Fermented SBM B	-	-	37.00	-	-	-	-	-
Fermented SBM C	-	-	-	37.00	-	-	-	-
Fermented SBM D	-	-	-	-	37.00	-	-	-
Soybean meal, 48%	40.00	-	-	-	-	-	-	-
Fishmeal	-	-	-	-	-	-	30.00	-
PBM	-	-	-	-	-	30.00	-	-
Soybean oil	3.00	3.00	3.00	3.00	3.00	-	-	4.00
Solka floc ¹	-	-	-	-	-	-	-	4.00
Monocalcium phosphate	1.30	1.30	1.30	1.30	1.30	-	-	2.40
Limestone	1.30	1.30	1.30	1.30	1.30	-	-	0.50

Table 6.2 (Cont.)

Ingredient, %	Diet ²							
	Fermented Soybean Meal					PBM	Fishmeal	N-free
	SBM	A	B	C	D			
Sucrose	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Corn starch	33.30	36.30	36.30	36.30	36.30	48.90	48.90	67.50
Magnesium oxide	-	-	-	-	-	-	-	0.10
Potassium carbonate	-	-	-	-	-	-	-	0.40
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin Mineral premix ³	0.30	0.30	0.30	0.30	0.30	-	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

¹Fiber Sales and Development Corp., Urbana, OH.

²Diets containing protein sources were formulated to 20% CP.

³The 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 D3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66

Table 6.2 (Cont.)

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.

Table 6.3. Analyzed nutrient composition of experimental diets containing soybean meal (SBM), 4 sources of fermented SBM, poultry by-product meal (PBM), or fishmeal

Item, %	SBM	Fermented SBM				PBM	Fishmeal
		A	B	C	D		
DM	92.07	92.48	92.67	92.89	92.47	93.41	91.86
Ash	6.04	6.19	6.34	5.67	5.44	3.92	7.24
CP	20.71	22.14	21.82	19.52	20.29	21.57	19.03
GE, kcal/kg	3,982	3,915	4,039	4,004	3,925	4,187	3,863
Indispensable AA							
Arg	1.29	1.35	1.55	1.31	1.34	1.31	1.08
His	0.50	0.51	0.58	0.48	0.52	0.37	0.38
Ile	0.81	0.99	0.99	0.95	0.85	0.84	0.77
Leu	1.42	1.67	1.74	1.62	1.53	1.54	1.36
Lys	1.13	1.33	1.32	1.22	1.17	1.13	1.47
Met	0.23	0.27	0.27	0.27	0.25	0.34	0.51
Phe	0.92	1.13	1.12	1.07	0.98	0.87	0.77

Table 6.3 (Cont.)

Item, %	Ingredient								
	Fermented SBM					PBM	Fishmeal	SEM	P-value
	SBM	A	B	C	D				
Thr	0.69		0.81	0.85		0.79	0.76	0.82	0.76
Trp	0.24		0.29	0.27		0.27	0.29	0.16	0.20
Val	0.87		1.02	1.06		0.98	0.92	1.07	0.88
Mean	8.10		9.39	9.75		8.96	8.61	8.45	8.18
Dispensable AA									
Ala	0.80		0.99	0.98		0.94	0.88	1.29	1.23
Asp	2.10		2.39	2.50		2.27	2.25	1.60	1.68
Cys	0.25		0.29	0.30		0.29	0.28	0.36	0.14
Glu	3.21		3.86	3.75		3.59	3.43	2.63	2.53
Gly	0.76		0.94	0.90		0.90	0.83	1.82	1.41
Pro	0.90		1.09	1.09		1.04	0.96	1.34	0.91
Ser	0.83		0.94	0.99		0.93	0.89	1.00	0.65

Table 6.3 (Cont.)

Item, %	Ingredient									
	Fermented SBM					PBM	Fishmeal	SEM	P-value	
	SBM	A	B	C	D					
Tyr	0.59		0.63		0.73		0.64		0.56	0.49
Mean	9.44		11.13		11.24		10.60		10.16	10.60
All AA	17.62		20.74		21.13		19.79		18.96	19.93
										17.94

Table 6.4. Apparent ileal digestibility (AID, %) of CP and AA in soybean meal (SBM), 4 sources of fermented SBM, poultry by-product meal (PBM), and fishmeal by growing pigs¹

Item, %	Ingredient					PBM	Fishmeal	SEM	P-value
	Fermented SBM								
	SBM	A	B	C	D				
CP	78.4 ^b	70.5 ^c	82.9 ^a	77.0 ^b	76.0 ^b	56.3 ^d	68.9 ^c	1.78	0.03
Indispensable AA									
Arg	91.9 ^{ab}	89.8 ^{bc}	93.5 ^a	92.5 ^{ab}	88.6 ^c	69.2 ^e	84.3 ^d	1.03	0.05
His	88.4 ^a	79.8 ^c	89.3 ^a	88.1 ^a	83.4 ^b	55.5 ^d	80.3 ^c	1.21	0.05
Ile	87.1 ^{ab}	82.3 ^c	89.0 ^a	88.0 ^a	84.0 ^{bc}	60.0 ^d	82.2 ^c	1.38	0.05
Leu	86.7 ^{ab}	81.8 ^c	88.4 ^a	87.5 ^a	83.9 ^{bc}	59.4 ^d	81.8 ^c	1.39	0.03
Lys	86.9 ^a	75.7 ^c	83.2 ^b	83.5 ^{ab}	77.1 ^c	56.2 ^d	82.3 ^b	1.48	0.04
Met	88.5 ^{ab}	83.0 ^d	90.0 ^a	90.7 ^a	86.7 ^{bc}	63.0 ^e	84.3 ^{cd}	1.30	0.04
Phe	87.5 ^{ab}	84.1 ^c	89.5 ^a	88.4 ^a	84.8 ^{bc}	61.4 ^e	81.0 ^d	1.32	0.04
Thr	79.7 ^a	70.3 ^c	79.5 ^a	80.4 ^a	73.8 ^{bc}	49.5 ^d	76.5 ^{ab}	1.75	0.01
Trp	87.6 ^a	83.5 ^a	88.1 ^a	86.9 ^a	87.7 ^a	66.6 ^b	83.5 ^a	2.15	0.01

Table 6.4 (Cont.)

Item, %	Ingredient					PBM	Fishmeal	SEM	P-value
	Fermented SBM								
	SBM	A	B	C	D				
Val	82.8 ^a	75.5 ^b	83.2 ^a	83.5 ^a	78.1 ^b	53.9 ^c	77.0 ^b	1.60	0.02
Mean	86.7 ^a	80.5 ^b	87.2 ^a	86.9 ^a	82.5 ^b	59.1 ^c	81.5 ^b	1.30	0.01
Dispensable AA									
Ala	79.1 ^a	72.7 ^c	80.6 ^a	80.4 ^a	73.7 ^{bc}	59.1 ^d	77.6 ^{ab}	1.83	0.04
Asp	85.4 ^a	78.4 ^b	86.2 ^a	85.2 ^a	78.8 ^b	42.5 ^d	74.5 ^c	1.38	0.03
Cys	77.7 ^a	58.7 ^c	74.9 ^a	75.5 ^a	65.9 ^b	34.4 ^d	56.1 ^c	2.48	0.02
Glu	87.4 ^a	78.2 ^c	87.4 ^a	86.0 ^{ab}	77.4 ^b	61.7 ^d	82.6 ^b	1.51	0.02
Gly	65.8 ^a	54.8 ^b	65.6 ^a	70.4 ^a	51.9 ^b	54.8 ^b	69.4 ^a	3.57	0.02
Pro	48.1 ^{ab}	42.6 ^b	53.5 ^{ab}	60.2 ^a	49.1 ^{ab}	21.6 ^c	52.2 ^{ab}	7.52	0.03
Ser	85.9 ^{ab}	78.8 ^{cd}	86.3 ^a	84.9 ^{ab}	82.4 ^{bc}	56.4 ^e	75.1 ^d	1.42	0.05
Tyr	87.5 ^{ab}	83.4 ^c	89.5 ^a	89.9 ^a	86.0 ^{bc}	55.2 ^e	79.3 ^d	1.39	0.05
Mean	78.0 ^a	68.9 ^b	79.4 ^a	81.1 ^a	71.7 ^b	48.3 ^c	71.5 ^b	2.19	0.01

Table 6.4 (Cont.)

Item, %	Ingredient					PBM	Fishmeal	SEM	P-value
	Fermented SBM								
	SBM	A	B	C	D				
All AA	82.1 ^a	74.2 ^b	83.3 ^a	83.7 ^a	76.6 ^b	53.2 ^c	76.3 ^b	1.60	0.01

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

¹Data are least square means of 10 observations.

Table 6.5. Standardized ileal digestibility (SID, %) of CP and AA in soybean meal (SBM), 4 sources of fermented SBM, poultry by-product meal (PBM), and fishmeal by growing pigs¹

Item, %	Ingredient					PBM	Fishmeal	SEM	P-value
	Fermented SBM								
	SBM	A	B	C	D				
CP	90.9 ^{ab}	81.1 ^d	93.2 ^a	87.9 ^{bc}	86.2 ^c	66.2 ^f	75.7 ^e	1.75	0.04
Indispensable AA									
Arg	97.3 ^{ab}	95.0 ^{bc}	98.6 ^a	97.1 ^{ab}	93.8 ^c	74.5 ^e	88.2 ^d	1.04	0.01
His	93.8 ^a	85.3 ^c	94.5 ^a	92.7 ^a	88.7 ^b	62.9 ^d	83.5 ^c	1.22	0.03
Ile	92.4 ^a	86.7 ^{cd}	93.4 ^a	92.1 ^{ab}	89.1 ^{bc}	65.0 ^e	85.3 ^d	1.37	0.05
Leu	92.4 ^a	86.6 ^{cd}	93.5 ^a	92.0 ^{ab}	89.2 ^{bc}	64.6 ^d	85.3 ^d	1.37	0.04
Lys	92.7 ^a	80.6 ^d	90.0 ^{ab}	88.5 ^b	82.8 ^{cd}	62.0 ^e	84.3 ^c	1.51	0.05
Met	93.3 ^{ab}	87.1 ^c	94.4 ^a	94.4 ^a	91.1 ^b	66.1 ^d	85.6 ^c	1.30	0.04
Phe	92.8 ^a	88.4 ^b	94.2 ^a	92.7 ^a	89.8 ^b	66.9 ^d	84.2 ^c	1.30	0.05
Thr	90.8 ^a	79.7 ^c	90.2 ^a	89.4 ^a	84.0 ^b	58.7 ^d	82.2 ^{bc}	1.72	0.01
Trp	93.8 ^{ab}	88.7 ^{ab}	94.4 ^a	93.0 ^{ab}	93.0 ^{ab}	76.1 ^c	88.0 ^b	2.15	0.05

Table 6.5 (Cont.)

Item, %	Ingredient							SEM	P-value
	Fermented SBM					PBM	Fishmeal		
	SBM	A	B	C	D				
Val	92.4 ^a	83.6 ^{bc}	92.4 ^a	91.0 ^{ab}	87.3 ^b	61.6 ^d	81.4 ^c	1.58	0.05
Mean	93.2 ^a	86.0 ^{bc}	93.5 ^a	92.1 ^a	88.6 ^{bc}	65.3 ^d	84.8 ^c	1.28	0.02
Dispensable AA									
Ala	90.7 ^a	80.6 ^b	91.1 ^a	89.6 ^a	84.7 ^b	66.3 ^c	81.8 ^b	1.86	0.04
Asp	90.0 ^a	82.2 ^b	90.7 ^a	88.9 ^a	83.1 ^b	48.5 ^d	78.0 ^c	1.35	0.02
Cys	87.2 ^a	66.9 ^c	85.2 ^a	83.1 ^a	74.6 ^b	40.8 ^d	64.9 ^c	2.52	0.01
Glu	91.7 ^a	82.0 ^b	92.2 ^a	89.7 ^a	81.6 ^b	66.9 ^c	85.3 ^b	1.46	0.01
Gly	92.9 ^a	77.6 ^b	93.2 ^a	90.7 ^a	77.1 ^b	66.3 ^c	76.8 ^b	3.61	0.03
Pro	128.2 ^a	114.8 ^{ab}	127.7 ^a	117.5 ^{ab}	121.9 ^{ab}	76.6 ^c	105.0 ^b	7.44	0.04
Ser	92.9 ^a	84.8 ^c	93.6 ^a	90.8 ^{ab}	88.9 ^b	62.2 ^e	80.3 ^d	1.43	0.04
Tyr	93.7 ^a	88.8 ^b	95.0 ^a	94.7 ^a	91.8 ^{ab}	61.8 ^d	83.0 ^c	1.36	0.05
Mean	92.2 ^a	81.2 ^{bc}	94.4 ^a	92.6 ^a	85.0 ^b	61.2 ^d	79.8 ^c	2.17	0.04

Table 6.5 (Cont.)

Item, %	Ingredient							SEM	P-value
	Fermented SBM					PBM	Fishmeal		
	SBM	A	B	C	D				
All AA	92.7 ^a	83.4 ^{bc}	94.2 ^a	92.4 ^a	86.6 ^b	63.0 ^d	82.2 ^c	1.57	0.02

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

¹Data are least square means of 10 observations.

CHAPTER 7: CONCENTRATIONS OF NITROGEN-CORRECTED APPARENT METABOLIZABLE ENERGY AND AMINO ACID DIGESTIBILITY IN SOYBEAN MEAL FROM ARGENTINA, BRAZIL, CHINA, THAILAND AND THE UNITED STATES FED TO BROILERS

ABSTRACT: The Philippines import soybean meal (SBM) from many different countries, but the quality of the SBM from the different sources is not known. Therefore, 2 experiments were conducted using SBM from Argentina (ARG 1 and ARG 2), Brazil, China, Thailand, and the U.S. (US1, US2, and US3) that was collected at feed mills in the Philippines. The objective was to determine concentrations of nitrogen-corrected apparent metabolizable energy (AMEn) and standardized ileal digestibility (SID) of AA in each source of SBM. In both experiments, ANOVA was used with the PROC MIXED function in SAS. In Exp. 1, 72 d-old male broilers were allotted to 1 of 9 treatments using a completely randomized design with 8 broilers per treatment. Treatments included a corn-SBM based basal diet and 8 diets that were formulated by mixing 70% basal diet and 30% of each SBM source. Broilers were placed in individual metabolism crates equipped with an aluminum tray for total collection of excreta. Excreta were collected for 3 d after a 10 d adaptation period. The AMEn (2,762 kcal/kg) of Chinese SBM was greater ($P < 0.05$) than in ARG 1 (2,699 kg/kcal) and ARG2 (2,737 kcal/kg), but not different from the other sources. No differences in BW gain were observed, but there was reduced ($P < 0.05$) feed intake and improved ($P < 0.05$) G:F for birds fed US1 SBM compared with birds fed Argentinian or US2 SBM. In Exp. 2, 48 cecectomized roosters were allotted to 1 of 8 treatments using a completely randomized design with 6 roosters per treatment. The cecectomized roosters were tube fed 30 g of SBM and excreta were collected for 48 h following feeding. There was a

tendency for greater ($P < 0.10$) SID of indispensable AA for US3 SBM than for the other sources of SBM. The SBM from US3 had greater ($P < 0.05$) SID of Lys compared with Brazilian SBM. The SBM from US3 also had greater ($P < 0.05$) SID of dispensable AA and total AA than SBM from China, Thailand, US1 and US2. These studies demonstrated that differences in energy and AA digestibility exist among different SBM sources.

Key words: amino acid digestibility, apparent metabolizable energy, broilers, nitrogen-corrected apparent metabolizable energy, soybean meal

INTRODUCTION

In 2013, the United States, Brazil, Argentina, China, and India produced 90% of all soybeans grown in the world (ASA, 2014). The U.S. was the top soybean producer, with a total soybean production of approximately 90 million t. From the 90 million t of soybeans produced, approximately 36.3 million t of SBM (SBM) were produced in the U. S. for livestock consumption and export (ASA, 2014), and 26.5 million t of this amount was fed domestically to livestock and poultry, with the balance being exported or fed to other animal species. Poultry consume approximately 50% of all SBM consumed by livestock (ASA, 2014).

Soybeans, and therefore SBM, produced in different countries or in different areas of the U.S. have different energy and nutrient compositions because of differences in environmental conditions or in soybean genetics (Grieshop et al., 2001; Karr-Lilienthal et al., 2004; Sotak and Stein, 2014). These differences impact energy, CP, and total AA concentrations of SBM (Grieshop et al., 2001; Karr-Lilienthal et al., 2004). The apparent metabolizable energy (**AME**) and ileal digestibility of CP and AA for U.S. SBM may be greater compared with Argentinian, Brazilian, and Indian SBM (Ravindran et al., 2014). However, the SID of many indispensable

AA in U.S. or Brazilian SBM was not different when fed to broilers, but the SID of AA in U.S. or Brazilian SBM was greater ($P < 0.05$) than in Argentinian SBM (Frikha et al., 2012).

The Philippines import SBM from many different countries, but the nutritional quality of SBM from the different origins is not known. It is, therefore, not known if the same matrix values can be used in formulations for all sources of SBM used in the Philippines. Therefore, 2 experiments were conducted to determine the concentrations of AME and nitrogen-corrected apparent metabolizable energy (**AMEn**) and SID of AA by broilers fed SBM from Argentina, Brazil, China, Thailand, and the U.S that was imported to the Philippines.

MATERIALS AND METHODS

Experiment 1 was conducted at the University of the Philippines, Los Baños, and the protocol for Exp. 1 followed the standards and regulations of the Philippine Animal Welfare Act of 1998 (Republic Act No. 8485). Experiment 2 was conducted at the University of Illinois at Urbana, and the protocol for Exp. 2 was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois.

Samples of 8 sources of soybean meal were procured from Argentina (2 sources: ARG1 and ARG2), Brazil (1 source), China (1 source), Thailand (1 source), and the United States (3 sources: US1, US2, and US3; Tables 7.1 and 7.2). All sources of SBM were collected from feed mills in the Philippines and were expected to be representative of the sources of SBM imported to the Philippines. Two kg of each source was shipped to the University of Illinois, whereas the remaining SBM was used in the experiment in the Philippines.

Exp. 1: Nitrogen-corrected Apparent Metabolizable Energy

A total of 72 day-old (Cobb 500) male broiler chickens were used in this experiment. Chicks were group-brooded and fed a commercial starter diet for 12 d. On d 12, birds were fasted for 4 h and then allotted to 1 of 9 dietary treatments using a completely randomized design with 8 broilers per treatment. The BW of each chicken was recorded prior to allotment. Dietary treatments included a corn-SBM basal diet and 8 diets based on a mixture of the basal diet (70%) and each source of SBM (30%; Tables 7.3 and 7.4). Broilers were placed in individual metabolism crates (50 × 60 cm) that were equipped with aluminum trays that allowed for total collection of excreta.

The 9 experimental diets were fed from d 12 to 22, with d 12 to 18 being the adaptation to the diets. Birds were then fasted for 17 h, and excreta were collected for 96 h from d 19 to 22. On d 22, birds were fasted again for 17 h, and individual bird weights were recorded. Daily feed allotments were recorded, and the weight of feed left in the feeders was recorded on the last day of the experiment.

At the conclusion of the experiment, excreta samples from each bird were thawed, mixed homogenously using a commercial blender, dried at 70°C in a forced-air oven, and ground through a 40-mesh sieve prior to analysis. Samples of diets, excreta, and ingredients were analyzed in duplicate for DM (Method 930.15; AOAC, 2007) and GE (Model 6200, Parr Instruments, Moline, IL). Single samples of SBM were also analyzed for AA [Method 982.30 E (a, b, c); AOAC Int., 2007]. The SBM was also analyzed in duplicate for ADF (Method 973.18; AOAC Int., 2007), NDF (Holst, 1973), lignin [Method 973.18 (A-D); AOAC Int., 2007], acid hydrolyzed ether extract (**AEE**; Method 2003.06; AOAC Int., 2007), Ca and P (Method 985.01

A, B, and C; AOAC Int., 2007), ash (Method 942.05; AOAC Int., 2007), trypsin inhibitors (Method Ba 12-75; AOCS, 2006), and starch (Method 979.10; AOAC Int., 2007). Each source of SBM was also analyzed in duplicate for glucose, sucrose, maltose, fructose, stachyose, raffinose, and verbascose as described by Cervantes-Pahm and Stein (2010).

The AMEn of the corn-based basal diet were determined using the direct procedure, and the AMEn of each SBM source were determined using the difference procedure (Leeson and Summers, 2001). Data for feed intake and individual BW gain were summarized to calculate ADG, ADFI, and G:F for each treatment. Data were analyzed as a completely randomized design with each broiler chick as the experimental unit. Analysis of variance was used with the PROC MIXED function in SAS (SAS Institute Inc., Cary, NC). Homogeneity of the variances was confirmed using the UNIVARIATE procedure in SAS. Outliers were determined using the UNIVARIATE procedure. Means were calculated using the LS Means statement in SAS and if significance was observed, means were separated using the PDIFF option. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Exp. 2: Standardized Ileal Digestibility of Amino Acids

A total of 48 cecectomized Single Comb White Leghorn roosters were used to determine AA digestibility in the 8 sources of SBM (Parsons, 1985). Birds were allotted to 1 of 8 dietary treatments using a completely randomized design with 6 birds per treatment. Birds were housed individually in 22.5 × 36 cm cages with raised wire floors in an environmentally controlled room. Each of the cecectomized roosters were tube fed 30 g of SBM. Excreta were collected once 48 h after tube feeding and stored at -20°C to prevent bacterial degradation of the AA in the excreta.

At the conclusion of the experiment, excreta samples were thawed and mixed within animal, lyophilized, and finely ground prior to chemical analysis. Samples of excreta were analyzed for DM, CP, and AA as described for Exp. 1.

Calculations and Statistical Analysis

The SID of AA was calculated as described by Sibbald (1979). The correction for basal endogenous losses was made using averaged values for AA excreted by cecectomized roosters that were fasted in a prior study. Data for SID of AA in the 8 sources of SBM were analyzed as described for Exp. 1.

RESULTS

Chemical Characteristics of Ingredients

Concentration of GE was 4,156, 4,154, 4,154, 4,123, 4,125, 4,190, 4,206, and 4,094 kcal/kg (as fed basis) for SBM from ARG1, ARG2, Brazil, China, Thailand, US1, US2, and US3, respectively (Table 7.2). Concentration of AEE was 1.35, 0.53, 1.01, 0.93, 0.29, 1.07, 1.47, and 0.67 for SBM from ARG1, ARG2, Brazil, China, Thailand, US1, US2, and US3, respectively. The stachyose and raffinose concentrations for SBM from ARG1, ARG2, Brazil, China, Thailand, US1, US2, and US3 were 5.14 and 1.42%, 5.00 and 1.39%, 3.96 and 1.61%, 4.22 and 1.53%, 5.41 and 1.11%, 5.52 and 1.26%, 5.54 and 1.29% and 5.52 and 1.36%, respectively. The concentrations of CP, Lys, and total AA were 45.28, 2.91, and 44.50%, 45.35, 2.88, 44.22%, 47.73, 2.98, and 45.91%, 48.67, 3.07, and 47.69%, 47.66, 2.96, and 45.49%, 46.66, 2.95, and 45.24%, 47.20, 2.94, and 44.72%, and 47.18, 3.04, and 46.22% for SBM from ARG1, ARG2, Brazil, China, Thailand, US1, US2, and US3, respectively. The Lys:CP ratio was

above 6% for all SBM sources. Trypsin inhibitor values were all below 4 TIU/mg, except US3 SBM, indicating that it may have been under processed (Chang et al., 1987; Monari, 1993; Lallès, 2000).

Exp.1: Nitrogen-corrected Apparent Metabolizable Energy

The initial and final weights and feed intake for broilers fed US1 and Chinese SBM were less ($P \leq 0.05$) compared with broilers fed the other sources of SBM, but there were no differences in ADG among treatments (Table 7.5). However, because of similar ADG and lower feed intake, broilers fed US1 or Chinese SBM had improved ($P \leq 0.05$) G:F compared with broilers fed ARG2, US2, or Thailand SBM.

Gross energy intake was greater ($P \leq 0.05$) in diets containing US2 or SBM from Thailand compared with the other diets (Table 7.6). Excretion of GE in excreta was greater ($P \leq 0.05$) from chicks fed diets containing ARG2, Thailand, or US2 SBM compared with chicks fed diets containing the other sources of SBM. The AMEn was greater ($P \leq 0.05$) for diets containing SBM China compared with diets containing SBM from Argentina. Diets containing SBM from Argentina had less ($P < 0.05$) AMEn than all other diets except diets containing US3 SBM or SBM from Brazil. The AMEn was also reduced ($P \leq 0.05$) in SBM from Argentina compared with SBM from China, Thailand, US1, and US2. However, no differences in AMEn among SBM from China, Thailand, or the U.S. were observed.

Exp. 2 Standardized Ileal Digestibility of Amino Acids

Soybean meal from US3 had greater ($P < 0.05$) SID of Arg compared with SBM from Thailand, China, and Brazil, but this value was not different from the SID of AA in ARG1, ARG2, US1, and US2 (Table 7.7). Soybean meal from US3 also had greater ($P < 0.05$) SID of

His compared with SBM from Thailand, China, and U2, but this value was not different from that of SBM from ARG1, ARG2, Brazil, and US1. There was a tendency for greater ($P < 0.10$) SID of Ile, Leu, Val, and indispensable AA for US3 SBM compared with the other 7 sources of SBM. Soybean meal from US3 had greater ($P < 0.05$) SID of Lys compared with SBM from Brazil. There were no differences in the SID of Met among the 8 sources of SBM. Brazilian SBM had greater ($P < 0.05$) SID of Phe than US1 and greater ($P < 0.05$) SID of Thr than ARG1, but the SID of Thr was not different among SBM from ARG1, ARG2, China, Thailand, US2, and US3. Soybean meal from US1 had greater ($P < 0.05$) SID of Trp compared with Chinese SBM.

There were only minor differences among sources of SBM in the SID of dispensable AA. Soybean meal from US3 had greater ($P < 0.05$) SID of total dispensable AA than SBM from ARG1, ARG2, and Brazil, but this value was not different from the other 4 sources of SBM. Soybean meal US3 had greater ($P < 0.05$) SID of total AA compared with SBM from US2 and Thailand, but the SID of total AA in the other 5 SBM sources was not different from that of US3.

DISCUSSION

The composition concentration of most nutrients in SBM and corn used in the experiment is mostly in agreement with previous values for most nutrients (NRC, 2012). Variability in the nutrient composition among sources of SBM are caused by differences in environmental conditions including, but not limited to, growing areas, soil type, variety of soybeans, and processing conditions (Grieshop et al., 2003; Karr-Lilienthal et al., 2004). Crude protein for both Argentinian sources of SBM was less than published values, but soy hulls may have been mixed back in to the SBM, which will reduce the CP concentration (Stein et al., 2008). Soybeans from

China have a greater concentration of CP than soybeans from Brazil, with intermediate concentrations of CP in American soybeans (Grieshop et al., 2001). Differences in CP were reported among different sources of SBM from 4 zones in the U.S., with reduced CP for SBM produced in the western US compared with SBM produced in IL or the northern and eastern U.S. (Sotak and Stein, 2014). Frikha et al. (2012) reported that Brazilian SBM had greater concentrations of CP compared with American and Argentinian SBM, with the American SBM having intermediate concentrations of CP. Ravindran et al. (2014) reported that Brazilian SBM had greater CP concentration than SBM from the U.S. or Argentina SBM. Differences in CP were also reported among sources of SBM from different regions of Brazil, with greater CP for SBM produced in Goiás and Mato Grosso do Sul compared with other Brazilian states (Goldflus et al., 2006).

Trypsin inhibitors may reduce protein digestibility in SBM by reducing the activity of trypsin, chymotrypsin, and other proteases, but the concentrations of trypsin inhibitors is reduced by heat treatment (Yen et al., 1977). The trypsin inhibitor units in SBM used in this experiment was less than 4, except for US3 SBM, which indicates that the US3 SBM source may have been less processed than the other sources (Chang et al., 1987; Monari, 1993; Lallès, 2000). However, the fact that SID of several AA in US3 was greater than that of other sources indicate that the processing of US3 was sufficient to inactivate trypsin inhibitors to a degree that they did not reduce AA digestibility. The Lys:CP ratio for all sources of SBM was greater than 6.0, indicating that these sources of SBM were not heat damaged or over processed (Gonzalez-Vega et al., 2011).

Oligosaccharides, primarily stachyose and raffinose, are poorly digested carbohydrates that reduce utilization of energy and produce greater amounts of flatulence in poultry and pigs

(Rackis, et al., 1970; Leske et al., 1995). The concentration of stachyose in most sources of SBM used in the present experiments was less than NRC (2012) values, but greater than values reported by Sotak and Stein (2014) and Baker and Stein (2011). Concentrations of raffinose were in agreement with some previous data (Baker et al., 2011; Sotak and Stein, 2014), but less than values reported by NRC (2012).

Soybean meal from Argentina, Brazil, China, and US1 and US2 had similar concentrations of Ca compared with published values (NRC, 2012). Soybean meal from US3 had greater Ca concentration than published values, but limestone may have been added to aid in flowability at the plant (Chiba, 2001). Soybean meal from the western U.S. had a tendency for greater concentrations of Ca compared with other zones of the U.S. (Sotak and Stein, 2014), indicating that limestone sometimes is added to SBM.

Ravindran et al. (2014) reported AME being greater for SBM from the U.S. compared with SBM from Argentina, but in this experiment, only ARG2 had less AME than US1 and US2 SBM. Energy utilization of SBM has been reported to be 20% less for chicks compared with pigs (McGinnis, 1983), and this may be due to the inability of chickens to ferment oligosaccharides, such as stachyose and raffinose. Soybean meal varieties containing higher levels of stachyose and raffinose reduce AMEn in broiler chicks compared with SBM with lower levels of stachyose and raffinose (Parsons et al., 2000; Perryman and Dozier, 2012). Furthermore, total tract digestibility varies greatly based on stachyose and raffinose concentrations and may range from 84 to 90% (Coon, 1990). The AMEn values in this study are in agreement with AMEn from previous research (Leske and Coon, 1999). Combined, results of this experiment indicate that SBM from Argentina have reduced AMEn compared with SBM

from other countries, which may be a consequence of the reduced CP in the SBM from Argentina.

The increased G:F in broiler chicks fed US1 SBM compared with chicks fed ARG2, Brazil, or Thailand SBM was a result of differences in feed intake. In studies with differences in stachyose, raffinose, or fiber concentrations, broilers fed SBM containing greater levels of these components experienced lower digestibility compared with broilers fed SBM containing less fiber or oligosaccharides (Perryman et al., 2013). However, differences in concentrations of fiber or oligosaccharides among sources of SBM were not observed in this experiment.

The SID of most AA was in agreement with previous data (Parsons et al., 2000; Baker et al., 2011; Frikha et al., 2012). However, the SID of AA were greater in this experiment than values reported by Chen et al. (2013) and Ravindran et al. (2014), but the SID of AA in this experiment were similar to values from SBM produced from commercial conventional soybeans (Edwards et al., 2000). Ravindran et al. (2014) observed a reduction ($P < 0.05$) in SID of AA for broilers fed SBM from India compared with broilers fed SBM from the U.S., Brazil, or Argentina, but there were no differences observed in the SID of most AA among SBM from the U.S., Brazil, or Argentina.

CONCLUSION

Results of this experiment indicate that SBM from different countries have concentrations of most nutrients and antinutritional factors that are not different. The AMEn of Chinese SBM was greater than in Argentinian SBM, but not different from the AMEn of SBM from Brazil, Thailand, and the U.S. The ADG for broiler chicks was not affected by source of

SBM, but G:F was different among sources. The SID of total AA was greater for birds fed US3 SBM compared with birds fed SBM from China, Thailand, or US2. Overall, whereas nutrient composition may not vary, differences in energy and AA digestibility may exist among sources of SBM from different countries. However, the variation among sources obtained within the same country may be as big as the variation among countries.

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TABLES

Table 7.1. Country of origin for the 8 sources of soybean meal used in the experiment

Country of origin	No. of samples
Argentina	2
Brazil	1
China	1
Thailand	1
United States	3
Total	8

Table 7.2. Analyzed nutrient composition of corn and soybean meal

Item	Corn	Basal SBM ²	Country ¹								Average ³
			ARG1	ARG2	Brazil	China	Thailand	US1	US2	US3	
GE, kcal/kg	3,871	4,184	4,156	4,154	4,154	4,123	4,125	4,190	4,206	4,094	4,150
DM	87.66	90.04	89.38	89.55	89.07	87.96	89.01	90.00	90.62	88.58	89.27
CP	8.36	46.78	45.28	45.35	47.73	48.67	47.66	46.66	47.20	47.18	46.97
AEE ⁴	3.37	1.73	1.35	0.53	1.01	0.93	0.29	1.07	1.47	0.67	0.79
ADF	4.05	5.79	6.84	6.55	10.03	7.69	8.09	7.68	6.29	6.19	7.42
NDF	9.99	7.43	7.66	9.61	11.01	8.85	10.15	9.05	9.77	8.78	9.36
Lignin	1.00	0.32	1.03	0.35	1.70	0.76	0.84	0.97	0.47	0.93	0.98
Ash	1.16	7.73	6.93	6.83	6.68	5.74	5.77	5.85	5.93	7.00	6.34
Ca	0.01	0.27	0.25	0.26	0.30	0.27	0.29	0.25	0.25	0.55	0.30
P	0.24	0.67	0.65	0.67	0.60	0.64	0.62	0.65	0.67	0.67	0.64
TIU ⁵ , TIU/mg	-	2.46	1.44	1.33	3.95	2.21	2.74	1.29	1.43	4.23	2.15
Carbohydrates											
Starch	61.40	1.80	1.80	1.80	ND ⁶	ND	1.80	1.50	1.40	1.80	1.68

Table 7.2 (Cont.)

Item	Corn	Basal SBM ²	Country ¹								Average ³
			ARG1	ARG2	Brazil	China	Thailand	US1	US2	US3	
Glucose	0.64	ND	ND	ND	ND	ND	ND	ND	ND	ND	-
Maltose	0.30	0.19	0.19	0.25	0.37	0.37	0.22	0.28	0.24	0.14	0.28
Fructose	0.26	0.06	0.10	0.09	0.08	0.07	0.07	0.08	0.08	0.07	0.08
Sucrose	0.88	7.32	7.29	7.21	5.65	5.16	6.61	7.84	7.94	6.32	7.66
Stachyose	-	5.26	5.14	5.00	3.96	4.22	5.41	5.52	5.54	5.52	5.04
Raffinose	0.31	1.43	1.42	1.39	1.61	1.53	1.11	1.26	1.29	1.36	1.37
Indispensable, AA %											
Arg	0.40	3.31	3.23	3.22	3.37	3.49	3.29	3.27	3.25	3.43	3.32
His	0.26	1.23	1.20	1.19	1.23	1.26	1.22	1.22	1.22	1.24	1.22
Ile	0.29	2.13	2.09	2.09	2.19	2.28	2.13	2.14	2.14	2.18	2.16
Leu	0.93	3.61	3.54	3.52	3.64	3.81	3.57	3.61	3.59	3.64	3.62
Lys	0.33	2.99	2.91	2.88	2.98	3.07	2.96	2.95	2.94	3.04	2.97
Met	0.19	0.64	0.62	0.62	0.62	0.62	0.65	0.64	0.63	0.65	0.63

Table 7.2 (Cont.)

Item	Corn	Basal SBM ²	Country ¹								Average ³
			ARG1	ARG2	Brazil	China	Thailand	US1	US2	US3	
Phe	0.39	2.35	2.30	2.30	2.40	2.52	2.32	2.35	2.34	2.36	2.36
Thr	0.31	1.82	1.80	1.78	1.82	1.87	1.83	1.83	1.82	1.83	1.82
Trp	0.05	0.67	0.65	0.66	0.71	0.69	0.72	0.67	0.66	0.63	0.67
Val	0.42	2.24	2.21	2.20	2.26	2.34	2.23	2.25	2.26	2.27	2.25
Dispensable, AA %											
Ala	0.61	2.05	2.03	2.01	2.07	2.14	2.03	2.05	2.04	2.06	2.05
Asp	0.55	5.09	4.99	4.95	5.17	5.40	5.15	5.10	5.07	5.26	5.14
Cys	0.17	0.62	0.59	0.60	0.61	0.60	0.63	0.60	0.57	0.65	0.61
Glu	1.47	8.34	8.13	8.10	8.38	8.80	8.37	8.29	8.25	8.56	8.36
Gly	0.36	1.93	1.90	1.88	1.95	2.06	2.01	1.90	1.92	1.95	1.95
Pro	0.69	2.36	2.32	2.33	2.38	2.43	2.34	2.36	2.09	2.37	2.33
Ser	0.38	2.22	2.17	2.14	2.23	2.35	2.21	2.18	2.16	2.23	2.21
Tyr	0.17	1.63	1.62	1.60	1.71	1.76	1.65	1.69	1.64	1.70	1.67

Table 7.2 (Cont.)

Item	Corn	Basal SBM ²	Country ¹								Average ³
			ARG1	ARG2	Brazil	China	Thailand	US1	US2	US3	
Total AA	8.03	45.36	44.50	44.22	45.91	47.69	45.49	45.24	44.72	46.22	45.50
Lys:CP ratio ⁷	3.95	6.39	6.43	6.35	6.24	6.31	6.21	6.32	6.23	6.44	6.32

¹There were 2 sources of soybean meal from Argentina (ARG1 and ARG2), 1 source of soybean meal from Brazil, China, and Thailand, and 3 sources of soybean meal from the United States (US1, US2, and US3).

²A separate soybean meal source was used in the corn-soybean meal basal diet.

³Average for the 8 experimental soybean meals.

⁴AEE = acid hydrolyzed ether extract.

⁵TIU = trypsin inhibitor units.

⁶ND = Not detected.

⁷Lys: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 7.3. Ingredient composition of experimental diets (Exp. 1; as-fed basis)

Item	Diets	
	Basal diet	Soybean meal diets ¹
Basal diet	-	70.00
Corn	59.44	-
Soybean meal, 48% CP	35.71	30.00
Limestone	1.66	-
Monocalcium phosphate, 21% P	2.36	-
Vitamin-mineral premix ²	0.33	-
Sodium chloride	0.50	-
Total	100.00	100.00

¹Eight soybean-meal diets were formulated using soybean meal from Argentina (2 sources), United States (3 sources), China (1 source), Thailand (1 source), and Brazil (1 source). A separate soybean meal source was used in the corn-soybean meal basal diet. Soybean meal diets were formulated to 29% CP. Basal diet was formulated to 21% CP.

²The vitamin-micromineral premix contained the following quantities of vitamins and micro minerals per kilogram of premix: Vitamin A, 11,000,000 IU/kg; Vitamin D, 5,000,000 IU/kg; Vitamin E, 50,000 mg/kg; Vitamin K, 3,000 mg/kg; thiamine, 2,000 mg/kg; riboflavin, 7,000 mg/kg; pyridoxine, 3,000 mg/kg; niacin, 40,000 mg/kg; pantothenic acid, 15,000 mg/kg; vitamin B₁₂, 15 mg/kg; folic acid, 1,5000 mg/kg; Fe, 92,000 mg/kg; Cu, 7,500 mg/kg; Zn, 60,000 mg/kg; Mn, 50,000 mg/kg; I, 700 mg/kg; Se, 150 mg/kg.

Table 7.4. Analyzed composition of diets (Exp. 1)

Item	Basal diet ²	Country ¹								Average ³
		ARG1	ARG2	Brazil	China	Thailand	US1	US2	US3	
GE, kcal/kg	3,712	3,843	3,876	3,904	3,975	4,022	3,977	4,035	3,901	3,942
DM, %	89.18	89.09	88.20	88.57	89.12	88.68	88.86	88.97	87.43	88.61

¹There were 2 sources of soybean meal from Argentina (ARG1 and ARG2), 1 source of soybean meal from Brazil, China, Thailand, and 3 sources of soybean meal from the United States (US1, US2, and US3).

²A separate soybean meal source was used in the corn-soybean meal basal diet.

³Average of the 8 experimental diets.

Table 7.5. Growth performance from d 12 to 23 post hatch of broiler chicks fed the basal diet based on corn or diets containing soybean meal (SBM) and SBM from Argentina, Brazil, China, Thailand, or the United States (Exp. 1)¹

Item, g	Basal	Country ²								Average ³	SEM	P-value ⁴
		ARG1	ARG2	Brazil	China	Thailand	US1	US2	US3			
Initial BW	673.08	679.88 ^a	705.50 ^a	678.09 ^a	545.88 ^b	714.90 ^a	529.24 ^b	684.75 ^a	632.09 ^{ab}	642.22	2.71	0.03
Final BW	872.99	893.16 ^a	907.24 ^a	880.55 ^a	754.51 ^b	914.06 ^a	738.39 ^b	886.76 ^a	825.85 ^{ab}	842.80	2.74	0.04
ADG	18.17	19.39	18.34	18.41	18.97	18.11	19.01	18.36	17.61	18.26	0.54	0.12
Feed intake	356.53	356.11 ^{ab}	360.00 ^a	346.41 ^{abc}	321.23 ^{bc}	360.00 ^a	316.25 ^c	354.45 ^{ab}	335.70 ^{abc}	0.34	0.82	0.04
G:F (g/g)	0.56	0.60 ^{abc}	0.56 ^c	0.59 ^{bc}	0.65 ^{ab}	0.55 ^c	0.67 ^a	0.57 ^c	0.59 ^{abc}	0.60	0.02	0.04

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

¹Values are for means of 8 replicate chicks per treatment.

²There were 2 sources of SBM from Argentina (ARG1 and ARG2), 1 source of SBM from Brazil, China, and Thailand, and 3 sources of SBM from the United States (US1, US2, and US3) used in this experiment. A separate source of SBM was used in the corn-SBM basal diet.

³Average of the 8 experimental diets.

Table 7.5 (Cont.)

⁴*P*-values comparing the 8 experimental SBM.

Table 7.6. Intake and output of energy, and concentrations of AME and AMEn in experimental diets and soybean meals (Exp. 1; as-fed basis)

Item, kcal/kg	Country ¹									Average ²	SEM	P-value ³
	Basal	ARG1	ARG2	Brazil	China	Thailand	US1	US2	US3			
GE intake, kcal	1,327	1,369 ^{ab}	1,395 ^{ab}	1,352 ^{ab}	1,277 ^b	1,448 ^a	1,258 ^b	1,431 ^a	1,309 ^{ab}	1,355	35.9	0.04
GE excreta, kcal	351	418 ^{ab}	450 ^a	398 ^{ab}	363 ^b	449 ^a	379 ^b	445 ^a	397 ^{ab}	412	16.3	0.05
AMEn of diet ⁴	2,733	2,662 ^{bc}	2,620 ^c	2,746 ^{abc}	2,831 ^a	2,768 ^{ab}	2,775 ^{ab}	2,775 ^{ab}	2,725 ^{abc}	2,738	34.0	0.03
AMEn of SBM ⁵	-	2,712 ^{bc}	2,699 ^c	2,737 ^{abc}	2,762 ^a	2,744 ^{ab}	2,746 ^{ab}	2,746 ^{ab}	2,731 ^{abc}	2,734	10.2	0.03

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

¹There were 2 sources of soybean meal from Argentina (ARG1 and ARG2), 1 source of soybean meal from Brazil, China, and Thailand, and 3 sources of soybean meal from the United States (US1, US2, and US3) used in this experiment. A separate soybean meal source was used in the corn-soybean meal basal diet.

²Average for the 8 experimental diets or soybean meals.

³P-values for the comparison of the 8 experimental soybean meals.

⁴AMEn of diet = AME of diet - (N gain $\times$ 8.22/DM intake), where N gain = BW gain $\times$ 0.20/6.235; Bourdillon et al., 1990.

Table 7.6 (Cont.)

⁵AMEn of SBM = AMEn of basal diet - [(AMEn of basal diet - AMEn of experimental diet)/0.30]; Leeson and Summers, 2001.

Table 7.7. Standardized ileal digestibility of soybean meals from Argentina, Brazil, China, Thailand, and the United States fed to cecectomized roosters (Exp. 2)¹

	Country ²										
Item	ARG1	ARG2	Brazil	China	Thailand	US1	US2	US3	Average ³	SEM	P-value
Indispensable AA											
Arg	91.71 ^{abc}	92.58 ^{ab}	88.34 ^c	89.10 ^c	89.49 ^{bc}	92.76 ^{ab}	92.64 ^{ab}	93.42 ^a	91.19	0.83	0.04
His	88.57 ^{ab}	88.15 ^{ab}	88.27 ^{ab}	87.37 ^b	87.98 ^b	88.16 ^{ab}	87.70 ^b	90.34 ^a	88.41	0.57	0.05
Ile	92.12	92.05	92.81	91.98	91.27	91.32	91.94	93.06	92.07	0.45	0.06
Leu	92.12	91.90	92.72	91.77	91.01	90.98	91.10	92.57	91.77	0.48	0.08
Lys	87.97 ^{ab}	88.34 ^{ab}	87.09 ^b	87.56 ^{ab}	88.60 ^{ab}	87.60 ^{ab}	87.43 ^{ab}	90.57 ^a	88.15	0.80	0.04
Met	92.03	91.98	92.72	91.89	91.61	91.07	91.09	92.50	91.86	0.50	0.11
Phe	92.71 ^{ab}	92.60 ^{ab}	93.37 ^a	92.62 ^{ab}	91.79 ^{ab}	91.60 ^b	91.74 ^{ab}	93.27 ^{ab}	92.46	0.44	0.05
Thr	88.16 ^{ab}	86.66 ^b	89.34 ^a	86.74 ^b	86.49 ^b	86.51 ^b	85.92 ^b	88.30 ^b	87.26 ^{ab}	0.61	0.04
Trp	96.49 ^{ab}	96.68 ^{ab}	96.99 ^{ab}	96.25 ^b	96.61 ^{ab}	97.16 ^a	96.77 ^{ab}	96.45 ^{ab}	96.67	0.20	0.03
Val	91.36	91.11	91.94	90.88	90.32	90.60	90.76	92.22	91.23	0.51	0.07
Mean	91.32	91.21	91.36	90.62	90.52	90.77	90.71	97.27	91.10	0.44	0.06

Table 7.7 (Cont.)

	Country ²										
Item	ARG1	ARG2	Brazil	China	Thailand	US1	US2	US3	Average ³	SEM	P-value
Dispensable AA, %											
Ala	88.40	88.41	89.32	88.25	87.75	87.02	87.27	89.22	88.19	88.19	0.06
Asp	90.28 ^{abc}	89.38 ^{bc}	91.11 ^{ab}	89.55 ^{bc}	89.46 ^{bc}	89.19 ^c	88.54 ^a	91.71 ^c	89.90	89.90	0.05
Cys	79.93 ^{ab}	78.02 ^b	83.18 ^{ab}	78.70 ^{ab}	79.39 ^{ab}	78.30 ^{ab}	79.23 ^{ab}	83.61 ^a	80.04	1.33	0.04
Glu	93.71 ^{ab}	93.07 ^{ab}	94.28 ^a	93.05 ^{ab}	92.77 ^{ab}	92.26 ^b	92.17 ^b	94.08 ^a	93.17	0.38	0.01
Gly	88.25 ^{bc}	88.63 ^{bc}	87.63 ^{bc}	85.80 ^c	85.31 ^c	91.15 ^{ab}	87.57 ^{bc}	95.08 ^a	88.68	1.14	0.02
Pro	92.31	91.57	92.65	91.44	91.11	91.12	90.53	92.83	91.69	0.62	0.07
Ser	91.24 ^{ab}	90.35 ^{ab}	91.65 ^a	90.02 ^{ab}	89.47 ^{ab}	88.93 ^b	89.62 ^{ab}	91.10 ^{ab}	90.30	0.62	0.03
Tyr	92.63	92.01	92.85	90.03	91.45	91.52	91.96	92.99	92.18	0.42	0.08
Mean	85.59 ^{ab}	88.93 ^{ab}	90.33 ^{ab}	88.61 ^b	88.34 ^b	88.69 ^b	88.36 ^b	91.33 ^a	89.15	0.63	0.02
Total AA	90.55 ^{ab}	90.20 ^{ab}	90.90 ^{ab}	89.72 ^b	89.55 ^b	89.85 ^{ab}	89.66 ^b	91.85 ^a	90.29	0.51	0.04

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

¹Values are means of 6 replicate roosters per treatment.

Table 7.7 (Cont.)

²There were 2 sources of soybean meal from Argentina (ARG1 and ARG2), 1 source of soybean meal from Brazil, China, and Thailand, and 3 sources of soybean meal from the United States (US1, US2, and US3).

³Average for the 8 soybean meals.

CHAPTER 8: GENERAL CONCLUSIONS

Soybean meal (**SBM**) produced from soybeans located in different growing regions vary in nutritional composition based on environmental factors, such as soil type and climate, and processing procedures. This research determined the effect of origin on nutritional value of SBM when fed to growing pigs and broilers. Energy concentrations of soybeans, and therefore SBM, vary among different growing zones within the U.S. and among different countries of origin. The apparent total tract digestibility (**ATTD**) of GE was not different among the 4 zones in the U.S. where sources of SBM were produced, but the concentrations of DE, ME, and NE for SBM from the western U.S. was less compared with SBM from the eastern and northern U.S. and IL. Values for energy concentrations are greater in this experiment, as well as in numerous publications from the University of IL, compared with published reference values, indicating that the energy contribution from SBM may be underestimated by reference publications. Soybean meal from the western U.S. contained less CP and AA compared with SBM from the other 3 zones. However, SBM from IL had the least apparent ileal digestibility (**AID**) of CP compared with the other zones. There were no differences in AID of AA, with the exception of a few dispensable AA, among zones, but differences were detected for standardized ileal digestibility (**SID**) of AA. However, if AA are expressed as g per kg of SBM, no major differences among zones were observed, indicating that production region does not influence the protein value of U.S. produced SBM.

Soybean meal from Argentina had reduced nitrogen-corrected apparent metabolizable energy (**AMEn**) compared with SBM from China, Thailand, and the U.S. One of the sources of SBM from the United States had greater ($P < 0.05$) SID of total AA compared with SBM from

one of the other sources of SBM from the United States and SBM from Thailand. These differences in SID of AA indicate differences in AA digestibility may be as large within the growing region as they are among these regions. There was a tendency for a reduction in ATTD and standardized total tract digestibility (**STTD**) of P, with SBM from the western U.S. being less digestible than SBM from Illinois. However, the addition of microbial phytase resulted in increased ATTD and STTD of P among SBM from all 4 zones.

Many different types of fermented SBM are produced, and differences in AID and SID among 4 sources of fermented SBM were demonstrated. The 4 sources of fermented SBM (A, B, C, and D) were compared with conventional SBM, poultry by-product meal, and fishmeal. The AID and SID of CP was greater ($P < 0.05$) for fermented SBM B compared with fermented SBM A, C, and D, poultry by-product meal, and fishmeal, but not different from conventional SBM. The AID and SID for the average of indispensable AA, dispensable AA, and total AA in conventional SBM and fermented SBM B and C were greater ($P < 0.05$) than in fermented SBM A and D, poultry by-product meal, and fishmeal, but not different from the AID and SID of SBM. These results indicate that not all sources of fermented SBM produce the same results when fed to weanling pigs; however, when higher quality fermented SBM is fed, it may replace poultry by-product meal and fishmeal in weanling pig diets without any negative effects.

In conclusion, differences in concentrations and digestibility of energy, CP, AA, and P exist among sources of SBM from different growing regions and countries. Differences also exist among sources of SBM from within the same country and growing region. Depending on source, fermented SBM may replace other protein sources present in weanling pig diets without negatively affecting performance. Variation among sources of SBM may be a direct result of varying growing conditions, environmental differences, and processing procedures.