NUTRITIONAL VALUE OF HIGH-PROTEIN AND LOW OLIGOSACCHARIDE VARIETIES OF SOYBEANS FED TO PIGS AND POULTRY

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B.S., University of Illinois at Urbana-Champaign, 2007

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Animal Sciences
with a concentration in Animal Nutrition
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2009

Urbana, Illinois

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DEDICATION

I dedicate this to my Father and Brother, who have supported me throughout my entire education, with that I am truly grateful.

ACKNOWLEDGEMENTS

This thesis is the combination of over 2 years of work that incorporated helpful people from the University of Illinois. The person whom has been the most inspirational and deserves the most appreciation is my advisor, Dr. Hans Stein. He has been inspirational and motivational by pushing me to be the best that I can be. Your guidance has made me such a better person, and I more than thankful to that. You will always hold a special place in wonderful memories on my journey in life.

The University of Illinois was first home to me for 2 years in undergrad and then stayed my home for my masters. There have been many people along this journey that have been so helpful to me. I have made some wonderful friends along this path. I want to acknowledge the Stein lab as a whole, which as grown into a much larger group than when I first began, but everyone is wonderful. I am especially thankful for all the help from Dr. Beob Kim and Kate Horsman, whom have both gone above and beyond to guide me.

To Corbin, my husband, you really have supported me through all the good and bad. Together we can endure the most trying of obstructions and jump the highest of hurdles. With you, life is no obstacle, just a series of mornings filled with smiles and evenings overflowing with delight. I truly could not have done this without your love and support.

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CHAPTER 1: INTRODUCTION

The soybean is a species of legume that is classified as an oilseed. Soybeans contain significant amounts of indispensable AA for human and animal consumption. Soybeans are an important source of vegetable protein and vegetable oil that is used worldwide. The major producers in the world of soybean products are the United States, Brazil, Argentina, China, and India. Soybeans produce a high yield per acre of land, but is limited to be grown under agronomic conditions that include high quality soil, warm weather, and sufficient rainfall.

Raw soybeans contain antinutritional factors including trypsin inhibitors and oligosaccharides that can effect digestion and absorption of nutrients, but there are methods available to inactive the antinutritional factors and improve the digestibility of AA. Heating of soybeans is one method necessary to inactive antinutritional factors, but it must be done properly to be beneficial.

Soybeans can be fed to animals as either full-fat soybeans (**FFSB**) or can undergo different processes of oil removal, such as extrusion-expelling or solvent extraction and made into soybean meal (**SBM**). Full fat soybeans contain approximately 37% crude protein (CP) and 18% fat, whereas extruded-expelled SBM contain approximately 42% CP, and 5% oil, and solvent extracted SBM contain approximately 48% CP and 1% fat. Due to the differences in protein and fat, animals can be fed diets formulated to meet their requirements using FFSB or SBM.

There are currently new varieties of high-protein soybeans that contain 6 to 10% more CP than conventional soybeans, and low oligosaccharide varieties that contain 70 to 90% less oligosaccharide concentrations than conventional soybeans. These varieties have been processed into both FFSB and SBM. Improving the quality of soybean product should improve digestibility for both pigs and poultry.

CHAPTER 2. SOYBEANS IN SWINE AND POULTY NUTRITION: LITERATURE REVIEW

INTRODUCTION

Soybean meal (**SBM**) is the premier protein source used in feed for poultry and livestock throughout the world (Stein et. al., 2008). Therefore, SBM is commonly used in both swine and poultry diets in the United States and SBM accounts for more than 50% of the global usage of protein meal in poultry and livestock feeding (Kohlmeier, 1990).

Soybean products that have been subjected to heat treatments are well utilized by growing pigs (Hancock et al., 1990). The reason heat treatment is needed is that raw soybean products contain trypsin inhibitors and other antinutritional factors (Liener, 1994). Soybeans and other soybean products may be subjected to various types of heat treatments such as extrusion, jet-sploding, micronization, and roasting to inactivate the antinutritional factors (Marty et. al., 1994). Antinutritional factors, if not inactivated, will reduce digestibility of AA, and consequently the growth performance of swine and poultry (Herkelman et al., 1992).

Although heat treatment is needed to inactivate antinutritional factors, over-heating of soybeans will reduce the nutritional value of SBM because of reduced availability of Lys (Parsons et al., 1992). The digestibilities of all AA are reduced by under-heating, whereas only the digestibility of Lys, and to some extent Cys, is reduced by overheating (Parsons, 2000). Part of the reduced nutritive value of over-processed SBM may also be due to reduced energy availability because the TME_n content of SBM is reduced by extreme overcooking (Sibbald, 1980). The proper temperature of processing plays a large role in achieving a satisfactory nutritional value of soybeans products.

COMPOSITION OF CONVENTIONAL SOYBEANS AND SOYBEAN MEAL

Whole soybeans that have not had oil extracted are referred to as full fat soybeans (Barbi, 1996). Soybeans contain approximately 37% CP and 18% crude fat (Table 2.1; Karr-Lilienthal et al., 2005). Due to the high oil content, most soybeans are processed to remove the oil. However, full-fat soybeans (**FFSB**) may be used in diets for both pigs and poultry. To use FFSB in a practical diet, the soybeans must be heat-treated to inactivate antinutritional factors. Although heating destroys most of the anti-nutritional factors, care must be taken to avoid under or over-heating of FFSB (Van der Poel, 1989).

Soybeans can be processed in different ways. Generally, soybeans are made into conventional SBM via solvent extraction of oil and removal of hulls. This results in a product containing approximately 47.5% CP and 1% oil (NRC, 1998). An alternative processing technology is dry extrusion-expelling that combines extrusion with mechanical expelling of oil. Dry extrusion-expelling of soybeans produces a product with a greater oil concentration compared with regular, solvent-extracted SBM (Woodworth et al., 2001). Extruded-expelled meals also contain more fiber than SBM because they are not dehulled. Dehulled solvent-extracted SBM is the most widely used soybean product because of its large production and higher protein and energy content than lower protein meals that contain hulls (Stein et al., 2008). Most soy products supply more protein than most other vegetable feedstuffs. The protein quality of SBM is high for poultry and pigs and SBM is a particularly good source of both Lys and Trp (Stein et al., 2008).

The total non-starch polysaccharides make up about half of the carbohydrates in soybeans and SBM, and the non-starch polysaccharides are mostly composed of storage polysaccharides. In soybeans, the concentrations of non-starch polysaccharides range from 12.3% to 16.0% of DM and in SBM, concentrations range from 18.3% to 21.2% of DM (Grieshop et al., 2003). The carbohydrates that are not non-starch polysaccharides are mainly free sugars, sucrose, and oligosaccharides.

The oligosaccharides in soybeans and SBM are also considered antinutritional factors that may reduce animal performance (Anderson and Wolf, 1995). Soybean oligosaccharides include raffinose, stachyose, and verbascose, but the main oligosaccharides in soybeans are raffinose and stachyose which are present at about 1% and 6% in SBM DM, respectively (Grieshop et al., 2003), if they are not eliminated by processing (Leske et al., 1993). Soybean oligosaccharides are likely responsible for increasing viscosity of digesta, which interferes with the digestion of nutrients by decreasing their interaction with digestive enzymes in the small intestine (Smits and Annison, 1996). Oligosaccharides are considered indigestible in the pig small intestine because pigs do not synthesize α-galactosidase, which is the enzyme responsible for cleaving the glycosidic bonds in the oligosaccharides (Karr-Lilienthal et al., 2005). However, in a study by Smiricky et al. (2002), apparent ileal digestibility of raffinose and stachyose ranged from 62.2 to 91.2% and 84 to 97%, respectively. This observation suggests that there is a considerable bacterial colonization in the small intestine because microbes produce the α-galactosidase that is needed for the digestion of oligosaccharides. Results from a study by Liying et al. (2003), indicate that the addition of 1 or 2% stachyose to a diet fed to weanling pigs had a depressing effect on piglet weight gain. In a study by Parsons et al. (2000) to evaluate SBM varying in oligosaccharide content, it was observed that there was an increase in TME_n in low oligosaccharide variety SBM compared with conventional SBM. It has also been reported that a low stachyose content is important for maximizing ileal energy digestibility of SBM in pigs (van Kempen et al., 2006).

DIGESTIBITY OF AMINO ACIDS IN SOYBEANS AND SOYBEAN MEAL

Swine total tract digestibility estimates the bioavailability of AA from the feces. Unfortunately, it is not an accurate estimate because AA are absorbed from the small intestine and microbial fermentation affects AA disappearance in the large intestine. Values based on the ileal digestibility of AA are, therefore, more accurate than values for fecal digestibilities (Stein et al., 2007). In pigs ileal digestibility values can be expressed as apparent ileal digestibility (**AID**) or standardized ileal digestibility (**SID**). The AID are estimated when ileal outflow of AA is related to dietary AA intake. The concern with AID values is that they are not always additive in mixtures of feed ingredients (Stein et al., 2005). This concern may be overcome by using SID values, which correct AID values for basal endogenous losses of AA (Stein et al., 2007). It is recommended that basal ileal endogenous losses of AA are measured in digestibility experiments by using a protein-free diet (Stein et al., 2007).

In poultry, AA digestibility can be influenced by the presence of the ceca because the microbes in the ceca may deaminate AA entering from the ileum. In conventional roosters, therefore, excreta AA composition is influenced by microbial AA (Parsons, 1985). To avoid this, cecectomized roosters are usually used to measure AA digestibility

(Parsons, 1985). Basal endogenous losses are measured using fasted cecectomized roosters. By correcting the apparent digestibility of AA for basal endogenous losses of AA, the standardized digestibility (**SDD**) of AA can be calculated. Standardized ileal AA digestibilities can also be measured using chicks. Ileal digesta samples are collected from the terminal ileum after the birds have been euthanized (Garcia et al., 2007). The advantage of this procedure is that there is no interference by colon bacteria on AA digestibilities. The disadvantages is that each bird can be used for only 1 sample. The SID of AA for pigs and the SDD of AA for poultry are greater in SBM than in other vegetable feed ingredients (NRC, 1994; NRC, 1998), which in combination with the high concentrations of digestible Lys and Trp, makes SBM more nutritional valuable than most other protein ingredients (Table 2.2).

The AID of AA by growing pigs is increased if oil is used in the diet (Albin et al., 2001). The SID of most AA in SBM fed to growing pigs is also increased if oil is added to the diet (Cervantes-Pahm and Stein, 2008). When comparing FFSB and SBM, apparent ileal CP and AA digestibilities were greater in SBM than in extruded FFSB and greater in extruded FFSB than in roasted FFSB (Marty and Chavez, 1995). The reason for this observation is mostly likely that FFSB are often over-processed compared with SBM. When FFSB are extruded at a temperature of 155°, the SID of AA is greater than in SBM (Cervantes-Pahm and Stein, 2008). Therefore, if FFSB are processed correctly, the AA are well digested by pigs.

Factors that affect the standardized ileal digestibility of AA in SBM and therefore, the overall value of SBM, include soyhulls. The addition of 1% soyhulls to a semipurified diet, results in a 0.3% decrease in digestibilities of indispensable AA (Dilger et al., 2004).

Supplemental microbial phytase does not improve the utilization of AA from SBM, although it does improve Ca and P utilization in growing pigs (Traylor et al., 2001). Particle size reduction of SBM results in a small increase in digestibility of AA, with the indispensable AA being more affected than the dispensable AA (Fastinger and Mahan, 2003).

Differences in processing technologies of soybeans also have an effect on digestibilities of AA. Soybean meal that is produced in the United States by crushing soybeans grown in 4 other countries had lower AA digestibilities than SBM produced from soybeans grown in the United States (Karr-Lilienthal et al., 2004). Soybean meal produced in Argentina and Brazil also had lower digestibility of AA than SBM from the United States, which indicates that processing plants in those countries may produce less digestible SBM or may over-process SBM compared with what is produced in the United States (Karr-Lilienthal et al., 2004).

NEW VARIETIES OF SOYBEANS

High Protein Soybeans

There have been advances in both plant breeding and genetic engineering that have resulted in new varieties of soybeans. Some new varieties are selected for reduced concentrations of antinutritional factors such as trypsin inhibitors (Han et al., 1991) and some varieties if soybeans have been selected for higher concentrations of protein. Conventional soybeans contain 35-37% CP, but high-protein soybeans contain at least 41% CP (NRC, 1998; Yaklich, 2001). The higher concentration of protein also increases the AA concentration compared with the AA concentration in conventional soybeans.

The SID of AA in high-protein FFSB is similar to the SID in conventional FFSB when fed to growing pigs (Cervantes-Pahm and Stein, 2008). The FFSB produced from high-protein beans, therefore, contain more digestible AA than FFSB produced from conventional soybeans. For broiler chickens, the concentration of digestible Lys, Met, Cys, Thr, and Val and the TME_n is greater and the concentration of NDF and fat is lower in SBM produced from high-protein varieties of soybeans than in SBM produced from conventional soybeans (Edwards et al., 2000). However, no research has been conducted to investigate the effects of SBM produced form high-protein varieties of soybeans and fed to weanling or growing pigs. There is also no research on AA digestibility in high-protein SBM and the digestible and metabolizable energy in high-protein SBM fed to weanling or growing pigs have not been measured.

Low Oligosaccharide Soybeans

The presence of oligosaccharides in soybeans and SBM has been associated with negative effects in diets fed to swine and poultry. The oligosaccharide stachyose has a negative effect on weanling pig performance and its presence may partially explain the poor performance observed when SBM is used as the sole source of supplemental protein in diets fed to weanling pigs (Liying et al., 2003). Soybean meal produced from low oligosaccharide varieties of soybeans also have greater energy values when fed to poultry than SBM produced from conventional soybeans, and it has been shown that the TME_n values in low-oligosaccharide SBM is 9.8% greater than in conventional SBM (Parsons et al., 2000).

However, no research has been conducted with pigs fed SBM produced from low oligosaccharide varieties of soybeans and there is no information on AA digestibility or energy concentration in low oligosaccharide soybeans fed to weanling or growing pigs. There is also no research on the SDD of AA in low oligosaccharide SBM fed to poultry.

CONCLUSIONS

It is concluded that SBM is a valuable vegetable protein source that is used in poultry and livestock feeding all over the world. There are different sources of soybean products available, including FFSB, SBM with and without hulls, and new varieties of soybeans. The SID of AA in pigs can be increased with the inclusion of soybean oil to the diet. Full fat soybeans contain more oil, and if processed correctly may result in increased digestibility of AA, compared with SBM. If soybeans are processed correctly, heating inactivates antinutritional factors, which improves AA digestibility. Soybean products contain oligosaccharides that may to decrease performance in pigs and decrease TME_n in poultry. There are a number of factors including the concentration of soy hulls, particle size, and the location of soybean processing plants that influence AA digestibility in SBM. New varieties of soybeans have been developed to increase the quality of SBM. These varieties include soybeans selected for high protein concentration, which is beneficial because it results in an increase in the concentration of digestible AA. Soybeans have also been selected for low oligosaccharide concentrations, which may increase performance in pigs and increase TME_n in poultry. There is however, a lack of research with pigs and poultry to document the advantage of these new varieties in feeding of pigs and poultry.

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TABLES

Table 1. Composition of full fat soybeans (FFSB) and extruded-expelled or solvent

	FFSB	Extracted-expelled SBM		Solvent extracted SBM	
	Not dehulled	Dehulled	Not dehulled	Dehulled	Not dehulled
Moisture, %	10.4	88.3	88.7	89.0	94.6
Minerals, %	4.9	6.8	6.5	6.7	6.03
Fat, %	16.7	1.1	1.2	3.9	4.9
Protein, %	37.1	47.1	45.4	48.2	47.5
Sucrose, %	4.3	-	-	5.9	-
Oligosaccharides, %	4.0	-	-	5.7	-
Raffinose, %	0.6	-	-	1.1	-
Staychyose, %	3.36	-	-	4.4	-
Verbascose, %	0.1	-	-	0.2	-
Non-starch polysaccharides, %	18.1	3.6	6.6	12.5	4.8

extracted soybean meal (SBM), as-fed basis[1]

[1]Data from Grieshop et al. (2003), and Woodworth et al. (2001).

Table 2. Standardized ileal digestibility (%) of indispensable AA in full fat soybeans (FFSB) and solvent extracted SBM without or with hulls fed to pigs, and standardized AA digestibility (%) of AA in dehulled SBM fed to poultry[1]

	Pigs			Poultry
	FFSB	Solvent-extracted SBM		SBM
Item	Not Dehulled	Not dehulled	Dehulled	Dehulled
Indispensable AA (%)				
Arg	93	93	94	92
Cys	80	84	87	82
His	88	90	91	88
Ile	84	88	89	93
Leu	86	88	89	92
Lys	86	89	90	91
Met	85	91	91	92
Phe	88	88	89	92
Thr	83	85	87	88
Trp	82	87	90	-
Val	83	86	88	91

[1] Data from NRC (1994) and NRC (1998).

CHAPTER 3. AMINO ACID DIGESTIBILITY AND CONCENTRATION OF DIGESTIBLE AND METABOLIZABLE ENERGY IN SOYBEAN MEAL PRODUCED FROM CONVENTIONAL, HIGH-PROTEIN, OR LOW-OLIGOSACCHARIDE VARIETIES OF SOYBEANS AND FED TO GROWING PIGS

ABSTRACT: Two experiments were conducted to determine AA digestibility and the concentration of DE and ME in 5 sources of soybean meal (SBM). The 5 sources included hexane extracted SBM produced from high-protein soybeans (SBM-HP) and conventional soybeans (SBM-CV), and mechanically extruded-expelled SBM produced from high-protein soybeans (EE-SBM-HP), low-oligosaccharide soybeans (EE-SBM-LO), and conventional soybeans (EE-SBM-CV). Five diets that each contained 1 source of SBM and a N-free diet were used in Exp. 1 to determine AA digestibility in each meal. Twelve growing barrows (initial BW: 67.7 ± 1.34 kg) were allotted to a replicated 6 x 6 Latin square design with 6 periods and 6 diets in each square. Each period lasted 7 d and ileal digesta were collected on d 6 and 7 of each period. Results of the experiment showed that the standardized ileal digestibility (SID) of all AA except Trp was similar for SBM-HP and SBM-CV, but EE-SBM-HP and EE-SBM-LO had greater ($P < 0.05$) SID of His, Ile, Lys, Thr, and Val than EE-SBM-CV. The SID of all indispensable AA in EE-SBM-HP was greater ($P < 0.05$) than in SBM-HP. The SID of Arg, Ile, Leu, and Phe in EE-SBM-CV was greater ($P < 0.05$) than in SBM-CV, but the SID of Trp was greater ($P < 0.05$) in SBM-CV than in EE-SBM-CV. Experiment 2 was conducted to measure DE and ME in the same 5 sources of SBM as used in Exp. 1. Forty-eight growing barrows

(initial BW: 38.6 ± 3.46 kg) were placed in metabolism cages and randomly allotted to 6 diets with 8 replicates per diet. A corn-based diet and 5 diets based on a mixture of corn and each source of SBM were formulated. Urine and feces were collected during a 5-d collection period, and values for DE and ME in each source of SBM were calculated using the difference procedure. Results showed that the ME in SBM-HP tended to be greater (*P* = 0.10) than in SBM-CV (4,074 vs. 3,672 kcal/kg DM). The ME in EE-SBM-HP also tended to be greater (*P* = 0.10) than in EE-SBM-CV and in EE-SBM-LO (4,069 vs. 3,620 and 3,721 kcal/kg DM), but there was no difference in ME between extracted and extruded-expelled meals. It is concluded that SBM-HP has a greater feeding value than SBM-CV because of greater concentrations of digestible AA and ME. Likewise, EE-SBM-LO has a greater concentration of most indispensable AA than EE-SBM-CV, but the concentration of ME is similar in these 2 meals. Results of this experiment also showed that AA digestibility values in extruded-expelled SBM are greater than in hexane extracted SBM.
Key words: amino acids, digestibility, energy, high-protein soybean meal, low-oligosaccharide soybean meal, pigs

INTRODUCTION

Soybeans can be fed to swine as full-fat soybeans or they can be de-oiled and made into soybean meal (**SBM**) after grinding of the de-oiled flakes (Johnson, 2008). The removal of oil can be accomplished using the solvent extraction method or the extruded-expeller method (Wang and Johnson, 2001). Less than 1.5% oil is usually left in the meal if the extraction method is used, but up to 8% oil is left in the meal if they are extruded-expelled (Zhang et al., 1993; Wang and Johnson, 2001). Extracted meals are usually dehulled, but that is not the case for extruded-expelled meals and the concentration of non-starch polysaccharides is, therefore, greater in extruded-expelled meals than in extracted meals. The concentration of CP is greater in extracted SBM than in extruded-expelled SBM, but the AA composition of the protein and the relative AA concentration is similar in the 2 types of meal (Wang and Johnson, 2001).

New varieties of high-protein soybeans that contain 6 to 10% more CP than conventional soybeans and low-oligosaccharide varieties that contain 70 to 90% less oligosaccharides than conventional soybeans have recently been introduced to the feed industry. Soybean meal produced from low-oliogosaccharide varieties of soybeans contains 7 to 9% more ME if fed to poultry (Parsons et al., 2000), but there are no data on the digestibility of energy or AA in low-oligosaccharide SBM fed to pigs. The digestibility of most indispensable AA in high-protein full-fat soybeans is greater than in conventional full-fat soybeans (Cervantes-Pahm and Stein, 2008), but there is no information on the digestibility of AA or on the energy concentration in SBM produced from high-protein soybeans fed to pigs. The objective of the present work was, therefore, to test the hypothesis that SBM produced from high-protein or low-oligosaccharide soybeans have different digestibilities of AA and energy than SBM produced from conventional soybeans.

MATERIALS AND METHODS

General

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for the experiments. Two experiments were conducted. Pigs used in the experiments were the offspring of line 337 boars that were mated to C 22 females (Pig Improvement Company, Hendersonville, TN). Five SBM were used (Table 3.1). Two of the SBM were produced via hexane extraction of high-protein or conventional soybeans (**SBM-HP** and **SBM-CV**, respectively). Three extruded-expelled meals produced from high-protein, low-oligosaccharide, and conventional soybeans (**EE-SBM-HP**, **EE-SBM-LO**, and **EE-SBM-CV**, respectively) were also used. The same batch of high-protein soybeans (446F.HP, Schillinger Seeds Inc., Des Moines, IA) was used to produce SBM-HP and EE-SBM-HP. The beans were grown in Southern Indiana in 2006 and their identities were preserved throughout the process. The low-oligosaccharide soybeans and the commercial soybeans (247F.HD and 435.TCS, respectively, Schillinger Seeds Inc., Des Moines, IA) were grown in North-East Indiana in 2006. These beans' identities were also preserved throughout the process. The solvent extracted soybean meals were produced at a commercial facility (Rose Acre Farms Inc., Seymour, IN). The extruded-expelled soybean meals were extruded at 145^{o}C on a double flight screw extruder with a 1.59-cm nose cone (Model 2000, Insta Pro, Urbandale, IA) and oil was subsequently expelled using a mechanical oil press (Model 5005, Insta Pro, Urbandale, IA). The expelled cake was then ground in a hammer mill and cooled using a counter flow cooler.

Amino Acid Digestibility

Experiment 1 was designed to measure the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) for CP and AA in the 5 SBM. Twelve growing barrows (initial BW: 67.7 ± 1.34 kg) were randomly allotted to a replicated 6 x 6 Latin square design with 6 diets and 6 periods in each square. A T-cannula was surgically installed in the distal ileum of each pig (Stein et al., 1998) when they had a BW of approximately 25 kg, and all pigs had been used in a 6-wk experiment before being used in the present experiment. Pigs were housed individually in pens (0.9 x 1.8 m) that had fully slatted concrete floors. A feeder and a nipple drinker were installed in each pen.

Six diets were prepared (Tables 3.2 and 3.3). Five of the diets contained 1 of the SBM and starch, sugar, and soybean oil. The last diet was a N-free diet that was used to measure basal endogenous losses of AA and CP. All diets contained 0.4% chromic oxide as an indigestible marker. Solka floc was included in the N-free diet (4%) to increase the concentration of crude fiber. It was assumed that the ingredients used in the N-free diet contained no Mg and K; therefore, these minerals were included in the form of magnesium oxide and potassium carbonate, respectively. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998). Pig weights were recorded at the beginning and at the end of each period. Pigs were fed once daily at 3 times the estimated maintenance energy requirement (i.e., 106 kcal ME per kg $^{0.75}$; NRC, 1998) and water was available at all times throughout the experiment.

Each experimental period lasted 7 d and the initial 5 d was considered an adaptation period to the diet. On d 6 and 7 of each period, cannulas were opened and a 225-mL plastic bag was attached to the cannula barrel with a cable tie and digesta that flowed into the bag were collected for 8 consecutive hours. Bags were removed whenever they were filled with digesta, or at least once every 30 min and digesta were stored at –20°C to prevent bacterial degradation of the AA in the digesta.

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a sub-sample was collected for chemical analysis. A sample of each diet and of each of the SBM was collected as well. Digesta samples were lyophilized and finely ground prior to chemical analysis. All samples of feed ingredients, diets, and ileal digesta were analyzed for DM (method 930.15; AOAC, 2005) and CP (method 990.03; AOAC, 2005). Chromium concentrations of diets and ileal digesta were also analyzed (method 990.08; AOAC, 2005) and the 5 sources of SBM were analyzed for sucrose, raffinose, and stachyose (Janauer and Englmaier, 1978), ADF (method 973.18; AOAC, 2005), NDF (Holst, 1973), Ca (method 978.02; AOAC, 2005), and P (method 946.06; AOAC, 2005). Ingredients were analyzed for trypsin inhibitors (method Ba 12-75; AOCS, 1998). Ingredients and diets were also analyzed for ether extract (method 920.39; AOAC, 2005), and ingredients, diets, and digesta were analyzed for AA on a Beckman 6300 Amino Acid Analyzer (Beckman Instruments Corp., Palo Alto, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Samples were hydrolyzed with 6 *N* HCL for 24 h at 110°C (method 982.30; AOAC, 2005) before analysis. Methionine and Cys were determined as Met sulfone and cysteic acid, respectively, after cold performic acid oxidation overnight prior to hydrolysis (method 982.30; AOAC, 2005). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (method 982.30; AOAC, 2005).

Values for AID of CP and AA in digesta samples obtained from feeding the 5 diets containing SBM were calculated. Because SBM was the only feed ingredient contributing CP and AA in each of the diets, these digestibility values also represent the digestibility values for CP and AA in each source of SBM. The basal endogenous losses of CP and AA were calculated using the data from pigs fed the N-free diet, and these values were used to correct AID values for endogenous losses to calculate SID values for CP and AA in each source of SBM. All calculations were completed using published equations (Stein et al., 2007).

Data were analyzed using the GLM procedure of SAS (SAS Institute Inc., Cary, NC). An analysis of variance was conducted with pigs, periods, and diets in the model. If a significant overall treatment effect was detected, means were separated using the Least Significant Difference test. A contrast was used to compare data for the 2 extracted SBM with data for the 3 extruded-expelled SBM. The pig was the experimental unit for all calculations and a P-value of 0.05 was used to assess significant differences among means.

Energy Measurements

Experiment 2 was designed to measure the DE and ME and the apparent total tract digestibility **(ATTD)** of energy in the 5 sources of SBM that were used in the AA digestibility experiment. A total of 48 barrows (initial BW: 38.6 ± 3.46 kg) were placed in metabolism cages equipped with a feeder and a nipple drinker. The experiment was conducted as a randomized complete block design with 6 diets and 8 replications per diet.

The 6 diets were based on corn or corn and 1 of the 5 sources of SBM (Table 3.4). Corn and SBM were the sole sources of energy in the diets.

The quantity of feed provided per pig daily was calculated as 2 times the estimated requirement for maintenance energy for the smallest pig in each replicate and divided into 2 equal meals. Water was available at all times. Pigs were fed experimental diets for 14 d and the initial 5 d was considered an adaptation period to the diet. Chromic oxide (0.5%) and ferric oxide (0.5%) were added to the diet in the morning meals on d 6 and 11, respectively. Collections of fecal samples were initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared in the feces according to the marker to marker approach (Adeola, 2001). Fecal samples were collected twice daily during the collection period. Urine collection was initiated after feeding the morning meal on d 6 and ceased after feeding the morning meal on d 11. Urine buckets were placed under the metabolism cages and emptied twice daily. Immediately after collection, fecal samples and 20% of the collected urine were stored at -20^{o}C. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a sub-sample was collected for analysis.

Fecal samples were dried in a forced-air oven and finely ground prior to analysis, and urine samples were lyophilized before analysis. Fecal, urine, diet, and ingredient samples were analyzed in duplicate for GE using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Diets and ingredients were also analyzed for DM (method 930.15; AOAC, 2005). Following chemical analysis, the ATTD was calculated for energy in each diet as previously described (Stein et al., 2004). The amounts of energy lost in the feces and urine were calculated as well, and the quantities of DE and ME in each of the 6 diets were calculated (Stein et al., 2004). By subtracting the contribution of corn to the corn-SBM diets, the concentration of DE and ME in each of the 5 sources of SBM was calculated using the difference procedure (Widmer et al., 2007). Data were analyzed as described for the AA digestibility experiment.

RESULTS

Nutrient Composition

The concentrations of CP and AA were greater in SBM-HP and EE-SBM-HP compared with SBM-CV and EE-SBM-CV (Table 3.1). Ether extract concentrations were lower in the extracted SBM than in the extruded-expelled SBM, but the concentrations of NDF and ADF were greater in the extruded-expelled SBM compared with the extracted SBM. The concentration of sucrose was lower in SBM-HP than in the other SBM, but the concentration of raffinose and stachyose was lower in EE-SBM-LO compared with all other SBM.

Amino Acid Digestibility

The AID of CP in SBM-HP (81.0 %) was not different from the AID in SBM-CV (79.8%) and EE-SBM-CV (81.4%; Table 5). The AID of CP in EE-SBM-HP (82.9%) was greater ($P < 0.05$) than for SBM-CV, but similar to the other SBM. The AID of CP in SBM-LO (83.6%) was not different from the AID in the other extruded-expelled SBM, but greater ($P < 0.05$) than in SBM-HP and SBM-CV. The AID of CP in all the extruded-expelled SBM was also greater ($P < 0.05$) than in the extracted SBM.

There were no differences in the AID of the indispensable AA in SBM-HP and SBM-CV with the exception that the AID of Trp was greater in SBM-CV than in SBM-HP ($P < 0.001$). The AID of His, Ile, Lys, Val, Asp, and Cys were greater ($P < 0.05$) for EE-SBM-HP and EE-SBM-LO compared with EE-SBM-CV, but there were no differences between EE-SBM-HP and EE-SBM-LO in the AID of any AA. The AID of all AA in the extruded-expelled SBM were greater ($P < 0.05$) than in the extracted SBM, except for Trp, Cys, Glu, Gly, and Pro.

The SID of CP in EE-SBM-HP (90.9%) and EE-SBM- LO (91.5%) were greater ($P < 0.05$) than in SBM-HP (88.3%) and SBM-CV (87.3%), but not different from EE-SBM-CV (89.1%; Table 3.6). The SID of Trp was greater ($P < 0.05$) in SBM-CV compared with SBM-HP, but for all other AA, no differences between these 2 meals were observed. The SID of His, Ile, Lys, Thr, Val, Asp, and Cys was greater ($P < 0.05$) for EE-SBM-HP and EE-SBM-LO compared with EE-SBM-CV, but there were no differences between EE-SBM-HP and EE-SBM-LO. The extruded-expelled SBM had greater ($P < 0.05$) SID of all AA except Trp, Cys, Glu, and Gly compared with the extracted SBM.

Energy Measurements

There were no differences in GE intake among pigs fed any of the diets (Table 3.7). Pigs fed diets containing SBM-HP or EE-SBM-HP had a lower ($P < 0.05$) fecal excretion of GE than pigs fed the diet containing EE-SBM-CV, but pigs fed the corn diet had a lower ($P < 0.05$) fecal excretion of GE than pigs fed all the SBM containing diets. There were no differences among treatments for the GE excreted in the urine.

Pigs fed the SBM-HP diet, EE-SBM-HP diet, or the corn diet had greater (*P* < 0.05) ATTD of GE (88.8, 88.9, and 90.6%, respectively) than pigs fed the EE-SBM-CV diet (86.9%). Pigs fed the corn diet also had a greater (*P* < 0.05) ATTD of GE than pigs fed SBM-CV (87.2%) and EE-SBM-LO (87.3%) diets. The DE in the EE-SBM-HP diet was greater (*P* < 0.05) than the DE of all other diets, but there were no differences among the other diets. No differences among diets were observed for ME.

The DE for EE-SBM-HP was greater (*P* < 0.05) than the DE for the other 4 SBM and corn (Table 3.8), and the DE for the extruded-expelled SBM were greater (*P* < 0.05) than for the extracted SBM. The ME was, however not different among ingredients.

The DE for EE-SBM-HP was greater (*P* < 0.05) than the DE for corn, SBM-CV, EE-SBM-LO, and EE-SBM-CV when calculated on a DM basis (4,293 vs. 3,910, 3,845 3,923 and 3,827 kcal/kg DM), but not different from the DE for SBM-HP (4,178 kcal/kg DM). The DE for SBM-HP was also greater (*P* < 0.05) than the DE for EE-SBM-CV. The ME for SBM-HP (4,074 kcal/kg DM) and EE-SBM-HP (4,069 kcal/kg DM) tended to be greater (*P* = 0.10) than the ME of the other SBM (3672, 3721, and 3620 kcal/kg DM for SBM-CV, EE-SBM-LO, and EE-SBM-CV, respectively), but none of these values were different from corn (3,779 kcal/kg DM). The DE and ME measured on a DM basis were not different between the extracted SBM and the extruded-expelled SBM.

DISCUSSION

Composition of Ingredients

The nutrient composition of SBM-CV concurs with published values (NRC, 1998) and the nutrient composition of EE-SBM-CV is in agreement with previous data for extruded-expelled SBM (Woodworth et al., 2001; Opapeju et al., 2006). The concentration of ether extract in EE-SBM-CV was also comparable to published values for extruded-expelled meals (Woodworth et al., 2001). The greater concentrations of NDF and ADF in the extruded-expelled SBM compared with the extracted SBM are likely a result of the fact that the extracted SBM were dehulled, but this was not the case for the extruded-expelled SBM. The concentration of DM was greater in the extruded-expelled SMB than in the extracted SBM, which is likely a result of the heat that is generated during the extrusion process. The differences in DM are not expected to have influenced the data for AA digestibility because these data were calculated on a percentage basis, but the DE and ME concentrations were likely influenced by the differences in DM concentrations. Data for DE and ME are, therefore, presented on a DM basis as well as on an as-fed basis.

The CP concentration in SBM-HP was greater than in SBM-CV, which agrees with data showing that the concentration of CP in high-protein soybeans is greater than in conventional soybeans (Cervantes-Pahm and Stein, 2008). The concentrations of raffinose and stachyose were lower in EE-SBM-LO than in the other SBM, which is a result of this variety being selected for low concentrations of oligosaccharides. The concentration of sucrose was lowest in the 2 high-protein meals, which is also in agreement with previous data (Cervantes-Pahm and Stein, 2008). An adverse relationship between CP and sucrose is often observed in soybeans (Hartwig et al., 1997). The extracted meals contained less raffinose and stachyose than the extruded-expelled meals, which is most likely a result of the extracted meals being dehulled.

Amino Acid Digestibility

Values for AID and SID of AA in SBM-CV agree with previously measured values (NRC, 1998) and the AID of AA in EE-SBM-CV were in agreement with results from previous studies (Woodworth et al., 2001; Opapeju et al., 2006). The AID and SID of AA in the 2 SBM produced from high-protein soybeans were similar to the AID and SID in the 2 conventional meals, but because of the greater concentration of AA in the high-protein SBM than in conventional SBM, greater quantities of digestible AA are provided by the SBM from high-protein soybeans than in SBM from conventional soybeans. This observation is in agreement with Cervantes-Pahm and Stein (2008) who also reported that concentration of digestible AA in high-protein full-fat soybeans is greater than in conventional full-fat beans.

The reason for the greater digestibility of most AA in EE-SBM-LO and EE-SBM-HP than in EE-SBM-CV may be that the concentration of NDF and ADF in EE-SBM-CV is greater than in the other 2 extruded-expelled meals. This observation also indicates that there are no detrimental effects on AA digestibility of removing the oligosaccharides or increasing the protein concentration in soybeans. To our knowledge, there are no other published data on AA digestibility in SBM from low-oligosaccharide or high-protein soybeans fed to pigs.

The greater AID and SID in extruded-expelled meals compared with extracted meals is likely a result of the greater concentration of oil in the extruded-expelled meals, because increased concentrations of dietary soybean oil increase AA digestibility in SBM (Cervantes-Pahm and Stein, 2008). In the extruded-expelled meals, there was also an increase in the concentration of NDF and ADF compared with the extracted meals because of the presence of hulls. Soy hulls may reduce AA digestibility (Dilger et al., 2004), but results of this experiment indicate that the positive effect of soy oil in the extruded-expelled meals is greater than the negative effects of NDF and ADF.

Energy Measurements

The values for DE and ME for SBM-CV that were measured in this experiment are in close agreement with previously published values (NRC, 1998; Woodworth et al., 2001). Likewise, the ME for corn that was measured in this experiment agrees with previous data (NRC, 1998; Pedersen et al., 2007; Widmer et al., 2007). The greater DE and ME in SBM-HP and EE-SBM-HP compared with the DE and ME in SBM-CV and EE-SBM-CV, respectively, is most likely a result of the greater protein concentration in the high-protein meals. In contrast, the DE and ME of EE-SBM-LO were not different from the DE and ME in EE-SBM-CV, but the protein and ether extract concentrations were also similar in these 2 meals. The extruded-expelled meals did not contain more DE and ME than the extracted meals, despite an increased concentration of ether extract. However, the extruded-expelled meals contained more NDF and ADF than the extracted meal, which is likely the reason for this observation.

Summary

Soybean meal produced from high-protein varieties of soybeans has a similar digestibility of AA as SBM produced from conventional soybeans, which results in greater concentrations of digestible AA in SBM produced from high-protein soybeans than in SBM produced from conventional SBM. This is true for extracted SBM as well as for extruded-expelled SBM. Likewise, SBM produced from high-protein varieties of soybeans contain more DE and ME than conventional SBM. Soybean meal from low-oligosaccharide varieties of soybeans have AID and SID values for most AA that are greater than the AID and SID in conventional SBM, but the DE and ME in low-oligosaccharide SBM is comparable to the DE and ME in conventional SBM. There were no differences in DE and ME between extracted and extruded-expelled SBM, but the digestibility of AA was greater in extruded-expelled SBM.

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TABLES

Table 3.1. Analyzed energy and nutrient composition of high-protein (HP), low-oligosaccharide (LO), and conventional (CV) soybean meals (SBM), as-fed basis

Item	Extracted SBM		Extruded-expelled SBM		
	SBM-HP	SBM-CV	SBM-HP	SBM-LO	SBM-CV
DM, %	89.20	89.10	94.50	94.60	96.70

Table 3.1 (cont.)

GE, kcal/kg	4,253	4,197	4,784	4,737	4,725
CP, %	55.65	48.36	55.97	49.33	47.09
Ether extract, %	0.30	0.83	5.13	4.62	4.26
Ca, %	0.56	0.35	0.29	0.29	0.28
P, %	0.77	0.72	0.63	0.63	0.66
NDF, %	5.50	6.74	9.99	9.98	14.42
ADF, %	2.95	3.87	6.30	6.81	7.17
Sucrose, %	4.28	7.82	4.91	7.10	7.10
Raffinose, %	0.68	1.05	0.67	0.18	0.77
Stachyose, %	3.12	4.72	4.58	1.55	4.88
Trypsin inhibitor Activity, TIU/mg	6.40	5.90	6.00	4.90	4.60
Indispensable AA, %					
Arg	4.30	3.62	4.13	3.77	3.48
His	1.47	1.30	1.39	1.29	1.26
Ile	2.56	2.30	2.42	2.24	2.19
Leu	4.31	3.81	4.09	3.75	3.65
Lys	3.51	3.20	3.33	3.12	2.93

Table 3.1 (cont.)

Met	0.78	0.70	0.72	0.68	0.65

Phe	2.85	2.50	2.71	2.47	2.39
Thr	2.09	1.86	1.96	1.81	1.76
Trp	0.75	0.69	0.71	0.66	0.68
Val	2.74	2.45	2.59	2.43	2.40
Dispensable AA, %					
Ala	2.35	2.14	2.21	2.07	2.03
Asp	6.47	5.58	6.10	5.66	5.36
Cys	0.91	0.77	0.80	0.78	0.68
Glu	10.39	8.93	9.82	8.94	8.51
Gly	2.35	2.11	2.27	2.11	2.06
Pro	2.86	2.51	2.74	2.47	2.38
Ser	2.64	2.25	2.50	2.24	2.09
Tyr	1.98	1.79	1.88	1.71	1.67

Table 3.2. Ingredient composition (as-fed basis) of experimental diets containing high-protein (HP), low-oligosaccharide (LO), and conventional (CV) soybean meals (SBM) and used in the AA experiment (Exp. 1)

Ingredient, %	Extracted SBM		Extruded-expelled SBM			
	SBM-HP	SBM-CV	SBM-HP	SBM-LO	SBM-CV	N-Free
SBM-HP[1]	32.50	-	-	-	-	-
SBM-CV[1]	-	38.00	-	-	-	-
SMB-EE-HP[1]	-	-	35.00	-	-	-
SMB-EE-LO[1]	-	-	-	35.00	-	-
SMB-EE-CV[1]	-	-	-	-	40.00	-
Cornstarch	51.15	45.75	50.10	50.10	45.35	68.60
Soybean oil	3.70	3.60	2.25	2.25	2.00	4.00
Sugar	10.00	10.00	10.00	10.00	10.00	20.00
Solka floc [2]	-	-	-	-	-	4.00
Limestone	0.75	0.75	0.75	0.75	0.75	0.60
Monocalcium phosphate	0.80	0.80	0.80	0.80	0.80	1.20

Table 3.2 (cont.)

Magnesium oxide	-	-	-	-	-	0.10
Potassium carbonate	-	-	-	-	-	0.40
Chromic oxide	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
Vitamin mineral premix [3]	0.30	0.30	0.30	0.30	0.30	0.30

[1]SBM-HP = extracted high-protein SBM; SBM-CV = extracted conventional SBM; EE-SBM-HP = extruded-expelled high-protein SBM; EE-SBM-LO = extruded-expelled low-oligosaccharide SBM; and EE-SBM-CV = extruded-expelled conventional SBM.

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

[3]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A, 11,120 IU; vitamin D_3, 2,204 IU; vitamin E, 66 IU; vitamin K, 1.41 mg; thiamin, 0.24 mg; riboflavin, 6.6 mg; pyridoxine, 0.24 mg; vitamin B_{12}, 0.031 mg; D-pantothenic acid, 24 mg; niacin, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 0.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 125 mg as zinc oxide.

Table 3.3. Analyzed nutrient composition (as-fed basis) of experimental diets containing high-protein (HP), low-oligosaccharide (LO), and conventional (CV) soybean meals (SBM) and used in the AA experiment (Exp. 1)

Item	Extracted SBM		Extruded-expelled SBM			
	SBM-HP	SBM-CV	SBM-HP	SBM-LO	SBM-CV	N-Free
DM, %	90.35	88.74	92.32	92.13	93.12	91.25
CP, %	19.68	18.65	18.41	18.59	19.23	0.57
Indispensable AA, %						
Arg	1.47	1.38	1.47	1.44	1.44	0.01
His	0.51	0.50	0.51	0.50	0.52	0.01
Ile	0.89	0.87	0.87	0.88	0.87	0.01
Leu	1.51	1.48	1.49	1.48	1.53	0.03
Lys	1.23	1.23	1.21	1.22	1.23	0.02
Met	0.25	0.26	0.24	0.25	0.25	0.01
Phe	0.99	0.96	0.98	0.97	0.99	0.02
Thr	0.73	0.73	0.71	0.71	0.77	0.01
Trp	0.24	0.37	0.24	0.26	0.30	0.01

Table 3.3 (cont.)

Val	0.95	0.94	0.95	0.94	0.94	0.01
Dispensable AA, %						
Ala	0.83	0.83	0.82	0.82	0.86	0.02
Asp	2.23	2.17	2.23	2.22	2.25	0.03
Cys	0.32	0.30	0.30	0.32	0.30	0.01
Glu	3.66	3.46	3.63	3.55	3.60	0.08
Gly	0.82	0.82	0.83	0.83	0.86	0.01
Pro	1.02	0.96	1.00	0.97	1.02	0.01
Ser	0.92	0.89	0.90	0.88	0.96	0.01
Tyr	0.59	0.62	0.56	0.58	0.62	0.01

Table 3.4. Composition (as-fed basis) of experimental diets containing high-protein (HP), low-oligosaccharide (LO), and conventional (CV) soybean meals (SBM) and used in the energy experiment (Exp. 2)

Ingredient, %		Extracted SBM		Extruded-expelled SBM		
	Corn	SBM-HP	SBM-CV	SBM-HP	SBM-LO	SBM-CV
Corn	97.50	77.25	73.25	75.50	74.25	73.00
SBM-HP[1]	-	20.50	-	-	-	-
SBM-CV[1]	-	-	24.50	-	-	-
EE-SBM-HP[1]	-	-	-	22.25	-	-
EE-SBM-LO[1]	-	-	-	-	23.50	-
EE-SBM-CV[1]	-	-	-	-	-	24.75
Limestone	0.70	0.70	0.70	0.70	0.70	0.70
Dicalcium phosphate	1.10	0.85	0.85	0.85	0.85	0.85
Salt	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
Total	100	100	100	100	100	100
Analyzed composition						

Table 3.4 (cont.)

Energy, kcal/kg	3,684	3,838	3,833	3,905	3,901	3,908

[1]SBM-HP = extracted high-protein SBM; SBM-CV = extracted conventional SBM; EE-SBM-HP = extruded-expelled high-protein SBM; EE-SBM-LO = extruded-expelled low-oligosaccharide SBM; and EE-SBM-CV = extruded-expelled conventional SBM.

[2]Provided the following quantities of vitamins per kilogram of complete diet: Vitamin A, 10,990 IU; vitamin D_3, 1,648 IU; vitamin E, 55 IU; vitamin K, 4.4 mg; thiamin, 3.3 mg; riboflavin, 9.9 mg; pyridoxine, 3.3 mg; vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg; niacin, 55 mg; folic acid, 1.1 mg; biotin, 0.17 mg; Cu, 16 mg as copper sulfate; Fe, 165 mg as iron sulfate; I, 0.36 mg as potassium iodate; Mn, 44 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 165 mg as zinc oxide.

Table 3.5. Apparent ileal digestibility (%) of CP and AA in high-protein (HP), low-oligosaccharide (LO), and conventional (CV) soybean meals (SBM) by growing pigs, AA experiment (Exp. 1)[1, 2]

Item	Extracted SBM		Extruded-expelled SBM					Contrast
	SBM-HP	SBM-CV	SBM-HP	SBM-LO	SBM-CV	SEM	*P*-value	*P*-value[3]
CP	81.0[ab]	79.8[a]	82.9[bc]	83.6[c]	81.4[abc]	0.86	0.020	0.006
Indispensable AA								
Arg	91.1[a]	91.0[a]	93.4[b]	93.9[b]	92.6[b]	0.47	<0.001	< 0.001
His	86.4[a]	87.3[ab]	89.2[bc]	89.6[c]	87.1[a]	0.72	0.009	0.009
Ile	85.0[a]	85.0[a]	88.8[c]	89.2[c]	87.0[b]	0.63	<0.001	< 0.001
Leu	85.0[a]	84.8[a]	89.0[b]	89.1[b]	87.6[b]	0.62	<0.001	< 0.001
Lys	86.2[a]	86.2[a]	89.2[b]	89.2[b]	86.4[a]	0.80	0.006	0.006
Met	85.5[a]	86.4[ab]	88.8[c]	89.4[c]	87.9[bc]	0.73	0.002	< 0.001
Phe	85.7[a]	85.5[a]	89.7[b]	89.7[b]	88.2[b]	0.59	<0.001	< 0.001
Thr	77.8	78.1	80.6	80.6	78.4	0.92	0.071	0.025
Trp	84.5[a]	90.5[c]	86.5[b]	87.6[b]	87.1[b]	0.65	<0.001	0.470
Val	82.2[a]	82.4[a]	86.0[b]	85.8[b]	83.6[a]	0.72	<0.001	< 0.001
Mean	85.5[a]	85.7[a]	88.7[bc]	88.9[c]	87.0[ab]	0.64	0.001	< 0.001

Table 3.5 (cont.)

Dispensable AA								
Ala	77.9^{a}	78.1^{a}	83.3^{b}	83.1^{b}	81.2^{b}	1.05	<0.001	< 0.001
Asp	82.8^{a}	82.7^{a}	85.8^{b}	86.2^{b}	82.8^{a}	0.93	0.010	0.011
Cys	77.1^{b}	76.9^{b}	77.4^{b}	79.2^{b}	73.2^{a}	1.26	0.026	0.754
Glu	84.8	84.9	86.5	86.7	84.3	1.07	<0.001	0.411
Gly	69.9	70.3	73.2	71.6	68.4	2.06	<0.001	0.541
Pro	77.5	73.1	80.1	81.5	79.4	3.00	<0.001	0.325
Ser	83.7^{a}	83.4^{a}	85.9^{b}	85.9^{b}	84.5^{ab}	0.67	0.021	0.003
Tyr	84.1^{a}	84.8^{ab}	86.6^{bc}	87.0^{c}	86.0^{bc}	0.67	0.016	< 0.001
Mean	81.3	81.0	83.9^{ab}	84.1	81.6	1.06	0.107	0.039
All AA	83.2^{a}	83.2^{a}	86.1^{b}	86.3^{b}	84.0^{ab}	0.84	0.016	0.004

[a-c]Means within a row lacking a common superscript letter differ (*P* < 0.05).

[1]Data are means of 12 observations per treatment.

[2]Apparent ileal digestibilities (%) were calculated as (1-[(CP or AA in digesta/CP or AA in feed) x (chromium in feed/chromium in digesta)]) x 100.

[3]*P*-value for the contrast comparing the 2 extracted SBM and the 3 extruded-expelled SBM.

Table 3.6. Standardized ileal digestibility (%) of CP and AA in high-protein (HP), low-oligosaccharide (LO), and conventional (CV) soybean meals (SBM) by growing pigs, AA experiment (Exp. 1)[1, 2]

Item Diet:	Extracted SBM		Extruded-expelled SBM					Contrast
	SBM-HP	SBM-CV	SBM-HP	SBM-LO	SBM-CV	SEM	*P*-value	*P*-value[3]
CP	88.3^{a}	87.3^{a}	90.9^{b}	91.5^{b}	89.1^{ab}	0.86	0.006	<0.001
Indispensable AA								
Arg	94.7^{a}	94.7^{a}	97.0^{b}	97.6^{b}	96.3^{b}	0.47	<0.001	< 0.001
His	89.7^{a}	90.6^{ab}	92.6^{bc}	93.0^{c}	90.4^{a}	0.71	0.006	0.006
Ile	88.3^{a}	88.4^{a}	92.3^{c}	92.7^{c}	90.5^{b}	0.63	<0.001	< 0.001
Leu	88.3^{a}	88.1^{a}	92.4^{b}	92.5^{b}	91.0^{b}	0.62	<0.001	< 0.001
Lys	90.1^{a}	90.0^{a}	93.2^{b}	93.3^{b}	90.4^{a}	0.80	0.003	0.003
Met	88.6^{a}	89.3^{ab}	92.1^{c}	92.4^{c}	91.0^{bc}	0.73	<0.001	<0.001
Phe	88.7^{a}	88.6^{a}	92.8^{b}	92.9^{b}	91.3^{b}	0.59	<0.001	< 0.001
Thr	85.3^{a}	85.5^{a}	88.5^{b}	88.4^{b}	85.7^{a}	0.92	0.020	0.012
Trp	89.6^{a}	93.8^{c}	91.7^{b}	92.5^{bc}	91.3^{ab}	0.65	<0.001	0.802
Val	86.8^{a}	86.8^{a}	90.6^{b}	90.5^{b}	88.3^{a}	0.72	<0.001	< 0.001
Mean	89.4^{a}	89.6^{a}	92.8^{b}	93.0^{b}	91.0^{a}	0.63	<0.001	< 0.001

Table 3.6 (cont.)

Dispensable AA

Ala	84.9[a]	85.0[a]	90.5[b]	90.3[b]	88.1[b]	1.05	<0.001	< 0.001
Asp	86.1[a]	86.0[a]	89.2[b]	89.7[b]	86.3[a]	0.93	0.007	0.008
Cys	82.9[ab]	83.0[ab]	83.8[b]	85.2[b]	79.6[a]	1.26	0.045	0.927
Glu	87.5	87.7	89.3	89.5	87.2	1.06	0.394	0.283
Gly	88.1	88.2	91.6	89.9	86.3	2.06	0.433	0.551
Pro	117.1	114.4 [a]	121.4	124.0	120.2	3.00	0.198	0.030
Ser	89.2[a]	89.0[a]	91.7[b]	91.8[b]	89.9[ab]	0.67	0.007	0.002
Tyr	88.3[a]	88.7[a]	91.1[b]	91.4[b]	90.2[ab]	0.67	0.004	< 0.001
Mean	89.9	89.7	92.7	93.0	90.3	1.06	0.070	0.025
All AA	89.6[a]	89.6[a]	90.8[b]	93.0[b]	90.6[ab]	0.84	0.008	0.002

[a-c] Means within a row lacking a common superscript letter differ (*P* < 0.05).

[1]Data are least square means of 12 observations per treatment.

[2]Standardized ileal digestibility values 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 DMI): CP, 15.9; Arg, 0.57; His, 0.19; Ile, 0.33; Leu, 0.55; Lys, 0.54; Met, 0.08; Phe, 0.33; Thr, 0.61; Trp, 0.14; Val, 0.48; Ala, 0.64; Asp, 0.83; Cys, 0.21; Glu, 1.11; Gly, 1.65; Pro, 4.47; Ser, 0.56; Tyr, 0.28.

[3]*P*-value for the contrast comparing the 2 extracted SBM and the 3 extruded-expelled SBM.

Table 3.7. Daily energy balance (as-fed basis) for pigs fed diets containing high-protein (HP), low-oligosaccharide (LO), and conventional (CV) soybean meals (SBM), Exp. 2[1, 2]

Item		Extracted SBM		Extruded-expelled SBM				
	Corn	SBM-HP	SBM-CV	SBM-HP	SBM-LO	SBM-CV	SEM	P-value
GE intake, kcal	3,395	3,918	3,972	3,905	4062	4,227	225	0.028
GE in feces, kcal	317[a]	447[b]	510[bc]	446[b]	514[bc]	556[c]	175	0.002
GE in urine, kcal	122	109	126	132	129	144	74	0.71
ATTD[2] GE, %	90.6[c]	88.8[bc]	87.2[ab]	88.9[bc]	87.3[ab]	86.9[a]	0.66	0.005
DE, diet, kcal/kg	3,332[a]	3,402[a]	3,340[a]	3,471[b]	3,401[a]	3,394[a]	25	0.006
ME, diet, kcal/kg	3,220	3,294	3,219	3,338	3,272	3,261	33	0.12

[a-c] Values within a row lacking a common superscript letter are different ($P \leq$ 0.05).

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

[2]ATTD = apparent total tract digestibility.

Table 3.8. Energy concentration in corn, high-protein (HP), low-oligosaccharide (LO), and conventional (CON) soybean meals (SBM) Exp. 2[1]

Item		Extracted SBM		Extruded-expelled SBM					Contrast
	Corn	SBM-HP	SBM-CV	SBM-HP	SBM-LO	SBM-CV	SEM	*P*- value	*P*- value[2]
DE, kcal/kg,	3,417[a]	3,717[a]	3,418[a]	4,005[b]	3,679[a]	3,632[a]	108	0.005	0.04
ME, kcal/kg,	3,303	3,625	3,265	3,795	3,490	3,436	139	0.095	0.31
DE, kcal/kg DM	3,910[ab]	4,178[bc]	3,845[ab]	4,293[c]	3,923[ab]	3,827[a]	118	0.025	0.98
ME, kcal/kg DM	3,779	4,074	3,672	4,069	3,721	3,620	150	0.108	0.61

[a-c] Values within a row lacking a common superscript letter are different ($P \leq 0.05$).

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

[2]*P*-value for the contrast comparing the 2 extracted SBM and the 3 extruded-expelled SBM.

CHAPTER 4. EVALUATION OF CONVENTIONAL, HIGH PROTEIN, AND LOW OLIGOSACCHARIDE VARIETIES OF FULL FAT SOYBEANS FED TO WEANLING PIGS

ABSTRACT: Three experiments were conducted to evaluate the use of 3 sources of full fat soybeans (FFSB) by weanling pigs. The FFSB were produced from conventional (FFSB-CV), high-protein (FFSB-HP), and low oligosaccharide (FFSB-LO) varieties of soybeans that contained 36.8, 43.5, and 39.3% CP, respectively. A source of soybean meal (SBM) that was produced from a conventional variety of soybeans and contained 48.7% CP was also used. The standardized ileal digestibility (SID) of AA in the 4 ingredients was measured using 10 barrows (initial BW: 10.1 ± 1.82 kg) that were equipped with a T-cannula in the distal ileum and allotted to a replicated 5 × 5 Latin square design with 5 periods and 5 diets per square. Diets containing FFSB-CV, FFSB-HP, FFSB-LO, or SBM as the sole source of AA were formulated. A N-free diet was used to determine basal ileal endogenous losses of AA. The SID of Leu, Lys, and Phe in FFSB-CV was greater ($P < 0.05$) than in SBM, but the SID of AA in FFSB-HP and FFSB-LO were not different from the SID of AA in SBM. With the exception of Met, Trp, and Cys, no differences in SID of AA among the 3 sources of FFSB were observed. The DE and ME in the 3 sources of FFSB and in SBM were measured using 40 barrows (initial BW: 18.5 ± 1.54 kg) that were placed in metabolism cages and randomly allotted to 5 diets. A corn-based diet and 4 diets containing corn and each source of FFSB or SBM were formulated. The ME in FFSB-CV, FFSB-HP, FFSB-LO, and in SBM was 4,990, 4,515, 4,769, and 3,970 kcal/kg DM, respectively. All these values were different ($P < 0.05$). A 33 d performance experiment was conducted using 128 weanling barrows (initial BW: 6.65 ± 2.85 kg). Phase 1 and phase 2 diets that contained each source of FFSB and SBM were formulated based on the values for SID AA and ME that were measured in the previous 2 experiments. Each diet was fed to 8 pens of 4 pigs. Pigs fed the diet containing FFSB-LO had greater ($P < 0.05$) ADFI than pigs fed diets containing SBM. The G:F for pigs fed SBM was greater ($P < 0.05$) than for pigs fed diets containing FFSB-HP, but not different from that of pigs fed diets containing FFSB-LO or FFSB-CV. We conclude that FFSB-CV has a greater SID of Leu, Lys, and Phe and a greater concentration of ME than SBM if fed to weanling pigs. Likewise, the ME in FFSB-HP and FFSB-LO are greater than in SBM. For the growth experiment the ADG of pigs fed the FFSB-HP diets was not different from the pigs fed the FFSB-CV and FFSB-LO diets, although a lower concentration of FFSB-HP was used.

Key Words: Amino acids, energy, full fat soybeans, soybean meal, weanling pigs

INTRODUCTION

Soybeans can be fed to swine as full-fat soybeans (**FFSB**) or made into soybean meal (**SBM**). Full fat soybeans contain approximately 37% CP and approximately 18% oil (Marty and Chavez, 1993). The standardized ileal digestibility (**SID**) of AA in FFSB is greater than in SBM if fed to growing finishing pigs (Cervantes-Pahm and Stein, 2008) and FFSB is an excellent source of AA and energy in poultry diets (Mateos, 1996). Performance of weanling pigs may be also improved if FFSB rather than SBM is used (Kim and Kim, 1997). New varieties of FFSB with increased protein concentration (**FFSB-HP**) or low concentration of oligosaccharide (**FFSB-LO**) compared with conventional FFSB (**FFSB-CV**) have recently been selected. The SID of AA in FFSB-

HP is similar to the SID of AA in FFSB-CV if fed to growing pigs (Cervantes-Pahm and Stein, 2008), but there is no information on the apparent ileal digestibility (**AID**) or the SID of CP and AA in FFSB-HP or FFSB-LO fed to weanling pigs. Likewise, there is no information about the energy concentration in these new varieties of FFSB and it is not known how weanling pigs will perform if FFSB-HP or FFSB-LO are included in the diets.

Therefore, the objective of this experiment was to measure the SID of AA and the concentration of DE and ME by weanling pigs in FFSB-HP and FFSB-LO and to compare these values to values for FFSB-CV and SBM. The second objective was to test the hypothesis that performance of weanling pigs is not compromised if FFSB-HP or FFSB-LO are included in the diet.

MATERIALS AND METHODS

General

Three experiments were conducted and the Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for each experiment. Pigs used in Exp. 1 (AA digestibility) and 2 (energy experiment) were the offspring of line 337 boars that were mated to C 22 females (Pig Improvement Company, Hendersonville, TN), but pigs used in Exp. 3 (performance experiment) were the offspring of Landrace boars mated to Yorkshire-duroc females (Pig Improvement Company, Hendersonville, TN). Three sources of FFSB and 1 source of SBM were used (Table 1). The FFSB were produced from conventional, high-protein, or low oligosaccharide varieties of soybeans (Schillinger Seed Inc., Des Moines, IA). All the FFSB were extruded using an Insta Pro 2000 extruder with a counter flow cooler. The extruder temperature was between 149 and 157°C. The SBM was produced from conventional soybeans (Rose Acre Farms Inc., Seymour, IN). The soybeans used for the production of the SBM were dehulled, but this was not the case for the soybeans used to produce the FFSB.

Exp 1. Amino Acid Digestibility

Experiment 1 was designed to measure the AID and SID of CP and AA in the 3 FFSB and in SBM. Ten barrows (initial BW: 10.1 ± 1.82 kg) were randomly allotted to a replicated 5 × 5 Latin square design with 5 diets and 5 periods. A T-cannula was surgically installed in the distal ileum of each pig according to procedures adapted from Stein et al. (1998). Pigs were housed individually in pens (0.9 × 1.8 m) that had fully slatted concrete floors. A feeder and a nipple drinker were installed in each pen.

Five diets were prepared (Tables 4.2 and 4.3). Four of the diets contained 1 source of FFSB or SBM and starch, sugar, and soybean oil. The last diet was a N-free diet that was used to measure basal endogenous losses of AA and CP. All diets also contained 0.4% chromic oxide as an indigestible marker. Solka floc was included in the N-free diet (4%) to increase the concentration of crude fiber. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998). All pigs were fed once daily at a level of 3.2 times the maintenance energy requirement (i.e., 106 kcal ME per $kg^{0.75}$; NRC, 1998), and water was available at all times throughout the experiment. Procedures for sample collection, chemical analysis of samples, and calculations of values for AID and SID were similar to those described in chapter 3.

Data were analyzed using the Mixed procedure of SAS (SAS Institute Inc., Cary, NC). The model included the fixed effect of treatment, the random effects of pig and period, and the residual error. If significant differences were detected, treatment means were separated using the PDIFF option adjusted by the Tukey-Kramer method. The pig was the experimental unit for all calculations and a *P*-value of 0.05 was used to assess significance among means.

Exp 2. Energy Experiment

Experiment 2 was designed to measure the DE and ME and the apparent total tract digestibility **(ATTD)** of energy in the 3 sources of FFSB and in the SBM that were used in Exp. 1. A total of 40 barrows (initial BW: 18.5 ± 1.54 kg) were placed in metabolism cages that were equipped with a feeder and a nipple drinker. The experiment was conducted as a randomized complete block design with 5 diets and 8 replications per diet. Pigs were allotted to their diets using the Experimental Animal Allotment Program (Kim and Lindemann, 2007). The 5 diets were based on corn or corn mixed with FFSB-CV, FFSB-HP, FFSB-LO, or SBM (Table 4). Corn, FFSB, and SBM were the sole sources of energy in the diets. The quantity of feed provided per pig daily was calculated as 3.2 times the estimated requirement for maintenance energy for the smallest pig in each replicate and divided into 2 equal meals. Water was available at all times. Pigs were fed experimental diets for 14 d. The initial 7 d was considered an adaptation period to the diet. Chromic oxide (0.5%) and ferric oxide (0.5%) were added to the diet in the morning meals on d 8 and 13, respectively. Fecal collections were initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared in the feces according to the marker to marker approach (Adeola, 2001). During collection periods, feces were collected twice daily. Urine collection was initiated after feeding the morning meal on d 8 and ceased after feeding the morning meal on d 13. Urine buckets were placed under the metabolism cages and emptied twice daily. A preservative of 20 mL of sulfuric acid was added to each bucket every time they were emptied to reduce volatilization of nitrogenous compounds in the urine. Procedures for sample collection, analysis of samples, and calculations of ATTD, DE, and ME were similar to those described by Baker and Stein (2009). Data were analyzed using the GLM procedure of SAS (SAS Institute Inc., Cary, NC). The MIXED model included the fixed effect of treatment, the random effect of block, and the residual error. Other statistical analysis were performed as described for the AA digestibility experiment.

Exp 3. Performance Experiment

Experiment 3 was designed to measure growth performance of pigs fed diets containing each of the 3 FFSB or the SBM that were used in the previous 2 experiments. A total of 128 pigs (initial BW: 6.65 ± 2.85 kg) were weaned at approximately 20 d of age. All pigs were fed a common transition diet for 3 d post-weaning before being allotted to experimental diets. Phase 1 diets were fed during the initial 14 d of the experiment and Phase 2 diets were fed during the following 19 d. All diets (Table 5 and 6) were formulated to meet or exceed current estimates for nutrient requirements (NRC, 1998). All diets within each phase were formulated to contain the same quantities of SID AA and ME. Values for SID of AA and ME of the 3 FFSB and SBM were obtained from

Exp. 1 and 2. Values for the SID of AA and ME for all other ingredients were from NRC (1998).

Pigs were allotted to 4 dietary treatments with 4 pigs per pen and 8 pen replicates per treatment in a randomized complete block design based on BW (Kim and Lindemann, 2007). Pigs were housed in 1.2 × 1.2 m pens that have fully slatted floors. A feeder and a nipple drinker were installed in each pen. Feed and water were provided on an ad libitum basis throughout the experiment.

Individual pig BW were recorded at the start of the experiment, at the end of Phase 1, and at the end of the experiment. Daily feed allotments were recorded as well. At the end of phase 1, a pig fed the FFSB-CV diet was removed from the experiment due to growth retardation and the feed intake of the remaining pigs in the pen was estimated using the procedure described by Lindemann and Kim (2007). At the conclusion of the experiment, data were summarized to calculate ADG, ADFI, and G:F for each pen and treatment group. The pen was the experimental unit for all calculations. Data were analyzed as described for the energy experiment.

RESULTS

Nutrient Composition

The concentration of CP and AA were greater in FFSB-HP and SBM compared with FFSB-CV and FFSB-LO (Table 4.1). Concentrations of ether extract, NDF, and ADF were lower in SBM than in the 3 FFSB. The concentration of sucrose was lower in FFSB-HP compared with all other meals, but the concentration of stachyose and raffinose was lower in FFSB-LO compared with all other meals. Among the FFSB, the concentration of stachyose was greatest in FFSB-HP and the concentration of raffinose was greatest in FFSB-CV. The concentration of ether extract was greatest in FFSB-CV compared with the other FFSB. The concentration of NDF and ADF was greatest in FFSB-LO compared with the other 2 FFSB.

Exp 1. Amino Acid Digestibility

The AID of CP in FFSB-CV (85.0%) was greater ($P < 0.05$) than in SBM (81.2%; Table 7), but the AID of CP in FFSB-HP (82.8%) and FFSB-LO (81.7%) were not different from the AID of CP in FFSB-CV and SBM. The AID of His, Ile, Leu, Met, Trp, Val, Cys, and Tyr were greater ($P < 0.05$) in FFSB-CV than in FFSB-HP, but for all other AA, no differences between these 2 meals were observed.

There were no differences in the AID of AA between FFSB-CV and FFSB-LO with the exception that the AID of Trp was greater ($P < 0.05$) in FFSB-CV than in FFSB-LO. The AID of AA in FFSB-CV and in SBM were not different with the exception that the AID of Lys, Phe, and Asp were greater ($P < 0.05$) in FFSB-CV than in SBM. Likewise, no differences in AID between FFSB-HP and SBM were observed except that the AID of Cys was lower ($P < 0.05$) in FFSB-HP than in SBM.

The SID of CP in FFSB-CV (92.0%) was greater ($P < 0.05$) than in SBM (88.1%), but none of these values were different from the SID of CP in FFSB-HP (90.1%) and FFSB-LO (89.2%; Table 4.8). There were no differences between FFSB-CV and FFSB-HP in the SID of AA with the exception that the SID of Met, Trp, and Cys were greater in FFSB-CV than in FFSB-HP. The SID of Trp was also greater ($P < 0.001$) in FFSB-CV compared with FFSB-LO, but for all other AA, no differences between these 2 meals were observed. Likewise, no differences between FFSB-HP and FFSB-LO were observed. The SID of Leu, Lys, Phe, and Asp, but not for any other AA, was greater ($P < 0.05$) in FFSB-CV than in SBM, but there were no differences between SBM and FFSB-HP or between SBM and FFSB-LO.

Exp 2. Energy Experiment

Pigs fed the FFSB-CV diet consumed more ($P < 0.05$) GE (3,314 kcal/d) than pigs fed any of the other diets (Table 4.9), and pigs fed the FFSB-HP or the FFSB-LO diets consumed more ($P < 0.05$) GE (3,078 and 3,047 kcal/d, respectively) than pigs fed the SBM or the corn diets (2,841 and 2,519 kcal/d, respectively). The fecal excretion of GE did not differ among diets. Pigs fed the FFSB-HP diet excreted more ($P < 0.05$) GE in the urine (130 kcal/d) than pigs fed the FFSB-LO or the corn diets (98 and 57 kcal/d, respectively). Pigs fed the diets containing FFSB-CV or SBM also excreted more ($P < 0.05$) GE in the urine (110 and 120 kcal/d, respectively) than pigs fed the corn diet.

Pigs fed the FFSB-CV diet, the FFSB-HP diet, and the FFSB-LO diet had greater ($P < 0.05$) ATTD of GE than pigs fed the corn diet (87.6, 87.0, and 86.8 vs. 84.3%), but pigs fed the SBM diet had an ATTD of GE (86.0%) that was not different from any of the other diets. The DE and ME in the FFSB-CV diet (3,939 and 3,789 kcal/kg, respectively) was greater ($P < 0.05$) than the DE and ME of all other diets. The DE and ME in the FFSB-HP diet (3,620 and 3,444 kcal/kg) and in the FFSB-LO diet (3,688 and 3,552 kcal/kg) diets were greater ($P < 0.05$) than the DE and ME in the SBM and corn diets (3,296 and 3,135 kcal/kg and 3,030 and 2,948 kcal/kg, respectively)

The DE in FFSB-CV (4,931 kcal/kg), FFSB-HP (4,554 kcal/kg), FFSB-LO (4,721 kcal/kg), SBM (3,818 kcal/kg), and corn (3,142 kcal/kg) were all different from each other ($P < 0.05$; Table 10). Likewise, the ME for FFSB-CV (4,712 kcal/kg), FFSB-LO (4,503 kcal/kg), FFSB-HP (4,238 kcal/kg), SBM (3,523 kcal/kg), and corn (3,057 kcal/kg) were all different ($P < 0.05$).

On a DM basis, the DE for FFSB-CV was also greater ($P < 0.05$) than the DE for FFSB-LO, FFSB-HP, SBM, and corn (5,223 vs. 4,999, 4,851, 4,303, and 3,689 kcal/kg DM, respectively). The DE for FFSB-LO and FFSB-HP were not different, but both of these values were greater ($P < 0.05$) than the DE in SBM and corn. The DE in corn was lower ($P < 0.05$) than in all other ingredients. The ME for FFSB-CV (4,990 kcal/kg DM), FFSB-LO (4,769 kcal/kg DM), FFSB-HP (4,515 kcal/kg DM), and SBM (3,970 kcal/kg DM) were different ($P < 0.05$), but all these values were greater ($P < 0.05$) than the ME of corn (3,590 kcal/kg DM).

Exp 3. Performance Experiment

There were no differences among treatments in the initial BW of the pigs. Likewise, pig BW at the end of phase 1 and at the end of phase 2 were not influenced by dietary treatments. The ADFI and the ADG were not influenced by dietary treatments in phase 1, but pigs fed the diet containing SBM had a greater ($P < 0.05$) G:F than pigs fed the FFSB-HP diet (0.78 vs. 0.63). In phase 2, no differences among dietary treatments were observed for ADFI, ADG, or G:F. For the entire period, pigs fed the diets containing FFSB-LO had a greater ($P < 0.05$) ADFI than pigs fed SBM, but pigs fed FFSB-HP and FFSB-CV were not different from FFSB-LO or SBM. The ADG was not different among treatments. Pigs fed the SBM diet had a greater ($P < 0.05$) G:F than pigs fed the FFSB-HP diets (0.68 vs. 0.61), but pigs fed the FFSB-LO or FFSB-CV diets had G:F values that were not different from pigs fed the FFSB-CV or the FFSB-LO diets (0.64 and 0.64, respectively).

DISCUSSION

Composition of Ingredients

The nutrient composition of SBM concurs with published values (NRC, 1998) and the nutrient composition for FFSB-CV and FFSB-HP is in agreement with previous data (Cervantes-Pahm and Stein, 2008). The concentration of NDF and ADF were greater in all the FFSB compared with SBM, which is likely because the FFSB were not dehulled as were the soybeans used to produce the SBM.

The CP and AA concentration in FFSB-HP was greater than in the FFSB-CV and FFSB-LO, which is a result of the FFSB-HP being selected for a greater concentration of CP. The concentrations of stachyose and raffinose were lower in FFSB-LO compared with the other FFSB and SBM, which was expected because this variety was selected for low concentrations of oligosaccharides. The concentration of sucrose was lowest in FFSB-HP compared with the other FFSB and SBM, which is in agreement with previous data (Cervantes-Pahm and Stein, 2008; Baker and Stein, 2009). An inverse relationship between CP and sucrose is often observed in soybeans (Hartwig et al., 1997). The SBM contained less stachyose and raffinose than FFSB-CV and FFSB-HP, which may be a result of the SBM being dehulled.

Exp 1. Amino Acid Digestibility

The AID and SID for most AA in FFSB-CV were similar to values for FFSB-HP, but because of the increased concentration of AA in FFSB-HP compared with FFSB-CV, greater quantities of digestible AA are provided by FFSB-HP than by FFSB-CV. This observation is in agreement with data obtained for FFSB-HP and FFSB-CV fed to growing-finishing pigs (Cervantes-Pahm and Stein, 2008).

The AID and SID of AA in FFSB-CV and FFSB-LO were similar, which shows that the digestibility of AA was not compromised when varieties with low concentrations of oligosaccharides were selected. This conclusion also agrees with previous results obtained for extruded-expelled SBM fed to growing-finishing pigs (Baker and Stein, 2009). The greater SID of some AA in FFSB-CV compared with SBM was expected because the SID of most AA in FFSB is greater than in SBM fed to growing-finishing pigs (Cervantes-Pahm and Stein, 2008). This increase in the SID of AA in FFSB compared with SBM is due to the greater concentration of ether extract in FFSB than in SBM (Cervantes-Pahm and Stein, 2008).

The AID values for SBM were greater than values obtained by Caine et al. (1997) who also fed SBM to weanling pigs. The AID values obtained in the present experiment are also greater than AID values by weanling pigs for SBM and FFSB reported by Fan et al. (1995) and by growing pigs reported by Kim et al. (2000). However, SID values for SBM and FFSB obtained in the present experiment are in close agreement with values reported by Marty et al. (1994). Values for the SID of AA in SBM from the present experiment also agree with values from NRC (1998). It is possible that differences among varieties of soybeans, in processing procedures, or in experimental methodologies are responsible for the different results obtained among experiments.

The SBM used in the present experiment was from the same batch as the SBM used by Baker and Stein (2009) and fed to growing-finishing pigs. The values that were measured for SID for all AA were very similar between the 2 experiments and also similar to SID values reported for a different batch of conventional SBM that was fed to growing-finishing pigs by Cervantes-Pahm and Stein (2008). Likewise, the SID values obtained for FFSB-CV and FFSB-HP in the present experiment are within 2 to 3 percentage units of the values obtained for different batches of FFSB-CV and FFSB-HP fed to growing-finishing pigs (Cervantes-Pahm and Stein, 2008). These data, therefore, indicate that the digestibility of AA in FFSB-CV, FFSB-HP, and SBM is not different in weanling pigs compared with growing-finishing pigs.

Exp 2. Energy Experiment

The greater DE and ME in all the FFSB compared with SBM is most likely a result of the greater GE concentration in FFSB compared with SBM, which is a result of the greater concentration of ether extract in FFSB. The differences in ME among the 3 sources of FFSB are closely related to the concentration of ether extract in these soybeans with FFSB-CV having the greatest and FFSB-HP having the lowest concentration of ether extract. The values for DE and ME for corn that were measured in this experiment are lower than previously published values, but values for FFSB-CV and SBM are slightly greater than previous values (NRC, 1998). However, the DE values obtained in this experiment for SBM and FFSB-CV (3,970 and 4,990 kcal/kg DM, respectively) are in very close agreement with values reported by Marty and Chavez (1993) for SBM and FFSB (3,968 and 5,019 kcal/kg DM, respectively). We are not aware of any other data for the ME of SBM and FFSB fed to weanling pigs. Inclusion of FFSB in diets fed to weanling pigs will, therefore, increase the ME concentration of the diet.

Exp 3. Performance Experiment

The diets that were used in the performance experiment were formulated using the values for SID of AA and ME that were measured in Exp. 1 and 2. The ADG of pigs fed the FFSB-HP diets was not different from that of pigs fed the FFSB-CV and the FFSB-LO diets, although a lower concentration of FFSB-HP than of the other FFSB was used. This observation indicates that the greater concentration of digestible AA in FFSB-HP that was measured in Exp. 1 can be utilized by the pigs. However, the lower G:F for pigs fed the diets containing FFSB-HP compared with pigs fed the SBM diets indicates that the ME for the FFSB-HP may have been overestimated compared with the ME of SBM. The SBM-diet contained 5.5% soybean oil to compensate for the lower ME in SBM than in FFSB that was measured in Exp. 2. However, based on the G:F for pigs fed the diet containing SBM it may be speculated that the difference in ME between SBM and FFSB may be less than indicated from Exp. 2. It has been previously shown that weanling pig performance is not reduced if FFSB is included in the diet (Burnham et. al., 2000), but it has also been reported that pigs have greater ADFI and ADG if corn-barley based diets for weanling pigs are supplemented with SBM rather than with FFSB (Valencia et al., 2008). Thus, there seems to be some disagreements in the literature about the effects of including FFSB in diets fed to weanling pigs. In the present experiment, the extra fat in the SBM diet prevents us from making a direct comparison between SBM and FFSB.

Summary

Full fat soybeans produced from high protein varieties of soybeans have similar digestibility of AA as conventional soybeans when fed to weanling pigs, which results in greater concentrations of digestible AA in FFSB-HP than in FFSB-CV. Likewise, FFSB produced from conventional, high protein, or low oligosaccharide varieties of soybeans contain more DE and ME than SBM. Full fat soybeans produced from a low-oligosaccharide variety of soybeans have SID of AA that are not different from the SID in FFSB-CV and SBM. The DE and ME in FFSB-LO are also greater than in SBM, but lower than in FFSB-CV.

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TABLES

Table 4.1. Analyzed energy and nutrient composition of full fat soybeans from conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans and in conventional soybean meal (SBM), as fed-basis

	Ingredient			
Item	FFSB-CV	FFSB-HP	FFSB-LO	SBM
DM, %	94.44	93.88	94.41	88.76
GE, kcal/kg	5,439	5,295	5,279	4,197
CP, %	36.78	43.51	39.34	48.68
Ether extract, %	19.57	16.61	17.74	0.83
Ca, %	0.31	0.28	0.36	0.44
P, %	0.55	0.65	0.60	0.75
NDF, %	8.15	7.75	10.33	6.41
ADF, %	6.22	5.40	7.50	3.96
Sucrose, %	5.25	4.84	5.77	6.27
Stachyose, %	3.72	3.90	1.36	4.70
Raffinose, %	1.01	0.52	0.14	0.89
Trypsin inhibitor activity, TIU/mg	4.50	7.70	7.00	3.60
Indispensable AA, %				

Table 4.1 (cont.)

Arg	2.81	3.38	2.79	3.63
His	1.04	1.15	1.02	1.31
Ile	1.93	2.08	1.88	2.40
Leu	3.04	3.39	3.01	3.88
Lys	2.60	2.83	2.56	3.23
Met	0.60	0.64	0.56	0.73
Phe	1.99	2.24	1.96	2.54
Thr	1.45	1.60	1.44	1.87
Trp	0.64	0.62	0.61	0.72
Val	2.03	2.21	1.96	2.53
Dispensable AA, %				
Ala	1.73	1.86	1.66	2.19
Asp	4.43	5.05	4.45	5.66
Cys	0.62	0.66	0.65	0.73
Glu	6.88	7.93	6.83	8.81
Gly	1.73	1.89	1.67	2.13
Pro	1.93	2.04	1.92	2.46

Table 4.1 (cont.)

Ser	1.60	1.87	1.67	2.09

Tyr	1.39	1.54	1.40	1.77

Table 4.2. Ingredient composition (as-fed basis) of experimental diets containing conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans and in conventional soybean meal (SBM), AA experiment

Ingredient ,%	Diet				
	FFSB-CV	FFSB-HP	FFSB-LO	SBM	N-Free
FFSB-CV	51.60	-	-	-	-
FFSB-HP	-	43.60	-	-	-
FFSB-LO	-	-	48.30	-	-
SBM	-	-	-	39.00	-
Cornstarch	34.75	42.60	38.05	47.20	67.10
Soybean oil	-	-	-	-	4.00
Sugar	10.00	10.00	10.00	10.00	20.00
Solka floc[1]	-	-	-	-	4.00
Limestone	0.90	0.95	0.95	1.00	1.20
Monocalcium phosphate	1.65	1.75	1.60	1.70	1.20
Magnesium oxide	-	-	-	-	0.10
Potassium carbonate	-	-	-	-	0.40
Chromic oxide	0.40	0.40	0.40	0.40	0.40
Salt	0.40	0.40	0.40	0.40	0.40

Table 4.2 (cont.)

Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30

[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, 11,120 IU; vitamin D_3, 2,204 IU; vitamin E, 66 IU; vitamin K, 1.41 mg; thiamin, 0.24 mg; riboflavin, 6.6 mg; pyridoxine, 0.24 mg; vitamin B_{12}, 0.031 mg; D-pantothenic acid, 24 mg; niacin, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 0.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 125 mg as zinc oxide.

Table 4.3. Analyzed nutrient composition (as-fed basis) of experimental diets containing conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans and in conventional soybean meal (SBM), AA experiment

Item	Diet				
	FFSB-CV	FFSB-HP	FFSB-LO	SBM	N-Free
DM, %	92.65	91.87	92.59	90.22	85.26
CP, %	20.24	20.76	19.64	21.59	0.71
Indispensable AA, %					
Arg	1.48	1.51	1.64	1.64	0.01
His	0.55	0.52	0.61	0.60	0.01
Ile	1.00	0.93	1.09	1.07	0.01
Leu	1.64	1.56	1.81	1.79	0.03
Lys	1.38	1.29	1.52	1.47	0.02
Met	0.31	0.28	0.35	0.33	0.00
Phe	1.06	1.02	1.17	1.16	0.02
Thr	0.79	0.75	0.88	0.88	0.01

Table 4.3 (cont.)

Trp	0.30	0.28	0.28	0.32	< 0.04
Val	1.06	0.99	1.15	1.13	0.02
Dispensable AA, %					
Ala	0.92	0.86	1.02	1.00	0.02
Asp	2.37	2.31	2.69	2.61	0.02
Cys	0.33	0.29	0.37	0.34	0.00
Glu	3.67	3.66	4.10	4.07	0.07
Gly	0.91	0.86	1.01	0.96	0.01
Pro	1.00	0.97	1.07	1.13	0.02
Ser	0.90	0.88	1.03	1.02	0.01
Tyr	0.66	0.63	0.74	0.73	0.01

Table 4.4. Composition (as-fed basis) of experimental diets containing conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans and in conventional soybean meal (SBM), energy experiment

Item	Diet				
	Corn	FFSB-CV	FFSB-HP	FFSB-LO	SBM
Ingredient, %					
Corn	96.45	46.90	55.80	55.80	58.75
FFSB-CV	-	50.00	-	-	-
FFSB-HP	-	-	41.00	-	-
FFSB-LO	-	-	-	41.00	-
SBM	-	-	-	-	38.00
Limestone	1.35	1.00	1.05	1.05	1.10
Monocalcium phosphate	1.50	1.40	1.45	1.45	1.45
Salt	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix [1]	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00
Analyzed composition					
Energy, kcal/kg	3,596	4,495	4,160	4,248	3,834
DM, %	85.08	89.44	87.92	88.50	85.26

[1]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A, 10,990 IU; vitamin D_3, 1,648 IU; vitamin E, 55 IU; vitamin K, 4.4 mg; thiamin, 3.3 mg; riboflavin, 9.9 mg; pyridoxine, 3.3 mg; vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg; niacin, 55 mg; folic acid, 1.1 mg; biotin, 0.17 mg; Cu, 16 mg as copper sulfate; Fe, 165 mg as iron sulfate; I, 0.36 mg as potassium iodate; Mn, 44 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 125 mg as zinc oxide.

Table 4.5. Ingredient composition (as-fed basis) of diets containing conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans or conventional soybean meal (SBM), performance experiment

	Phase 1				Phase 2			
Item	FFSB-CV	FFSB-HP	FFSB-LO	SBM	FFSB-CV	FFSB-HP	FFSB-LO	SBM
Ingredient, %								
Corn	41.20	43.00	40.30	41.05	60.80	62.53	59.85	60.85
Whey, dried	20.00	20.00	20.00	20.00	-	-	-	-
FFSB-CV	30.00	-	-	-	31.75	-	-	-
FFSB-HP	-	28.20	-	-	-	30.00	-	-
FFSB-LO	-	-	31.00	-	-	-	32.75	-
SBM	-	-	-	24.75	-	-	-	26.25
Fish meal	6.00	6.00	6.00	6.00	4.00	4.00	4.00	4.00
Soybean oil	-	-	-	5.50	-	-	-	5.50
Mecadox premix[1]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L-Lys HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL-Met	0.08	0.09	0.08	0.09	0.09	0.10	0.09	0.10
L-Thr	0.14	0.14	0.14	0.12	0.13	0.12	0.13	0.11
Limestone	0.50	0.52	0.43	0.45	0.43	0.50	0.43	0.44
Dicalcium phosphate	0.23	0.20	0.20	0.19	0.95	0.90	0.90	0.90
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
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1]The Mecadox premix (Phibro Animal Health, Ridgefield Park, NJ) provided 55 ppm of carbadox in the complete diet.

[2]Provided the following quantities of vitamins and microminerals per kilogram of complete diet: Vitamin A, 10,990 IU; vitamin D_3, 1,648 IU; vitamin E, 55 IU; vitamin K, 4.4 mg; thiamin, 3.3 mg; riboflavin, 9.9 mg; pyridoxine, 3.3 mg; vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg; niacin, 55 mg; folic acid, 1.1 mg; biotin, 0.17 mg; Cu, 16 mg as copper sulfate; Fe, 165 mg as iron sulfate; I, 0.36 mg as potassium iodate; Mn, 44 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 165 mg as zinc oxide.

Table 4.6. Analyzed nutrient composition (as-fed basis) of experimental diets containing conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans or conventional soybean meal (SBM), performance experiment

Diet	Phase 1				Phase 2			
Item	FFSB-CV	FFSB-HP	FFSB-LO	SBM	FFSB-CV	FFSB-HP	FFSB-LO	SBM
CP, %	21.05	21.89	23.68	23.22	18.60	20.48	18.66	21.75
GE, kcal/kg	4,312	4,131	4,241	4,134	4,323	4,127	4,268	4,193
Indispensable AA								
Arg	1.23	1.36	1.59	1.35	1.16	1.42	1.24	1.26
His	0.50	0.53	0.63	0.55	0.48	0.54	0.50	0.51
Ile	0.93	0.98	1.15	0.98	0.80	0.89	0.84	0.86
Leu	1.71	1.80	2.05	1.79	1.50	1.69	1.61	1.66
Lys	1.45	1.44	1.69	1.49	1.21	1.37	1.26	1.25
Met	0.43	0.44	0.47	0.42	0.37	0.44	0.44	0.43
Phe	0.95	1.01	1.20	1.01	0.85	0.98	0.93	0.96
Thr	0.91	0.91	1.07	0.95	0.76	0.85	0.81	0.80
Trp	0.27	0.27	0.32	0.29	0.25	0.26	0.26	0.26

Table 4.6 (cont.)

Val	1.01	1.07	1.24	1.08	0.90	1.00	0.94	0.97
Dispensable AA								
Ala	1.04	1.08	1.20	1.09	0.93	1.02	0.99	1.02
Asp	2.02	2.16	2.63	2.17	1.80	2.09	1.91	1.92
Cys	0.32	0.34	0.42	0.33	0.30	0.34	0.33	0.32
Glu	3.41	3.72	4.27	3.36	3.09	3.61	3.30	3.37
Gly	0.94	0.97	1.11	0.97	0.85	0.96	0.92	0.90
Pro	1.03	1.10	1.23	1.08	0.96	1.07	1.01	1.02
Ser	0.77	0.78	0.96	0.81	0.70	0.79	0.71	0.72
Tyr	0.65	0.66	0.82	0.69	0.58	0.65	0.63	0.63

Table 4.7. Apparent ileal digestibility (%) of CP and AA in conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans and in conventional soybean meal (SBM) fed to weanling pigs, AA experiment[1, 2]

Item	Diet					
	FFSB-CV	FFSB-HP	FFSB-LO	SBM	SEM	*P*-value
CP, %	85.0[a]	82.8[ab]	81.7[ab]	81.2[b]	1.19	0.049
Indispensable AA						
Arg	94.0	92.2	93.0	92.2	0.66	0.106
His	90.8[a]	88.3[b]	89.6[ab]	89.7[ab]	0.67	0.048
Ile	89.9[a]	87.3[b]	88.4[ab]	87.6[ab]	0.71	0.035
Leu	89.6[a]	87.0[b]	88.2[ab]	87.1[ab]	0.73	0.034
Lys	90.9[a]	88.0[ab]	89.9[ab]	87.9[b]	0.83	0.023
Met	90.9[a]	87.6[b]	89.5[ab]	89.6[ab]	0.72	0.013
Phe	90.5[a]	88.3[ab]	89.2[ab]	87.7[b]	0.67	0.016
Thr	83.4	80.0	82.5	82.5	1.04	0.090
Trp	89.4[a]	85.4[b]	84.1[b]	86.7[ab]	0.78	< 0.001

Table 4.7 (cont.)

Val	86.8[a]	83.5[b]	85.2[ab]	84.6[ab]	0.87	0.038
Mean	89.9[a]	87.3[b]	88.5[ab]	87.7[ab]	0.71	0.034
Dispensable AA						
Ala	85.4	81.8	84.6	82.5	1.11	0.044
Asp	89.4[a]	87.4[ab]	89.0[ab]	86.2[b]	0.81	0.022
Cys	82.9[a]	75.3[b]	80.6[ab]	81.9[a]	1.79	0.010
Glu	91.2	88.9	89.9	87.7	1.06	0.099
Gly	77.9	73.2	77.1	73.9	2.28	0.136
Pro	71.5	58.4	70.3	62.8	9.83	0.342
Ser	87.6	84.7	86.5	85.9	0.90	0.097
Tyr	89.7[a]	86.7[b]	88.0[ab]	88.1[ab]	0.74	0.042
Mean	86.6	83.0	85.5	83.1	1.49	0.051

Table 4.7 (cont.)

All AA	88.6	85.0	86.9	85.2	1.08	0.036

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

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

[2]Apparent ileal digestibilities were calculated as (1-[(AA in digesta/AA in feed) × (Cr in feed/Cr in digesta)]) × 100%.

Table 4.8. Standardized ileal digestibility (%) of CP and AA in conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans and in conventional soybean meal (SBM) fed to weanling pigs, AA experiment[1,2]

Item	Diet					
	FFSB-CV	FFSB-HP	FFSB-LO	SBM	SEM	*P*-value
CP, %	92.0[a]	90.1[ab]	89.2[ab]	88.1[b]	1.19	0.051
Indispensable AA						
Arg	97.1	95.4	95.9	95.1	0.66	0.091
His	93.7	91.5	92.2	92.3	0.67	0.093
Ile	92.8	90.6	91.2	90.4	0.71	0.054
Leu	92.4[a]	90.2[ab]	90.9[ab]	89.8[b]	0.73	0.041
Lys	94.3[a]	91.9[ab]	93.1[ab]	91.3[b]	0.83	0.038
Met	93.3[a]	90.3[b]	91.6[ab]	91.9[ab]	0.72	0.034
Phe	93.2[a]	91.3[ab]	91.8[ab]	90.3[b]	0.67	0.015
Thr	89.7	87.0	88.4	88.4	1.04	0.264
Trp	92.4[a]	88.7[b]	87.3[b]	89.6[ab]	0.78	< 0.001

Table 4.8 (cont.)

Val	91.4	88.5	89.5	89.0	0.87	0.083
Mean	93.3	91.0	91.8	91.0	0.71	0.049
Dispensable AA						
Ala	91.0	88.1	89.8	87.9	1.11	0.094
Asp	92.3[a]	90.6[ab]	91.7[ab]	88.9[b]	0.81	0.023
Cys	87.9[a]	81.2[b]	85.1[ab]	86.8[ab]	1.79	0.030
Glu	93.5	91.3	92.0	89.8	1.06	0.090
Gly	92.0	88.9	90.2	87.8	2.28	0.317
Pro	105.2	94.9	102.9	93.9	9.83	0.422
Ser	92.6	90.0	91.0	90.4	0.90	0.145
Tyr	93.2	90.6	91.3	91.4	0.74	0.071
Mean	93.7	90.6	92.0	89.7	1.49	0.066

Table 4.8 (cont.)

All AA	93.5[a]	90.8[ab]	91.9[ab]	90.3[b]	1.08	0.051

[a,b]Means within a row lacking a common superscript letter differ (*P* < 0.05).

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

[2]Standardized ileal digestibility values 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 DMI): CP, 16.89; Arg, 0.57; His, 0.19; Ile, 0.36; Leu, 0.58; Lys, 0.59; Met, 0.09; Phe, 0.35; Thr, 0.11; Trp, 0.14; Val, 0.59; Ala, 0.64; Asp, 0.85; Cys, 0.20; Glu, 1.02; Gly, 1.59; Pro, 4.18; Ser, 0.55; and Tyr, 0.29.

Table 4.9. Daily energy balance for pigs fed diets containing corn or diets containing corn and full fat soybeans from conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans or conventional soybean meal (SBM), energy experiment[1,2]

Item	Diet						
	Corn	FFSB-CV	FFSB-HP	FFSB-LO	SBM	SEM	*P*-value
GE intake, kcal/d	2,519[d]	3,314[a]	3,078[b]	3,047[b]	2,841[c]	30.9	0.001
GE in feces, kcal/d	396	410	399	401	398	20.0	0.988
GE in urine, kcal/d	57[c]	110[ab]	130[a]	98[b]	120[ab]	7.8	0.001
ATTD GE, %[2]	84.3[b]	87.6[a]	87.0[a]	86.8[a]	86.0[ab]	0.65	0.008
DE, diet, kcal/kg	3,030[d]	3,939[a]	3,620[b]	3,688[b]	3,296[c]	26.5	0.001
ME, diet, kcal/kg	2,948[d]	3,789[a]	3,444[b]	3,552[b]	3,135[c]	26.1	0.001

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

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

[2]ATTD = apparent total tract digestibility.

Table 4.10. Energy concentration in corn and in full fat soybeans from conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans, and in conventional soybean meal (SBM), energy experiment[1]

Item	Ingredient						
	Corn	FFSB-CV	FFSB-HP	FFSB-LO	SBM	SEM	*P*-value
DE, kcal/kg	3,142[e]	4,931[a]	4,554[c]	4,721[b]	3,818[d]	59.1	0.001
ME, kcal/kg	3,057[e]	4,712[a]	4,238[c]	4,503[b]	3,523[d]	58.9	0.001
DE, kcal/kg DM	3,689[d]	5,223[a]	4,851[b]	4,999[b]	4,303[c]	63.9	0.001
ME, kcal/kg DM	3,590[e]	4,990[a]	4,515[c]	4,769[b]	3,970[d]	63.9	0.001

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

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

Table 4.11. Performance of weanling pigs fed diets containing full fat soybeans from conventional (FFSB-CV), high protein (FFSB-HP), or low oligosaccharide (FFSB-LO) varieties of soybeans, and in conventional soybean meal (SBM), performance experiment[1]

Item	Diet					
	FFSB-CV	FFSB-HP	FFSB-LO	SBM	SEM	*P*-value
D 1-14						
Initial wt, kg	6.64	6.65	6.64	6.65	0.365	0.617
ADFI, g	399	443	455	387	0.029	0.110
ADG, g	283	272	306	297	0.015	0.317
G:F, g/g	0.71[ab]	0.63[b]	0.68[ab]	0.78[a]	0.04	0.028
Final BW, kg	10.60	10.46	10.92	10.80	0.499	0.338
D 14-33						
ADFI, g	851	875	905	836	0.026	0.103
ADG, g	529	526	564	545	0.020	0.369
G:F, g/g	0.62	0.60	0.62	0.65	0.013	0.075
Final BW, kg	20.66	20.45	21.62	21.15	0.817	0.294
D 1-33						
ADFI, g	659[ab]	692[ab]	714[a]	645[b]	0.024	0.035
ADG, g	425	418	454	440	0.016	0.283

Table 4.11 (cont.)

G:F, g/g	0.64^{ab}	0.61^{b}	0.64^{ab}	0.68^{a}	0.015	0.010

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

[1]Values are means of 8 observations per treatment.

CHAPTER 5. NUTRITIONAL VALUE OF SOYBEAN MEAL PRODUCED FROM HIGH PROTEIN OR LOW OLIGOSACCHARIDE VARIETIES OF SOYBEANS WHEN FED TO BROILER CHICKS AND ROOSTERS.

ABSTRACT: Three experiments were conducted to determine the feeding value to poultry of soybean meal (SBM) produced from high protein (SBM-HP), low oligosaccharide (SBM-LO), and conventional (SBM-CV) varieties of soybeans. The 3 SBM contained 54.9, 53.6, and 47.5% CP, respectively. The standardized digestibility (SDD) of AA in the 3 ingredients was measured using a precision-fed rooster assay with cecectomized Single Comb White Leghorn roosters (68 wk old). Twelve roosters were allotted to the 3 SBM sources in a completely randomized design. After a 24 h feed withdrawal, birds were precision-fed 30 g of their assigned source of SBM via crop intubation. Excreta samples were collected for 48 h after intubation. Results showed that the SDD of AA was not different among the 3 sources of SBM. The concentrations of TME_n were measured in the 3 sources of SBM using a precision-fed rooster assay with conventional Single Comb White Leghorn roosters (68 wk). Twelve roosters were allotted to the 3 SBM in a completely randomized block design. Feeding and excreta collections were conducted as described for the cecectomized roosters. Results showed that the TME_n in SBM-HP and SBM-CV were greater ($P < 0.001$) than in SBM-LO (3.355 and 3.286 vs. 2.971 kcal/g DM). A 14 d growth performance experiment was also conducted using 240 Ross 308 commercial broiler male chicks (mean BW: 86.4 ± 1.0 g) that were allotted to a completely randomized block design. There were 5 chicks per pen and 8 pen replicates per diet. Three higher-energy (3,266 kcal TME_n/kg) and 3 lower-energy (3,166 kcal TME_n /kg) corn-soybean meal diets were formulated. Each source of SBM was used in 1 higher-energy and 1 lower-energy diet. Results showed that within energy level, no differences among the 3 sources of SBM was observed for the final BW of the chicks for ADG, but chicks fed high-energy diets had greater ($P < 0.005$) final BW and ADG than chicks fed low-energy diets. The G:F was greater ($P < 0.05$) for chicks fed the diet containing SBM-HP compared with chicks fed diets containing SBM-LO or SBM-CV at the lower-energy level, but at the higher-energy level, G:F was greater ($P < 0.05$) for chicks fed the diet containing SBM-LO than those fed the diet containing SBM-HP. It is concluded that the concentration of SBM in diets fed to broiler chicks can be reduced if SBM-HP or SBM-LO is used rather than SBM-CV without any negative effects on growth performance of the chicks.

Keywords: chick, high-protein soybean meal, low oligosaccharide soybean meal, rooster, TME_n.

INTRODUCTION

Soybeans can be fed to poultry as soybean meal (**SBM**) that is produced when the defatted flakes are ground. New varieties of soybeans with increased protein concentration or reduced concentrations of oligosaccharides compared with conventional soybeans have recently been identified. The concentration of CP in high-protein SBM (**SBM-HP**) is greater than in conventional SBM (**SBM-CV**) and the standardized ileal digestibility of AA in SBM-HP is similar to the digestibility of AA in SBM-CV when fed to growing pigs (Baker and Stein, 2009). Due to the greater concentration of AA in SBM-HP than in SBM-CV, greater quantities of digestible AA are provided in the SBM from

HP varieties than in SBM produced from conventional soybeans (Baker and Stein, 2009). The DE and ME in SBM-HP is similar to the DE and ME in SBM-CV when fed to pigs (Baker and Stein, 2009). The digestibility of AA and the concentration of ME by growing chicks in SBM-HP has, however, not been measured.

The concentration of stachyose and raffinose is lower in low oligosaccharide SBM (**SBM-LO**) than in SBM produced from other varieties of soybeans. The digestibility of AA in SBM-LO is, however, not different from the digestibility of AA in SBM-CV when fed to growing pigs, which shows that there are no detrimental effects of removing the oligosaccharides on AA digestibility (Baker and Stein, 2009). Soybean meal produced from low oligosaccharide varieties of soybeans contain 7 to 9% more ME if fed to poultry (Parsons et al., 2000), but the digestibility by chickens of AA in SBM-LO has not been measured. The presence of oligosaccharides in SBM also has a negative effect on pig performance (Liying et al., 2003), but there is no information about the effect of feeding SBM-LO to chicks.

Therefore, the objectives of this experiment were to measure the TME_n and AA digestibility by roosters in SBM-HP, SBM-LO, and SBM-CV. The second objective was to measure growth performance of growing chicks fed diets based on each of the 3 sources of SBM.

MATERIAL AND METHODS

General

All experimental protocols were approved by the Animal Care and Use Committee at the University of Illinois. Three sources of SBM were used in these experiments (Table 1). The SBM were produced from high-protein, low oligosaccharide, or conventional varieties of soybeans. Samples were processed at the ZFS (Zeeland Farm Services) processing plant (Zeeland, MI). Soybeans were processed in a 3-stage process. In the first stage, soybeans underwent cleaning, drying, conditioning, cracking, removal of hulls, more cracking, and flacking. In the second stage, soybeans underwent oil extraction using hexane solvent, which was subsequently removed by distillation. In the third stage, flakes were toasted, de-solvenized, dried, cooled, and ground into SBM.

The 3 sources of SBM were analyzed for sucrose, raffinose, and stachyose (Janauer and Englmaier, 1978), DM (method 930.15; AOAC, 2005), CP (method 990.03; AOAC, 2005), ADF (method 973.18; AOAC, 2005), NDF (Holst, 1973), Ca (method 978.02; AOAC, 2005), P (method 946.06; AOAC, 2005), trypsin inhibitors (method Ba 12-75; AOCS, 1998), and ether extract (method 920.39; AOAC, 2005). They were also analyzed for GE using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL) and for AA on a Hitachi Amino Acid Analyzer, Model No. L8800 (Hitachi High Technologies America, Inc; Pleasaton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Prior to analysis samples were hydrolyzed with 6 *N* HCl for 24 h at 110°C (method 982.30, alternative 3; AOAC, 2005). Methionine and Cys were determined as Met sulfone and cysteic acid, respectively, after cold performic acid oxidation overnight prior to hydrolysis (method 982.30, alternative 1; AOAC, 2005). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (method 982.30; AOAC, 2005).

Amino Acid Digestibility

Amino acid digestibility in the 3 sources of SBM was measured using a precision-fed rooster assay with cecectomized Single Comb White Leghorn roosters (68 wk old). Twelve roosters were cecectomized according to the procedure described by Parsons (1985). Birds were housed individually in 22.5 × 36 cm cages with raised wire floors in an environmentally controlled room. A 16-h light and 8-h dark cycle was provided, and water was accessible at all times. The 12 roosters were allotted to the 3 SBM sources in a completely randomized design with 4 birds per source of SBM. After a 24-h feed withdrawal, birds were precision-fed 30 g of their assigned source of SBM via crop intubation. Excreta samples were collected for 48 h after intubation using plastic collection trays that were placed under each rooster.

The basal endogenous losses of AA were measured from 4 additional roosters that were deprived of feed for 48 h. Plastic collection trays were placed under each rooster to collect extreta. Excreta samples were lyophilized and finely ground prior to chemical analysis.

Excreta from all the roosters were analyzed for AA as described for the 3 sources of SBM. The standardized digestibility (**SDD**) of AA was calculated using the method described by Sibbald (1979). Data for SDD of AA in the 3 sources of SBM were analyzed by ANOVA using SAS. Significance of differences among individual treatments were assessed using the Least Significant Difference test. The individual rooster was the experimental unit for all calculations and a P-value of 0.05 was used to assess differences among means.

TME_n Experiment

True metabolizable energy in the 3 sources of SBM was measured using a precision-fed rooster assay with conventional Single Comb White Leghorn roosters (68 wk old). Twelve intact roosters were housed individually in 22.5 × 36.0 cm cages with raised wire floors in an environmentally controlled room. A 16-h light and 8-h dark cycle was provided, and water was accessible at all times. The twelve roosters were allotted to the 3 SBM sources in a completely randomized design with 4 birds per source of SBM. After a 24-h feed withdrawal, birds were precision-fed 30 g of their assigned source of SBM via crop intubation. Excreta samples were collected for 48 h after intubation as described for the AA experiment. Excreta samples were lyophilized and analyzed in duplicate for GE using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). The instrument was standardized using benzoic acid and TME_n in each source of SBM was calculated as described by Parsons et al. (1992). Data were analyzed as described for the AA experiment.

Growth Performance Experiment

A growth assay was conducted using diets that contained SBM-HP, SBM-LO, and SBM-CV. A total of 240 Ross 308 commercial broiler male chicks were fed a corn and soybean meal-based starter diet for 7 d. This diet was formulated to contain nutrients according to NRC (1994) requirements. On d 8 post hatch, chicks (mean BW of 86.4 ± 1.0 g) were randomly allotted to 6 diets in a completely randomized design with 5 chicks per pen and 8 replicate pens per diet. Chicks were housed in battery cages with raised wire floors in an environmentally controlled room. Water and artificial light was provided at all times. The 6 diets included 2 diets with each source of SBM. A higher-energy diet with each source of SBM was formulated to contain 3,266 kcal TME_n/kg, 23% CP, 0.95% Met + Cys, and 1.3% Lys and a lower-energy diet with each source of SBM was formulated to contain 3,166 kcal TME_n/kg, 20% CP, 0.80% Met + Cys, and 1.0% Lys (Table 2). Diets were formulated based on data for SDD and TME_n that were measured in the AA and the TME_n experiments. Soybean oil was used to equalize concentrations of TME_n among the 3 higher-energy diets and among the 3 lower-energy diets. All chicks were weighed at the start of the experiment and at the conclusion of the experiment 14 d later. Daily feed allotments were recorded as well. At the conclusion of the experiment, data for ADG, ADFI, and G:F were calculated. Data were analyzed as described for the AA experiment.

RESULTS

Nutrient Composition

The concentration of CP and AA were greater in SBM-HP and SBM-LO compared with SBM-CV (Table 1). Concentrations of ADF, and NDF were lower in SBM-LO than in SBM-HP and SBM-CV. The concentration of sucrose was lower in SBM-HP compared with SBM-LO and SBM-CV, but the concentration of stachyose and raffinose was lower in SBM-LO compared with SBM-HP and SBM-CV. The concentration of stachyose was greater in SBM-HP than in SBM-CV but the concentration of raffinose was similar in SBM-HP and SBM-LO. The concentration of ether extract was greater in SBM-CV compared with SBM-HP and SBM-LO.

Amino Acid Digestibility and TME_n Values

There were no differences among the 3 sources of SBM in values for SDD of any of the indispensable AA (Table 3). Likewise, for the dispensable AA, no differences among the 3 sources were observed. The TME_n in SBM-HP and SBM-CV were greater ($P < 0.001$) than in SBM-LO (3.355 and 3.286 vs. 2.971 kcal/kg DM respectively), but the values for SBM-HP and SBM-CV were not different.

Growth Performance Experiment

There were no differences among treatments in the initial BW of the chicks (Table 4). Chicks fed the high-energy diets had greater ($P < 0.05$) final BW and ADG than chicks fed the low-energy diets, but within energy level, no differences among the 3 SBM were observed. The feed intake for chicks fed the low-energy diet containing SBM-HP was lower ($P < 0.05$) than for chicks fed the low-energy diet containing SBM-CV, but among chicks fed the high-energy diets, no differences among diets were observed.

The G:F was greater ($P < 0.001$) for chicks fed the high-energy diet containing SBM-LO compared with chicks fed the diet containing SBM-HP. In contrast, for the low-energy diets, chicks fed the diet containing SBM-HP had a greater ($P < 0.05$) G:F than chicks fed the diet containing SBM-LO or SBM-CV.

DISCUSSION

Composition of Ingredients

The nutrient composition of SBM concurs with published values (NRC, 1998) and the digestibilities of AA in SBM are generally greater than in other oilseed meals

(Stein et. al., 2008). The nutrient composition of SBM-HP compared with SBM-CV and the increased AA concentration is in agreement with previous data (Baker and Stein, 2009). The concentrations of stachyose and raffinose were lower in the SBM-LO compared with the other SBM, which was expected because this variety was selected to contain lower concentrations of oligosaccharides. This decrease in oligosaccharides is in agreement with previous data (Baker and Stein, 2009).

SDD of AA

The standardized digestibility of AA in SBM-CV was similar to previous data (Parsons et. al., 2000). The SDD of AA in SBM-HP and SBM-LO has not been previously measured in poultry, but the lack of a difference among the 3 meals agree with previous research with pigs (Cervantes-Pahm and Stein, 2008; Baker and Stein, 2009). This observation shows that the AA in SBM-HP and SBM-LO are absorbed to the same degree as AA in SBM-CV, but because of the greater concentration of AA in SBM-HP and SBM-LO, less SBM needs to be added to the diet when SBM-HP or SBM-LO is used. Another implication of this research is that the same SDD values for AA can be used in the formulation of diets for poultry regardless of the source of SBM being used.

TME_n

The TME_n in SBM-CV that was obtained in this experiment is similar to previously published data (NRC, 1994; Edwards et. al., 2000). Previous research has also shown that the TME_n in SBM-HP is greater than in SBM-CV because of the increased CP concentrations (Edwards et. al., 2000), this was also shown in the present experiment, there were no differences between SBM-LO and SBM-CV observed. It was reported that the concentration of TME_n is greater in SBM-LO than in SBM-CV (Parsons et. al. 2000), but the present data did not show this. It is possible that differences among varieties of soybeans is responsible for these differences among experiments.

Performance

The overall performance of the chicks is similar to data reported by Douglas and Parsons (2000). There were only minor differences within energy levels between chicks fed the different diets although chicks fed diets containing SBM-HP and SBM-LO contained less SBM than the diets containing SBM-CV. This observation indicates that the data for AA concentrations and SDD that were measured in the AA experiment are correct. The implication of this observation is that less SBM is needed if SBM-HP or SBM-LO are used in diets fed to growing chicks. This research also shows that chicks fed low-energy diets have growth performance that is inferior compared with chicks fed diets containing more energy.

In conclusion SBM-HP and SBM-LO have a greater nutritional value in diets for broilers because of the increased concentration of SDD of AA, which reduces the quantity of SBM that is needed in the diet.

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TABLES

Table 5.1. Analyzed energy and nutrient composition of soybean meal produced from high protein (SBM-HP), low oligosaccharide (SBM-LO), or conventional (SBM-CV) varieties of soybeans, as-fed basis

	Ingredient		
Item	SBM-HP	SBM-LO	SBM-CV
DM, %	88.7	88.7	87.5
GE, kcal/kg	4,280	4,266	4,171
CP, %	54.86	53.63	47.47
Ether extract, %	0.76	0.96	1.48
Ca, %	0.34	0.33	0.24
P, %	0.73	0.68	0.67
NDF, %	5.04	4.96	6.68
ADF, %	3.54	3.09	3.91
Sucrose, %	4.27	7.35	7.05
Stachyose, %	4.97	1.38	4.61

Table 5.1 (cont.)

Raffinose, %	0.93	0.18	0.93
Trypsin inhibitor activity, TIU/mg	4.50	3.50	3.20
Indispensable AA, %			
Arg	4.27	4.05	3.56
His	1.44	1.35	1.25
Ile	2.54	2.41	2.25
Leu	4.35	4.10	3.76
Lys	3.56	3.33	3.14
Met	0.78	0.71	0.68
Phe	2.89	2.72	2.48
Thr	2.13	1.96	1.83
Trp	0.78	0.72	0.69
Val	2.64	2.50	2.36
Dispensable AA, %			
Ala	2.34	2.18	2.07

Table 5.1 (cont.)

Asp	6.42	6.00	5.40

Cys	0.78	0.73	0.65
Glu	10.31	9.51	8.54
Gly	2.31	2.14	2.00
Pro	2.72	2.42	2.36
Ser	2.57	2.36	2.10
Tyr	2.01	1.84	1.70

Table 5.2. Composition of diets containing soybean meal produced from high protein (SBM-HP), low oligosaccharide (SBM-LO), or conventional (SBM-CV) varieties of soybeans, as fed basis, that were used in the broiler growth performance experiment.

Diet	Higher energy			Lower energy		
Item	SBM-HP	SBM-LO	SBM-CV	SBM-HP	SBM-LO	SBM-CV
Ingredient						
Corn	60.87	56.88	53.16	69.76	66.64	63.61
SBM-HP	31.20	-	-	24.90	-	-
SBM-LO	-	32.90	-	-	26.23	-
SBM-CV	-	-	37.90	-	-	30.20
Soybean oil	3.39	5.61	4.50	1.00	2.75	1.90
Dicalcium phosphate	2.08	2.08	2.00	2.09	2.08	2.08
Limestone	1.17	1.17	1.17	1.20	1.20	1.17
Vitamin mix[1]	0.20	0.20	0.20	0.20	0.20	0.20
Mineral mix[2]	0.15	0.15	0.15	0.15	0.15	0.15
Salt	0.45	0.45	0.45	0.45	0.45	0.45
DL-Met	0.29	0.33	0.30	0.20	0.23	0.20
L-Lys·HCl	0.16	0.19	0.13	0.01	0.03	-
Bacitracin-MD premix[3]	0.04	0.04	0.04	0.04	0.04	0.04
Analyzed composition						
DM, %	86.32	85.58	84.95	84.46	85.74	85.19
GE, kcal/kg	4,024	4,098	4,037	3,801	3,959	3,912
CP, %	23.5	22.7	23.3	20.3	20.0	20.4
Ether extract, %	4.08	7.09	6.02	2.74	4.25	3.59

Table 5.2 (cont.)

Ca, %	1.12	1.03	0.96	1.08	1.10	1.08

[1]Provided per kilogram of complete diet: retinyl acetate, 4,400 IU; cholecalciferol, 25µ; DL-α-tocopheryl acetate, 11 IU; vitamin B_{12}, 0.01 mg; riboflavin, 4.41 mg; D-pantothenic acid, 10 mg; niacin, 22 mg; and menadione sodium bisulfite, 2.33 mg.

[2]Provided per kilogram of complete diet: manganese, 75 mg as $MnSO_4 \cdot H_2O$; iron, 75 mg as $FeSO_4 \cdot H_2O$; Zinc, 75 mg from ZnO; copper, 5 mg from $CuO_4 \cdot 5H_2O$; iodine, 0.75 mg from ethylene diamine dihydroiodide; and selenium, 0.1 mg from Na_2SeO_3.

[3]Contributed 13.75 mg/kg of bacitracin methylene disalicylate (5.5%).

Table 5.3. Standardized AA digestibility (%) and TME_n of soybean meal produced from high protein (SBM-HP), low oligosaccharide (SBM-LO), or conventional (SBM-CV) varieties of soybeans and fed to rooster, as fed basis[1]

Item	Ingredient				
	SBM-HP	SBM-LO	SBM-CV	SEM	*P*-value
Indispensable AA					
Arg	92.16	90.60	90.13	0.90	0.296
His	90.32	89.10	88.20	0.74	0.183
Ile	93.10	92.68	91.05	0.73	0.164
Leu	92.89	92.59	91.04	0.81	0.274
Lys	92.47	89.85	88.54	1.03	0.065
Met	93.15	92.51	91.56	0.66	0.277
Phe	93.90	92.83	91.48	0.76	0.132
Thr	89.84	89.30	89.00	0.96	0.826
Trp	97.66	97.28	97.87	0.42	0.614
Val	89.43	90.10	89.53	1.08	0.896

Table 5.3 (cont.)

Dispensable AA					
Ala	90.47	89.70	87.80	0.82	0.112
Asp	92.31	92.38	91.30	0.63	0.436
Cys	86.34	85.85	87.19	1.03	0.660
Glu	94.82	94.20	93.65	0.52	0.325
Pro	93.01	93.46	92.32	0.77	0.593
Ser	92.80	93.37	93.26	1.04	0.919
Tyr	92.94	92.18	91.91	0.82	0.666
$TME_{n,}$ (kcal/g DM)	3.104[a]	2.984[b]	2.963[b]	0.02	0.031

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

[1]Data are means of 4 observations per treatment.

Table 5.4. Growth performance from d 8 to 21 post-hatch of broiler chicks fed soybean meal produced from high protein (SBM-HP), low oligosaccharide (SBM-LO), or conventional (SBM-CV) varieties of soybeans[1]

	High energy diets			Low energy diets				
Item	SBM-HP	SBM-LO	SBM-CV	SBM-HP	SBM-LO	SBM-CV	SEM	*P*-value
D 0-14								
Initial wt, g	87	87	86	87	87	86	0.20	0.993
Final wt, g	689[ab]	709[a]	697[a]	635[c]	643[c]	656[bc]	12.18	0.002
Weight gain, g	602[ab]	622[a]	610[a]	548[c]	556[c]	569[bc]	12.19	0.002
Feed intake, g	824[a]	803[ab]	809[ab]	767[b]	817[ab]	838[a]	18.65	0.158
Gain:feed, g/kg	732[b]	775[a]	755[ab]	722[b]	679[c]	680[c]	13.00	<0.001

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

[1]Values are means of 8 observations per treatment.