EFFECTS OF GENETIC SELECTION AND PROCESSING OF SOYBEANS AND SOYBEAN MEAL ON NUTRITIONAL QUALITY

BY

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THESIS

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ABSTRACT

Five experiments were conducted to study the effects of genetic selection and processing of soybeans and soybean meal on nutritional quality when fed to pigs. The objectives of Exp. 1 and 2 were to determine standardized ileal digestibility (**SID**) of AA, and the DE and ME in de-hulled conventional full fat soybeans (**FFSB-CV**), high-protein full fat soybeans (**FFSB-HP**), and low-oligosaccharide full fat soybeans (**FFSB-LO**). Results indicate that the SID of most AA in FFSB-LO is similar to values in FFSB-CV, but greater ($P < 0.05$) than values in FFSB-HP. This may have been due to heat damage in FFSB-HP, which resulted in reduced AA digestibility due to Maillard reaction. Results also indicate that there were no significant differences in DE and ME among the 3 sources of FFSB. The objectives of Exp. 3 and 4 were to determine SID of AA, and the DE and ME in expeller soybean meals (**ESBM**) produced from conventional soybeans (**ESBM-CV**) and soybeans with low (**ESBM-LT**) or ultra-low (**ESBM-ULT**) concentrations of trypsin inhibitor soybeans. Results indicate that the SID of all AA was greater ($P < 0.05$) in SBM than in all the ESBM, therefore, it is not possible to use these low-trypsin inhibitor beans in diets fed to pigs without heat treatment with only 7 to 12 units of trypsin inhibitors. The results also indicate that the concentration of trypsin inhibitors does not seem to affect energy concentration in the meals. The objective of Exp. 5 was to determine SID of AA in 4 sources of fermented soybean meal (**FSBM**). The results indicate that there are differences among commercial sources of FSBM in the SID of most AA. Relatively low SID of most AA in some sources of FSBM is most likely due to overheating during production of these ingredients, resulting in Maillard reactions and subsequent destruction of Lys and reduction in AA digestibility.

Key words: amino acids, digestible energy, expeller soybeans, fermented soybean meal, full fat soybeans, metabolizable energy, oligosaccharide, protein, trypsin inhibitor, pigs

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CHAPTER 1

INTRODUCTION

Soybean (*Glycine max*) is an oilseed crop produced in the United States and around the world for both human and animal consumption. Most swine diets contain soybean products, most commonly as soybean meal (**SBM**), to increase the dietary concentration of AA economically because plant protein sources are usually cheaper than animal proteins. However, due to the increasing price of soybeans and SBM, researchers are investigating ways to maximize the nutritional quality in soybeans. Processing of soybeans is important and effective not only to extract the oil for the human food industry, but also to produce SBM that contains nutrients that are more digestible and utilizable for the animals.

Raw soybeans contain several antinutritional factors that can have adverse effects on the performance and health of pigs. Adequate heating is essential to achieving the maximum nutritional value of soybean products by reducing the concentration of heat-labile antinutritional factors. In addition, exogenous enzyme supplementation with conventional SBM or further processing of conventional SBM is ideal to reduce the concentration of heat-stable antinutritional factors that could affect the performance of pigs, especially in young pigs.

A newer method of reducing these antinutritional factors in soybean products added to swine diet is by using genetic selection in plant breeding to identify new varieties of soybeans with lower concentration of antinutritional factors. Another way to reduce the concentration of these antinutritional factors is fermentation, in which microbes ferment the substrates that are not readily usable by pigs thereby reducing the concentration of the antinutritional factors.

Newer varieties of soybeans have been identified, as well as various methods of producing further processed SBM. Therefore, the objectives of this thesis are:

1) To test the hypothesis that DE and ME, and SID of CP and AA are greater in de-hulled FFSB produced from high-protein or low-oligosaccharide varieties of soybeans than in conventional FFSB,
2) To test the hypothesis that DE and ME, and SID of CP and AA are greater in expeller soybean meal produced from low or ultra-low trypsin inhibitor soybeans than in conventional expeller soybean meal, and
3) To measure the AID and SID of CP and AA in 4 sources of fermented soybean meals by weanling pigs and compare these values to AID and SID of CP and AA in conventional soybean meal and in fish meal.

CHAPTER 2

SOYBEANS IN SWINE NUTRITION: LITERATURE REVIEW

INTRODUCTION

Soybean is major oilseed crop produced in the United States and around the world. The major countries that produce soybeans are the United States, Brazil, Argentina, and China, in the order of production yield (Table 2.1; USDA-FAS, 2012). Approximately 237 million metric tons of soybeans were produced around the world in 2011 and approximately 35% were produced in the United States (Table 2.1; USDA-FAS, 2012). Within the United States, approximately 55% of soybeans produced are crushed and turned into soy oil and soybean meal (**SBM**; USDA-ERS, 2012). Soybean meal is used in livestock diets as a protein source because plant protein sources are usually cheaper than animal proteins. However, the cost of soybean and SBM has been steadily increasing in recent years and SBM price is projected to be in the range of $485-515 which is almost 3 times the price of SBM a decade ago (USDA-ERS, 2012). Due to the increasing price of soybeans and SBM, researchers are investigating alternative protein-rich crops; however, it is also important to discover ways to maximize the nutritional quality in soybeans.

PROCESSING OF SOYBEANS

Soybean products added to swine diets are mostly byproducts of the human food industry. Processing of soybeans is important and effective not only to extract the oil for the human food industry, but also to produce SBM that contains nutrients that are more digestible and utilizable for the animals. Different types of SBM are produced by different methods of oil

extraction from soybeans. Before the solvent extraction method was developed, mechanical methods, such as hydraulic pressing or continuous screw pressing (expeller) were commonly used (Nelson et al., 1987). Soybeans may be de-hulled before oil extraction to reduce the fiber content and produce high protein SBM with 48-50% CP (Serrato, 1981). De-hulled SBM contains more energy than non-de-hulled SBM (NRC, 2012), which is most likely due to the lower fiber content. Moreover, de-hulled SBM has greater digestibility of AA than non-de-hulled SBM (Kang et al., 2003). This has also been confirmed by a study where added soy hulls, which mainly consist of fiber, decreased the digestibility of AA in SBM (Dilger et al., 2004). Therefore, adding the de-hulling step during processing may produce SBM with greater concentration of digestible nutrients (Table 2.2).

In the early days of oil extraction from soybeans, the mechanical extraction method was commonly used. Using this method, soybeans are fed to screw presses to extract oil, and the remnant is ground to make SBM expellers (Johnson, 2008). This produces SBM with a fat content of approximately 6.6% (NRC, 2012). The solvent extraction method is now the conventional method of extracting oil from soybeans, and oil is extracted from soybeans using a solvent, usually hexane, and the remnant is ground to make solvent-extracted SBM (Johnson, 2008). This produces SBM with approximately 1.5% fat (NRC, 2012). Expeller SBM contains more energy than solvent-extracted SBM due to a greater concentration of fat (Woodworth et al., 2001). Therefore, different methods of processing soybeans can produce SBM with variable nutritional value (Table 2.2). The mechanical extraction method is exclusively used in small crushing plants or specialty soybean processing plants, either due to lower capital required to run the plant and low throughput or to preserve the native characteristics of different varieties of soybeans. Approximately 40 million metric ton of SBM was produced in the United States in

2011 (ASA, 2012), but mechanically extracted SBM accounts for less than 1% of all the SBM produced in the United States (Ericson, 1995).

After solvent-extracted SBM became available in the early fifties, the corn-SBM diet was developed and was quickly adopted by the United States swine industry (Becker et al., 1963). In the early days, animal protein and fermentation products were used in swine diets because plant ingredients lack vitamin B_{12}, but as crystalline vitamin B_{12} became available, a diet composed of only plant ingredients was possible (Baker, 2003). As the corn-SBM diet became the standard for the swine industry, SBM became the most widely used plant protein source in swine diets. Soybean meal is a valuable source of protein for feeding animals due to the high nutritional value contributed by the AA composition of the protein (Liener, 1981). A method to compare protein sources with respect to protein quality is to compare the Lys to CP ratio because Lys is the first limiting AA in swine diets (Cromwell, 2000). Among the plant protein sources, soybean products have the greatest Lys to CP ratio (Cromwell, 2000). Moreover, digestibility coefficients for Lys in SBM tend to be greater than those in most other oilseed meals (Cromwell, 2000). Another attractive quality of SBM as a protein and AA source is that SBM is relatively rich in both Lys and Trp, whereas the cereal grains used in swine diets, especially corn, are relatively low in Lys and Trp (Stein et al., 2008). Therefore, SBM has a good balance of AA that complements the AA composition of cereal grains used in swine diets. This complementary effect allows corn-SBM diet to meet all essential AA requirements of pigs (Baker, 2000).

ANTINUTRITIONAL FACTORS

Despite the favorable characteristics of SBM as a protein source for pigs, raw soybeans contain several antinutritional factors that can have adverse effects on the performance and

health of pigs. These antinutritional factors can be categorized into 2 groups, heat-labile and heat-stable antinutritional factors (Liener, 2000). Heat-labile antinutritional factors include protease inhibitors, lectins, goitrogens, and antivitamins (Liener, 2000). Among the heat-labile antinutritional factors, the most important in raw soybeans are protease inhibitors. These protease inhibitors, also known as trypsin inhibitors, can be separated mainly into 2 types, Kunitz trypsin inhibitors and Bowman-Birk inhibitors, and they reduce the activity of the pancreatic proteolytic enzymes (Rackis, 1972). Although there are conflicting results regarding differences in heat stability of Kunitz trypsin inhibitors and Bowman-Birk inhibitors, it is generally believed that Bowman-Birk inhibitors are more heat stable than Kunitz trypsin inhibitors due to the stability of Bowman-Birk inhibitors in heated aqueous solutions (Birk, 1961). Even before the currently used processing methods were developed, it was shown that heat is required to achieve the full nutritional potential of soybeans (Osborne and Mendel, 1917). Heating of the soybeans decreases the concentration of trypsin inhibitors, which in turn increases AA digestibility and also improves growth performance in pigs (Herkelman et al., 1992; Goebel and Stein, 2011). Although heating is necessary to inactivate the heat-labile antinutritional factors in the soybeans, excessive heat will decrease Lys concentration, the Lys to CP ratio, and the digestibility of CP and AA due to Maillard reactions (Gonzalez-Vega et al., 2011). Therefore, adequate heating or other methods of reducing the trypsin inhibitor concentration is essential to achieving the maximum nutritional value of soybean products, but over-heating will reduce AA digestibility. One way of reducing trypsin inhibitor concentrations in soybean products added to swine diet is by using genetic selection in plant breeding to identify new low-trypsin inhibitor varieties of soybeans (Goebel and Stein, 2011).

The heat-stable antinutritional factors in soybeans include oligosaccharides, phytate, antigens, and others (Liener, 2000). Soybean oligosaccharides constitute approximately 5% of the soybean DM (Karr-Lilienthal et al., 2005). Soybean oligosaccharides, which are mainly raffinose and stachyose that cause flatulence in animals (Rackis, 1981), do not get eliminated by traditional processing (Leske et al., 1993; Grieshop et al., 2003). Because pigs lack α-galactosidase, the enzyme needed to cleave the α-1,6 glycosidic bond in oligosaccharides (Karr-Lilienthal et al., 2005), pigs cannot digest oligosaccharides. Instead, oligosaccharides are hydrolyzed by microbial fermentation in the intestinal tract (Choct et al., 2010). Bacterial digestion of oligosaccharides leads to production of volatile fatty acids (Grieshop et al., 2000), which are easily utilized by pigs. However, young pigs have a low capacity for fermentation; therefore, feeding soybean products to young pigs will result in reduced growth rate and may affect fecal consistency in weanling pigs (Liying et al., 2003). Due to the increasing fermentation of nonstarch polysaccharides with increasing age of pigs by intestinal microflora (Choct et al., 2010), oligosaccharides are not a concern for older pigs that easily ferment oligosaccharides. Adding α-galactosidase to the diets may ameliorate the adverse effect on growth performance of young pigs by increasing the digestibility of oligosaccharides, accompanied by increased digestibility of GE and CP (Pan et al., 2002). However, this is not always the case because in some cases, added α-galactosidase did not improve digestibility of oligosaccharides (Smiricky et al., 2002). Therefore, there is a need for another method to reduce the concentration of oligosaccharides in soybeans to reduce the unfavorable effect when fed to young pigs. One method to reduce the concentration of dietary oligosaccharides in soybeans is to utilize low-oligosaccharide varieties of soybeans, which have been selected using genetic selection (Hou et al., 2009; Skoneczka et al., 2009). Another way to reduce the concentration of oligosaccharides

in SBM is by fermentation, in which microbes most commonly used in fermented SBM production secretes α-galactosidase, thereby breaking down the oligosaccharides and use the intermediate products as carbon sources for subsequent fermentation (Chen et al., 2010).

Another heat-stable antinutritional factor in soybeans is phytic acid, also known as phytate. Like other plant ingredients used in swine diets, approximately two-thirds of the P in soybeans is bound to the phytate molecule (Nelson et al., 1968). Phytate is the main storage form of phosphate and inositol in most plants, and phytate bound P in soybeans and SBM is mostly unavailable to swine (Erdman, 1979). Pigs do not secrete phytase, the enzyme necessary to release the phosphate groups from the phytate complex, and phytate bound P is, therefore, poorly utilized (Cromwell, 2000). As a consequence, commercial corn-SBM diets are often supplemented with inorganic P to meet the P requirement of pigs and this results in large amounts of P being excreted by pigs, which may result in pollution (Cromwell and Coffey, 1991). The negatively charged phosphate groups of phytic acid also bind to different cations such as Ca, Mg, Fe, Zn, Cu, and Mn, which are nutritionally important for pigs (Rimbach et al., 2008). One way to make the phytate bound P bioavailable to pigs is to add microbial phytase to the diet. Microbially derived phytase from *Aspergillus niger* or *Escherichia coli* is effective in improving the utilization of phytate bound P in corn and SBM by growing pigs, which in turn reduces the need for supplementation of inorganic P to the diet and reduce the amount of P excreted into the environment (Cromwell et al., 1993; Rojas and Stein, 2012). Mutant soybeans with reduced phytate bound P and increased inorganic P with comparable concentration of total P as conventional varieties have been identified (Wilcox et al., 2000). Use of low-phytate SBM can improve P digestibility by approximately 40% compared with conventional SBM, which is directly related to the phytate bound P concentration because most other nutrient concentration

were similar among the SBM varieties (Dilger and Adeola, 2006). Therefore, the usage of these low-phytate varieties may reduce the need for inorganic P supplementation in diets and consequently reduce the amount of P excreted from animals (Wilcox et al., 2000; Dilger and Adeola, 2006).

NEW VARIETIES

New varieties of soybeans have been developed by genetic selection in plant breeding. One of the new varieties of soybeans developed is a high-protein variety. Full fat high-protein soybeans have greater concentration of CP and AA compared with conventional soybeans (Cervantes-Pahm and Stein, 2008; Baker et al., 2010; Table 2.2). Likewise, SBM produced from a high-protein variety of soybeans has greater concentration of CP and AA (Baker and Stein, 2009). The digestibility of most AA in high-protein full fat soybeans is comparable to that in conventional full fat soybeans (Cervantes-Pahm and Stein, 2008; Baker et al., 2010). However, due to the greater concentration of AA, high protein full fat soybeans contains more digestible AA, which indicates that this new variety of soybeans may have a greater feeding value than conventional soybeans (Cervantes-Pahm and Stein, 2008). Likewise, the digestibility of AA in SBM produced from high-protein soybeans is similar to that in conventional SBM, which indicates that there is a greater concentration of digestible AA in SBM produced from high-protein soybeans compared with conventional soybeans (Baker and Stein, 2009). Soybean meal produced from high-protein soybeans also contains more DE and ME than conventional SBM, most likely due to the greater protein concentration in the high-protein SBM (Baker and Stein, 2009). Therefore, high-protein soybeans developed via genetic selection seems to be beneficial to feed to pigs.

Another new variety of soybeans developed by genetic selection is low-oligosaccharide soybeans. Low-oligosaccharide full fat soybeans contain less stachyose and raffinose compared with conventional soybeans (Baker et al., 2010; Table 2.2). Likewise, SBM produced from low-oligosaccharide soybeans contains less oligosaccharides than conventional SBM (Baker and Stein, 2009). The digestibility of AA in low-oligosaccharide full fat soybeans and conventional full fat soybeans is similar, which indicates that the digestibility of AA is not compromised in the new variety of soybeans (Baker et al., 2010). However, the digestibility of AA in SBM produced from low-oligosaccharide soybeans is greater than that in conventional SBM, most likely due to the lower fiber content in low-oligosaccharide SBM compared with conventional SBM (Baker and Stein, 2009). In another study, SBM produced from low-oligosaccharide soybeans had not significantly different, but numerically higher, SID of AA compared with conventional SBM, which indicates that SBM produced from low-oligosaccharide soybeans is at least as good a source of digestible AA as conventional SBM (Jendza and Baidoo, 2012). Soybean meal produced from low-oligosaccharide soybeans has concentrations of DE and ME that are comparable to those in conventional SBM (Baker and Stein, 2009). Therefore, low-oligosaccharide soybeans may be used in diets for young pigs without the adverse effects of oligosaccharides that may reduce growth performance of young pigs.

Low-trypsin-inhibitor varieties of soybeans were also developed by genetic selections. Low-trypsin-inhibitor soybeans contain less of trypsin inhibitors compared with conventional soybeans (Herkelman et al., 1992; Goebel and Stein, 2011). Although low-trypsin-inhibitor soybeans have considerably less trypsin inhibitor concentrations, they are not completely devoid of trypsin inhibitors so heat treatment still reduces the concentration of trypsin inhibitors (Herkelman et al., 1992; Goebel and Stein, 2011). Low-trypsin-inhibitor soybeans have greater

digestibility and retention of N than high-trypsin-inhibitor soybeans but dietary energy utilization was similar (Cook et al., 1988). However, conventional SBM had greater N retention than low-trypsin-inhibitor soybeans most likely due to low level of trypsin inhibitor and other antinutritional factors present in low-trypsin-inhibitor soybeans (Cook et al., 1988). Raw low-trypsin-inhibitor soybeans had greater digestibility of AA than raw conventional soybeans (Herkelman et al., 1992; Goebel and Stein, 2011) and growth performance in pigs was improved when pigs were fed raw low-trypsin-inhibitor soybeans instead of raw conventional soybeans (Cook et al., 1988; Herkelman et al., 1992; Palacios et al., 2004). Therefore, low-trypsin-inhibitor soybeans, developed using genetic selection, seem to be more beneficial to feed to pigs than conventional soybeans when used without processing. However, to maximize performance soybean products need to be heat treated to inactivate all trypsin inhibitors.

FERMENTED SBM

Further processing the conventional SBM may serve as another method to ameliorate the negative effects of antinutritional factors in conventional SBM. One such method is fermentation of conventional SBM. Fermented SBM is produced by bacterial and/or fungal fermentation of conventional SBM (Chen et al., 2010). The concentrations of AA, CP, P, and other nutrients are greater in fermented SBM than in conventional SBM, which is most likely due to removal of sucrose and oligosaccharides during fermentation (Cervantes-Pahm and Stein, 2010; Rojas and Stein, 2012). The trypsin inhibitor concentration in SBM is also reduced following fermentation (Hong et al., 2004; Rojas and Stein, 2012). The peptide size in soybeans and conventional SBM may be reduced following fermentation (Hong et al., 2004), but that is not always the case (Cervantes-Pahm and Stein, 2010). Newly weaned pigs may benefit from the reduced peptide

size in fermented SBM, because they may have inadequate gastric enzyme secretion to effectively initiate protein digestion (Lindemann et al., 1986; Hedemann and Jensen, 2004). It has been observed that fermented SBM with appropriate crystalline AA supplementation can be used in diets for young pigs as an alternative to animal protein sources fed to nursery pigs, such as dried skim milk or plasma protein (Kim et al., 2010). Increasing the inclusion rate of fermented SBM at the expense of conventional SBM improved feed efficiency, AA digestibility, blood urea N, and total protein concentrations in blood (Cho et al., 2007), and improved growth performance may be observed as well (Jones et al., 2010). The digestibility of AA in fermented SBM is not different from the digestibility in conventional SBM, but fermented SBM contains more digestible AA than conventional SBM because of the greater concentration of AA (Cervantes-Pahm and Stein, 2010). Results of some studies have indicated that fermented SBM increases growth performance and digestibilities of nutrients (Min et al., 2004; Kim et al., 2007). Fermented SBM also has a greater digestibility of P than conventional SBM, which is most likely due to the reduced concentration of phytate bound P (Rojas and Stein, 2012) and an improved P availability, which is a result of hydrolysis of the phytate bonds during microbial fermentation (Ilyas et al., 1995). Adding microbial phytase improves digestibilities of P in both fermented SBM and conventional SBM (Rojas and Stein, 2012), which indicates that there are residual phytate bound P that was converted to available P by the enzyme, even after the fermentation process. Reduced incidence of diarrhea after weaning was also observed when fermented SBM was used as a substitute for conventional SBM (Song et al., 2010). Therefore, a well-controlled fermentation process may serve as an effective method to ameliorate the negative effects of residual antinutritional factors in conventional SBM.

CONCLUSIONS

Soybean meal is a valuable and popular plant protein source in swine diets. This is due to its exceptional AA composition that can complement cereal grains commonly used in swine diets. Soybean meal, being a plant protein source, is cheaper than animal protein sources. However, due to the increasing cost of soybeans and SBM, it is necessary to look for methods to maximize the utilization of nutritional quality in soybeans. Soybeans in nature contain antinutritional factors, such as trypsin inhibitor, oligosaccharides, and phytate, which can negatively affect growth performance of pigs. To maximize the nutritional quality, concentration of these antinutritional factors must be reduced. New varieties of soybeans, as well as different processing methods, have been developed to reduce the antinutritional factors in soybeans and SBM. Newer variety of soybeans and processing methods of SBM may provide more economical use of soybeans and SBM in diets fed to swine.

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TABLES

Table 2.1. Soybean production in different countries[1]

Country/Region	Production (million metric tons)			Change in production from last year	
	2010/2011	Prel. 2011/2012	Proj. 2012/2013	MMT	Percent
Dosmestic					
United States	90.6	83.2	71.7	-11.5	-13.8
Foreign					
Brazil	75.5	66.5	81.0	14.5	21.8
Argentina	49.0	41.0	55.0	14.0	34.2
China	15.1	13.5	12.6	-0.9	-6.7
India	9.8	11.0	11.4	0.4	3.6
Other	24.7	21.9	26.4	4.5	20.5
Total	174.1	153.9	186.4	32.5	21.1
World	264.7	237.1	258.1	21.0	8.9

[1]Adapted from USDA-FAS (2012).

Table 2.2. Composition of soybeans and soybean meal (SBM)[1]

Item	FFSB[2]			ESBM[2]		SBM[2]		FSBM[2]
	Conventional	HP[3]	LO[3]	De-hulled	Non-de-hulled	De-hulled	Non-de-hulled	
DM, %	92.36	92.38	94.40	95.57	93.85	89.98	88.79	92.88
CP, %	37.56	42.77	39.30	45.13	44.56	47.73	43.90	54.07
Fat, %	20.18	15.59	17.70	6.64	5.69	1.52	1.24	2.30
GE, kcal/kg	5,227	5,306	5,282	4,710	4,692	4,256	4,257	4,533
Sucrose, %	6.42	4.75	5.80	-	7.10	4.30	7.63	0.00
Raffinose, %	0.77	0.85	0.10	-	0.77	3.78	0.90	0.00
Stachyose, %	3.89	4.01	1.40	-	4.88	7.33	4.32	0.00

[1]Adapted from NRC (2012), and Rojas and Stein (2012).
[2]FFSB = full fat soybeans, ESBM = expelled soybean meal, SBM = solvent-extracted soybean meal, and FSBM = fermented soybean meal.
[3]HP = high-protein, and LO = low-oligosaccharide.

CHAPTER 3

AMINO ACID DIGESTIBILITY AND ENERGY CONCENTRATION OF HIGH-PROTEIN, LOW-OLIGOSACCHARIDE, AND CONVENTIONAL FULL FAT, BUT DE-HULLED, SOYBEANS FED TO GROWING PIGS

ABSTRACT

Two experiments were conducted to determine AA and energy digestibility in full fat soybeans (FFSB). Conventional (FFSB-CV; 43.5% CP and 24.1% crude fat), high-protein (FFSB-HP; 50.2% CP and 20.5% crude fat), and low-oligosaccharide (FFSB-LO; 46.8% CP and 21.1% crude fat) varieties of FFSB were used. In Exp. 1, the standardized ileal digestibility (SID) of CP and AA in the 3 ingredients was determined using 8 growing barrows (initial BW: 20.6 ± 1.1 kg) that were equipped with a T-cannula in the distal ileum. All diets contained FFSB as the sole source of AA. An N-free diet was used to determine basal endogenous losses of AA. The pigs were allotted to a replicated 4 × 4 Latin square design with 4 periods and 4 diets. The mean AID and the mean SID of indispensable AA were greater ($P < 0.05$) in FFSB-CV than in FFSB-HP, but no difference were observed between FFSB-CV and FFSB-LO. The mean AID and SID of dispensable AA and the mean AID and SID of all AA were greater ($P < 0.05$) in FFSB-CV than in FFSB-HP, but values obtained for FFSB-LO were not different from the other 2 sources of FFSB. In Exp. 2, the DE and ME in the 3 sources of FFSB were determined using 24 growing barrows (initial BW: 28.3 ± 3.7 kg). A corn-based basal diet and 3 diets containing corn and 1 source of FFSB were formulated. Pigs were placed in metabolism cages and randomly allotted to the 4 diets with 6 replicate pigs per diet. After a 5 d adaptation period, feces and urine were collected for the next 5 d. The DE and ME in each source of FFSB were calculated using the

difference procedure. The concentrations of DE and ME in FFSB-CV, FFSB-HP, and FFSB-LO were 4,495 and 4,192; 4,765 and 4,447; and 4,694 and 4,349 kcal/kg DM, respectively, but no differences among the 3 sources of FFSB were observed. Results indicate that the SID of most AA in FFSB-LO, but not in FFSB-HP, is similar to values in FFSB-CV, but significant differences in DE and ME among the 3 sources of FFSB were not observed.

Key words: amino acids, energy, full fat soybeans, pigs

INTRODUCTION

Soybean meal (**SBM**) is the most commonly used protein source in swine diets in the United States (Kohlmeier, 1990). However, soybeans contain several anti-nutritional factors, one of which is oligosaccharides. Oligosaccharides are not digested in the small intestine of pigs, but they are fermented by the residing bacteria (Hayakawa et al., 1990; Slominski, 1994). This results in decreased digestibility of energy, reduced growth rate, and may affect fecal consistency in weanling pigs (Liying et at., 2003). Therefore, the soybean industry has developed new varieties of soybeans that have concentrations of oligosaccharides that are less than 0.5%, whereas conventional soybeans contain 4 to 6% oligosaccharides, which are mainly raffinose and stachyose (Grieshop et al., 2003). Research with low oligosaccharide extruded-expelled SBM fed to growing pigs indicates that there is no difference in DE, ME, and standardized ileal digestibility (**SID**) of AA between SBM produced from low oligosaccharide and conventional varieties (Baker and Stein, 2009).

In addition to the low-oligosaccharide soybeans, high protein varieties of soybeans have been selected. According to Cervantes-Pahm and Stein (2008), non-de-hulled high protein full fat soybeans (**FFSB-HP**) has greater concentration of digestible CP and AA than non-de-hulled

conventional full fat soybeans (**FFSB-CV**) due to the greater concentration of CP and AA in FFSB-HP. However, SID values for AA do not differ between FFSB-HP and FFSB-CV (Cervantes-Pahm and Stein, 2008; Baker et al., 2010), and ME values of SBM are not different between high protein and conventional varieties (Baker and Stein, 2009). There are, however, no data on the SID of AA and on the DE and ME of FFSB that have been de-hulled, although most soybeans are de-hulled prior to being used in diets fed to pigs.

Therefore, 2 experiments were conducted to test the hypothesis that DE and ME, and SID of CP and AA are greater in de-hulled FFSB produced from high-protein or low-oligosaccharide varieties of soybeans than in conventional FFSB. The objectives of the experiments were to determine SID of CP and AA, and the DE and ME in de-hulled FFSB-CV, FFSB-HP, and low-oligosaccharide full fat soybeans (**FFSB-LO**).

MATERIALS AND METHODS

General

The experimental protocols for these experiments were reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Two experiments were conducted using the same batches of FFSB (Schillinger Genetics, Inc., Des Moines, IA). The 3 sources of FFSB included FFSB-CV, FFSB-HP, and FFSB-LO (Table 3.1). All 3 sources of FFSB were processed at Natural Products (Grinnell, IA) and roasted via microwave, then ground to meal specification mesh. Pigs used in both experiments were sired by G performer (Duroc × Pietrain) boars that were mated to Fertilis 25 (¾ Landrace ¼ Large White) females (Genetiporc Inc., Alexandria, MN).

Amino Acid Digestibility, Exp. 1

Animals, Housing, and Experimental Design. Eight growing barrows were used in this experiment. Pigs (initial BW: 20.6 ± 1.1 kg) had been surgically equipped with a T-cannula in the distal ileum using procedures adapted from Stein et al. (1998). Pigs were housed in individual pens with tri-bar stainless steel floors (1.2 × 1.5 m) in an environmentally controlled room. Pigs were allowed to recover for a 7 d period following surgery and were then randomly allotted to a replicated 4 × 4 Latin square design with 4 diets and 4 periods. A feeder and a nipple drinker were installed in each pen.

Diets and Feeding. Four diets were formulated (Tables 3.2 and 3.3). Three of the diets contained 1 of each source of FFSB and starch, sugar, and oil. The last diet was a N-free diet that was used to calculate basal endogenous losses of AA and CP. Solka floc (4.0%), magnesium oxide (0.1%), and potassium carbonate (0.4%) were added to the N-free diet to increase the concentration of crude fiber, Mg, and K in the diet. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998). All diets also contained 0.4% chromic oxide as an indigestible marker. All pigs were fed once daily at 0600 h at a level of 3 times the estimated maintenance energy requirement (i.e., 106 kcal of ME per $kg^{0.75}$; NRC, 1998). Water was available at all times throughout the experiment.

Data Recording and Sample Collection. Pig BW were recorded at the beginning and at the end of each period and the amount of feed supplied each day was recorded. Each experimental period lasted 7 d. The initial 5 d of each period were considered an adaptation period to the diet. On d 6 and 7, ileal digesta were collected for 8 consecutive h. A 225-mL plastic bag was attached to the cannula barrel with a cable tie and digesta flowing into the bag was collected as described by Stein et al. (1999). Bags were removed whenever they were filled with digesta, or at least once

every 30 min and immediately frozen at -20 ℃ to prevent bacterial degradation of the AA in the digesta. On the completion of 1 experimental period, animals were deprived of feed overnight and the following morning, a new experimental diet was offered.

Chemical Analysis. 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 source of FFSB was collected as well. Ileal samples were lyophilized and finely ground prior to chemical analysis. All samples were analyzed in duplicate. Diets and ingredients were analyzed for DM, CP, AA, and acid hydrolyzed ether extract (**AEE**). Ileal samples were analyzed for DM, CP, and AA. Diets and ileal samples were analyzed for chromium, as well. Dry matter was analyzed in a drying oven at 135 ℃ for 2 h (method 930.15; AOAC Int., 2007). Crude protein was analyzed by the combustion method (method 990.03; AOAC Int., 2007) using a Rapid N cube (Elementar Americas Inc., Mt. Laurel, NJ). For AA analysis, samples were hydrolyzed with 6 *N* HCl for 24 h at 110 ℃, then analyzed on a Hitichi Amino Acid Analyzer (Model L8800, Hitachi High Technologies America, Inc., Pleasaton, CA) using ninhydrin for postcolum derivatization and norleucine as the internal standard [method 982.30 E (a, b, c); AOAC Int., 2007]. Acid hydrolyzed ether extract was analyzed by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (method 2003.06; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Chromium was analyzed in diet and ileal samples using an inductive coupled plasma atomic emission spectrometric method (method 990.08; AOAC Int., 2007). Ingredient samples were also analyzed for GE using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL), ash (method 942.05; AOAC Int., 2007), Ca and P (method 975.03; AOAC Int., 2007), ADF

(method 973.18; AOAC Int., 2007), NDF (Holst, 1973), sucrose, stachyose, and raffinose (Janauer and Englmaier, 1978), and trypsin inhibitors (method Ba 12-75; AOCS, 2006).

Calculations and Statistical Analysis. Apparent ileal digestibility (**AID**) values for CP and AA in samples obtained from feeding the 3 diets containing FFSB were calculated. Because the FFSB were the only feed ingredients contributing CP and AA to each diet, these digestibility values also represent the digestibility values for each source of FFSB. AID values of AA were calculated using equation [1] (Stein et al., 2007):

$$\mathrm{AID_{AA}}, \% = 100 - [\left(\frac{\mathrm{AA_{digesta}}}{\mathrm{AA_{feed}}}\right) \times \left(\frac{\mathrm{Cr_{feed}}}{\mathrm{Cr_{digesta}}}\right)] \times 100 \quad [1]$$

where AID_{AA} is the apparent ileal digestibility of an AA (%), $AA_{digesta}$ is the concentration of that AA in the ileal digesta DM, AA_{feed} is the AA concentration of that AA in the feed DM, Cr_{feed} is the chromium concentration in the feed DM, and $Cr_{digesta}$ is the chromium concentration in the ileal digesta DM. The AID for CP will also be 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):

$$\mathrm{IAA_{end}} = [\mathrm{AA_{digesta}} \times \left(\frac{\mathrm{Cr_{feed}}}{\mathrm{Cr_{digesta}}}\right)] \quad [2]$$

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

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

$$\mathrm{SID_{AA}} = [\frac{\mathrm{AID + IAA_{end}}}{\mathrm{AA_{feed}}}] \quad [3]$$

where SID_{AA} is the SID value (%) of each AA. The SID for AA was also calculated using the same equation.

The Proc UNIVARIATE procedure of SAS was used to identify outliers (SAS Institute Inc., Cary, NC). Data were analyzed using the Proc MIXED procedure of SAS. An analysis of variance was conducted with diet as fixed effects and pig and period as random effects. When significant differences were detected, treatment means were separated using the Least Significant Difference test in Proc MIXED. The pig was the experimental unit for all analyses and an alpha value of 0.05 was used to assess significance among treatments.

Energy Digestibility, Exp. 2

Diets, Animals, and Experimental Design. Four diets were formulated (Table 3.4). Three of the diets contained one of the sources of FFSB and corn. The last diet was a corn diet that did not contain any FFSB. Corn and FFSB were the only sources of energy in these diets. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998).

A total of 24 growing barrows (initial BW: 28.3 ± 3.7 kg) was obtained from the Swine Research Center. Pigs were placed in metabolism cages equipped with a feeder and a nipple drinker. The experiment was conducted as a randomized complete block design with 4 diets and 6 replications per diet.

Feeding and Sample Collection. The quantity of feed provided per pig daily was calculated as 3 times the estimated requirement for maintenance energy (i.e., 106 kcal ME per $kg^{0.75}$; NRC, 1998) and divided into 2 equal meals that were fed at 0700 h and 0300 h. Water was available at all times. The experiment lasted 12 d. The initial 5 d was considered an adaptation period to the diet, while urine and fecal materials were collected during the next 5 d according to standard procedures using the marker to marker approach (Adeola, 2001). Urine was collected in urine buckets over a preservative of 40 mL of 6 *N* HCl. Fecal samples and 20% of the collected urine were stored at -20 ℃ immediately after collection. At the conclusion of the experiment, urine

samples were thawed and mixed within animal and diet, and a subsample was collected for chemical analysis.

Sample Analysis and Data Processing. Fecal samples were dried in a forced air oven and finely ground prior to analysis. Fecal, urine, diet, and ingredient samples were analyzed in duplicate for GE using a bomb calorimeter (Model 6300, Parr Instruments, Moline, IL). Diets and ingredients were also analyzed for DM, CP, and AEE as explained for Exp. 1. Following chemical analysis, total tract digestibility values were calculated for energy using procedures previously described (Stein et al., 2004). The amount of energy lost in the feces and urine was calculated as well, and the quantities of DE and ME in each of the 4 diets were calculated (Stein et al., 2004). The amount of DE and ME that was contributed by corn to the 3 diets containing FFSB were then subtracted from the amount of DE and ME in each of these diets. This allowed for the calculation of the DE and ME in each source of FFSB, using the difference procedure (Adeola, 2001). Data were analyzed as explained for Exp. 1 using the Proc MIXED of SAS (SAS Institute Inc., Cary, NC).

RESULTS

Amino Acid Digestibility, Exp. 1

The AID and SID of CP were less ($P < 0.05$) in FFSB-HP than in FFSB-CV and FFSB-LO (Table 3.5). The AID and SID of Arg, His, Met, and Trp were not different among ingredients. The AID and SID of Ile, Leu, Lys, Phe, and Val were greater ($P < 0.05$) in FFSB-CV than in FFSB-HP, but the AID and SID of these AA in FFSB-LO was not different from values obtained for FFSB-CV and FFSB-HP. The AID and SID of Thr were less ($P < 0.01$) in FFSB-HP than in FFSB-CV and FFSB-LO. The mean AID and the mean SID of indispensable

AA were greater ($P < 0.05$) in FFSB-CV than in FFSB-HP, but no difference were observed between FFSB-CV and FFSB-LO.

The AID and SID of Ala, Gly, and Tyr were greater ($P < 0.05$) in FFSB-CV than in FFSB-HP, but the AID and SID of these AA in FFSB-LO were not different from the other 2 sources of FFSB. The AID and SID of Asp, Cys, and Ser were less ($P < 0.05$) in FFSB-HP than in FFSB-CV and FFSB-LO, but no difference between FFSB-CV and FFSB-LO were observed. The AID and SID of Glu and Pro were not different among ingredients. The mean AID and SID of dispensable AA and the mean AID and SID of all AA were greater ($P < 0.05$) in FFSB-CV than in FFSB-HP, but values obtained for FFSB-LO were not different from the other 2 sources of FFSB.

Energy Digestibility, Exp. 2

The intake of GE was less ($P < 0.05$) in pigs fed the corn diet than in pigs fed the FFSB-CV, FFSB-HP, or the FFSB-LO diets (Table 3.6). Intake of GE was greater ($P < 0.05$) in pigs fed the FFSB-CV diet than in pigs fed the FFSB-LO diet; however, the GE intake in pigs fed the FFSB-HP diet was not different from that of pigs fed the FFSB-CV diet or the FFSB-LO diet. Pigs fed the corn diet had less ($P < 0.05$) fecal excretion of GE than pigs fed the FFSB-CV, FFSB-HP, or FFSB-LO diets. Fecal excretion of GE was greater ($P < 0.05$) for pigs fed the FFSB-CV diet than for pigs fed the FFSB-LO diet, but fecal excretion of GE from pigs fed the FFSB-HP diet was not different from that of pigs fed the FFSB-CV diet or the FFSB-LO diet. Urine excretion of GE was not different among diets. The ATTD of GE was greater ($P < 0.05$) for the corn diet than for the FFSB-CV diet, but the ATTD of GE for the FFSB-HP and FFSB-LO diets was not different from that of the corn diet or the FFSB-CV diet. The DE and ME were less ($P < 0.05$) in the corn diet than in the FFSB-CV, FFSB-HP, and FFSB-LO diets, but there

were no differences in DE and ME among the 3 FFSB diets. The DE and ME in corn were less ($P < 0.05$) than in FFSB-CV, FFSB-HP, and FFSB-LO (Table 3.7), but there was no difference in DE and ME among the 3 sources of FFSB; this was true when values were calculated on an as-fed basis as well as on a DM-basis.

DISCUSSION

Amino Acid Digestibility, Exp. 1

Cervantes-Pahm and Stein (2008) used growing pigs to determine AA digestibility in FFSB-CV and FFSB-HP. Baker et al. (2010) used weanling pigs to determine AA digestibility in FFSB-CV, FFSB-HP, and FFSB-LO. The concentration of CP, AA, and fat in FFSB-CV, FFSB-HP, and FFSB-LO used in current experiment were greater than the values reported by Cervantes-Pahm and Stein (2008) and by Baker et al. (2010), which is likely due to the de-hulling of the beans used in this experiment. However, the concentration of NDF was greater in the FFSB used in this experiment compared with the beans used in previous experiments. We have no explanation for this observation because de-hulling was expected to reduce the concentration of NDF. The concentration of DM in FFSB used in the current experiment was greater than the reported DM value of FFSB used in other experiments, which indicates that the FFSB were extensively dried, which may result in heat damage. Heat damage in SBM reduces AA concentration and digestibility due to Maillard reactions (Gonzalez-Vega et al., 2011). The Lys to CP ratio for FFSB-CV used in this experiment (5.81%) was less than that from the previous experiments (Cervantes-Pahm and Stein, 2008; Baker et al., 2010; 6.57% and 7.06%, respectively). We observed lower AA digestibility values in FFSB-HP than FFSB-CV which was not in accordance with previous studies which reported similar digestibility values for FFSB-HP

and FFSB-CV (Cervantes-Pahm and Stein, 2008; Baker et al., 2010). This may have been due to the lower Lys to CP ratio for FFSB-HP used in the current experiment (5.67%), compared with the Lys to CP ratio in FFSB-HP used in the previous experiments (Cervantes-Pahm and Stein, 2008; Baker et al., 2010; 5.89% and 6.5%, respectively). The Lys to CP ratio for FFSB-LO used in the present experiment was 5.79% whereas the ratio was 6.5% in the FFSB-LO used by Baker et al. (2010). Thus, for all the FFSB used in this experiment, Lys to CP ratios were less than that observed in previous experiments. A reduced Lys to CP ratio indicates heat damage in the meals (Gonzales-Vega et al., 2011), which in addition to the high DM concentration indicates that all the FFSB used in this experiment were overheated and that some of the Lys was destroyed. This over-heating also explains the low values for AID and SID of all AA that were calculated in this experiment when compared with the values reported by Cervantes-Pahm and Stein (2008) and Baker et al. (2010).The AID and SID values obtained from this experiment for FFSB-CV were greater compared with NRC (2012), but the values for FFSB-HP and FFSB-LO were lower than the values in NRC (2012). Severe heat damage to SBM results in reduced AID and SID of all AA (Gonzalez-Vega et al., 2011), and data from this experiment indicate that this is also the case for the AID and SID in FFSB.

Energy Digestibility, Exp. 2

The DE and ME for corn used in this experiment are in accordance with the values reported by Baker and Stein (2009). However, FFSB-CV used in this experiment contained more CP and fat than reported by NRC (1998, as wells as the values reported by NRC (2012). It was, therefore, expected that the FFSB-CV used in current experiment would contain more DE and ME compared with the DE and ME values reported by NRC (1998), as well as the values reported by NRC (2012).

Baker and Stein (2009) reported that extruded-expelled SBM produced from high protein soybeans had greater concentration of DE compared with extruded-expelled SBM produced from low oligosaccharide or conventional varieties of soybeans. According to Baker and Stein (2009), greater protein concentration in the high-protein meal was responsible for the greater DE and ME concentration. However in the present experiment, we did not observe any difference in DE and ME values among the different varieties of FFSB. This is most likely a consequence of the reduced concentration of fat in the FFSB-HP and FFSB-LO that were used in this experiment compared with FFSB-CV. Thus, it appears that the increased DE and ME that were expected for FFSB-HP and FFSB-LO due to the greater concentration of CP in these beans were negated by the greater concentration of fat in FFSB-CV.

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TABLES

Table 3.1. Chemical composition of conventional full fat soybeans (FFSB-CV), high protein full fat soybeans (FFSB-HP), and high protein-low oligosaccharide full fat soybeans (FFSB-LO), as-fed basis

Item	Ingredient		
	FFSB-CV	FFSB-HP	FFSB-LO
DM, %	95.97	96.99	94.75
GE, kcal/kg	5,536	5,485	5,428
CP, %	43.54	50.24	46.81
AEE[1], %	24.09	20.50	21.14
Ash, %	5.20	4.40	4.14
Ca, %	0.31	0.22	0.22
P, %	0.64	0.66	0.55
ADF, %	3.41	2.14	2.56
NDF, %	13.06	14.65	14.51
Sucrose, %	5.63	3.94	7.96
Raffinose, %	0.81	0.59	0.06
Stachyose, %	4.07	3.87	0.46
TIU[2]/mg	1.50	1.90	1.30
Indispensable AA, %			
Arg	3.18	3.78	3.52
His	1.11	1.26	1.19
Ile	2.01	2.24	2.12

Table 3.1. (Cont.)

Leu	3.36	3.82	3.54
Lys	2.53	2.85	2.71
Met	0.57	0.64	0.63
Phe	2.27	2.60	2.38
Thr	1.63	1.89	1.74
Trp	0.61	0.69	0.67
Val	2.08	2.33	2.23
Dispensable AA, %			
Ala	1.80	2.05	1.90
Asp	4.81	5.61	5.11
Cys	0.55	0.56	0.59
Glu	7.51	9.25	8.03
Gly	1.73	2.02	1.85
Pro	2.10	2.44	2.28
Ser	1.87	2.37	1.99
Tyr	1.63	1.85	1.72
Calculated values			
Lys:CP, %	5.81	5.67	5.79

[1]AEE = acid hydrolyzed ether extract.
[2]TIU = trypsin inhibitor units.

Table 3.2. Ingredient composition of experimental diets containing conventional full fat soybeans (FFSB-CV), high protein full fat soybeans (FFSB-HP), or high protein-low oligosaccharide full fat soybeans (FFSB-LO), as-fed basis, Exp. 1

Ingredient, %	Diet			
	FFSB-CV	FFSB-HP	FFSB-LO	N-free
FFSB-CV	48.00	-	-	-
FFSB-HP	-	40.00	-	-
FFSB-LO	-	-	40.00	-
Cornstarch	38.95	46.85	46.85	67.10
Soybean oil	-	-	-	4.00
Sugar	10.00	10.00	10.00	20.00
Solka floc[1]	-	-	-	4.00
Ground limestone	0.75	0.75	0.75	1.20
Monocalcium phosphate	1.20	1.30	1.30	2.10
Magnesium oxide	-	-	-	0.10
Potassium carbonate	-	-	-	0.40
Chromic oxide	0.40	0.40	0.40	0.40
Salt	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00

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

[2]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 3.3. Chemical composition of experimental diets containing conventional full fat soybeans (FFSB-CV), high protein full fat soybeans (FFSB-HP), or high protein-low oligosaccharide full fat soybeans (FFSB-LO), as-fed basis, Exp. 1

Item	Diets			
	FFSB-CV	FFSB-HP	FFSB-LO	N-free
DM, %	94.59	94.37	94.14	93.58
CP, %	22.77	21.08	21.24	0.39
AEE[1], %	11.15	8.18	8.70	1.77
Indispensable AA, %				
Arg	1.54	1.54	1.51	0.01
His	0.54	0.52	0.51	0.00
Ile	0.97	0.95	0.88	0.01
Leu	1.66	1.59	1.54	0.03
Lys	1.25	1.19	1.17	0.02
Met	0.26	0.26	0.27	0.00
Phe	1.11	1.07	1.02	0.01
Thr	0.81	0.77	0.78	0.01
Trp	0.27	0.26	0.28	0.03
Val	1.01	0.99	0.92	0.01
Dispensable AA, %				
Ala	0.90	0.87	0.85	0.02
Asp	2.42	2.34	2.27	0.02
Cys	0.26	0.24	0.27	0.01

Table 3.3. (Cont.)

Glu	3.83	3.81	3.63	0.04
Cly	0.86	0.86	0.82	0.01
Pro	1.04	1.03	0.99	0.02
Ser	0.93	0.88	0.90	0.01
Tyr	0.73	0.67	0.65	0.01

[1]AEE = acid hydrolyzed ether extract.

Table 3.4. Composition of experimental diets containing corn, conventional full fat soybeans (FFSB-CV), high protein full fat soybeans (FFSB-HP), or high protein-low oligosaccharide full fat soybeans (FFSB-LO), as-fed basis, Exp. 2

Ingredient, %	Diet			
	Corn	FFSB-CV	FFSB-HP	FFSB-LO
Corn	97.20	63.20	69.10	67.60
FFSB-CV	-	34.50	-	-
FFSB-HP	-	-	28.50	-
FFSB-LO	-	-	-	30.00
Ground limestone	1.10	1.00	1.05	1.05
Monocalcium phosphate	1.00	0.60	0.65	0.65
Salt	0.40	0.40	0.40	0.40
Vitamin mineral premix[1]	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Analyzed composition				
DM, %	88.68	91.23	90.67	90.47
GE, kcal/kg	3,794	4,388	4,297	4,257
CP, %	7.60	21.64	20.48	20.12
AEE[2], %	3.09	10.30	8.15	8.26

[1]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[2]AEE = acid hydrolyzed ether extract.

Table 3.5. Apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of CP and AA in conventional full fat soybeans (FFSB-CV), high protein full fat soybeans (FFSB-HP), and high protein-low oligosaccharide full fat soybeans (FFSB-LO) by growing pigs, Exp. 1[1]

	AID					SID[2]				
Item	Ingredient					Ingredient				
	FFSB-CV	FFSB-HP	FFSB-LO	SEM	*P*-value	FFSB-CV	FFSB-HP	FFSB-LO	SEM	*P*-value
CP, %	74.91[a]	64.91[b]	70.63[a]	4.0	< 0.01	83.99[a]	74.70[b]	80.31[a]	4.0	< 0.01
Indispensable AA, %										
Arg	87.51	81.26	84.92	3.3	0.14	91.58	85.32	89.04	3.3	0.14
His	83.73	76.97	80.26	3.2	0.06	87.08	80.44	83.78	3.2	0.07
Ile	80.81[a]	73.67[b]	76.63[ab]	3.6	0.03	84.39[a]	77.32[b]	80.57[ab]	3.6	0.04
Leu	81.78[a]	74.59[b]	78.47[ab]	3.4	0.03	85.14[a]	78.10[b]	82.08[ab]	3.4	0.03
Lys	83.11[a]	76.54[b]	80.06[ab]	3.2	0.04	86.38[a]	79.97[b]	83.54[ab]	3.2	0.04
Met	80.98	75.31	79.28	3.4	0.06	84.45	78.77	82.60	3.4	0.06
Phe	82.53[a]	75.46[b]	78.97[ab]	3.5	0.04	85.59[a]	78.63[b]	82.29[ab]	3.5	0.04
Thr	75.80[a]	68.28[b]	73.27[a]	3.4	< 0.01	82.71[a]	75.53[b]	80.41[a]	3.4	< 0.01

Table 3.5. (Cont.)

Trp	81.36	76.59	81.69	2.6	0.07	85.20	80.57	85.37	2.6	0.09
Val	77.45[a]	70.21[b]	72.93[ab]	3.9	0.03	82.88[a]	75.74[b]	78.86[ab]	3.9	0.04
Mean	81.98[a]	75.18[b]	78.85[ab]	3.4	0.04	85.98[a]	79.29[b]	83.07[ab]	3.4	0.04
Dispensable AA, %										
Ala	74.34[a]	66.44[b]	69.55[ab]	4.1	0.02	81.82[a]	74.16[b]	77.44[ab]	4.1	0.03
Asp	80.52[a]	73.35[b]	78.32[a]	3.3	0.02	83.64[a]	76.57[b]	81.63[a]	3.3	0.02
Cys	73.73[a]	66.62[b]	73.62[a]	3.4	< 0.01	80.52[a]	73.96[b]	80.13[a]	3.4	0.01
Glu	85.33	79.32	82.64	2.9	0.06	87.90	81.89	85.34	2.9	0.06
Gly	65.93[a]	55.05[b]	60.41[ab]	5.9	0.02	86.79[a]	75.86[b]	82.18[ab]	5.9	0.02
Pro	34.39	11.11	25.76	17.5	0.19	103.90	81.14	98.45	17.5	0.18
Ser	81.23[a]	74.82[b]	80.14[a]	2.9	0.02	86.01[a]	79.85[b]	85.05[a]	2.9	0.03
Tyr	82.23[a]	74.61[b]	78.19[ab]	3.4	0.01	86.26[a]	78.89[b]	82.59[ab]	3.4	0.02
Mean	76.19[a]	67.50[b]	72.71[ab]	4.3	0.03	87.45[a]	79.01[b]	84.55[ab]	4.3	0.03
Total	78.87[a]	71.04[b]	75.54[ab]	3.8	0.03	86.77[a]	79.14[b]	83.86[ab]	3.8	0.03

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

[1]Data are the least square means of 8 observations per treatment.

[2] Values for SID were calculated by correcting the values for apparent ileal digestibility for the basal ileal endogenous losses. Basal ileal endogenous losses were determined from pigs fed the N-free diet as (g/kg of DMI) as CP, 21.85; Arg, 0.66; His, 0.19; Ile, 0.37; Leu, 0.59; Lys, 0.43; Met, 0.10; Phe, 0.36; Thr, 0.59; Trp, 0.11; Val, 0.58; Ala, 0.71; Asp, 0.80; Cys, 0.19; Glu, 1.04; Gly, 1.90; Pro, 7.64; Ser, 0.47; Tyr, 0.30.

Table 3.6. Daily energy balance and apparent total tract digestibility (ATTD) of energy of experimental diets containing corn, or corn and conventional full fat soybeans (FFSB-CV), high protein full fat soybeans (FFSB-HP), or high protein-low oligosaccharide full fat soybeans (FFSB-LO), as-fed basis, Exp. 2[1]

Item	Diet				SEM	*P*-Value
	Corn	FFSB-CV	FFSB-HP	FFSB-LO		
GE intake, kcal/d	4,399[c]	4,976[a]	4,966[ab]	4,852[b]	128.67	< 0.01
GE in feces, kcal/d	560[c]	850[a]	723[ab]	703[b]	47.01	< 0.01
GE in urine, kcal/d	119	189	186	192	23.25	0.11
ATTD of GE, %	87.25[a]	82.98[b]	85.43[ab]	85.43[ab]	0.91	0.02
DE in diet, kcal/kg	3,311[b]	3,641[a]	3,671[a]	3,637[a]	38.69	< 0.01
ME in diet, kcal/kg	3,208[b]	3,474[a]	3,510[a]	3,467[a]	45.80	< 0.01

[a-c]Means within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Data are the least square means of 6 observations per treatment.

Table 3.7. Concentration of energy in corn, conventional full fat soybeans (FFSB-CV), high protein full fat soybeans (FFSB-HP), and high protein-low oligosaccharide full fat soybeans (FFSB-LO), Exp. 2[1]

Item	Ingredient				SEM	*P*-Value
	Corn	FFSB-CV	FFSB-HP	FFSB-LO		
DE, kcal/kg	3,406[b]	4,314[a]	4,622[a]	4,448[a]	121.15	< 0.01
ME, kcal/kg	3,300[b]	4,023[a]	4,313[a]	4,121[a]	143.66	<0.01
DE, kcal/kg DM	3,864[b]	4,495[a]	4,765[a]	4,694[a]	126.46	< 0.01
ME, kcal/kg DM	3,744[b]	4,192[a]	4,447[a]	4,349[a]	150.25	< 0.01

[a-b]Means within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Data are the least square means of 6 observations per treatment.

CHAPTER 4

AMINO ACID DIGESTIBILITY AND ENERGY CONCENTRATION IN LOW-TRYPSIN INHIBITOR EXPELLER SOYBEAN MEAL FED TO GROWING PIGS

ABSTRACT

Two experiments were conducted to determine AA and energy digestibility in expeller soybean meal (ESBM). Three sources of ESBM were produced from conventional (ESBM-CV), low trypsin inhibitor (ESBM-LT), and ultra-low trypsin inhibitor (ESBM-ULT) soybeans using cold pressing procedure. Approximately 50% of each source was roasted via a heated thermal screw (ESBM-CV-H, ESBM-LT-H, and ESBM-ULT-H, respectively), whereas 50% was used without used without heating. A source of conventional soybean meal (SBM) was also used. In Exp. 1, the standardized ileal digestibility (SID) of CP and AA in the 7 ingredients was determined using 8 growing barrows (initial BW: 21.8 ± 1.2 kg) that were equipped with a T-cannula in the distal ileum. All diets contained ESBM or SBM as the sole source of AA. A N-free diet was used to determine basal endogenous losses of AA. Pigs were allotted to an 8 × 8 Latin square design with 8 periods and 8 diets. The SID of CP and all AA were greater ($P < 0.01$) in SBM than in all the ESBM. The SID of CP and all AA was less ($P < 0.01$) in ESBM-CV compared with ESBM-LT and ESBM-ULT, but all values for ESBM-ULT were greater ($P < 0.01$) than the values for ESBM-LT. For most AA, ESBM-CV-H and ESBM-LT-H had greater ($P < 0.01$) AID and SID values ESBM-CV and ESBM-LT. In contrast, the AID and SID values for AA were not different in the ESBM-ULT-H compared with the ESBM-ULT. In Exp. 2, the DE and ME in the 7 sources of ESBM and SBM were determined using 48 growing barrows (initial BW: 36.3 ±3.2 kg). A corn-based basal diet and 7 diets containing corn and 1 source of

ESBM or SBM were formulated. Pigs were placed in metabolism cages and randomly allotted to the 8 diets. After a 5 d adaptation period, feces and urine were collected for 5 d. The DE and ME in each source of ESBM and SBM were calculated using the difference procedure. The concentration of DE and ME in ESBM-CV, ESBM-LT, ESBM-ULT, ESBM-CV-H, ESBM-LT-H, ESBM-ULT-H, and SBM were 4,519 and 4,086; 4,962 and 4,430; 4,652 and 4,359; 4,495 and 4,494; 4,674 and 4,305; 4,826 and 4,494; and 4,427 and 4,006 kcal/kg DM, respectively. The DE of both the cold pressed and the heated sources of ESBM-ULT and ESBM-LT were greater ($P < 0.01$) than the DE of SBM. The DE was greater ($P < 0.01$) in ESBM-LT than in ESBM-ULT, but there was no difference between ESBM-LT-H and ESBM-ULT-H. The ME in ESBM-ULT and ESBM-LT-H were greater ($P < 0.01$) than in corn, and ESBM-LT and ESBM-ULT-H had a greater ($P < 0.01$) ME than ESBM-CV and SBM. Therefore, it is not possible to use these low-trypsin beans in diets fed to pigs without heat treatment, even with only 7 to 12 units of trypsin inhibitors. Results of this research also indicate that the only negative effects of trypsin inhibitors is the reduction in AA digestibility because energy digestibility does not seem to be affected by the presence of trypsin inhibitors in the meals.

Key words: amino acids, expeller soybean meal, pigs, soybean meal, trypsin inhibitors

INTRODUCTION

Soybeans contain trypsin inhibitors (Rackis, 1972) that are detrimental to protein digestion in monogastric animals (Rackis et al., 1979; Combs et al., 1967; Herkelman et al., 1993). It is, therefore, established that soybean products need to be heat treated prior to use in diets for monogastric animals because heat treatment destroys the trypsin inhibitors in the meals, and AA digestibility in heat treated soybean products is much greater than in unheated products

(Goebel and Stein, 2011). The most commonly fed source of soybean products for monogastric animals is soybean meal (**SBM**), which is heat treated in the form of toasting after the oil has been extracted. Soybean meal, therefore, usually has a low concentration of trypsin inhibitors (i.e., less than 4 trypsin inhibitor units). In contrast, unheated SBM usually contains more than 35 trypsin inhibitor units.

Selection of soybeans with low concentrations of trypsin inhibitors has resulted in newer soybean varieties that contain less trypsin inhibitor units than conventional soybeans. It was recently demonstrated that the standardized ileal digestibility (**SID**) of AA in soybeans containing 23 trypsin inhibitor units is greater than in conventional soybeans that contain 35 trypsin inhibitor units, but SID values of AA in the low-trypsin soybeans were not as high as in SBM containing 3 trypsin inhibitor units (Goebel and Stein, 2011). However, additional selection for varieties with low concentrations of trypsin inhibitors has resulted in identification of soybean varieties containing only 7 or 12 trypsin inhibitor units. It is believed that these low levels of trypsin inhibitors will result in further increases in the SID of AA compared with conventional soybeans, but that hypothesis has not yet been experimentally verified. It is also not known how the concentration of trypsin inhibitors in soybeans influences the digestibility of energy and the concentration of DE and ME.

Therefore, 2 experiments were conducted to test the hypothesis that SID of CP and AA are greater in expeller soybean meal (**ESBM**) produced from soybeans with low or ultra-low concentration of trypsin inhibitors than in ESBM produced from conventional soybeans, without affecting DE and ME negatively. The objective of these experiments is to determine the SID of CP and AA, and the DE and ME in ESBM produced from conventional soybeans, or soybeans with low or ultra- low concentrations of trypsin inhibitors.

MATERIALS AND METHODS

General

The experimental protocols for these experiments were reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Two experiments were conducted using the same batches of ESBM (Schillinger Genetics, Inc., Des Moines, IA). The 3 sources of ESBM were produced from a conventional source of soybeans (**ESBM-CV**), a source of soybeans with a low concentration of Kunitz and Bowman-Birk trypsin inhibitors (**ESBM-LT**), and a source of soybeans with an ultra-low concentration of trypsin inhibitors (**ESBM-ULT**; Table 4.1). All 3 sources of soybeans were defatted using a cold pressing procedure through a Kern Kraft S40 and then ground twice for meal specification. Approximately 50% of each source of soybeans were run back through a heated thermal screw to achieve a roasting effect (**ESBM-CV-H**, **ESBM-LT-H**, and **ESBM-ULT-H**, respectively; Table 4.1). A source of conventional SBM was also used in the experiment. Pigs used in both experiments were sired by G performer (Duroc × Pietrain) boars that were mated to Fertilis 25 (¾ Landrace ¼ Large White) females (Genetiporc Inc., Alexandria, MN).

Amino Acid Digestibility, Exp. 1

Animals, Housing, and Experimental Design. Eight growing barrows were used in this experiment. Pigs (initial BW: 21.8 ± 1.2 kg) were surgically equipped with a T-cannula in the distal ileum using procedures adapted from Stein et al. (1998). Pigs were housed in individual pens (1.5 × 1.2 m) with fully slatted floors in an environmentally controlled room. Pigs were allowed to recover for a 7 d period following surgery. Pigs were then randomly allotted to an 8 ×

8 Latin square design with 8 diets and 8 periods. A feeder and a nipple drinker were installed in each pen.

Diets and Feeding. Eight diets were formulated (Tables 4.2 and 4.3). Seven of the diets contained 1 of each source of SBM and starch, sugar, and oil. The last diet was a N-free diet that was used to calculate basal endogenous losses of AA and CP. Solka floc (4.0%), magnesium oxide (0.1%), and potassium carbonate (0.4%) were added to the N-free diet to increase the concentration of crude fiber, and to prevent deficiency of Mg and K in the diet, respectively. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998). All diets also contained 0.4% chromic oxide as an indigestible marker. All pigs were fed once daily at 0700 h at a level of 3 times the estimated maintenance energy requirement (i.e., 106 kcal of ME per $kg^{0.75}$; NRC, 1998). Water was available at all times throughout the experiment.

Data Recording and Sample Collection. Pig BW were recorded at the beginning and at the end of each period and the amount of feed supplied each day was recorded. Each experimental period lasted 7 d. The initial 5 d of each period were considered an adaptation period to the diet. On d 6 and 7, ileal digesta were collected for 8 consecutive h. A 225-mL plastic bag was attached to the cannula barrel with a cable tie and digesta flowing into the bag were collected as described by Stein et al. (1999). Bags were removed whenever they were filled with digesta, or at least once every 30 min, and immediately frozen at -20 ℃ to prevent bacterial degradation of AA in the digesta.

Chemical Analysis. 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 source of SBM was collected as well. Ileal samples were lyophilized and finely

ground prior to chemical analysis. All samples were analyzed in duplicate. Diets and ingredients were analyzed for DM, CP, and AA. Ileal samples were analyzed for DM, CP, and AA. Diets and ileal samples were analyzed for chromium, as well. Dry matter was analyzed in a drying oven at 135 ℃ for 2 h (method 930.15; AOAC Int., 2007), CP was analyzed by combustion method (method 990.03; AOAC Int., 2007) using a Rapid N cube (Elementar Americas Inc., Mt. Laurel, NJ). For AA analysis, samples were hydrolyzed with 6 *N* HCl for 24 h at 110 ℃, then analyzed on a Hitichi Amino Acid Analyzer (Model L8800, Hitachi High Technologies America, Inc., Pleasaton, CA) using ninhydrin for postcolum derivatization and norleucine as the internal standard [method 982.30 E (a, b, c); AOAC Int., 2007]. Chromium was analyzed in diet and ileal samples using an inductive coupled plasma atomic emission spectrometric method (method 990.08; AOAC Int., 2007). Ingredient samples were analyzed for GE using bomb calorimeter (Model 6300, Parr Instruments, Moline, IL), ash (method 942.05; AOAC Int., 2007), Ca and P (method 975.03; AOAC Int., 2007), ADF (method 973.18; AOAC Int., 2007), NDF (Holst, 1973), sucrose, stachyose, and raffinose (Janauer and Englmaier, 1978), and trypsin inhibitors (method Ba 12-75; AOCS, 2006). Ingredient samples were also analyzed for acid-hydrolyzed ether extract by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (method 2003.06; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN).

Calculations and Statistical Analysis. Apparent ileal digestibility (**AID**) values for CP and AA in samples obtained from feeding the 7 diets containing SBM were calculated. Because SBM was the only feed ingredient contributing CP and AA in each diet, these digestibility values also represent the digestibility values for each source of SBM. AID values of AA were calculated using equation [1] (Stein et al., 2007):

$$AID_{AA}, \% = 100 - [\left(\frac{AA_{digesta}}{AA_{feed}}\right) \times \left(\frac{Cr_{feed}}{Cr_{digesta}}\right)] \times 100 \quad [1]$$

where AID_{AA} is the apparent ileal digestibility of an AA (%), $AA_{digesta}$ is the concentration of that AA in the ileal digesta DM, AA_{feed} is the AA concentration of that AA in the feed DM, Cr_{feed} is the chromium concentration in the feed DM, and $Cr_{digesta}$ is the chromium concentration in the ileal digesta DM. The AID for CP will also be calculated using this equation.

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

$$IAA_{end} = [AA_{digesta} \times \left(\frac{Cr_{feed}}{Cr_{digesta}}\right)] \quad [2]$$

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

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

$$SID_{AA} = [\frac{AID + IAA_{end}}{AA_{feed}}] \quad [3]$$

where SID_{AA} is the SID value (%) of each AA. The SID for AA was also calculated using the same equation.

The Proc UNIVARIATE procedure of SAS was used to identify outliers (SAS Institute Inc., Cary, NC). Data were analyzed using the Proc MIXED procedure of SAS. An analysis of variance was conducted with diet as fixed effects and pig and period as random effects. When significant differences were detected, treatment means were separated using the Least Significant Difference test in Proc MIXED. The pig was the experimental unit for all analyses and an alpha value of 0.05 was used to assess significance among treatments.

Energy Digestibility and Concentration, Exp. 2

Diets, Animals, and Experimental Design. Eight diets were formulated (Tables 4.4 and 4.5). Seven of the diets contained 1 of the SBM and corn. The last diet was a corn diet that did not contain any SBM. Corn and SBM were the exclusive sources of energy for these diets. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998).

A total of 48 growing barrows (initial BW: 36.3±3.2 kg) was obtained from the Swine Research Center. Pigs were placed in metabolism cages equipped with a feeder and a nipple drinker. The experiment was conducted as a randomized complete block design with 8 diets and 6 replications per diet.

Feeding and Sample Collection. The quantity of feed provided per pig daily was calculated as 3 times the estimated requirement for maintenance energy (i.e., 106 kcal ME per $kg^{0.75}$; NRC, 1998) and divided into 2 equal meals that were fed at 0700 h and 0400 h. Water was available at all times. The experiment lasted 12 d. The initial 5 d was considered an adaptation period to the diet, while urine and fecal materials were collected during the next 5 d according to standard procedures using the marker to marker approach (Adeola, 2001). Urine was collected in urine buckets over a preservative of 40mL of 6 *N* HCl. Fecal samples and 20% of the collected urine were stored at -20 ℃ immediately after collection. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a subsample was taken for chemical analysis.

Sample Analysis and Data Processing. Fecal samples were dried in a forced air oven and finely ground prior to analysis. Fecal, urine, diet, and ingredient samples were analyzed in duplicate for GE using bomb calorimeter (Model 6300, Parr Instruments, Moline, IL). Diets and ingredients

were also analyzed for DM, CP, and AEE as explained for Exp. 1. Following chemical analysis, total tract digestibility values were calculated for energy using procedures previously described (Stein et al., 2004). The quantities of energy lost in the feces and urine were calculated as well, and the DE and ME in each of the 8 diets were calculated (Stein et al., 2004). The amounts of DE and ME that were contributed by corn to the 7 diets containing SBM were then subtracted from the DE and ME in each of these diets. This allowed for the calculation of the DE and ME in each source of SBM, using the difference procedure as described by Adeola (2001). Data were analyzed as explained for Exp. 1 using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC).

RESULTS

Amino Acid Digestibility, Exp. 1

The AID and SID of CP and all AA were greater ($P < 0.01$) in SBM than in all the expeller meals (Tables 4.6 and 4.7). Among the cold pressed meals, the ESBM-CV had less ($P < 0.01$) AID and SID of CP and all AA compared with ESBM-LT and ESBM-ULT, but all values for ESBM-ULT were greater ($P < 0.01$) than the values for ESBM-LT.

The AID and SID of CP was not different in the heat treated sources of ESBM-CV, ESBM-LT, and ESBM-ULT compared with the cold pressed sources. However, for most AA, the heat treated ESBM-CV and ESBM-LT had greater ($P < 0.01$) AID and SID values than the cold pressed. In contrast, the AID and SID values for AA were not different in the heat treated ESBM-ULT compared with the cold pressed source of ESBM-ULT.

Energy Digestibility, Exp. 2

The intake of GE was less ($P < 0.01$) in pigs fed the SBM diet than in pigs fed the ESBM-LT, ESBM-CV-H, and ESBM-LT-H diets; however, the intake of GE in pigs fed the diets containing the cold-pressed sources of ESBM-CV, ESBM-ULT, and ESBM-ULT H was not different from the intake of the diets in which the heated sources of these meals were used (Table 4.8). Fecal excretion of GE and the ATTD of GE were not different among diets. Urine excretion of GE was greater ($P < 0.01$) from pigs fed the ESBM-LT diet than from pigs fed the ESBM-ULT diet, but pigs fed the corn diet had the least ($P < 0.01$) urine excretion of GE. Diet DE values were greater ($P < 0.01$) for diets containing cold pressed ESBM-LT or heated ESBM-ULT or ESBM-LT compared with diets containing cold pressed ESBM-CV, SBM, or corn. The ME was greater ($P < 0.01$) in the diet containing heated ESBM-LT than in the diets containing ESBM-CV (cold pressed or heated), SBM, or corn, and the diets containing heat treated ESBM-CV also had a greater ($P < 0.01$) ME than diets containing corn or SBM.

The DE in both the cold pressed and the heated sources of ESBM-ULT and ESBM-LT were greater than in corn and SBM both on a DM-basis and on an as-fed basis (Table 4.9). On an as-fed basis, ESBM-CV also had greater ($P < 0.01$) DE than corn and SBM, and on a DM-basis, the ESBM-CV had a greater DE than corn. On an as-fed basis, there were no differences between ESBM-ULT and ESBM-LT, regardless of the processing procedure used. However, on a DM basis, ESBM-LT had a greater ($P < 0.01$) DE than ESBM-ULT, but that was not the case for the heated sources of ESBM-LT and ESBM-ULT.

Values for ME on an as-fed basis were greater ($P < 0.01$) for ESBM-LT and ESBM-ULT-H than in ESBM-CV, SBM, and corn, and the ME of the heated ESBM-CV was also greater than in corn and SBM, whereas the ME of cold pressed ESBM-CV was greater ($P <$

0.01) only compared with corn. When calculated on a DM basis, the ME in ESBM-ULT and ESBM-LT-H were greater ($P < 0.01$) than in corn, but only cold pressed ESBM-LT and heated ESBM-ULT had a greater ($P < 0.01$) ME than ESBM-CV and SBM.

DISCUSSION

Composition

The concentration of CP and fat in conventional SBM was close to expected values compared with previous experiments (Goebel and Stein, 2011; Baker et al., 2010) in which toasted conventional SBM has been used. However, the concentration of Lys was less in the source of SBM used in this experiment than in previous experiments. The concentration of fat in all the expeller SBM used in this experiment was greater than in conventional SBM, which was expected because mechanical extraction is less efficient in fat removal compared with hexane extraction. In terms of trypsin inhibitor concentration, measured in TIU/mg, ESBM-CV was greater than any other SBM, which is in agreement with values from Goebel and Stein (2011). The TIU value in conventional SBM was low as expected, due to the toasting that is used after hexane extraction. Trypsin inhibitor concentrations in the cold pressed ESBM-ULT and ESBM-LT were much less than in ESBM-CV, which clearly indicates that the genetic selection for low trypsin inhibitor concentrations in soybeans was successful in reducing trypsin inhibitor concentrations. However, the trypsin inhibitor concentrations in the heated sources of ESBM-CV, ESBM-ULT, and ESBM-LT were not reduced as much as expected compared with values for the cold-pressed sources of these meals. It was expected that the heat treatment would result in TIU values that were close to the value in SBM as was achieved in our previous experiment

(Goebel and Stein, 2011). The fact that the TIU values were not reduced by the heat treatment indicates that the heat treatment was insufficient to inactivate the trypsin inhibitors in the meals.

Amino Acid Digestibility, Exp. 1

The SID of AA and CP in conventional SBM was close to what was expected from previous experiments (Goebel and Stein, 2011; Baker et al., 2010). The SID of AA and CP in ESBM-CV was very low due to the high concentration of trypsin inhibitors. The SID of AA and CP in ESBM-ULT and ESBM-LT was much greater than that of ESBM-CV. This observation clearly indicates that the genetic selection for reduced concentration of trypsin inhibitors in these meals has been successful. However, the fact that the SID values of all AA were less in the cold-pressed sources of both ESBM-ULT and ESBM-LT compared with SBM also demonstrates that the concentration of trypsin inhibitors in these meals, although much less than in conventional cold-pressed meal, is not sufficiently reduced to completely negate the negative effects of trypsin inhibitors on AA digestibility. Although the reduction in the total concentration of trypsin inhibitors is impressive and only 7 TIU were measured in the cold pressed source of ESBM-ULT, this level was able to suppress the SID of most AA by 10 to 20 percentage units compared with the SID of the same AA in SBM. It is, therefore, necessary that the level of trypsin inhibitors be further reduced if the ULT beans are to be used without heat treatment in the feeding of pigs. It is, however, surprising that a level of only 7 units of trypsin inhibitors was able to reduce the SID of AA as much as observed in this experiment. It is, therefore, possible that the trypsin inhibitors that are left in the LT and the ULT beans are the most inhibiting trypsin inhibitors, and that the inhibitors that have been eliminated from these beans are the least inhibitive. However, further research is needed to verify this hypothesis.

The fact that the heat treatment of the ESBM was insufficient to reduce the trypsin inhibitors in the beans prevents us from making a direct comparison between cold-pressed and adequately heated sources of the same meals. We are, therefore, only able to compared the LT and ULT meals to conventional toasted SBM.

Energy Digestibility, Exp. 2

The values for DE and ME of corn and conventional SBM that were determined in this experiment were close to what was expected, which is in agreement with many previous experiments (NRC, 1998; Baker and Stein, 2009). The DE and ME for all the ESBM-ULT and ESBM-LT, whether with or without heat treatment, were greater than the DE and ME for conventional SBM. This was most likely due to much greater concentration of fat in the expeller SBM than in conventional SBM. The greater DE and ME for ESBM-ULT and ESBM-LT compared with ESBM-CV were also likely a consequence of the greater concentration of fat in these meals. The DE and ME values were not affected by trypsin inhibitor concentration in this experiment. However, trypsin inhibitor levels and fat concentrations were confounded, which prevents us from making conclusions about the influence of trypsin inhibitors on DE and ME.

Conclusions

Newly selected varieties of soybeans have greatly reduced concentrations of trypsin inhibitors compared with conventional soybeans. The meal from these low-trypsin inhibitor varieties contain only 7 to 12 units of trypsin inhibitors, which is believed to reduce or negate the negative impact of trypsin inhibitors in conventional soybeans. However, results of this present research indicated that although the SID of AA in low-trypsin inhibitor SBM is much greater than in un-heated conventional SBM, values are still 10 to 20 percentage units less than the values obtained for toasted SBM. It is therefore not possible to use these low-trypsin beans in

diets fed to pigs without heat treatment. Results of this research also indicated that the only negative effects of trypsin inhibitors is the reduction in AA digestibility because energy digestibility does not seem to be affected by the presence of trypsin inhibitors in the meals.

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TABLES

Table 4.1. Chemical composition of expeller soybean meal (ESBM) produced from unheated conventional soybeans (ESBM-CV), unheated ultra-low trypsin inhibitor soybeans (ESBM-ULT), unheated low trypsin inhibitor soybeans (ESBM-LT), heated conventional soybeans (ESBM-CV-H), heated ultra-low trypsin inhibitor soybeans (ESBM-ULT-H), heated low trypsin inhibitor soybeans (ESBM-LT-H), and toasted and defatted 47.5% soybean meal (SBM), as-fed basis

Item	Ingredient						
	ESBM-CV	ESBM-ULT	ESBM-LT	ESBM-CV-H	ESBM-ULT-H	ESBM-LT-H	SBM
DM, %	92.46	94.09	92.20	97.54	93.91	96.60	87.41
GE, kcal/kg	4,797	4,661	4,873	4,647	4,925	5,182	4,155
CP, %	42.97	45.55	42.51	47.41	44.44	45.67	47.22
AEE[1], %	11.87	7.89	11.16	7.16	6.18	9.91	1.81
Ca, %	0.32	0.30	0.25	0.30	0.34	0.26	0.40
P, %	0.57	0.56	0.47	0.54	0.62	0.50	0.72
ADF, %	7.35	6.84	5.71	7.50	6.82	6.44	4.81
NDF, %	9.37	9.89	7.99	11.24	10.00	10.15	8.77
Sucrose, %	5.27	5.48	5.73	5.51	5.79	6.85	6.16

Table 4.1. (Cont.)

Raffinose, %	0.78	0.68	0.65	0.89	0.77	0.93	0.93
Stachyose, %	4.77	4.36	4.03	4.76	4.76	4.76	5.17
TIU^2/mg	36.00	7.70	12.40	21.80	7.50	9.10	2.90
Indispensable AA, %							
Arg	3.00	3.27	3.11	3.16	2.97	3.18	3.16
His	1.15	1.25	1.17	1.22	1.14	1.18	1.16
Ile	1.89	2.01	1.84	1.98	1.85	1.90	2.00
Leu	3.12	3.37	3.12	3.32	3.09	3.24	3.41
Lys	2.68	2.82	2.63	2.84	2.56	2.66	2.82
Met	0.54	0.56	0.53	0.58	0.52	0.54	0.61
Phe	2.05	2.28	2.04	2.17	2.01	2.11	2.17
Thr	1.57	1.67	1.58	1.69	1.53	1.61	1.73
Trp	0.61	0.66	0.59	0.68	0.65	0.65	0.72
Val	1.97	2.14	1.94	2.07	1.99	2.03	2.10

Table 4.1. (Cont.)

Dispensable AA, %							
Ala	1.73	1.86	1.72	1.85	1.71	1.77	1.92
Asp	4.48	4.76	4.44	4.75	4.36	4.57	4.85
Cys	0.56	0.54	0.54	0.60	0.49	0.54	0.63
Glu	7.35	7.86	7.39	7.73	7.14	7.55	7.78
Gly	1.77	1.85	1.72	1.87	1.71	1.77	1.87
Ser	1.86	1.88	1.87	1.96	1.68	1.84	1.97
Tyr	1.50	1.67	1.51	1.59	1.49	1.55	1.64

[1]AEE = acid hydrolyzed ether extract.
[2]TIU = trypsin inhibitor units.

Table 4.2. Ingredient composition of experimental diets containing expeller soybean meal (ESBM) produced from unheated conventional soybeans (ESBM-CV), unheated ultra-low trypsin inhibitor soybeans (ESBM-ULT), unheated low trypsin inhibitor soybeans (ESBM-LT), heated conventional soybeans (ESBM-CV-H), heated ultra-low trypsin inhibitor soybeans (ESBM-ULT-H), heated low trypsin inhibitor soybeans (ESBM-LT-H), and toasted and defatted 47.5% soybean meal (SBM), as-fed basis, Exp. 1

Ingredient, %	Diet							
	ESBM-CV	ESBM-ULT	ESBM-LT	ESBM-CV-H	ESBM-ULT-H	ESBM-LT-H	SBM	N-Free
ESBM-CV	40.00	-	-	-	-	-	-	-
ESBM-ULT	-	40.00	-	-	-	-	-	-
ESBM-LT	-	-	40.00	-	-	-	-	-
ESBM-CV-H	-	-	-	40.00	-	-	-	-
ESBM-ULT-H	-	-	-	-	40.00	-	-	-
ESBM-LT-H	-	-	-	-	-	40.00	-	-
SBM	-	-	-	-	-	-	40.00	-
Cornstarch	43.20	43.20	43.20	43.20	43.20	43.20	43.20	67.85
Soybean oil	3.60	3.60	3.60	3.60	3.60	3.60	3.60	4.00
Sugar	10.00	10.00	10.00	10.00	10.00	10.00	10.00	20.00

Table 4.2. (Cont.)

Solka floc[1]	-	-	-	-	-	-	-	4.00
Ground limestone	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.85
Monocalcium phosphate	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.70
Magnesium oxide	-	-	-	-	-	-	-	0.10
Potassium carbonate	-	-	-	-	-	-	-	0.40
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Table 4.2. (Cont.)

Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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

[2]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 4.3. Chemical composition of experimental diets containing expeller soybean meal (ESBM) produced from unheated conventional soybeans (ESBM-CV), unheated ultra-low trypsin inhibitor soybeans (ESBM-ULT), unheated low trypsin inhibitor soybeans (ESBM-LT), heated conventional soybeans (ESBM-CV-H), heated ultra-low trypsin inhibitor soybeans (ESBM-ULT-H), heated low trypsin inhibitor soybeans (ESBM-LT-H), and toasted and defatted 47.5% soybean meal (SBM), as-fed basis, Exp. 1

Item	Diet							
	ESBM-CV	ESBM-ULT	ESBM-LT	ESBM-CV-H	ESBM-ULT-H	ESBM-LT-H	SBM	N-Free
DM, %	92.55	93.43	92.35	94.68	93.96	95.65	91.40	93.98
CP, %	20.01	20.20	17.82	20.28	20.23	18.83	20.10	0.44
Indispensable AA, %								
Arg	1.23	1.32	1.31	1.37	1.18	1.36	1.27	0.01
His	0.43	0.47	0.45	0.49	0.42	0.47	0.46	0.00
Ile	0.75	0.75	0.73	0.86	0.73	0.79	0.81	0.02
Leu	1.29	1.37	1.33	1.46	1.26	1.39	1.38	0.02
Lys	1.10	1.14	1.11	1.21	1.03	1.14	1.15	0.01
Met	0.24	0.25	0.25	0.28	0.23	0.25	0.27	0.00
Phe	0.87	0.90	0.88	0.98	0.84	0.93	0.91	0.01

Table 4.3. (Cont.)

Thr	0.65	0.70	0.67	0.73	0.63	0.70	0.69	0.01
Trp	0.21	0.25	0.21	0.26	0.22	0.21	0.23	0.03
Val	0.78	0.81	0.78	0.90	0.77	0.84	0.86	0.01
Dispensable AA, %								
Ala	0.75	0.79	0.77	0.84	0.73	0.79	0.79	0.02
Asp	1.91	2.03	1.98	2.15	1.83	2.06	2.03	0.02
Cys	0.24	0.23	0.24	0.27	0.21	0.23	0.26	0.00
Glu	3.01	3.21	3.16	3.35	2.94	3.26	3.12	0.06
Gly	0.74	0.77	0.75	0.83	0.71	0.78	0.77	0.01
Ser	0.80	0.87	0.85	0.89	0.75	0.86	0.81	0.01
Tyr	0.57	0.56	0.58	0.63	0.54	0.58	0.60	0.01

Table 4.4. Ingredient composition of experimental diets containing expeller soybean meal (ESBM) produced from unheated conventional soybeans (ESBM-CV), unheated ultra-low trypsin inhibitor soybeans (ESBM-ULT), unheated low trypsin inhibitor soybeans (ESBM-LT), heated conventional soybeans (ESBM-CV-H), heated ultra-low trypsin inhibitor soybeans (ESBM-ULT-H), heated low trypsin inhibitor soybeans (ESBM-LT-H), and toasted and defatted 47.5% soybean meal (SBM), as-fed basis, Exp. 2

Ingredient, %	Diet							
	Basal	ESBM-CV	ESBM-ULT	ESBM-LT	ESBM-CV-H	ESBM-ULT-H	ESBM-LT-H	SBM
Corn	97.40	69.60	69.60	69.60	69.60	69.60	69.60	69.60
ESBM-CV	-	28.00	-	-	-	-	-	-
ESBM-ULT	-	-	28.00	-	-	-	-	-
ESBM-LT	-	-	-	28.00	-	-	-	-
ESBM-CV-H	-	-	-	-	28.00	-	-	-
ESBM-ULT-H	-	-	-	-	-	28.00	-	-
ESBM-LT-H	-	-	-	-	-	-	28.00	-
SBM	-	-	-	-	-	-	-	28.00
Ground limestone	1.10	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4.4. (Cont.)

Monocalcium phosphate	0.80	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral Premix[1]	0.30	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

[1]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 4.5. Chemical composition of experimental diets containing expeller soybean meal (ESBM) produced from unheated conventional soybeans (ESBM-CV), unheated ultra-low trypsin inhibitor soybeans (ESBM-ULT), unheated low trypsin inhibitor soybeans (ESBM-LT), heated conventional soybeans (ESBM-CV-H), heated ultra-low trypsin inhibitor soybeans (ESBM-ULT-H), heated low trypsin inhibitor soybeans (ESBM-LT-H), and toasted and defatted 47.5% soybean meal (SBM), as-fed basis, Exp. 2

Item	Diet							
	Basal	ESBM-CV	ESBM-ULT	ESBM-LT	ESBM-CV-H	ESBM-ULT-H	ESBM-LT-H	SBM
DM, %	89.06	90.23	90.80	90.08	91.61	91.65	91.83	89.36
GE, kcal/kg	3,750	4,040	4,027	4,085	4,028	4,096	4,115	3,891
CP, %	7.76	18.49	19.04	18.42	19.92	19.16	19.15	19.79
AEE[1], %	3.17	5.69	4.75	5.79	4.77	5.94	6.29	3.07

[1]AEE = acid hydrolyzed ether extract.

Table 4.6. Apparent ileal digestibility (AID) of CP and AA in expeller soybean meal (ESBM) produced from unheated conventional soybeans (ESBM-CV), unheated ultra-low trypsin inhibitor soybeans (ESBM-ULT), unheated low trypsin inhibitor soybeans (ESBM-LT), heated conventional soybeans (ESBM-CV-H), heated ultra-low trypsin inhibitor soybeans (ESBM-ULT-H), heated low trypsin inhibitor soybeans (ESBM-LT-H), and toasted and defatted 47.5% SBM, Exp. 1[1]

Item	Ingredient							SEM	*P*-Value
	ESBM-CV	ESBM-ULT	ESBM-LT	ESBM-CV-H	ESBM-ULT-H	ESBM-LT-H	SBM		
CP, %	30.36^{e}	64.82^{b}	41.77^{d}	39.52^{d}	62.08^{b}	52.71^{c}	74.70^{a}	4.00	< 0.01
Indispensable AA, %									
Arg	36.93^{e}	77.67^{b}	63.17^{c}	53.58^{d}	72.19^{b}	72.60^{b}	89.17^{a}	3.60	< 0.01
His	32.90^{f}	74.37^{b}	58.31^{d}	50.34^{e}	70.08^{bc}	68.25^{c}	83.73^{a}	3.28	< 0.01
Ile	25.78^{d}	64.64^{b}	43.72^{c}	47.30^{c}	61.02^{b}	58.25^{b}	82.33^{a}	3.70	< 0.01
Leu	26.33^{e}	66.15^{b}	45.85^{d}	46.43^{d}	60.64^{bc}	58.75^{c}	82.05^{a}	3.64	< 0.01
Lys	33.47^{f}	74.60^{b}	57.25^{d}	51.90^{e}	69.12^{c}	66.97^{c}	83.31^{a}	2.97	< 0.01
Met	34.02^{e}	72.30^{b}	57.50^{d}	52.27^{d}	68.67^{bc}	65.07^{c}	83.39^{a}	2.89	< 0.01
Phe	27.68^{d}	66.43^{b}	46.49^{c}	47.63^{c}	61.30^{b}	59.99^{b}	82.48^{a}	3.77	< 0.01
Thr	29.92^{e}	63.54^{b}	45.41^{d}	46.68^{d}	59.37^{bc}	57.04^{c}	74.56^{a}	3.23	< 0.01

Table 4.6. (Cont.)

Trp	37.96[d]	70.85[b]	53.61[c]	53.79[c]	66.81[b]	57.29[c]	82.97[a]	2.92	< 0.01
Val	26.18[d]	63.01[b]	42.99[c]	46.20[c]	58.89[b]	56.66[b]	79.90[a]	3.51	< 0.01
Mean	30.43[e]	69.44[b]	51.28[d]	49.25[d]	64.50[bc]	62.68[c]	82.73[a]	3.35	< 0.01
Dispensable AA, %									
Ala	29.39[d]	62.77[b]	45.32[c]	43.68[c]	46.63[b]	56.84[b]	74.03[a]	3.72	< 0.01
Asp	34.35[e]	70.07[b]	52.45[d]	50.52[d]	64.42[bc]	63.58[c]	79.22[a]	3.24	< 0.01
Cys	16.84[e]	57.70[b]	33.41[d]	38.48[d]	54.50[b]	46.38[c]	70.42[a]	3.73	< 0.01
Glu	42.54[e]	74.68[b]	60.97[c]	54.65[d]	71.51[b]	70.42[b]	80.96[a]	2.85	< 0.01
Gly	10.44[d]	49.83[ab]	27.18[c]	24.79[c]	43.24[b]	40.71[b]	59.51[a]	6.35	< 0.01
Ser	38.63[e]	70.86[b]	54.55[d]	52.21[d]	64.80[c]	64.89[c]	81.85[a]	2.92	< 0.01
Tyr	32.89[e]	67.03[b]	50.34[d]	51.02[d]	64.05[bc]	60.78[c]	82.40[a]	3.46	< 0.01
Mean	33.28[e]	38.84[b]	52.26[d]	49.39[d]	64.18[bc]	62.38[c]	77.77[a]	3.49	< 0.01
Total	31.90[e]	69.13[b]	51.79[d]	49.32[d]	64.33[bc]	62.53[c]	80.20[a]	3.73	< 0.01

[a-i]Means within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Data are the least square means of 8 observations per treatment.

Table 4.7. Standardized ileal digestibility (SID) of CP and AA in expeller soybean meal (ESBM) produced from unheated conventional soybeans (ESBM-CV), unheated ultra-low trypsin inhibitor soybeans (ESBM-ULT), unheated low trypsin inhibitor soybeans (ESBM-LT), heated conventional soybeans (ESBM-CV-H), heated ultra-low trypsin inhibitor soybeans (ESBM-ULT-H), heated low trypsin inhibitor soybeans (ESBM-LT-H), and toasted and defatted 47.5% SBM, Exp. 1[1]

Item	Ingredient							SEM	*P*-Value
	ESBM-CV	ESBM-ULT	ESBM-LT	ESBM-CV-H	ESBM-ULT-H	ESBM-LT-H	SBM		
CP, %	39.53^{e}	73.99^{b}	52.04^{d}	48.78^{d}	71.29^{b}	62.78^{c}	83.72^{a}	4.00	< 0.01
Indispensable AA, %									
Arg	41.37^{e}	81.84^{b}	67.33^{c}	57.66^{d}	76.89^{b}	76.75^{b}	93.42^{a}	3.60	< 0.01
His	36.82^{f}	78.00^{b}	62.05^{d}	53.87^{e}	74.16^{bc}	71.96^{c}	87.35^{a}	3.28	< 0.01
Ile	30.28^{d}	69.18^{b}	48.33^{c}	51.31^{c}	65.71^{b}	62.66^{b}	86.44^{a}	3.70	< 0.01
Leu	30.32^{e}	69.94^{b}	49.71^{d}	50.04^{d}	64.78^{bc}	62.58^{c}	85.73^{a}	3.64	< 0.01
Lys	37.39^{f}	78.42^{b}	61.13^{d}	55.55^{e}	73.37^{bc}	70.88^{c}	87.01^{a}	2.97	< 0.01
Met	38.24^{e}	76.39^{b}	61.54^{d}	55.97^{d}	73.15^{bc}	69.26^{c}	87.10^{a}	2.89	< 0.01
Phe	31.39^{d}	70.05^{b}	50.15^{c}	51.00^{c}	65.20^{b}	63.58^{b}	85.98^{a}	3.77	< 0.01
Thr	37.91^{e}	71.03^{b}	53.13^{d}	53.96^{d}	67.74^{bc}	64.70^{c}	81.98^{a}	3.23	< 0.01

Table 4.7. (Cont.)

Trp	42.79^{d}	74.94^{b}	58.42^{c}	57.77^{c}	71.48^{b}	62.27^{c}	87.32^{a}	2.92	< 0.01
Val	31.34^{d}	68.02^{b}	48.14^{c}	50.78^{c}	64.20^{b}	61.61^{b}	84.52^{a}	3.51	< 0.01
Mean	35.00^{e}	73.81^{b}	55.74^{d}	53.38^{d}	69.29^{bc}	67.09^{c}	86.96^{a}	3.35	< 0.01
Dispensable AA, %									
Ala	38.10^{d}	71.12^{b}	53.79^{c}	51.65^{c}	65.72^{b}	65.39^{b}	82.20^{a}	3.72	< 0.01
Asp	38.23^{e}	73.76^{b}	56.18^{d}	54.05^{d}	68.53^{bc}	67.29^{c}	82.82^{a}	3.24	< 0.01
Cys	24.46^{e}	65.73^{b}	41.02^{d}	45.41^{d}	63.35^{b}	54.60^{c}	77.37^{a}	3.73	< 0.01
Glu	45.87^{e}	77.83^{b}	64.13^{c}	57.71^{d}	74.97^{b}	73.59^{b}	84.13^{a}	2.85	< 0.01
Gly	29.55^{d}	68.38^{ab}	46.00^{c}	42.23^{c}	63.47^{b}	59.45^{b}	77.66^{a}	6.35	< 0.01
Ser	43.95^{e}	75.80^{b}	59.55^{d}	57.11^{d}	70.56^{c}	70.00^{c}	87.04^{a}	2.92	< 0.01
Tyr	37.41^{e}	71.67^{b}	54.77^{d}	55.20^{d}	68.88^{bc}	65.37^{c}	86.64^{a}	3.46	< 0.01
Mean	39.11^{e}	74.42^{b}	57.87^{d}	54.73^{d}	70.33^{bc}	68.03^{c}	83.29^{a}	3.49	< 0.01
Total	37.12^{e}	74.12^{b}	56.84^{d}	54.07^{d}	69.82^{bc}	67.57^{c}	85.09^{a}	3.41	< 0.01

[a-f]Means within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Data are the least square means of 8 observations per treatment.

Table 4.8. Daily energy balance and apparent total tract digestibility (ATTD) of energy of experimental diets containing corn, or corn and expeller soybean meal (ESBM) produced from unheated conventional soybeans (ESBM-CV), unheated ultra-low trypsin inhibitor soybeans (ESBM-ULT), unheated low trypsin inhibitor soybeans (ESBM-LT), heated conventional soybeans (ESBM-CV-H), heated ultra-low trypsin inhibitor soybeans (ESBM-ULT-H), heated low trypsin inhibitor soybeans (ESBM-LT-H), and toasted and defatted 47.5% SBM, as-fed basis, Exp. 2[1]

Item	Diet									
	Corn	ESBM-CV	ESBM-ULT	ESBM-LT	ESBM-CV-H	ESBM-ULT-H	ESBM-LT-H	SBM	SEM	*P*-Value
GE intake, kcal/d	5,350[c]	5,772[ab]	5,763[ab]	5,850[a]	5,893[a]	5,760[ab]	5,938[a]	5,575[bc]	167.54	< 0.01
GE in feces, kcal/d	696	768	674	681	734	694	750	681	34.65	0.39
GE in urine, kcal/d	97.92[c]	228[ab]	180[b]	266[a]	211[ab]	194[ab]	214[ab]	221[ab]	26.51	< 0.01
ATTD of GE, %	86.96	86.65	88.29	88.40	88.30	87.86	87.34	87.73	0.57	0.19
DE in diet, kcal/kg	3,261[d]	3,500[b]	3,556[ab]	3,611[a]	3,557[ab]	3,599[a]	3,594[a]	3,413[c]	22.98	< 0.01
ME in diet, kcal/kg	3,192[e]	3,339[cd]	3,429[ab]	3,424[ab]	3,380[bc]	3,463[a]	3,445[ab]	3,261[de]	30.55	< 0.01

[a-e]Means within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Data are the least square means of 6 observations per treatment.

Table 4.9. Concentration of energy in corn and expeller soybean meal (ESBM) produced from unheated conventional soybeans (ESBM-CV), unheated ultra-low trypsin inhibitor soybeans (ESBM-ULT), unheated low trypsin inhibitor soybeans (ESBM-LT), heated conventional soybeans (ESBM-CV-H), heated ultra-low trypsin inhibitor soybeans (ESBM-ULT-H), heated low trypsin inhibitor soybeans (ESBM-LT-H), and toasted and defatted 47.5% SBM, Exp. 2[1]

Item	Diet									
	Corn	ESBM-CV	ESBM-ULT	ESBM-LT	ESBM-CV-H	ESBM-ULT-H	ESBM-LT-H	SBM	SEM	*P*-Value
DE, kcal/kg	3,348[d]	4,179[b]	4,377[ab]	4,575[a]	4,384[ab]	4,532[a]	4,515[a]	3,869[c]	78.42	< 0.01
ME, kcal/kg	3,277[e]	3,778[cd]	4,101[ab]	4,084[ab]	3,926[bc]	4,220[a]	4,158[ab]	3,501[de]	106.17	< 0.01
DE, kcal/kg DM	3,867[e]	4,519[cd]	4,652[bc]	4,962[a]	4,495[cd]	4,826[ab]	4,674[bc]	4,427[d]	83.80	< 0.01
ME, kcal/kg DM	3,785[d]	4,086[bcd]	4,359[ab]	4,430[a]	4,025[cd]	4,494[a]	4,305[abc]	4,006[cd]	113.52	< 0.01

[a-e]Means within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Data are the least square means of 6 observations per treatment.

CHAPTER 5

AMINO ACID DIGESTIBILITY IN 4 SOURCES OF FERMENTED SOYBEAN MEAL AND IN CONVENTIONAL SOYBEAN MEAL AND FISH MEAL FED TO WEANLING PIGS

ABSTRACT

An experiment was conducted to determine the apparent and standardized ileal digestibility (AID and SID, respectively) of AA in 4 sources of fermented soybean meal (FSBM) and to compare these values with the AID and SID of AA in conventional soybean meal (SBM) and fish meal. The 4 sources of FSBM included FSBM-A, FSBM-B, FSBM-C, and FSBM-D. The conventional SBM was obtained from the same batch of SBM that was used to produce FSBM-A. The AA digestibility in each of the 6 protein containing ingredients was determined using 14 weanling barrows (initial BW: 10.8 kg ± 3.4 kg) that were equipped with a T-cannula in the distal ileum. Seven diets were formulated. Six diets contained each source of FSBM, SBM, or fish meal as the sole source of AA and an N-free diet was used to determine basal endogenous losses of AA. Pigs were allotted to a replicated 7 × 5 Youden square design with 7 diets and 5 periods. Results indicated that the SID of CP was greater ($P < 0.01$) in FSBM-C than in FSBM-A, FSBM-B, SBM, and fish meal, but not different from the SID of CP in FSBM-D. The SID of CP was greater ($P < 0.01$) in FSBM-D than in FSBM-A, SBM, and fish meal, but not different from the SID of CP in FSBM-B. The SID of CP was not different among FSBM-A, FSBM-B, SBM, and fish meal. The SID of Lys was greater ($P < 0.01$) in FSBM-C, FSBM-D, and fish meal than in FSBM-A and FSBM-B, but not different from SBM, but greater ($P < 0.01$) in SBM than in FSBM-A. The SID of Lys was also greater ($P < 0.01$) in FSBM-B than in FSBM-A. The SID of

most other indispensable AA was greater ($P < 0.05$) in FSBM-C than in FSBM-A, FSBM-B, SBM, and fish meal and the SID of most AA in FSBM-D was greater than in SBM. However, for most indispensable AA other than Lys, no differences among FSBM-A, FSBM-B, and fish meal were observed. The SID of the mean of indispensable AA, the mean of the dispensable AA and for all AA also followed this trend. The Lys:CP ratio was less in FSBM-A and FSBM-B than in FSBM-C, FSBM-D, and conventional SBM, which indicates that FSBM-A and FSBM-B were heat damaged during production. It is, therefore, likely that the reason for the relatively low SID of most AA in FSBM-A and FSBM-B is that the heat used during production of these ingredients resulted in Maillard reactions and subsequent destruction of Lys and reduction in AA digestibility.

Key words: amino acids, fermented soybean meal, fish meal, pigs, soybean meal

INTRODUCTION

Conventional soybean meal (**SBM**) is not well tolerated by young pigs due to the transient hypersensitivity and allergic reactions caused by the antigens in SBM (Li et al., 1990). Soybean meal also contains oligosaccharides that can cause decreased digestibility of energy and reduced growth rate, and may negatively affect fecal consistency in weanling pigs (Liying et at., 2003). To avoid the allergic reactions caused by SBM in young pigs, animal proteins such as fish meal are used in starter diets instead of SBM. However, fermentation of conventional SBM can reduce the concentration of oligosaccharides and possibly the concentration of antigens (Hong et al., 2004; Cervantes-Pahm and Stein, 2010).

There are several procedures for producing fermented soybean meal (**FSBM**). These include enzymatic fermentation and bacterial and/or fungal fermentation, which are used to

reduce the concentrations of trypsin inhibitors, oligosaccharides, and other anti-nutritional components in conventional SBM. One source of FSBM is produced using a proprietary enzymatic procedure that involves treatment of conventional de-hulled SBM with a mixture of enzymes and yeast (Goebel and Stein, 2011b). Other fermented SBM products are produced by bacterial and/or fungal fermentation of conventional SBM, but different bacteria or mixtures of bacteria are used in the production of these ingredients. *Aspergillus oryzae, Bacillus subtilis, and Lactobacilus acidophilus* are examples of bacteria that may be used in the production of FSBM.

Previous research with FSBM has mainly used FSBM-C or FSBM-D. Values for the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of CP and AA in FSBM-C and FSBM-D have been reported (Cervantes-Pahm and Stein, 2010). However, there are no data for FSBM-B and FSBM-A and there are no comparative data for the AID and SID of AA in different sources of FSBM. Therefore, an experiment was conducted to measure the AID and SID of CP and AA by weanling pigs in 4 sources of FSBM and to compare these values to the digestibility of CP and AA in conventional SBM and in fish meal.

MATERIALS AND METHODS

General

The experimental protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Four sources of FSBM, 1 source of conventional SBM, and 1 source of fish meal were used in the experiment (Table 5.1). The 4 sources of FSBM included FSBM-A, FSBM-B, FSBM-C, and FSBM-D. Conventional SBM and FSBM-A were sourced from the same batch of SBM. Fish meal (Menhaden Select) was sourced from Omega Protein, Houston, TX. Pigs used in the experiment

were sired by G Performer boars (Duroc × Pietrain) that were mated to Fertilis 25 (¾ Landrace, ¼ Large White) females (Genetiporc Inc., Alexandria, MN).

Animals, Housing, and Experimental Design

Fourteen weanling barrows were used in the experiment. Pigs (initial BW: 10.8 kg ± 3.4 kg) had been surgically equipped with a T-cannula in the distal ileum using a procedure adapted from Stein et al. (1998). Pigs were housed in individual pens with tri-bar stainless steel floors (1.2 × 1.5 m) in an environmentally controlled room. Pigs were allowed to recover for a 7 d period following surgery and were then randomly allotted to a replicated 7 × 5 Youden square design with 7 diets and 5 periods. A feeder and a nipple drinker were installed in each pen.

Diets and Feeding

Seven diets were formulated (Tables 5.2 and 5.3). Six of the diets contained 1 source of FSBM, conventional SBM, or fish meal and starch, sugar, and oil. The last diet was a N-free diet that was used to calculate basal endogenous losses of AA and CP. Solka floc (4.0%), magnesium oxide (0.1%), and potassium carbonate (0.4%) were added to the N-free diet to increase the concentration of crude fiber, and to prevent deficiency of Mg and K in the diet, respectively. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998). All diets also contained 0.4% chromic oxide as an indigestible marker. All pigs were fed once daily at 0700 h at a level of 3 times the estimated maintenance energy requirement (i.e., 106 kcal of ME per kg 0.75; NRC, 1998). Water was available at all times throughout the experiment.

Data Recording and Sample Collection

Pig BW were recorded at the beginning and at the end of each period and the amount of feed supplied each day was recorded. Each experimental period lasted 7 d. The initial 5 d of each

period were considered an adaptation period to the diet. On d 6 and 7, ileal digesta were collected for 8 consecutive h. A 225-mL plastic bag was attached to the cannula barrel with a cable tie and digesta flowing into the bag were collected as described by Stein et al. (1999). Bags were removed whenever they were filled with digesta, or at least once every 30 min and immediately frozen at -20 ℃ to prevent bacterial degradation of the AA in the digesta. On the completion of 1 experimental period, animals were deprived of feed overnight and the following morning, a new experimental diet was offered.

Chemical Analysis

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a sub-sample was collected for chemical analyses. A sample of each diet and of each source of FSBM, SBM, and fish meal was collected as well. Ileal samples were lyophilized and finely ground prior to chemical analysis. All samples were analyzed in duplicate. Diets, ingredients, and ileal samples were analyzed for DM, CP, and AA. Diets and ileal samples were analyzed for chromium as well. Samples were analyzed for DM in a drying oven at 135 ℃ for 2 h (Method 930.15; AOAC Int., 2007). Crude protein was analyzed by the combustion method (Method 990.03; AOAC Int., 2007) using a Rapid N cube apapratus (Elementar Americas Inc., Mt. Laurel, NJ). Amino acids were analyzed on an amino acid analyzer using ninhydrin for postcolum derivatization and norleucine as the internal standard. Prior to analysis, samples were hydrolyzed with 6 *N* HCl for 24 h at 110 ℃ [Method 982.30 E (a, b, c); AOAC Int., 2007]. Chromium was analyzed using an inductive coupled plasma atomic emission spectrometric method (Method 990.08; AOAC Int., 2007). Ingredient samples were also analyzed for trypsin inhibitors (method Ba 12-75; AOCS, 2006), ADF (Method 973.18; AOAC Int., 2007), NDF (Holst, 1973), P and Ca (Method 975.03; AOAC Int., 2007), and for sucrose, stachyose, and

raffinose (Janauer and Englmaier, 1978). Ingredient samples were also analyzed for acid-hydrolyzed ether extract by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (method 2003.06; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN).

Calculations and Statistical Analysis

Apparent ileal digestibility values for CP and AA in samples obtained from feeding the 6 diets containing FSBM, SBM, or fish meal were calculated. Because the FSBM, SBM, and fish meal were the only feed ingredients contributing CP and AA to each diet, these digestibility values also represent the digestibility values for each source of FSBM, SBM, and fish meal. AID values of AA were calculated using equation [1] (Stein et al., 2007):

$$\text{AID}_{\text{AA}}, \% = 100 - [(\frac{\text{AA}_{\text{digesta}}}{\text{AA}_{\text{feed}}}) \times (\frac{\text{Cr}_{\text{feed}}}{\text{Cr}_{\text{digesta}}})] \times 100 \quad [1]$$

where AID_{AA} is the apparent ileal digestibility of an AA (%), $\text{AA}_{\text{digesta}}$ is the concentration of that AA in the ileal digesta DM, AA_{feed} is the AA concentration of that AA in the feed DM, Cr_{feed} is the chromium concentration in the feed DM, and $\text{Cr}_{\text{digesta}}$ is the chromium concentration in the ileal digesta DM. The AID for CP will also be 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):

$$\text{IAA}_{\text{end}} = [\text{AA}_{\text{digesta}} \times (\frac{\text{Cr}_{\text{feed}}}{\text{Cr}_{\text{digesta}}})] \quad [2]$$

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

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

$$SID_{AA} = [\frac{AID + IAA_{end}}{AA_{feed}}] \quad [3]$$

where SID_{AA} is the SID value (%) of each AA. The SID for AA was also calculated using the same equation.

The Proc UNIVARIATE procedure of SAS was used to identify outliers (SAS Institute Inc., Cary, NC). Data were analyzed using the Proc MIXED procedure of SAS. An analysis of variance was conducted with diet as fixed effects and pig and period as random effects. When significant differences were detected, treatment means were separated using the Least Significant Difference test in Proc MIXED. The pig was the experimental unit for all analyses and an alpha value of 0.05 was used to assess significance among treatments.

RESULTS

The AID of CP was greater ($P < 0.05$) in FSBM-C than in FSBM-A, FSBM-B, SBM, and fish meal, but not different from the AID in FSBM-D (Table 5.4). The AID of CP was greater ($P < 0.05$) in FSBM-D than in SBM and fish meal, but not different from FSBM-A and FSBM-B. There was no difference in the AID of CP among FSBM-A, FSBM-B, SBM, and fish meal. The AID of Lys was greater ($P < 0.05$) in FSBM-D than in FSBM-A, FSBM-B, and SBM, but not different from FSBM-C and fish meal and the AID of Lys was greater ($P < 0.05$) in FSBM-C and fish meal than in FSBM-A and FSBM-B, but not different from SBM. The AID of Lys was also greater ($P < 0.05$) in SBM than in FSBM-A, but not different from FSBM-B and the AID of Lys was greater ($P < 0.05$) in FSBM-B than in FSBM-A. The AID of the mean of indispensable AA was greater ($P < 0.05$) in FSBM-C than in FSBM-A, FSBM-B, SBM, and fish meal, but not different from FSBM-D. The AID of the mean of indispensable AA was also greater ($P < 0.05$) in FSBM-D than in FSBM-A, SBM, and fish meal, but not different from FSBM-B, but the AID

was greater ($P < 0.05$) in FSBM-B than in SBM and not different from FSBM-A and fish meal. The AID of the mean of the indispensable AA was also greater ($P < 0.05$) in FSBM-A than in SBM, but not different from fish meal and no difference between fish meal and SBM was observed. The AID of the mean of dispensable AA was greater ($P < 0.05$) in FSBM-C than in FSBM-A, FSBM-B, SBM, and fish meal, but not different from FSBM-D. The AID of the mean of dispensable AA was also greater ($P < 0.05$) in FSBM-D than in SBM and fish meal, but not different from FSBM-A and FSBM-B. The AID of the mean of dispensable AA was greater ($P < 0.05$) in FSBM-A than in fish meal, but not different from FSBM-B and SBM and no difference among FSBM-B, SBM, and fish meal was observed.

The AID of all AA was greater ($P < 0.05$) in FSBM-C than in FSBM-A, FSBM-B, SBM, and fish meal, but not different from FSBM-D and the AID was greater ($P < 0.05$) in FSBM-D than in FSBM-B, SBM, and fish meal, but not different from FSBM-A. The AID of all AA was also greater ($P < 0.05$) in FSBM-A than in fish meal, but not different from FSBM-B and SBM, but no difference among FSBM-B, SBM, and fish meal was observed.

The SID of CP was greater ($P < 0.05$) in FSBM-C than in FSBM-A, FSBM-B, SBM, and fish meal, but not different from FSBM-D, and the SID of CP was greater ($P < 0.05$) in FSBM-D than in FSBM-A, SBM, and fish meal, but not different from FSBM-B (Table 5.5). The SID of CP was not different among FSBM-A, FSBM-B, SBM, and fish meal. The SID of Lys was greater ($P < 0.05$) in FSBM-C, FSBM-D, and fish meal than in FSBM-A and FSBM-B, but not different from SBM, but greater ($P < 0.01$) in SBM than in FSBM-A. The SID of Lys was also greater ($P < 0.05$) in FSBM-B than in FSBM-A. The SID of most other indispensable AA was greater ($P < 0.05$) in FSBM-C than in FSBM-A, FSBM-B, SBM, and fish meal and the SID of most AA in FSBM-D was greater than in SBM. However, for most indispensable AA other than

Lys, no differences among FSBM-A, FSBM-B, and fish meal were observed. The SID of the mean of indispensable AA, the mean of the dispensable AA and for all AA also followed this trend.

DISCUSSION

All ingredients had DM concentration greater than 90%, except conventional SBM at 87%, which is in accordance with previous experiments (Hong et al., 2004; Cervantes-Pahm and Stein, 2010; Kim et al., 2010). The concentration of CP in the 4 sources of FSBM varied among sources with FSBM-A, FSBM-B, FSBM-C, and FSBM-D containing 57.52, 53.16, 58.08, and 56.83%, respectively. Most of the FSBM used in this experiment contained slightly more CP than the sources used in previous experiments (Hong et al., 2004; Cervantes-Pahm and Stein, 2010; Kim et al., 2010). Conventional SBM contained 49.95% CP and fish meal contained 61.69% CP. The fat concentration among the 4 sources of FSBM ranged between 0.7 and 2.0%, whereas conventional SBM contained 2.13% fat and fish meal contained 8.01% fat. The ash concentration among different sources of FSBM was fairly similar at 6 to 7%, whereas fish meal contained 23.10% ash. The concentrations of sucrose, oligosaccharide, and trypsin inhibitors were less in each of the 4 sources of FSBM than in conventional SBM. This observation is in accordance with previous research that indicated that the fermentation process, whether enzymatic or bacterial, reduces the antinutritional factors in conventional SBM (Hong et al., 2004; Cervantes-Pahm and Stein, 2010).

The SID of AA in the conventional SBM that was used in this experiment was less than what has been observed in previous experiments using weanling pigs (Baker et al., 2010; Cervantes-Pahm and Stein, 2010). The main reason for this observation is most likely that this

particular source of SBM was not correctly heat treated following solvent extraction, which is indicated by the high concentration of Trypsin inhibitors. A concentration of trypsin inhibitors greater than 4 per mg is believed to reduce AA digestibility (Goebel and Stein, 2011a) and the concentration of trypsin inhibitors in the sample used in this experiment was almost twice this level. It is, therefore, not surprising that the SID of most AA in the SBM was less than what has been previously reported.

The fish meal that was used in the experiment contained more ash and less CP and AA than most other sources of fish meal (NRC, 2012). Fish meal is produced from defatted and dehydrated fish and offal from the fish industry including fish bones from the fish filet industry. The high ash content in the fish meal used in this experiment indicates that the concentration of fish bones was greater compared with products used in previous experiments, which also explains the reduced concentration of CP and AA. The SID of most AA in the fish meal used in this experiment was, however, in good agreement with data from previous experiments (NRC, 2012).

The SID of AA in FSBM-C was in agreement with data from a previous experiment (Cervantes-Pahm and Stein, 2010), and the SID of AA in FSBM-D is close to values reported by Rojas and Stein (2011). The reason for the increased SID of indispensable AA in FSBM-C and FSBM-D compared with the other feed ingredients is most likely that the process used to produce these 2 ingredients does not destroy any AA via overheating.

The SID of Lys was more variable among the different sources of FSBM than the SID of other AA. The reason for this observation is most likely that FSBM-A and FSBM-B were heat damaged during production. It is generally believed that a Lys:CP ratio above 6.0% is indicative of non-heat damaged SBM, whereas a ratio less than 6.0% indicates that the sample was heat

damaged and that the Maillard reaction destroyed some of the Lys (Gonzalez-Vega et al., 2011). The low Lys:CP ratio in FSBM-A and FSBM-B indicates that overheating damaged some of the Lys during production of these meals. This is specifically true for FSBM-A. In contrast, the Lys:CP ratio in FSBM-C and FSBM-D were greater than 6.0%, which indicates that these meals were not heat damaged. Maillard reactions will primarily destroy Lys and reduce the SID of Lys, but the SID of other AA will also be negatively affected by the Maillard reaction (Gonzalez-Vega et al., 2011). This is most likely the reason why the SID of most AA in FSBM-A and FSBM-B were less than in FSBM-C and FSBM-D. The SID of Lys was more negatively affected than the SID of other AA, which further indicates that FSBM-A and FSBM-B were heat damaged.

Conclusions

Results of this experiment confirm that fermentation reduces the concentration of sucrose, oligosaccharides, and trypsin inhibitors in SBM. Results also confirm that AA in FSBM-C and FSBM-D are well digested by young pigs. However, it appears that the particular batches of FSBM-A and FSBM-B that were used in this experiment were overheated during fermentation or drying, which resulted in reduced digestibilities of AA in these meals. The SID of AA in the conventional SBM that was used in this experiment was less than what has been reported from previous experiments, which is likely a result of a relatively high concentration of trypsin inhibitors in the source of SBM that was used.

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TABLES

Table 5.1. Chemical composition of FSBM-A, FSBM-B, FSBM-C, FSBM-D, soybean meal (SBM), and fish meal, as-fed basis

Item	Ingredient					
	FSBM-A	FSBM-B	FSBM-C	FSBM-D	SBM	Fish meal
DM, %	90.92	92.25	92.79	91.51	87.75	91.64
CP, %	57.52	53.16	58.08	56.83	49.95	61.69
AEE[1], %	1.17	0.71	1.68	1.86	2.13	8.01
Ca, %	0.36	0.30	0.30	0.33	0.28	7.41
P, %	0.71	0.67	0.76	0.74	0.64	3.98
Ash, %	7.38	6.27	6.29	6.56	5.73	23.10
ADF, %	4.12	4.95	4.42	5.50	4.24	-
NDF, %	18.87	10.27	19.67	7.83	8.65	-
Sucrose, %	0.00	1.46	0.00	0.00	4.19	0.00
Raffinose, %	0.00	0.40	0.00	0.00	0.70	0.00
Stachyose, %	0.00	1.15	0.00	0.00	1.89	0.00
TIU[2]/mg	ND[3]	ND[3]	1.01	1.60	7.80	ND[3]
Indispensable AA, %						
Arg	3.81	3.66	4.13	3.85	3.67	3.48
His	1.44	1.34	1.45	1.38	1.29	1.24
Ile	2.72	2.46	2.76	2.63	2.34	2.47
Leu	4.48	4.11	4.53	4.42	3.90	4.13
Lys	3.28	3.16	3.66	3.46	3.17	4.28

Table 5.1. (Cont.)

Met	0.81	0.73	0.74	0.79	0.69	1.70
Phe	2.93	2.73	3.05	2.95	2.57	2.32
Thr	2.16	2.00	2.16	2.15	1.92	2.29
Trp	0.80	0.64	0.85	0.79	0.60	0.53
Val	2.89	2.45	2.93	2.80	2.53	2.84
Dispensable AA, %						
Ala	2.52	2.36	2.55	2.49	2.21	3.88
Asp	6.42	5.98	6.55	6.34	5.71	5.15
Cys	0.79	0.72	0.71	0.80	0.68	0.47
Glu	10.32	9.27	10.22	9.63	9.23	7.41
Gly	2.41	2.24	2.41	2.43	2.12	4.71
Ser	2.51	2.22	2.44	2.59	2.31	1.94
Tyr	1.98	1.84	2.04	1.97	1.77	1.78
Calculated values						
Lys:CP, %	5.70	5.94	6.30	6.08	6.34	6.93

[1]AEE = acid-hydrolyzed ether extract.
[2]TIU = trypsin inhibitor units.
[3]ND = not detected.

Table 5.2. Ingredient composition of experimental diets containing FSBM-A, FSBM-B, FSBM-C, FSBM-D, soybean meal (SBM), or fish meal, as-fed basis

Ingredient, %	Diet						
	FSBM-A	FSBM-B	FSBM-C	FSBM-D	SBM	Fish meal	N-free
FSBM-A	35.00	-	-	-	-	-	-
FSBM-B	-	38.00	-	-	-	-	-
FSBM-C	-	-	35.00	-	-	-	-
FSBM-D	-	-	-	35.00	-	-	-
SBM	-	-	-	-	40.00	-	-
Fish meal	-	-	-	-	-	32.00	-
Cornstarch	38.30	35.30	38.30	38.30	33.30	46.90	67.50
Soybean oil	3.00	3.00	3.00	3.00	3.00	-	4.00
Sugar	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Solka floc[1]	-	-	-	-	-	-	4.00
Ground limestone	1.30	1.30	1.30	1.30	1.30	-	0.50
Monocalcium phosphate	1.30	1.30	1.30	1.30	1.30	-	2.40

Table 5.2. (Cont.)

Magnesium oxide	-	-	-	-	-	-	0.10
Potassium carbonate	-	-	-	-	-	-	0.40
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	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

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

[2]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 5.3. Chemical composition of experimental diets containing FSBM-A, FSBM-B, FSBM-C, FSBM-D, soybean meal (SBM), or fish meal, as-fed basis

Item	Diet						
	FSBM-A	FSBM-B	FSBM-C	FSBM-D	SBM	Fish meal	N-free
DM, %	93.29	93.70	93.64	93.32	92.70	93.54	93.11
CP, %	20.21	20.10	20.20	20.34	16.99	19.86	0.38
Indispensable AA, %							
Arg	1.29	1.44	1.31	1.32	1.06	1.09	0.01
His	0.49	0.53	0.46	0.48	0.37	0.39	0.00
Ile	0.89	0.95	0.83	0.89	0.67	0.78	0.01
Leu	1.54	1.64	1.41	1.56	1.15	1.32	0.03
Lys	1.12	1.25	1.18	1.22	0.94	1.45	0.02
Met	0.26	0.27	0.23	0.27	0.20	0.53	0.00
Phe	1.00	1.07	0.98	1.00	0.77	0.75	0.02
Thr	0.76	0.81	0.71	0.76	0.57	0.73	0.01
Trp	0.25	0.25	0.26	0.26	0.19	0.18	0.04

Table 5.3. (Cont.)

Val	0.96	1.03	0.91	0.97	0.67	0.87	0.00
Dispensable AA, %							
Ala	0.87	0.96	0.83	0.89	0.65	1.25	0.03
Asp	2.22	2.40	2.12	2.24	1.69	1.09	0.01
Cys	0.29	0.29	0.24	0.27	0.21	0.15	0.01
Glu	3.61	3.78	3.38	3.45	2.68	2.40	0.05
Gly	0.83	0.90	0.79	0.86	0.63	1.51	0.02
Ser	0.93	0.93	0.87	0.90	0.66	0.60	0.01
Tyr	0.63	0.68	0.60	0.63	0.48	0.49	0.01

Table 5.4. Apparent ileal digestibility (AID) of CP and AA in FSBM-A, FSBM-B, FSBM-C, FSBM-D, soybean meal (SBM), and fish meal

Item	Ingredient						SEM	*P*-value
	FSBM-A	FSBM-B	FSBM-C	FSBM-D	SBM	Fish meal		
CP, %	71.49^{bc}	72.11^{bc}	78.01^{a}	76.14^{ab}	68.68^{c}	67.63^{c}	2.67	< 0.01
Indispensable AA, %								
Arg	87.99^{ab}	86.77^{bc}	90.77^{a}	90.62^{a}	83.27^{d}	83.93^{cd}	1.37	< 0.01
His	81.77^{cd}	82.17^{bc}	87.94^{a}	85.42^{ab}	79.60^{cd}	78.18^{d}	1.43	< 0.01
Ile	83.41^{c}	83.43^{bc}	88.35^{a}	86.50^{ab}	79.02^{d}	81.36^{cd}	1.09	< 0.01
Leu	84.34^{b}	83.59^{bc}	88.42^{a}	86.06^{ab}	78.84^{d}	81.13^{cd}	1.17	< 0.01
Lys	73.89^{d}	78.32^{c}	83.78^{ab}	84.27^{a}	80.26^{bc}	83.02^{ab}	1.41	< 0.01
Met	86.66^{bc}	86.52^{c}	90.53^{a}	89.92^{ab}	82.54^{d}	82.08^{d}	1.24	< 0.01
Phe	84.93^{b}	83.81^{b}	89.70^{a}	86.94^{ab}	79.07^{c}	77.48^{c}	1.34	< 0.01
Thr	75.25^{b}	75.05^{b}	79.38^{a}	79.26^{ab}	69.50^{c}	75.16^{b}	1.56	< 0.01
Trp	83.03^{c}	82.27^{c}	87.87^{ab}	88.55^{a}	76.94^{d}	84.03^{bc}	1.50	< 0.01
Val	82.38^{b}	82.04^{b}	86.44^{a}	84.86^{ab}	75.14^{c}	78.25^{c}	1.29	< 0.01

Table 5.4. (Cont.)

Mean	82.32^{c}	82.36^{bc}	87.17^{a}	86.08^{ab}	78.80^{d}	80.01^{cd}	1.31	< 0.01
Dispensable AA, %								
Ala	74.56^{bc}	75.19^{bc}	80.45^{a}	78.44^{ab}	70.26^{c}	71.99^{c}	2.29	< 0.01
Asp	79.56^{b}	78.44^{bc}	83.57^{a}	85.03^{a}	75.98^{c}	71.37^{d}	1.46	< 0.01
Cys	64.93^{bc}	68.79^{ab}	73.47^{a}	73.92^{a}	68.88^{ab}	60.62^{c}	2.38	< 0.01
Glu	80.42^{b}	77.70^{b}	86.65^{a}	82.49^{ab}	79.06^{b}	77.58^{b}	2.05	< 0.01
Gly	59.51^{a}	56.78^{a}	64.42^{a}	64.43^{a}	45.57^{b}	68.08^{a}	4.78	< 0.01
Ser	84.16^{a}	83.78^{a}	85.54^{a}	84.52^{a}	78.40^{b}	70.65^{c}	1.91	< 0.01
Tyr	87.55^{a}	85.94^{a}	89.16^{a}	88.16^{a}	80.15^{b}	76.98^{b}	1.25	< 0.01
Mean	78.00^{bc}	76.58^{bcd}	83.18^{a}	80.42^{ab}	73.87^{cd}	71.50^{d}	2.18	< 0.01
Total AA, %	80.15^{bc}	79.30^{cd}	85.06^{a}	84.16^{ab}	76.41^{cd}	75.65^{d}	1.67	< 0.01

[a-d]Means within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Data are the least square means of 10 observations per treatment.

Table 5.5. Standardized ileal digestibility (SID) of CP and AA in FSBM-A, FSBM-B, FSBM-C, FSBM-D, soybean meal (SBM), and fish meal[1, 2]

Item	Ingredient						SEM	*P*-value
	FSBM-A	FSBM-B	FSBM-C	FSBM-D	SBM	Fish meal		
CP, %	81.77^{c}	84.38^{bc}	90.20^{a}	88.21^{ab}	80.83^{c}	80.02^{c}	2.67	< 0.01
Indispensable AA, %								
Arg	93.50^{ab}	91.72^{bc}	96.21^{a}	96.01^{a}	89.93^{c}	90.46^{bc}	1.37	< 0.01
His	86.34^{b}	86.72^{b}	93.17^{a}	90.41^{a}	85.61^{b}	84.35^{b}	1.43	< 0.01
Ile	88.00^{b}	87.89^{bc}	93.45^{a}	91.25^{a}	85.07^{c}	86.79^{bc}	1.09	< 0.01
Leu	88.78^{bc}	87.95^{bc}	93.50^{a}	90.63^{ab}	84.76^{d}	86.55^{cd}	1.17	< 0.01
Lys	78.80^{c}	82.89^{b}	88.63^{a}	88.95^{a}	86.08^{ab}	86.96^{a}	1.41	< 0.01
Met	91.44^{bc}	90.39^{c}	95.07^{a}	93.77^{ab}	88.72^{c}	84.05^{d}	1.24	< 0.01
Phe	89.26^{b}	88.02^{bc}	94.29^{a}	91.42^{ab}	84.67^{cd}	83.47^{d}	1.34	< 0.01
Thr	83.77^{c}	83.58^{c}	89.10^{a}	88.32^{ab}	80.79^{c}	84.60^{bc}	1.56	< 0.01
Trp	88.44^{b}	87.83^{bc}	93.22^{a}	93.87^{a}	84.02^{c}	91.74^{ab}	1.50	< 0.01
Val	87.86^{bc}	87.37^{bc}	92.47^{a}	90.50^{ab}	82.95^{d}	84.56^{cd}	1.29	< 0.01

Table 5.5. (Cont.)

Mean	87.51[b]	87.63[b]	93.05[a]	91.64[a]	85.50[b]	86.02[b]	1.31	< 0.01
Dispensable AA, %								
Ala	84.27[b]	84.03[b]	90.67[a]	87.94[ab]	83.18[bc]	78.77[c]	2.29	< 0.01
Asp	83.80[b]	82.15[b]	87.76[a]	88.98[a]	81.51[b]	76.71[c]	1.46	< 0.01
Cys	73.43[c]	77.52[bc]	84.01[a]	83.26[ab]	80.54[ab]	77.46[bc]	2.38	< 0.01
Glu	83.83[b]	81.12[b]	90.47[a]	86.23[ab]	83.64[b]	82.96[b]	2.05	0.01
Gly	79.79	75.57	85.81	84.01	72.12	79.26	4.78	0.09
Ser	89.67[ab]	89.77[ab]	91.94[a]	90.68[a]	86.13[b]	79.92[c]	1.91	< 0.01
Tyr	92.06[ab]	90.37[b]	94.18[a]	92.93[ab]	86.03[c]	83.12[d]	1.25	< 0.01
Mean	84.12[bc]	83.16[bc]	90.58[a]	87.48[ab]	82.03[c]	79.61[c]	2.18	< 0.01
Total AA, %	85.83[b]	85.25[b]	91.73[a]	90.49[a]	83.86[b]	82.70[b]	1.67	< 0.01

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

[1]Data are the least square means of 10 observations per treatment.

[2] Values for SID were calculated by correcting the values for apparent ileal digestibility for the basal ileal endogenous losses. Basal ileal endogenous losses were determined from pigs fed the N-free diet as (g/kg of DMI) as CP, 22.26; Arg, 0.76; His, 0.24; Ile, 0.44; Leu, 0.73; Lys, 0.59; Met, 0.13; Phe, 0.46; Thr, 0.69; Trp, 0.15; Val, 0.56; Ala, 0.91; Asp, 1.01; Cys, 0.26; Glu, 1.32; Gly, 1.80; Ser, 0.55; Tyr, 0.30.

CHAPTER 6

CONCLUSION

The standardized ileal digestibility (SID) of most AA in de-hulled low-oligosaccharide full fat soybeans (FFSB-LO), but not in de-hulled high-protein full fat soybeans (FFSB-HP), is similar to values in de-hulled conventional full fat soybeans (FFSB-CV), which was most likely due to heat damage. In addition, no significant differences in DE and ME among the 3 sources of FFSB were observed, which is most likely due to the negation of greater concentration of CP in FFSB-HP and FFSB-LO by greater concentration of fat in FFSB-CV.

It is not possible to use the low-trypsin inhibitor soybeans without heat treatment, even with only 7 to 12 units of trypsin inhibitors. It is also concluded that the only negative effects of trypsin inhibitors is the reduction in AA digestibility because energy digestibility does not seem to be affected by the presence of trypsin inhibitors in the meals.

Fermentation reduces the concentration of sucrose, oligosaccharides, and trypsin inhibitors in SBM. Amino acids in only 2 sources of fermented soybean meal (FSBM) used in the experiment are well digested by young pigs. It appears that the particular batches of other 2 sources of FSBM that were used were overheated during fermentation or drying, which resulted in reduced digestibilities of AA in these meals.

Therefore, it is concluded that genetic selection in plant breeding could affect the nutritional quality of soybeans and soybean meal. However, it is also concluded that processing of soybeans and soybean meal may be more of an importance for the quality of finished product when fed to pigs.