NUTRITIONAL EVALUATION OF FERMENTED SOYBEAN MEAL FED TO WEANLING PIGS

BY

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THESIS

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ABSTRACT

Three experiments were conducted to determine P, AA, and energy digestibility in fermented soybean meal (**FSBM**), conventional soybean meal (**SBM-CV**), and fish meal. Three growth performance experiments were also conducted using the values for the digestibility of P, AA, and energy determined in the initial 3 experiments to formulate diets. The objective of Exp. 1 was to determine the apparent total tract digestibility (**ATTD**) and the standardized total tract digestibility (**STTD**) of P without or with the addition of microbial phytase (Optiphos 2000, Enzyvia, Sheridan, IN) in FSBM and SBM-CV. Four diets were formulated to contain FSBM or SBM-CV and either 0 or 800 units/kg of microbial phytase. The only sources of P in these diets were FSBM and SBM-CV. A P-free diet that was used to estimate basal endogenous losses of P was also formulated. The ATTD and STTD of P were greater ($P< 0.01$) in FSBM than in SBM-CV if no phytase was used, but that was not the case if phytase was added to the diet (soybean meal × phytase interaction: $P< 0.01$). The objectives of experiments 2 and 3 were to determine the standardized ileal digestibility (**SID**) and the concentration of DE, ME, and NE in FSBM, SBM-CV, and fish meal, respectively. In Exp. 2, 3 cornstarch-based diets were formulated with FSBM, SBM-CV, or fish meal as the only source of AA in each diet. A N-free diet that was used to estimate basal endogenous losses of CP and AA was also formulated. The SID of all indispensable AA except Lys, Thr, and Trp was greater ($P< 0.01$) in FSBM than in fish meal. The SID of Met and Val were also greater ($P< 0.05$) in FSBM than in SBM-CV, but for the remaining indispensable AA, no differences between FSBM and SBM-CV were observed. In experiment 3, a corn-based diet consisting of 96.4% corn and vitamins and minerals was formulated. Three additional diets containing corn and each of the experimental ingredients (FSBM, SBM-CV, and fish meal, respectively) were also formulated. The concentrations of DE,

ME, and NE in SBM-CV were 4,553, 4,137, and 3,193 kcal/kg DM. These values were greater ($P < 0.01$) than the DE, ME, and NE in FSBM (4,296, 3,781, and 2,951 kcal/kg DM), corn (3,951, 3,819, and 2,864 kcal/kg DM), and fish meal (3,827, 3,412, and 2,626 kcal/kg DM). However, FSBM contained more DE, ME, and NE($P < 0.01$) than fish meal and more DE than corn($P < 0.01$). The objective of Exp. 4, 5, and 6 was to test the hypothesis that FSBM can replace animal protein sources in diets fed to weanling pigs during the initial 28 d post-weaning. Results from the 3 experiments indicated that inclusion of 10%FSBM may replace fish meal, chicken meal (**CM**), or poultry by-product meal (**PBM**) without impacting ADG, ADFI, or final BW of the pigs. However, in 1 of the 3 experiments, it was observed that G:F was less for pigs fed FSBM than for pigs fed fish meal, but it was also observed that during the first week post-weaning, FSBM could not replace protein plasma and whey powder without negatively impacting pig growth performance. In conclusion,FSBM contains more digestible P than SBM-CV, which reduced the need for inclusion of inorganic P in diets containing FSBM. Likewise, fermentation of SBM-CV reduces DE, ME, and NE, but does not affect AA digestibility and FSBM may replace fish meal, CM, and PBM in diets fed to pigs during the initial 28 d post-weaning without affecting pig growth performance except that G:F may be reduced.

Key words: amino acid digestibility, energy, fermented soybean meal, phosphorous digestibility, pigs, soybean meal.

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Lo logramos cresta !!!

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CHAPTER 1

INTRODUCTION

Conventional soybean meal (**SBM-CV)** is the most important vegetable protein source fed to pigs because it contains an excellent balance of indispensable AA. However, SBM-CV contains anti-nutritional factors such as antigens, lectins, trypsin inhibitors, and oligosaccharides that decrease nutrient availability and affect growth performance of young pigs (Li et al., 1991; Hong et al., 2004). Therefore, use of SBM-CV as the sole source of AA in weanling pigs diets is not recommended (Dunsford, 1989). On the other hand, animal proteins such as fish meal, chicken meal (**CM**), and poultry by-product meal (**PBM**) are often used in these diets because these ingredients have a high digestibility of nutrients and are free of anti-nutritional factors (Kim and Easter, 2001; Pierce et al., 2005). It is believed that fermented soybean meal(**FSBM**) may replace fish meal in diets fed to weanling pigs without reducing growth performance (Jones et al., 2010; Kim et al., 2010) because many of the anti-nutritional factors and in SBM-CV may be eliminated if SBM-CV is fermented (Hong et al., 2004; Cervantes-Pahm and Stein, 2010).

Recently, production of FSBM was initiated in the United States, but there are no data on the digestibility of P, energy and AA in this source of FSBM. Likewise, it is not know if FSBM can replace CM and PBM in diets fed to weanling pigs. There are also no data on inclusion of more than 10% FSBM in diets fed to weanling pigs, and there are no data on effects of replacing fish meal, CM, or PBM by FSBM during the initial 7 d post-weaning. Therefore, the objectives of this thesis are:

1) To determine apparent total tract digestibility and standardized total tract digestibility of P in FSBM without and with microbial phytase and to test the hypothesis that the ATTD and STTD of P in FSBM are greater than in SBM-CV.

2) To determine the concentration of DE, ME, and NE and the ileal digestibility of AA in FSBM.
3) To test the hypothesis that FSBM can replace all animal proteins in diets fed to weanling pigs during the initial 28 d post-weaning.

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CHAPTER 2

WEANING OF PIGS: LITERATURE REVIEW

INTRODUCTION

The weaning process is a complex stage in the pigs' life where young pigs are subjected to many changes in a short period of time. In nature, pigs are weaned at an age of approximately 13 weeks post-partum (Lalles et al., 2006), when the transition from the liquid to a solid diet is completed. However, the modern pig industry requires more efficiency and weaning is usually done when pigs are 3 - 4 weeks old. The small intestine of the pig has not yet adapted to a solid diet at this time, which sometimes results in poor digestion and low absorption of nutrients (Pluske et al., 1997).

The first feed that the newborn pig receives is called colostrum and is produced by the sow during the first 24 h after farrowing (Devillers et al., 2004**)**. Colostrum provides a concentrated source of energy and also maternal antibodies to provide immunity to the newborn pig. During the first hours of life, one of the biggest issues is the change of temperature and the lack of energy for the pig. Therefore, the newborn pig uses glycogen stored in the liver as the main source of energy after birth to stay warm and to provide energy to get access to the udder (Le Dividich et al., 1994). Colostrum has greater concentration of DM and CP and less concentration of fat and lactose than milk (Le Dividich et al., 1997; Lin et al., 2009). However, the biggest difference between colostrum and milk is the greater concentration of immunoglobulin G in colostrum than in milk. After 24 h, colostrum changes to milk and the main immunoglobulins are immunoglobulin A and immunoglobulin M (Klobasa et al., 1987). Immunoglobulins provide passive immune protection against pathogens such as *Colibacillosis*

and *Escherichia coli* (***E. coli***) until the pig's immune system is mature (Johnson et al., 1992; Rooke and Bland, 2002).

Weaning at 3-4 weeks is often associated with digestive disorders that may negatively affect the morphology of the small intestine and reduced villous height and increased crypt depth are often observed during the immediate post-weaning period. This may result in post-weaning diarrhea (Dunsford, 1989). To maintain the structure of the small intestine, diets fed to weanling pigs need to stimulate voluntary feed intake (Pluske et al., 1997). Therefore, diets fed to newly weaned pigs are composed of ingredients with high levels of digestible protein such as whey powder, spray dried plasma, fish meal, and blood meal (Kim and Easter, 2001). Usually, these animal protein ingredients are more expensive than vegetable protein sources such as conventional soybean meal (**SBM-CV**), but they are free of anti-nutritional factors (**ANF)** and, therefore, better tolerated by young pigs than vegetable protein sources.

During the weaning process, littermates are relocated and mixed with pigs from other litters, which produces aggressive behavior to establish the hierarchy inside the pen (McGlone and Curtis, 1985). This behavior results in wasting of energy and a reduction of feed intake and growth performance is negatively affected. Ogunbameru et al. (1992) reported that pigs weaned during the evening consumed more feed and grew faster than pigs weaned in the morning. The reason for this observation may be that weaning in the evening positively impacts diurnal eating behavior (Ogunbameru et al., 1992).

The combination of all the changes that take place when pigs are weaned results in a condition called the weaning lag, which is a result of the nutritional, environmental, and behavioral stress that pigs are exposed to at weaning. One of the major challenges in modern

swine production is to reduce the impact of the weaning lag and to make sure that neonatal pigs recover from the weaning lag as fast as possible after weaning.

PHYSIOLOGICAL AND ANATOMICAL CHANGES AT WEANING

The immune system of the unweaned pig is developed after consumption of immunoglobulins that are present in the sow's colostrum and milk (called passive immunity), but these immunoglobulins protect only against the antigens that the sow has developed immunity against (Van Berrs-Schreurs and Bruininx, 2002). Immunoglobulin A provides a barrier against pathogens in the gastric and intestinal mucosa and immunoglobulin G provides immunity against antigens (Bailey et al., 2001). However, after weaning, sow's milk is no longer consumed, which results in a decrease in passive immunity and weanling pigs do not develop their own immune system (called active immunity) until 1 to 3 weeks after weaning (Gaskins and Kelley, 1995).

Weaning of pigs involves removal of maternal antibodies, mixing stress, exposure to new environmental pathogens, and changes in gut morphology (Bailey et al., 2001).At weaning, pigs are also exposed to antigens that are present in dietary ingredients such as conglycinin and β-conglycinin in SBM-CV (Li et al., 1991) that were not present in the milk. Pigs may also get exposed to new pathogens such as *E. Coli*. The antigens may produce transient hypersensitivity in the small intestine, which affects the digestion and absorption of nutrients (Li et al., 1991) and *E. coli* may cause diarrhea because of the low levels of active and passive immunity that the pig has at this time (Kelly and King, 2001).

The transition from a liquid diet to solid feed at weaning disrupts the capacities for digestion and absorption in the gastrointestinal tract (**GIT**). Therefore, the objective of the GIT is to adapt as soon as possible to the new diet. This adaptation is a complex process and is

influenced by numerous interacting factors such as immunological status, presence of pathogens, weight at weaning, and digestibility of ingredients in the new diet (Fan, 2003).

The stomach, small intestine, pancreas, and liver cooperate to digest and absorb the nutrients in the diet. The small intestine and the stomach increase their weight during the initial 21 d post-weaning relative to total pig BW (Cera et al., 1988a; Cranwell, 1995). The same is true for the stomach, which may be a result of an increase of exocrine secretions such as proteolytic enzymes, gastric lipase, and hydrochloric acid (Cranwell, 1995).

The amounts of enzymes that are secreted into the GIT are related to the type of feed that is ingested by the pig. For instance, pancreatic secretion levels increase during the first 5 d after weaning because feed intake increases (Rantzer et al., 1997). However, during the same period of time, weanling pigs do not gain weight (Rantzer et al., 1997).

The exocrine pancreatic enzymes are secreted in the form of juice. This juice contains the major exocrine pancreatic lipase, α-amylase, and proteases such astrypsin and chymotrypsin (Fan, 2003). The enzyme activity of trypsin is not affected by the weaning process, but that is not the case for chymotrypsin and amylase (Jensen et al., 1997). However, the activity of these enzymes and the total gastric secretion capacity increase after one week post-weaning (Cranwell, 1995; Jensen et al., 1997).

The GIT of the unborn pig is free of any bacteria or pathogens. However, a few hours after birth, the GIT is colonized by microorganisms (Fan, 2003). Both aerobe and anaerobe microorganisms such as strains of E. coli, clostridia, lactobacilli, eubacteria, and bifidobacteria are present in the GIT (Maxwell and Stewart, 1995).

The fundic region is one of the 4 regions in the stomach. In this region, hydrochloric acid (**HCL**) is secreted from the parietal cells (Cranwell, 1995; Yen, 2001). Before weaning, bacterial

fermentation helps to mantein the pH low in the GIT, which allows the formation of milk clots in the intestine of the neonatal pig (Yen, 2001). After weaning, gastric pH is between 3 and 4, which is too high for complete digestion of proteins (Mavromichalis, 2006). Insuficient secretion of HCL results in increased pH in the stomach, which may result in colonization by pathogens such as *E.coli* (Yen, 2001).

The transition from a liquid to a solid diet reduces feed intake, which often is associated with changes of the intestinal morphology (Pluske et al., 1996; Maxwell and Carter, 2001). Villous height may, therefore, be reduced already 24 h after weaning, but reduction in villous height continuous 4-5 d after weaning (Hampson, 1986). One of the reasons for the reduction in villous height is that the production of crypt cells decreases during the first few days post-weaning. Enterocytes on the villi may also be destroyed (Cera et al., 1988; Dunsford, 1989; Bailey et al., 2001). The enterocytes that are present in the villus have an apical membrane that is called the brush-border membrane (Fan, 2003). This membrane has a high lactase activity, but after weaning, the lactase activity decreases and the activity of sucrase, maltase, and maltase-glucoamylase increases (Cranwell, 1995).

The main function of the enterocytes is to absorb nutrients (Fan, 2003). Enterocytes are synthesized in the intestinal crypts and migrate to the villus (Yen, 2001). When abrupt changes happen in the morphology in the small intestine, the capacity for synthesis of new enterocytes is reduced. Therefore, the capacity for digestion and absorption in the GIT decreases, which increases indigestion of nutrients in the small intestine. As a consequence, more substrate will reach the large intestine, which may result in microbial proliferation and subsequent diarrhea (Mavromichalis, 2006). One of the main objectives of feeding weanling pigs in, therefore, to

maintain the structure of the villi in the small intestine and avoid the reduction is villus height and crypt depth.

CHARACTERISTICS OF DIETS FED TO WEANLING PIGS

Different strategies have been used in the swine industry to ameliorate the negative effects of the weaning lag. Nutritional strategies such as reduction of the level of protein in the diets and also the use of animal protein ingredients (Chiba, 2001) are the most common strategies used. Excess protein in the small intestine contributes to more substrate in the large intestine, which increases the proliferation of pathogens such as *E.coli*, which is one of the causes of diarrhea (Heo, et al., 2009).

One of the objectives of feeding weanling pigs is to stimulate voluntary feed intake because weaned pigs often do not meet their energy and nutrient requirements due to insufficient feed consumption (Maxwell and Carter, 2001). Therefore, inclusion of milk products such as dried whey in weanling pig diets may improve the palatability of the diet and, therefore, increase daily feed intake (Lepine et al., 1991). Other animal protein sources such as spray dried protein plasma (**SDPP**), poultry by-product meal (**PBM**), and fish meal are also commonly used in weanling pigs diets due to the high digestibility of nutrients in these ingredients (Grinstead et al., 2000; Kim and Easter, 2001). However, the high cost of these ingredients limit their use, and the increase in the costs of these ingredients during recent years has made it necessary to identify alternatives to animal protein sources in diets fed to weanling pigs.

Spray dried protein plasmais commonly used in phase 1 and phase 2 diets (0 to 7 and 7 to 14 d, post-weaning, respectively) fed to weanling pigs because this ingredient stimulates feed intake (Ermer et al., 1994). Van Dijk et al. (2001) reported that 6% SDPP in diets fed to

weanling pigs increased ADG and ADFI and the positive effect was more noticeable during wk 1 and 2 after weaning than in subsequent weeks. However, SDPP is relatively low in methionine. Therefore, use of more than 6% SDPP usually is recommended only it DL-methionine is a added to the diet (Kats et al., 1994). One of the reasons dietary SDPP improve growth performance of weaning pigs is that the immunoglobulins in SDPP protect the pig against infections (Coffey and Cromwell, 1995). Nutrient digestibility in SDPP is also excellent (Van Dijk et al., 2001), and SDPP may help preserve the barrier function in the small intestine and decrease intestinal inflammation when pigs are switched from a liquid to a solid diet at weaning (Campbell et al., 2010).

Dried whey is another animal product that is used in weanling pigs starter diets. It contains 65-70% lactose and 12-15% protein(Chiba, 2001) and it usually is used as a source of lactose in weanling pigs diets (Cera et al., 1988). In a corn-soybean meal diet, the inclusion of 25% dried whey increased weight gain during the first 21 d post-weaning (Lepine et al., 1991), and lactose appears to be an important compound of the diet during the first 2 weeks after weanling. This is in agreement with data reported by Mahan (1993) who observed the same weight gain of pigs fed a corn-soybean meal diet supplement with either lactose or dried whey.

Poultry by-product meal is produced from rendered parts of chickens (Kellems and Church, 2009) and it has a concentration of AA that is similar to fish meal (Keegan et al., 2004). However, the quality of PBM may be variable and depends on the type of processing and the quality of the rendered parts to produce it (Dong et al., 1993). Keegan et al. (2004) and Zier et al. (2004) reported that pigs fed diets containing PBM from d 0 to 28 post-weaning had similar growth performance as pigs fed fish meal, blood meal, and SDPP. However, the concentration of ash in PBM may impact growth performance of pigs (Keegan et al., 2004).

Fish meal is an animal protein that is used in diets fed to weanling pigs because of its high digestibility and favorable AA composition (Kim and Easter, 2001). However, the quality of fish meal is variable and may depend on the processing methods and the type of fish used to produce the meal (Stoner et al., 1990; Kim and Easter, 2001). Fish meal usually is included by less than 10% in diets fed to weanling pigs (Chiba, 2001) and it has been reported that the G:F ratio increased linearly when fish meal is included in the diet (Bergstrom et al., 1997).

ALTERNATIVE PROTEIN INGREDIENTS

Conventional soybean meal is the most important vegetable protein source fed to pigs because it contains an excellent balance of indispensable AA (Baker, 2000).Also, the low fiber concentration in soybean meal results in a greater concentration of ME in SBM-CV than in other oilseed meals (Stein et al., 2008). Attempts to replace some of the animal protein ingredients, especially fish meal, in diets fed to weanling pigs have been made, but these attempts have largely been unsuccessful because of the presence of ANF such as antigens, trypsin inhibitors, and oligosaccharides in SBM-CV (Li et al., 1991; Jezierny et al., 2010). These ANF reduce the absorption and digestion of nutrients and thus, reduce the growth performance (Li et al., 1991). Therefore, inclusion of SBM-CV in wealing pig diets is limited (Dunsford et al., 1989; Hong et al., 2004).

Trypsin inhibitors or protease inhibitors are chemicals that are present in SBM-CV at concentration of approximately 2.70 mg/g (Hong et al., 2004). They inhibit the action of trypsin and chymotrypsin, and therefore, reduce the digestion of proteins (Deak et al., 2010). Also, SBM-CV contains antigenic proteins such as glycinin and β-conglycinin (Li et al., 1990). These proteins produce hypersensitivity in the small intestine, which has negative impacts on the

morphology in the small intestine (decreased villus height and increased crypt depth; Cromwell, 2000) and cause malabsorption and digestive disorders. Antigenic proteins, therefore, have a negative impact on growth performance in weanling pigs (Lalles, 2006). Oligosaccharides such as raffinose, stachyose, and verbascose are also present in SBM-CV (Karr-Lilienthal et al., 2005). Usually, the oligossacharide concentration in SBM-CV is around 8% of DM (Grieshop et al., 2003). The oligosaccharides cannot be digested by pigs (Li et al., 1991) because pigs cannot secrete α-galactosidase, which is the enzyme that breaks down the glycocidic bonds in oligossacharides (Karr-Lilienthal et al., 2005). Therefore, oligosaccharides in diets fed to weanling pigs results in diarrhea (Liying et al., 2003; Karr-Lilienthal et al., 2005). However, new varieties of soybeans with low concentrations of oligosaccharides have been developed, but it is unknown if these varieties can be used in diets fed to weanling pigs (Baker and Stein, 2009).

New technologies such as enzymatic treatment and fermentation have been developed to remove the ANF in SBM-CV (Cervantes-Pahm and Stein, 2010). Enzymatic treatment of SBM-CV is used to break down the glycosidic bonds in the carbohydrate fraction in soybean meal (Middelbos and Fahey, 2008) and enzyme treated soybean meal contains less oligossacharides than SBM-CV (Cervantes-Pahm and Stein, 2010; Goebel and Stein, 2011). Hamlet protein (Horsens, Denmark) is a company that produces soybean meal by enzymatic treatment of SBM-CV. This product has been developed to contain less antigens and oligosaccharides than SBM-CV (Zhu et al., 1998; Goebel and Stein, 2011), and it is, therefore, expected that enzyme treated soybean meal is better tolerated by weanling pigs than SBM-CV.

Fermented soybean meal (**FSBM**)is a fermented product that is produced by fermentation of SBM-CV in the presence of fungal and bacterial strains (*Aspergillus oryzae* and *Lactobacillus subtilis*, respectively*).* Fermentation is used to eliminate or reduce the concentration of ANF in

SBM-CV (Kaankuka et al., 1996; Hong et al., 2004; Cervantes-Pahm and Stein, 2010). Therefore, FSBM may be included in greater concentrations than SBM-CV in diets fed to weanling pigs because it is expected to be better tolerated by weanling pigs (Liu et al., 2007; Yang et al., 2007). Indeed, FSBM may replace animal protein sources in weanling pigs diets without negatively affecting pig growth performance (Jones et al., 2010; Kim et al., 2010). Song et al. (2010) also reported that a diet fed to weanling pigs containing FSBM reduced the incidence of diarrhea compared with a diet containing SBM-CV, which is likely a consequence of pigs fed the diet containing FSBM ingesting less antigens than pigs fed SBM-CV. Weanling pigs fed FSBM also had improved villous height and crypt depth after weaning compared with pigs fed SBM-CV (Kim et al., 2007). Use of FSBM rather than SBM-CV increased trypsin, lipase, and protease activity in the small intestine of broilers and also decreased crypt depth and increased villus height in the jejunum (Feng et al., 2007). It is also believed that during fermentation of SBM-CV, the size of the peptides decrease, which may improve AA digestibility by newly weaned pigs (Hong et al., 2004; Min et al., 2004; Gilbert et al., 2008). However, this is not always the case (Cervantes-Pahm and Stein, 2010). Likewise, the fermentation process may result in hydrolysis of phytate and release of phytate-bound phosphorous. The bioavailability of P in FSBM is therefore, expected to be greater than in conventional SBM (Ilyas et al., 1995), but data for the apparent and standardized total tract digestibility of P in FSBM haven not been reported.

CONCLUSIONS

Diets fed to weanling pigs need to be formulated in such a way that they protect the intestinal tract from pathogenic colonization and at the same time support the integrity of the

intestinal tissue. However, this is relatively complicated because a number of ANF are present in SBM-CV. Therefore, fish meal and other animal protein ingredients are commonly used in diets fed to weanling pigs despite that the fact they are more expensive than vegetable protein sources. However, recent technological developments have resulted in the opportunity to produce FSBM, and recently, production of FSBM was initiated in the USA. There are, however, no data on the digestibility of energy, P, and AA in this source of FSBM, and effects of replacing fish meal and other animal protein sources with this source of FSBM has not been fully investigated.

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CHAPTER 3

DIGESTIBILITY OF PHOSPHOROUS IN FERMENTED AND CONVENTIONAL SOYBEAN MEAL WITHOUT AND WITH MICROBIAL PHYTASE BY WEANLING PIGS

ABSTRACT

An experiment was conducted to test the hypothesis that the apparent total tract digestibility (ATTD) and the standardized total tract digestibility (STTD) of P in fermented soybean meal (FSBM) are greater than in conventional soybean meal (SBM-CV) when fed to weanling pigs. Four diets were formulated to contain FSBM or SBM-CV and either 0 or 800 units/kg of microbial phytase (Optiphos 2000, Enzyvia, Sheridan, IN). The only sources of P in these diets were FSBM and SBM-CV. A P-free diet that was used to estimate basal endogenous losses of P was also formulated. Thirty barrows (initial BW: 14.0 ± 2.28 kg) were placed in metabolism cages and allotted to a randomized complete block design with 5 diets and 6 pigs per diet. Feces were collected for 5 d after a 5 d adaptation period. All samples of ingredients, diets, and feces were analyzed for P and values for ATTD and STTD of P were calculated. Results indicated that the basal endogenous P losses were 187 mg/kg DMI. The ATTD and STTD of P increased (P< 0.01) from 60.9 to 67.5% and from 65.5 to 71.9% in pigs fed FSMB as phytase was added to the diet. Likewise, addition of phytase to SBM-CV increased (P< 0.01) the ATTD and STTD of P from 41.6 to 66.2% and from 46.1 to 71.4%, respectively. The ATTD and STTD of P were greater (P< 0.01) in FSBM than in SBM-CV if no phytase was used, but that was not the case if phytase was added to the diet (soybean meal × phytase interaction: P< 0.01). In conclusion, the ATTD and STTD of P in FSBM is greater than in SBM-CV, if no microbial phytase is used, but

if phytase is added to the diets, no differences in ATTD and STTD of P between FSBM and SBM-CV are observed.

Key Words: fermented soybean meal, phosphorus, phosphorus digestibility, phytase, pig, soybean meal

INTRODUCTION

Most P in soybean meal (**SBM**) is bound in the phytate complex (Eeckhout and De Paepe, 1994), which may contribute to environmental problems (Knowlton et al., 2004) and contribute to increased diet costs. However, the phytase enzyme may hydrolyze P that is bound in phytate and addition of microbial phytase increases the apparent total tract digestibility (**ATTD**) and the standardized total tract digestibility (**STTD**) of P in SBM (Almeida and Stein, 2010).

It is likely that fermentation of SBM results in hydrolysis of phytate and release of phytate-bound P because the concentration of phytate bound P in fermented corn products such as distillers dried grains with solubles and high protein distillers dried grainsare less than in corn (Almeida and Stein, 2010). The bioavailability of P in fermented SBM (**FSBM)** is, therefore, expected to be greater than in conventional SBM (**SBM-CV**; Ilyas et al., 1995), but previous research failed to demonstrate an increase in the bioavailability of P in FSBM compared with SBM-CV (Hong et al., 2004). The global production of FSBM is likely less than 100,000 ton, but the production has increased during recent years because FSBM is often used as a replacement for fish meal in the swine and poultry industries. Historically, most of the production has taken place in Asia, but a facility to produce FSBM in the United States was established a few years ago.

The total amount of P in the diets as well as the excretion of P from pigs may be reduced if diets are formulated based on values for STTD of P rather than on values for total P (Bünzen et al., 2008; 2009). Values for STTD of P are calculated by correcting values for the ATTD of P for the basal endogenous losses of P (**EPL**; Petersen and Stein, 2006). The reason for the reduced excretion of P in diets formulated based on STTD of P rather than ATTD of is most likely that values for STTD of P are additive in mixed diets, but this is not always the case for values for ATTD of P (Fan et al., 2001).Values for ATTD and STTD of P have been reported for SBM-CV without and with microbial phytase (Almeida and Stein, 2010), but that is not the case for FSBM. Therefore, the objectives of this experiment were to determine ATTD and STTD of P in FSBM without and with microbial phytase and to test the hypothesis that the ATTD and STTD of P in FSBM are greater than in SBM-CV.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for this experiment. Pigs used in the experiment were the offspring of G-performer boars mated to F-25 gilts (Genetiporc, Alexandria, MN). The ingredients that were used in the experiment (Table 1) included FSBM (PepSoyGen®, Nutra Ferma, North Sioux City, SD) and SBM-CV (Solae, Gibson City, IL). PepSoyGen® is produced by aerobic fermentation of SBM in the presence of *Aspergillus oryzae* and *Lactobacillus subtilis*.

Diets, Animals, and Experimental Design

Thirty growing barrows (initial BW: 14.0 ± 2.28 kg) were placed in metabolism cages and allotted to a randomized complete block design with 5 diets and 6 replicate pigs per diet. Each metabolism cage was equipped with a feeder and a nipple drinker.

Five diets were formulated (Table 2). Two diets contained 47.0% (as-fed basis) FSBM and either 0 or 800 phytase units (**FTU)** of microbial phytase (Optiphos 2000, Enzyvia, Sheridan, IN) per kilogram. Two additional diets contained 50.0% (as-fed basis) SBM-CV and either 0 or 800 FTU/kg of phytase. The only sources of P in the diets were FSBM and SBM-CV, respectively. The levels of SBM in the diets were determined to equalize the concentration of P among diets, and phytase was included at a level close to the greatest levels that are used in commercial diets. The last diet, a P-free diet, was used to measure basal EPL (Petersen and Stein, 2006). Vitamins and minerals except P were included in all diets to meet or exceed the requirements for weanling pigs (NRC, 1998).

Feeding and Sample Collection

Feed was supplied in the amount of 2.5 times the daily maintenance energy requirement (i.e., 106 kcal of ME/kg of $BW^{0.75}$; NRC, 1998). The daily amount of feed was divided into 2 equal meals that were fed at 800 and 1700 h. Water was available at all times. Individual pig BW was recorded at the beginning and at the end of the experiment and the amount of feed supplied each day was also recorded. Pigs were fed their experimental diets for 12 d. The initial 5 d were considered an adaptation period to the diet. Chromic oxide and ferric oxide were added as indigestible markers to the diet in the morning meals on d 6 and d 11, respectively. The fecal collections started when chromic oxide appeared in the feces and ceased when ferric oxide appeared as previously described (Adeola, 2001). Feces were collected twice daily and stored at -20ºC immediately after collection.

Chemical Analysis

All samples were analyzed in duplicate. Fecal samples were dried at 65ºC in a forced-air oven and ground through a 1-mm screen in a Wiley mill (model 4; Thomas Scientific,

Swedesboro, NJ) before analysis. Diets, ingredients, and fecal samples were analyzed for DM (method 930.15; AOAC Int., 2007). Phosphorous and Ca were analyzed in all samples by the inductively coupled plasma spectroscopy procedure (method 985.01 A, B, and C; AOAC, 2007) after wet ash sample preparation (method 975.03B(b); AOAC Int., 2007).Diets and ingredients were also analyzed for ADF (method 973.18; AOAC Int., 2007), NDF (Holst, 1973), ash (method 942.05; AOAC Int., 2007), and for CP by combustion (method 990.03; AOAC Int., 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Fermented soybean meal and SBM-CV were analyzed for AA on a Hitachi Amino Acid Analyzer, Model No. L8800. (Hitachi High Technologies America, Inc; Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Prior to analysis, samples were hydrolyzed with 6N HCl for 24 h at 110°C (method 982.30 E(a); AOAC Int., 2007). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (method 982.30 E(b); AOAC Int., 2007). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (method 982.30 E(c); AOAC Int., 2007) and total fat concentration was measured in both sources of SBM by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (method 2003.06, AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN).Diets and ingredients were also analyzed for GE using adiabatic bomb calorimetry (Model 6300 Parr Instruments, Moline, IL) and for phytase activity (Phytex Method, Version 1; Eurofins, Des Moines, IA). The 2 sources of SBM were analyzed for trypsin inhibitor concentrations (method Ba 12-75; AOCS; 2006), phytate (Ellis et al., 1977), and carbohydrates were analyzed as described by Cervantes-Pahm and Stein (2010).

Calculations and Statistical Analysis

The concentration of phytate bound P in the 2 sources of SBM was calculated as 28.2% of analyzed phytate (Tran and Sauvant, 2004) and the concentration of non-phytate bound P was calculated by subtracting phytate bound P from total P. The ATTD, STTD, and EPL in each diet were calculated as previously described (Almeida and Stein, 2010). Data were analyzed as a 2 × 2 factorial using the MIXED Procedure (SAS Inst. Inc., Cary, NC). Homogeneity of the variances among treatments was confirmed using the UNIVARIATE procedure and this procedure was also used to test for outliers, but no outliers were identified. The fixed effects were source of SBM, phytase, and the interaction between SBM and phytase. Replicate was considered a random effect. The Least Significant Means statement was used to calculate treatment means and the PDIFF option was used to separate means if differences were detected. The pig was the experimental unit for all analyses and an alpha level of 0.05 was used to assess significance among means.

RESULTS

The total amount of P in FSBM was 0.78% whereas there was 0.66% P in SBM-CV and the concentration of phytate was 1.38 and 1.51% in FSBM and SBM, respectively (Table 1). Therefore, 0.39 and 0.43% P was bound in phytate in FSBM and SBM-CV, respectively. This corresponds to 50.0 and 64.5% of the total P, in FSBM and SBM-CV, respectively. As a consequence, the concentration of non-phytate bound P was 0.39 and 0.23% in FSBM and SBM, respectively, which corresponds to 50.0 and 35.5% of the total P in FSBM and SBM, respectively.

There was no detectable phytase activity in FSBM or SBM-CV. Likewise, no phytase was detected in the 2 diets that contained no microbial phytase, but the phytase concentration was close to expected values for the 2 diets with added phytase although the FSBM-diet contained 110 FTU more than expected and the diet containing SBM-CV contained 110 FTU less than expected (Table 2).

One pig fed the diet containing SBM-CV and phytase failed to consume the allotted amount of feed and was removed from the experiment, but all other pigs successfully completed the experiment. Neither source of SBM nor the level of phytase influenced ADFI or basal EPL (Table 3). There was, however, an unintended interaction ($P < 0.05$) between source of SBM and phytase for daily P intake because pigs fed the diet containing SBM-CV with phytase had less P-intake than pigs fed SBM-CV without phytase, which was caused by the analyzed differences in P-concentrations between the 2 diets. However, no differences in P intake between pigs fed diets containing FSBM without and with phytase were observed. Phosphorus concentration in feces and daily P output were reduced ($P < 0.01$) when phytase was used in the diets and P concentration in feces and daily P output were less ($P < 0.01$) in pigs fed FSBM than in pigs fed SBM-CV. The reductions in fecal P concentration and in P output that were induced by phytase were, however, greater in pigs fed SBM-CV than in pigs fed FSBM, resulting in an interaction ($P < 0.01$) between source of SBM and phytase.

Daily absorption of P was greater ($P < 0.01$) in pigs fed FSBM than in pigs fed SBM-CV and greater ($P < 0.05$) if phytase was added to the diets than if no phytase was used. The ATTD and STTD of P were also greater ($P < 0.01$) when phytase was used than if no phytase was included in the diets, regardless of the source of SBM. The increase in ATTD and STTD when phytase was used was, however, greater for SBM-CV than for FSBM resulting in an interaction

($P < 0.01$) between SBM source and phytase. However, feeding FSBM rather than SBM-CV resulted in an increase ($P < 0.01$) in ATTD as well as in STTD of P.

The intake of Ca was less ($P < 0.01$) if pigs were fed FSBM without phytase than if the other diets were provided and the interaction between source of SBM and phytase was significant ($P < 0.01$) for Ca intake. The concentration of Ca in feces was greater ($P < 0.05$) in pigs fed SBM-CV than in pigs fed FSBM, and phytase reduced ($P < 0.01$) Ca concentration in the feces, but the reduction was greater for SBM-CV than for FSBM (interaction, $P< 0.05$). There was also a reduction ($P < 0.05$) of daily Ca output when phytase was added to SBM-CV, but this was not the case if phytase was added to FSBM, which resulted in an interaction between SBM source and phytase ($P < 0.05$). Daily absorption of Ca was greater ($P < 0.01$) in pigs fed SBM-CV than in pigs fed FSBM and the ATTD of Ca was less ($P < 0.05$) for pigs fed FSBM than for pigs fed SBM-CV. However, phytase increased ($P < 0.05$) the ATTD of Ca in the 2 phytase containing diets.

DISCUSSION

Soybean meal contains both phytate bound P and non-phytate bound P (Eeckhout and De Paepe, 1994). The chemical name of the phytate molecule is *myo*-inositol hexaphosphate (IP6) because it has 6 atoms of P bound to the inositol molecule and the molecular weight of this molecule is 660.04 g mol^{-1} (Selle et al., 2009). The molecular weight of P is 30.974 g mol^{-1} (Ham, 2008), and the 6 P in phytate, therefore, equates to 28.2% of the total weight of phytate (Tran and Sauvant, 2004).

The concentration of sucrose and oligosaccharides in SBM-CV was close to expected values (Grieshop et al., 2003). However, there was no sucrose or oligosaccharides detected in

FSBM, which indicates that these carbohydrates are fermented during production of FSBM. This observation is in agreement with Cervantes-Pahm and Stein (2010) who also reported that no sucrose or oligosaccharides are present in FSBM. The removal of the carbohydrates is the reason the concentration of CP, NDF, P, and other nutrients is greater in FSBM than in SBM-CV. As a consequence, the concentration of AA is also greater in FSBM than in SBM-CV, which is also in agreement with previous data (Cervantes-Pahm and Stein, 2010).

The P concentration in SBM-CV was close to the value of 0.69% reported by NRC (1998). The basal EPL that was calculated in this experiment (187 mg/kg of DMI) is in agreement with previously reported values (Stein et al., 2006; Widmer et al., 2007), which indicates that the basal endogenous loss of P is relatively constant among experiments.

The 2 diets that contained phytase were formulated to contain 800 FTU and the analyzed values were 910 and 690 FTU for FSBM and SBM-CV, respectively. The reason for these small differences from the expected value is most likely inaccuracies in the analyses of phytase and possibly also inaccuracies in diet formulation. It is unlikely that the analyzed difference between the 2 diets contributed to different responses to microbial phytase, because the response to microbial phytase that is obtained after inclusion of 500 FTU usually declines. The fact that the response to microbial phytase was much greater for SBM-CV than for FSBM also indicates that the P-digestibility in SBM-CV was not compromised because of the slightly lower analyzed value than expected.

The analyzed values for P were close to expected values in all diets, whereas some unintended variations in the analyzed values for Ca were observed. The main reason for the variations in Ca concentrations is most likely that SBM-CV contained twice as much Ca as expected (NRC, 1998).

To our knowledge, the ATTD and STTD of P in FSBM have never previously been reported, but the greater digestibility of P in FSBM compared with SBM-CV is likely a result of the reduced concentration of phytate bound P in FSBM compared with SBM-CV. It is likely that fermentation of FSBM resulted in hydrolysis of phytate bonds, which increased the concentration of free P in FSBM (Ilyas et al., 1995). We are not aware of other data showing effects of fermentation of SBM on the concentration of phytate bound P and on the digestibility of P. However, the effect of fermentation of SBM on P digestibility appears to be similar to the effect of fermentation of corn in ethanol plants because the digestibility of P in fermented corn co-products also is greater than in corn and non-fermented co-products (Pedersen et al., 2007; Widmer et al., 2007; Stein et al., 2009). Fermentation, therefore, seems to be an effective way of improving P-digestibility of feed ingredients that contain phytate bound P.

The ATTD and STTD of P in SBM-CV without phytase that were obtained in this experiment concur with previous values (Bohlke et al., 2005) and the ATTD and STTD of P that were obtained for SBM-CV with phytase were in agreement with the values reported by Almeida and Stein (2010). These values were also similar to the values obtained for FSBM. The effect of addition of microbial phytase on the ATTD and STTD of P, therefore, was much greater in SBM-CV than in FSBM. The reason for this observation is most likely that the amount of phytate-bound P is greater in SBM-CV than in FSBM, and therefore, phytase hydrolyzed more phytate in SBM-CV than in FSBM and increased the digestibility of P. This observation is in agreement with data showing that the effect of microbial phytase is much greater in corn than in corn distillers dried grains with solubles, which is also a fermented feed ingredient that has a relatively low concentration of phytate bond P (Almeida and Stein, 2010). It therefore appears that the response to phytase that is obtained in a particular feed ingredient depends on the amount

of substrate that is available. The practical consequence of these observations is that the response to addition of microbial phytase may vary among diets depending on the feed ingredients included in the diet. The greater the quantity of phytate bound P in the diet is, the greater will the response to microbial phytase be. Using a constant value for P release from microbial phytase in diet formulations across all types of diets regardless of the ingredients that are used may, therefore, not always give accurate estimates of digestible P in the diet.

The fact that the STTD of P in both sources of soybean meal was around 71% if microbial phytase was added to the diet indicates that this may be close to the maximum digestibility of P in SBM when fed to weanling pigs. However, it is possible that older pigs may have a slightly greater digestibility of P in SBM than the weanling pigs we used in this experiment because the digestibility of phytate bound P may increase as pigs get older (Baker, 2010).

The Ca in the diets originated from a combination of Ca in the SBM and Ca from limestone. The concentration of Ca was greater in SBM-CV than in FSBM, which is the reason Ca intake was greater for pigs fed diets containing SBM-CV than for pigs fed diets containing FSBM. The ATTD of Ca in the SBM-CV diet without phytase was similar to the value reported by Bohlke et al. (2005). The ATTD of Ca increased as phytase was used in the diet regardless of the source of SBM. It is possible that Ca that was bound in the phytate complex was released by phytase, but the majority of Ca in both diets originated from limestone. It is, therefore, likely that the increase in the ATTD of Ca that was observed when microbial phytase was used is a result of increased absorption of Ca from limestone. The reason for this observation may be that phytase reduced the amount of phytate in the intestine, which reduced the capacity of phytate to chelate Ca, which increased the amount of Ca available for absorption (Selle et al., 2009). The ATTD of

Ca in a corn-SBM-limestone diet is increased by microbial phytase, which supports the hypothesis that phytase may reduce the ability of phytate to chelate Ca in the intestinal tract of pigs (Selle et al., 2009).

In conclusion, the ATTD and STTD of P are greater in FSBM than in SBM-CV if microbial phytase is not added to the diet. However, if microbial phytase is used, there is no difference in ATTD or STTD of P between FSBM and SBM-CV, and both sources have STTD values around 71%. Fermented SBM contains more digestible P than SBM-CV, which reduces the need for inclusion of inorganic P in diets containing FSBM.

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Table 3.1. Nutrient composition of fermented soybean meal (FSBM) and conventional soybean meal (SBM-CV), as-fed basis

Item	Ingredient	
	FSBM	SBM-CV
GE, kcal/kg	4,511	4,313
DM, %	90.76	87.97
CP, %	55.54	47.22
Ca, %	0.29	0.56
P, %	0.78	0.66
Ash, %	6.69	6.30
Acid hydrolyzed ether extract, %	1.44	1.43
NDF, %	8.82	6.14
ADF, %	4.53	4.26
TIU[1], mg/kg	1.10	4.00
Phytase, FTU/kg	< 70	< 70
Phytate, %	1.38	1.51
Phytate bound P, %[2]	0.39	0.43
Phytate bound P, % of total P	50.00	64.5
Non-phytate P, %[3]	0.39	0.23
Non-phytate bound P, % of total P	50.00	35.5
Carbohydrates, %		
Glucose	0.23	0.00
Sucrose	0.00	9.36

Table 3.1 (cont.)

Maltose	0.00	0.27
Fructose	0.37	0.00
Stachyose	0.00	6.56
Raffinose	0.00	0.98
Indispensable AA, %		
Arg	3.78	3.42
His	1.37	1.21
Ile	2.60	2.17
Leu	4.29	3.57
Lys	3.13	2.97
Met	0.75	0.63
Phe	2.81	2.33
Thr	2.07	1.73
Trp	0.71	0.73
Val	2.77	2.30
Dispensable AA, %		
Ala	2.39	1.95
Asp	6.12	5.16
Cys	0.87	0.69
Glu	9.81	8.39
Gly	2.35	1.94
Pro	2.98	2.46
Ser	2.49	1.92

Table 3.1 (cont.)

Tyr	1.98	1.67
Total AA	53.27	45.24

[1]TIU = trypsin inhibitor unit.

[2]Phytate bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

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

Table 3.2. Composition of experimental diets, as-fed basis

	Diet[1]				
	FSBM		SBM-CV		P free
Phytase, FTU/kg[2]:	0	800	0	800	
Ingredient, %					
Fermented soybean meal	47.00	47.00	-	-	-
Soybean meal, 48% CP	-	-	50.00	50.00	-
Gelatin[3]	-	-	-	-	20.00
Soybean oil	-	-	-	-	4.00
Solka floc[4]	-	-	-	-	4.00
Ground limestone	1.00	1.00	1.00	1.00	0.80
Sucrose	15.00	15.00	15.00	15.00	20.00
Cornstarch	36.30	36.26	33.30	33.26	49.22
Amino acid mixture[5]	-	-	-	-	0.78
Sodium chloride	0.40	0.40	0.40	0.40	0.40
Phytase premix[6]	-	0.04	-	0.04	-
Vitamin mineral premix [7]	0.30	0.30	0.30	0.30	0.30
Potassium carbonate	-	-	-	-	0.40
Magnesium oxide	-	-	-	-	0.10
Total	100.00	100.00	100.00	100.00	100.00
Analyzed composition					
GE, kcal/kg	4,016	4,012	3,885	3,907	3,965
DM, %	92.36	92.09	91.15	91.00	92.22

Table 3.2 (cont.)

CP, %	27.36	27.70	24.28	22.19	24.31
Ca, %	0.54	0.62	0.78	0.65	0.32
P, %	0.38	0.39	0.38	0.33	0.01
Ash, %	4.62	4.37	4.52	4.24	1.17
NDF, %	4.35	4.21	3.17	2.93	3.44
ADF, %	2.12	2.09	2.21	2.20	3.24
Phytase, FTU/kg	<70	910	<70	690	-

[1]FSBM = fermented soybean meal; SBM-CV = conventional soybean meal; P-free = phosphorus-free diet.

[2]FTU = phytase units.One FTU is defined as the amount of phytase needed to release 1 g of phytate bound P.

[3]Pork gelatin obtained from Gelita Gelatine USA Inc. (Sioux City, IA).

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

[5]Contained the following AA (%, as-is basis): DL-methionine, 0.27; L-threonine, 0.08; L-tryptophan, 0.14; L-histidine, 0.08; L-isoleucine, 0.16; and L-valine, 0.05.

[6]Optiphos 2000 (2000 FTU/g), Enzyvia, Sheridan, IN.

[7]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg;

biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 3.3. Effects of phytase on apparent total tract digestibility (ATTD) of P and Ca and standardized total tract digestibility (STTD) of P in fermented soybean meal (FSBM) and conventional soybean meal (SBM-CV)[1]

	FSBM		SBM-CV		Pooled SEM	*P*-value		
Item	0 FTU/kg	800 FTU/kg	0 FTU/kg	800 FTU/kg		Source of SBM[3]	Phytase	Source of SBM × phytase
Phytase, FTU/kg[2]	< 70	910	< 70	690				
Feed intake, g DM/d	479.7	482.2	488.1	481.2	13.6	0.57	0.84	0.97
P intake, g/d	2.0	2.0	2.0	1.7	0.1	0.14	0.17	0.02
P in feces, %	2.8	2.1	4.2	2.4	0.1	< 0.01	< 0.01	< 0.01
P output, g/d	0.8	0.7	1.2	0.6	0.1	< 0.01	< 0.01	< 0.01
Absorbed P, g/d	1.2	1.4	0.8	1.2	0.1	< 0.01	< 0.01	0.19
ATTD of P, %	60.9	67.5	41.6	66.2	2.0	< 0.01	< 0.01	< 0.01
Basal EPL,[4] mg/d	89.5	90.0	91.1	90.0	2.9	0.57	0.84	0.97
STTD of P[5], %	65.5	71.9	46.1	71.4	2.0	< 0.01	< 0.01	< 0.01
Ca intake, g/d	2.8	3.2	4.2	3.4	0.1	< 0.01	0.33	< 0.01
Ca in feces, %	5.0	4.6	6.4	4.3	0.3	0.02	< 0.01	0.03
Ca output, g/d	1.4	1.4	1.8	1.1	0.1	0.46	0.02	0.01

Table 3.3 (cont.)

Absorbed Ca, g /d	1.4	1.8	2.3	2.3	0.1	< 0.01	0.08	0.06
ATTD of Ca %	50.7	55.9	56.5	67.4	3.1	0.02	0.02	0.45

[1]Data are means of 6 observations per treatment, except for the treatment with SBM-CV and phytase, which only had 5 observations.

[2]FTU = phytase units; Optiphos 2000. Enzyvia, Sheridan, IN.

[3]SBM = soybean meal.

[4]EPL = basal endogenous P loss. This value was measured in pigs fed the P-free diet and determined to be 187 mg/kg DMI. The daily basal EPL was calculated by multiplying daily DMI by 187 mg/kg DMI.

[5]Values for STTD were calculated by correcting values for ATTD for basal EPL.

CHAPTER 4

DIGESTIBILITY OF ENERGY, DRY MATTER, AND NUTRIENTS AND CONCENTRATION OF DIGESTIBLE METABOLIZABLE, AND NET ENERGY IN FERMENTED SOYBEAN MEAL, CONVENTIONAL SOYBEAN MEAL, AND FISH MEAL FED TO WEANLING PIGS

ABSTRACT

Two experiments were conducted to determine the digestibility of energy, DM, and nutrients and the concentration of DE, ME, and NE in fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), and fish mealfed to weanling pigs. In Exp. 1, 36 barrows (initial BW: 22.0 ± 3.85 kg) were placed in metabolism cages and allotted to a randomized complete block design with 4 diets and 9 pigs per diet. Feces and urine were collected for 5 d after a 5 d adaptation period. A corn-based diet consisting of 96.4% corn and vitamins and minerals was formulated. Three additional diets containing corn and each of the experimental ingredients (FSBM, SBM-CV, and fish meal) were also formulated. The apparent total tract digestibility (ATTD) of GE in corn, FSBM, and SBM-CV was 88.6, 88.2, and 90.3%, respectively. These values were not different ($P > 0.01$), but the ATTD of GE in fish meal (84.0%) was less ($P < 0.01$) than in the other ingredients. The concentrations of DE, ME, and NE in SBM-CV were 4,553, 4,137, and 3,193 kcal/kg DM. These values were greater ($P < 0.01$) than the DE, ME, and NE in FSBM (4,296, 3,781, and 2,951 kcal/kg DM), corn (3,951, 3,819, and 2,864 kcal/kg DM), and fish meal (3,827, 3,412, and 2,626 kcal/kg DM). However, FSBM contained more ($P < 0.01$) DE, ME, and NE than fish meal and more ($P < 0.01$) DE than corn. The biological value of the protein in fish

meal (75.4%) was greater ($P < 0.05$) than in corn (34.8%) and FSBM (62.8%), and the biological value of protein in SBM-CV (67.1%) was greater ($P < 0.05$) than the biological value of protein in corn, but not different ($P > 0.05$) from that in FSBM and fish meal. In Exp. 2, 8 barrows (initial BW: 10.4 ± 0.47 kg) were equipped with a T-cannula in the distal ileum and randomly allotted to a replicated 4 × 4 Latin square design with 4 diets and 4 periods per square. Three cornstarch-based diets were formulated with FSBM, SBM-CV, or fish meal as the only source of AA in each diet. A N-free diet that was used to estimate basal endogenous losses of CP and AA was also formulated. The standardized ileal digestibility (SID) of all indispensable AA except Lys, Thr, and Trp was greater ($P < 0.01$) in FSBM than in fish meal. The SID of Met and Val was also greater ($P < 0.05$) in FSBM than in SBM-CV, but for the remaining indispensable AA, no difference between FSBM and SBM-CV was observed.In conclusion, the concentration of DE, ME, and NE is less in FSBM than in SBM-CV. However, DE, ME, and NE are greater in FSBM than in fish meal, but the SID of most AA is not different between the 2 sources of SBM, although they are greater than in fish meal.

Key words:amino acid digestibility, energy, fermented soybean meal, fish meal, pigs, soybean meal.

INTRODUCTION

Protein from conventional soybean meal (**SBM-CV**) contains anti-nutritional factors such as antigens, oligosaccharides, lectins, and trypsin inhibitors that decrease nutrient availability and reduce growth performance of young pigs (Li et al., 1991; Hong et al., 2004). Therefore, inclusion of SBM-CV is restricted in diets fed to weanling pigs (Dunsford, 1989). Animal protein such as fish meal is often used in these diets (Kim and Easter, 2001) although animal

protein is more expensive than soy protein. However, many of the anti-nutritional factors in SBM-CV may be eliminated if SBM-CV is fermented (Kaankuka et al., 1996; Hong et al., 2004; Cervantes-Pahm and Stein, 2010) and fermented soybean meal (**FSBM**) is, therefore, better tolerated by young pigs than SBM-CV (Liu et al., 2007; Yang et al., 2007). Thus, it is believed that FSBM may replace fish meal in diets fed to weanling pigs without reducing growth performance (Jones et al., 2010; Kim et al., 2010),and FSBM may have a positive effect on intestinal health and gut morphology of weaned pigs compared with SBM-CV (Kim et al., 2007). An increase in the apparent ileal digestibility (**AID**) of DM and most AA may also be observed in FSBM compared with SBM-CV (Min et al., 2004) although that is not always the case (Cervantes-Pahm and Stein, 2010).

Recently, production of FSBM was initiated in the United States, but there are no data on the digestibility of energy and AA in this source of FSBM. Two experiments were, therefore, conducted with the objective of determining the concentration of DE, ME, and NE, apparent total tract digestibility (**ATTD**) of GE, DM, and nutrients, and the ileal digestibility of AA in FSBM produced in the United States and to compare these values to values obtained for SBM-CV and fish meal.

MATERIALS AND METHODS

Two experiments were conducted, and the Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for both experiments. Pigs used in the experiments were the offspring of G-performer boars mated to F-25 gilts (Genetiporc, Alexandria, MN). The ingredients that were used in the experiments included FSBM, SBM-CV, and fish meal (Table 1) and the same batches of these ingredients were used in both experiments.

The source of FSBM that was used was PepSoyGen® (Nutra Ferma, North Sioux City, SD), which is produced by fermentation of SBM in the presence of *Aspergillus oryzae* and *Lactobacillus subtilis*. The SBM-CV was sourced from Rose Acre Farms (Seymour, IN), and the fish meal was prepared from menhaden fish (Menhaden Select, Omega Protein, Houston, TX).

Exp. 1: Energy Concentration and Total Tract Digestibility

Diets, Animals, and Experimental Design. Experiment 1 was designed to determine the DE, ME, and NE, the N-balance, and the ATTD of GE, DM, and nutrients in FSBM, SBM-CV, and fish meal. Thirty-six barrows (initial BW: 22.2 ± 3.85 kg) were placed in metabolism cages equipped with a feeder and a nipple drinker in a randomized complete block design with 4 diets and 9 replicate pigs per diet.

Four corn-based diets were formulated (Table 2). The basal diet contained 96.4% corn (as-fed basis. The FSBM diet contained 69.3% corn and 28.0% FSBM (as-fed basis). The SBM-CV diet contained 65.2% corn and 31.0% SBM-CV (as-fed basis), and the fish meal diet contained 75.3% corn and 24.0% fish meal (as-fed basis). Vitamins and minerals were included in the diets to meet or exceed the requirements for weanling pigs (NRC, 1998).

Feeding and Sample Collection. Feed was supplied in a daily amount of 3 times the maintenance energy requirement (i.e., 106 kcal of ME/kg of $BW^{0.75}$; NRC, 1998) of the smallest pig in each replicate. The daily amount of feed was divided into 2 equal meals that were fed at 0800 and 1700 h. Water was available at all times.

Pigs were fed experimental diets for 12 d. The initial 5 d were considered an adaptation period to the diet. Fecal markers were fed on d 6 (chromic oxide) and on d 11, (ferric oxide) and fecal collections were initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared (Adeola, 2001). Feces were collected twice daily and stored at -20ºC

immediately after collection. Urine was also collected and urine collections started on d 6 at 1700 h and ceased on d 11 at 1700 h. Urine buckets were placed under the metabolism cages to permit total collection. They were emptied in the morning and afternoon and a preservative of 50 mL of sulfuric acid was added to each bucket when they were emptied. The collected urine was weighed and a 10% subsample was stored at -20ºC.

Chemical Analyses. After completing sample collections, urine samples were thawed, combined, and mixed within animal and diet, and a subsample was collected for chemical analysis. Fecal samples were dried at 65ºC in a forced-air oven and ground through a 1-mm screen in a Wiley mill (model 4; Thomas Scientific, Swedesboro, NJ) before analyses. Urine samples were prepared and lyophilized before energy analysis as previously described (Kim et al., 2009). All samples were analyzed in duplicate. Diets, ingredients, and fecal samples were analyzed for DM (method 930.15; AOAC Int., 2007), ash (method 975.03; AOAC Int., 2007), and acid hydrolyzed ether extraction (**AEE**), which was determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (method 2003.06, AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN).Diets, ingredients, fecal samples, and urine samples were also analyzed for CP by combustion (method 999.03; AOAC Int., 2007) using a Rapid N cube (Elementar Americas Inc, Mt. Laurel, NJ) and for GE using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Ingredients were analyzed for AA (method 982.30 E [a, b, c]; AOAC Int., 2007), and diets and ingredients were analyzed for ADF (method 973.18; AOAC Int., 2007), NDF (Holst, 1973), and for total starch using the glucoamylase procedure (method 979.10; AOAC Int., 2007). Phosphorus and Ca were analyzed in all ingredients by inductively coupled plasma spectroscopy (method 975.03; AOAC Int., 2007) after wet ash sample preparation (method 975.03; AOAC Int., 2007) and FSBM and

SBM-CV were analyzed for trypsin inhibitor concentration (method Ba 12-75; AOCS; 2006), phytic acid (Ellis et al., 1977), and monosaccharaides, sucrose, and oligosaccharides were analyzed as described by Cervantes-Pahm and Stein (2010).

Calculations and Statistical Analysis. Energy values that were determined from the excretion of GE in the feces and urine were subtracted from the intake of GE to calculate DE and ME for each diet (Adeola, 2001). The DE and ME in the corn diet were divided by 0.964 to calculate the DE and ME in corn. The contributions of DE and ME from corn to the diets containing FSBM, SBM-CV, and fish meal were then calculated and subtracted from the total DE and ME of these diets, and the concentrations of DE and ME in FSBM, SBM-CV, and fish meal were calculated by difference (Adeola, 2001). The DE and ME in all ingredients were calculated on an as-fed basis as well as on a DM basis. The ATTD of GE, DM, CP, AEE, and ash was also calculated in all diets and in each ingredient using the direct procedure and the difference procedure, respectively (Adeola, 2001). These procedures were also used to calculate the N-balance for each diet and ingredient and the biological value of the protein. The concentration of NE was calculated in diets and ingredients using the average value for equations 3, 5, 6, and 8 published by Noblet et al. (1994).

Data were analyzed by ANOVA using the Mixed Procedure of SAS (SAS Institute Inc., Cary, NC). Homogeneity of the variances among treatments was confirmed using the UNIVARIATE procedure and this procedure was also used to identify outliers, but no outliers were observed. Diet was the fixed effect and pig and replicate were random effects. The LSmeans statement was used to calculate treatment means and the PDIFF option was used to separate means if differences were detected. The pig was the experimental unit for all analyses and an alpha level of 0.05 was used to assess significance among means.

Exp. 2: AA Digestibility

Diets, Animals, and Experimental Design. Experiment 2 was designed to determine the AID and the standardized ileal digestibility (**SID**) of CP and AA in FSBM, SBM-CV, and fish meal fed to weanling pigs. Eight weanling barrows (initial BW: 10.4 ± 0.47 kg) were equipped with a T-cannula in the distal ileum according to procedures adapted from Stein et al. (1998). Pigs were allotted to a replicated 4 × 4 Latin square design with 4 periods and 4 diets in each square. Pigs were housed individually in pens (1.2 × 1.5 m) in an environmentally controlled room. Pens had fully slatted tri-bar floors and a feeder and a nipple drinker were installed in each pen.

Four diets were prepared (Tables 3 and 4). Three cornstarch-based diets contained FSBM (30.0%, as-fed basis), SBM-CV (33.0%, as-fed basis), or fish meal (25%, as-fed basis) as the only AA-containing ingredient. The last diet was a N-free diet that was used to estimate basal endogenous losses of CP and AA. Chromic oxide (0.4%) was included in all diets as an indigestible marker and vitamins and minerals were included to meet or exceed estimated nutrient requirements for weanling pigs (NRC, 1998).

Feeding and Sample Collection. Pigs were fed at a daily level of 2.5 times the estimated maintenance requirement for energy, and the daily allotment of feed was provided at 0700 h each day. Water was available at all times.

Individual pig BW were recorded at the beginning of each period and the amount of feed supplied each day was recorded. Each experimental period lasted 7 d. The initial 5 d was an adaptation period to the diet whereas ileal digesta were collected for 8 h on d 6 and 7. A 225-mL plastic bag was attached to the cannula barrel by a zip tie, and digesta that flowed into the bag were collected. Bags were removed whenever they were filled with digesta, or at least once

every 30 minutes. They were then stored at -20ºC to prevent bacterial degradation of AA in the digesta.

Chemical Analysis. At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a subsample was collected for chemical analyses. All ileal digesta samples were lyophilized and finely ground before chemical analyses. All samples of digesta and diets were analyzed in duplicate for DM, CP, and AA as described for Exp. 1, and for chromium (Fenton and Fenton, 1979). All diet samples were also analyzed for ADF, NDF, ash, AEE, and GE as described for Exp. 1.

Calculations and Statistical Analysis. Values for AID, endogenous losses, and SID of CP and AA in the diets containing FSBM, SBM-CV, and fish meal were calculated (Stein et al., 2007).Data were analyzed by ANOVA using the MIXED procedure (SAS Institute Inc., Cary, NC) as described for Exp. 1.

RESULTS

Exp. 1: Energy Concentration and Total Tract Digestibility

Gross energy intake was less ($P < 0.01$) in pigs fed the corn diet than in pigs fed the FSBM, SBM-CV, and fish meal diets (Table 5). Pigs fed the fish meal diet had a greater ($P < 0.05$) fecal excretion of GE than pigs fed the corn and SBM-CV diets, but the urine excretion of GE was less ($P < 0.01$) in pigs fed the corn diet than in pigs fed the FSBM, SBM-CV, and fish meal diets. The DE and NE in the FSBM and SBM-CV diets were not different, but DE and NE were greater ($P< 0.01$) in the SBM-CV diet than in the fish meal diet. However, pigs fed the fish meal diet had a greater ($P < 0.01$) DE than pigs fed the corn diet. The ME in the FSBM and SBM-CV diets was greater ($P < 0.01$) than in the corn diet, but no difference was observed

between pigs fed the fish meal and corn diets. Nitrogen intake, N-excretion in feces, and N-excretion in urine were less ($P < 0.01$) in pigs fed the corn diet than in pigs fed the FSBM, SBM-CV, and fish meal diets. However, there was no difference in N-intake between pigs fed the FSBM and SBM-CV diets and there was no difference in N-excretion in the feces and urine among pigs fed the FSBM, SBM-CV, and fish meal diets.

The ATTD of GE and DM was less ($P < 0.05$) in the fish meal diet than in the corn and SBM-CV diets and the ATTD of GE and DM in the SBM-CV diet was not different from that in pigs fed the corn or the FSBM diets. The ATTD of N was less ($P < 0.01$) in the corn diet than in the other diets, but there were no differences among FSBM, SBM-CV, and fish meal diets. The ATTD of AEE was greater ($P < 0.01$) in the FSBM diet than in the other diets. The ATTD of AEE was less in the corn diet than in the other diets, but no difference was observed between the SBM-CV and fish meal diets. The ATTD of ash was less ($P < 0.01$) in the corn diet than in the FSBM and SBM-CV diets, and the ATTD of ash was greater ($P < 0.01$) in the SBM-CV diet than in the FSBM and fish meal diets.

Pigs fed corn had a greater ($P < 0.01$) GE intake and fecal excretion of GE than pigs fed FSBM, SBM-CV, and fish meal (Table 6). There was no difference in urinary excretion of GE among ingredients. The DE, ME, and NE were greater ($P < 0.01$) in SBM-CV than in the other ingredients on an as-is as well as on a DM basis, but FSBM had a greater ($P < 0.01$) DE (as-is and DM basis) than corn and fish meal and a greater ($P < 0.01$) ME and NE (as-is and DM basis) than fish meal. Nitrogen intake was less ($P < 0.01$) in pigs fed corn than in pigs fed FSBM, SBM-CV, and fish meal, but there was no difference in N-intake between SBM-CV and fish meal. There were no differences among ingredients in fecal and urinary excretion of N. The retention of N was less ($P < 0.01$) in pigs fed corn than in pigs fed FSBM, SBM-CV, and fish

meal. The retention of N was also less ($P < 0.01$) in pigs fed FSBM than in pigs fed fish meal, but there was no difference in N-retention between pigs fed FSBM and pigs fed SBM-CV.

The biological value of the protein in corn was less ($P < 0.01$) than in all other ingredients and there was no difference in the biological value between FSBM and SBM-CV, but the biological value of protein was less ($P < 0.01$) in FSBM than in fish meal. The ATTD of GE was less ($P < 0.01$) in fish meal than in corn, FSBM, and SBM-CV and there was no difference in the ATTD of GE among corn, FSBM, and SBM-CV. The ATTD of DM was also less ($P < 0.01$) in fish meal than in the other ingredients, but there was no difference among corn, FSBM, and SBM-CV. The ATTD of N was less ($P < 0.01$) in corn than in the other ingredients, but there was no difference among FSBM, SBM-CV, and fish meal. The ATTD of AEE was greater ($P < 0.01$) in FSBM than in the other ingredients, but there was no difference between SBM-CV and fish meal in the ATTD of AEE, whereas corn had the least ($P < 0.01$) ATTD of AEE. The ATTD of ash was greater ($P < 0.01$) in SBM-CV than in all other ingredients, but the ATTD of ash was greater ($P < 0.01$) in FSBM than in corn, but not different from fish meal.

Exp. 2: AA Digestibility

The AID of CP was not different among ingredients (Table 7). The AID of Arg, His, Phe, and Trp were less ($P< 0.05$) in fish meal than in FSBM and SBM-CV. The AID of Ile, Leu, Met, Phe, Thr, and Val was greater ($P< 0.05$) in FSBM than in SBM-CV and fish meal, but the AID of Lys was not different among ingredients. The AID of Gly and Pro was also not different among ingredients, but the AID of Ala was less ($P< 0.01$) in SBM-CV than in FSBM and fish meal. The AID of Cys was less ($P < 0.01$) in fish meal than in FSBM and SBM-CV, and the AID of Glu was greater ($P < 0.01$) in SBM-CV than in FSBM and fish meal. The AID of Asp, Ser,

and Tyr was greater ($P < 0.01$) in FSBM than in SBM-CV and fish meal, and the AID of these AA was also greater ($P < 0.05$) in SBM-CV than in fish meal.

The SID of CP was not different among FSBM, SBM-CV, and fish meal. The SID of Arg, His, and Phe was less ($P < 0.05$) in fish meal than in SBM-CV and FSBM. The SID of Ile and Leu was also less ($P < 0.05$) in fish meal than in FSBM, but not different from SBM-CV. The SID of Met and Val were greater ($P < 0.01$) in FSBM than in SBM-CV and fish meal. However, for Lys, Thr, and Trp no differences among ingredients were observed.The SID of Asp, Cys, Ser, and Tyr were less ($P < 0.01$) in fish meal than in FSBM and SBM-CV, but the SID of Ala was greater ($P < 0.05$) in FSBM than in SBM-CV and fish meal. The SID of Glu, however, was greater ($P < 0.05$) in SBM-CV than in the other 2 ingredients, but for Gly and Pro, no differences among ingredients were observed.

DISCUSSION

Exp. 1: Energy Concentration and Total Tract Digestibility

The values for GE, DE, ME, and ATTD of GE in corn that were determined in this experiment are in close agreement with previously reported values (NRC, 1998; Pedersen et al., 2007; Widmer et al., 2007; Baker and Stein, 2009). Likewise, the DE and ME that were determined for SBM-CV concur with data from Baker and Stein (2009). The reason for the greater DE, ME, and NE in SBM-CV than in FSBM is most likely that during fermentation of soybean meal, the oligosaccharides and sucrose are removed. Sucrose is easily digested by pigs and oligosaccharides are almost completely fermented (Smiricky et al., 2002). If oligosaccharides and sucrose in soybean meal are removed by enzyme treatment, the concentration of DE and ME are not affected (Goebel and Stein, 2011), but results of this

experiment indicate that fermentation of soybean meal in the presence of *Aspergillussubtillis* and *Lactobacillus oryzae* may have a different impact on the concentration of DE and ME than enzyme treatment. Removal of sucrose and oligosaccharides from soybean meal results in a greater concentration of CP, ADF, and NDF, which is the reason the concentration of these nutrients is greater in FSBM than in SBM-CV. These changes in nutrient concentration in FSBM compared with SBM-CV were also reported by Cervantes-Pahm and Stein (2010). However, ADF and NDF are not completely fermented, and a greater concentration of ADF and NDF will result in reduced values for DE and ME.

The NE values that were calculated for corn and fish meal concur with previous values (NRC, 1998) and the DE and ME in fish meal that were determined in this experiment also agree with values reported by NRC (1998). Fish meal has a greater concentration of GE than FSBM and SBM-CV, which most likely is a result of the greater concentration of AEE in fish meal than in FSBM and SBM-CV. However, AEE and GE in fish meal are poorly digested, which is the reason the DE, ME, and NE were less in fish meal than in FSBM. To our knowledge, NE values have not been previously reported for FSBM, but the fact that the NE in FSBM is greater than in fish meal indicates that the NE of diets containing FSBM rather than fish meal will not be compromised.

The greater biological value of the protein in fish meal compared with the other ingredients indicates that the AA profile of protein in fish meal more closely resembles the requirements of the pigs than the AA profile of protein in the other ingredients. The biological value for protein in FSBM indicates that the protein in FSBM has the same value as protein in SBM-CV, but corn protein has a reduced value compared with protein from the other ingredients.

The fact that the ATTD of DM was not different between SBM-CV and FSBM indicates that fermentation of soybean meal does not affect DM digestibility. A similar observation was reported by Goebel and Stein (2011) when soybean meal was enzyme treated.

The ATTD of N in corn was slightly less than the value reported by Widmer et al. (2007), which may be a result of younger pigs being used in this experiment than in the experiment by Widmer et al. (2007). The reduced ATTD of N in corn compared with the other ingredients also is in agreement with Widmer et al. (2007) and may be a result of the reduced concentration of N in corn compared with the other ingredients because endogenous N output contribute more to the total output of N in ingredients with a low concentration of N than in ingredients with greater concentrations of N.

Exp. 2: AA Digestibility

The AA composition of FSBM, SBM-CV, and fish meal were in agreement with values reported by Hong et al. (2004) and Cervantes-Pahm and Stein (2010) who used FSBM that was produced in South Korea. The fact that the AID of most indispensable AA is greater in FSBM than in SBM-CV is in agreement with Yang et al. (2007). The reason for the greater AID of indispensable AA in FSBM than in SBM-CV may be that during fermentation, the concentration of small peptides have been reported to increase (Hong et al. (2004) and small peptides may be better absorbed in the small intestine than AA (Gilbert et al., 2008). However, Cervantes-Pahm and Stein (2010) did not observe differences in peptide size, AID, or SID of AA between FSBM and SBM-CV, but the FSBM used by Cervantes-Pahm and Stein (2010) was not produced in the United States and may have been of a different quality than the product used in this experiment. In addition, the FSBM that was used in this experiment was fermented in the presence of both *Aspergillus oryzae* and *Lactobacillus subtillis*, whereas the FSBM use in the previous

experiments was produced based on only *Aspergillus oryzae*. Nevertheless, the present data indicate that AA in FSMB are well digested by young pigs and FSBM may, therefore, be used as a source of digestible AA in diets fed to weanling pigs. Cervantes-Pahm and Stein (2010) reported that the SID of Lys in FSBM is less than in SBM-CV, but such an effect was not observed in this experiment. It is possible that the reason for the low SID of Lys in the experiment by Cervantes-Pahm and Stein (2010) is that the FSBM used in that experiment was heat damaged because heat damage of soybean meal will reduce the SID of Lys (Gonzales-Vega et al., 2011).

The AID and SID of indispensable AA in fish meal that were determined in this experiment were less than the values reported in previous experiments (NRC, 1998; Urbaityte et al., 2009; Cervantes-Pahm and Stein, 2010). The reason for this observation may be that the quality of fish meal that was use in this experiment was reduced compared with that used in previous experiments because the quality of fish meal may vary due to the species used and to the type of processing that is used to produce the meal (Wiseman et al., 1991; Kim and Easter, 2001).

Conclusions

Fermentation of soybean meal reduces the concentration of DE, ME, and NE, but increases the concentration of DM, CP, AEE, NDF, and ADF compared with SBM-CV. The concentration of DE, ME, and NE are greater in FSBM than in fish meal, but less than in SBM-CV. The SID of most AA is not different between SBM-CV and FSBM, but these values are greater than in fish meal. The biological value of protein in fish meal is greater than in FSBM and SBM-CV, but the biological value of corn protein is less than in fish meal, FSBM, and SBM-CV.

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Table 4.1. Analyzed nutrient composition of fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), fish meal, and corn, as-fed basis

Item	Ingredient			
	FSBM	SBM-CV	Fish meal	Corn
GE, kcal/kg	4,533	4,281	4,589	3,938
DM, %	91.0	89.39	91.80	87.04
CP, %	53.91	50.20	63.98	7.44
Ca, %	0.27	0.23	4.96	0.01
P, %	0.83	0.69	3.05	0.24
Ash, %	7.10	5.85	17.86	1.20
AEE[1], %	1.50	1.39	9.33	2.20
NDF, %	8.45	5.40	-	6.56
ADF, %	4.97	3.42	-	1.76
TIU[2] / mg/kg	< 1.00	4.20	-	-
Starch, %	0.90	0.61	-	55.77
Carbohydrates, %				
Glucose	0.33	0.00	-	-
Sucrose	0.00	8.77	-	-
Maltose	0.00	0.20	-	-
Fructose	0.54	0.00	-	-

Table 4.1 (cont.)

Stachyose	0.06	6.23	-	-
Raffinose	0.00	1.29	-	-
Indispensable, AA %				
Arg	3.59	3.61	3.58	0.33
His	1.34	1.33	1.41	0.19
Ile	2.45	2.35	2.54	0.24
Leu	4.11	3.79	4.17	0.75
Lys	3.15	3.17	4.76	0.24
Met	0.73	0.69	1.66	0.14
Phe	2.64	2.46	2.35	0.31
Thr	2.00	1.85	2.34	0.23
Trp	0.71	0.66	0.59	0.05
Val	2.60	2.50	3.03	0.33
Dispensable, AA %				
Ala	2.26	2.12	3.71	0.46
Asp	5.82	5.37	5.32	0.44
Cys	0.82	0.66	0.49	0.15
Glu	9.31	8.69	7.72	1.14
Gly	2.24	2.06	4.13	0.28
Pro	2.87	2.41	2.91	0.56
Ser	2.33	2.12	2.03	0.27
Tyr	1.89	1.71	1.82	0.20

Table 4.1 (cont.)

Total AA	50.86	47.55	54.56	6.31

[1]AEE = acid hydrolyzed ether extract.

[2]TIU = trypsin inhibitor units.

Table 4.2. Composition of experimental diets containing corn, fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), or fish meal, as-fed basis, Exp. 1

	Diet			
Item	Corn	FSBM	SBM-CV	Fish meal
Ingredients, %				
Ground corn	96.40	69.30	65.20	75.30
FSBM	-	28.00	-	-
SBM-CV	-	-	31.00	-
Fish meal	-	-	-	24.00
Monocalcium phosphate	1.70	-	2.00	-
Ground limestone	1.20	2.00	1.10	-
Sodium chloride	0.40	0.40	0.40	0.40
Vitamin mineral premix[1]	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Analyzed composition				
GE, kcal/kg	3,740	3,932	3,931	3,926
DM, %	86.86	89.80	88.30	88.53

Table 4.2 (cont.)

CP, %	6.87	20.49	20.30	21.30
ADF, %	1.86	3.02	2.67	2.04
NDF, %	9.92	11.49	9.92	15.59
AEE[2], %	1.16	2.55	2.17	2.58
Ash, %	3.44	5.06	7.03	6.09
Starch, %	56.11	40.97	39.75	46.06

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

[2]AEE = acid hydrolyzed ether extract.

Table 4.3. Composition of experimental diets, as-fed basis, Exp. 2

Item	Diet[1]			
	FSBM	SBM-CV	Fish meal	N-free[1]
Ingredient, %				
FSBM	30.00	-	-	-
SBM-CV	-	33.00	-	-
Fish meal	-	-	25.00	-
Soybean oil	3.00	3.00	-	4.00
Solka floc	-	-	-	4.00
Monocalcium phosphate	1.30	1.30	-	2.40
Ground limestone	1.30	1.30	-	0.50
Sucrose	20.00	20.00	20.00	20.00
Chromic oxide	0.40	0.40	0.40	0.40
Cornstarch	43.30	40.30	53.90	67.50
Magnesium oxide	-	-	-	0.10
Potassium carbonate	-	-	-	0.40
Sodium chloride	0.40	0.40	0.40	0.40
Vitamin mineral premix [2]	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00

[1]FSBM = fermented soybean meal; SBM-CV = conventional soybean meal.

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

Table 4.4. Analyzed nutrient composition of experimental diets, as-fed basis, Exp. 2

	Diet[1]			
Item	FSBM	SBM-CV	Fish meal	N free
GE, kcal/kg	4,034	3,937	3,857	3,788
Ash, %	5.90	4.16	6.76	3.87
DM, %	94.42	93.96	93.96	94.34
CP, %	15.43	12.07	16.91	0.32
ADF, %	1.75	1.73	0.28	3.19
NDF, %	3.70	2.60	5.44	2.84
AEE[2], %	2.44	2.39	2.46	1.54
Indispensable, AA %				
Arg	1.12	0.91	0.85	0.01
His	0.45	0.35	0.37	-
Ile	0.79	0.60	0.64	0.02
Leu	1.32	0.98	1.08	0.03
Lys	1.00	0.82	1.18	0.01
Met	0.24	0.18	0.41	-
Phe	0.83	0.63	0.58	0.01
Thr	0.65	0.49	0.60	0.01
Trp	0.22	0.19	0.16	< 0.04

Table 4.4 (cont.)

Val	0.84	0.60	0.74	0.01
Dispensable, AA %				
Ala	0.75	0.55	0.74	0.02
Asp	1.82	1.38	1.30	0.02
Cys	0.23	0.17	0.12	0.01
Glu	2.96	2.27	1.93	0.03
Gly	0.73	0.54	1.03	0.01
Pro	0.84	0.63	0.67	0.02
Ser	0.76	0.55	0.50	0.01
Tyr	0.52	0.39	0.36	0.01
Total AA	16.07	12.23	13.46	0.25

[1]FSBM = fermented soybean meal; SBM-CV = conventional soybean meal.

[2]AEE = acid hydrolyzed ether extract.

Table 4.5. Concentration of digestible and metabolizable energy, daily energy and nitrogen balance, and apparent total tract digestibility (ATTD) of energy, DM, and nutrients in experimental diets containing corn, fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), or fish meal, as-fed basis, Exp. 1[1]

Item	Corn	FSBM	SBM-CV	Fish meal	SEM	*P*-value
GE intake, kcal	3,266[b]	3,623[a]	3,755[a]	3,664[a]	122.2	< 0.01
GE in feces, kcal	374.5[b]	418.0[ab]	403.4[b]	464.8[a]	23.3	0.02
GE in urine, kcal	96.5[b]	192.6[a]	181.0[a]	168.8[a]	18.1	< 0.01
DE in diet kcal/kg	3,315[c]	3,478[ab]	3,504[a]	3,433[b]	16.6	< 0.01
ME in diet kcal/kg	3,204[b]	3,267[a]	3,314[a]	3,255[ab]	21.4	< 0.01
NE in diet kcal/kg	2,373[c]	2,453[ab]	2,481[a]	2,432[b]	13.2	< 0.01
N intake, g	6.0[c]	18.9[b]	19.4[ab]	19.8[a]	0.5	< 0.01
N in feces, g	1.4[b]	2.3[a]	2.2[a]	2.4[a]	0.1	< 0.01
N in urine, g	3.0[b]	7.1[a]	6.8[a]	5.9[a]	0.6	< 0.01
ATTDof GE, %	88.6[a]	88.4[ab]	89.2[a]	87.3[b]	0.4	0.02
ATTD of DM, %	89.1[a]	88.4[ab]	89.2[a]	87.3[b]	0.5	0.02
ATTD of N, %	76.0[b]	87.8[a]	88.5[a]	87.9[a]	1.0	< 0.01

Table 4.5 (cont.)

ATTD of AEE[2], %	28.5[c]	48.6[a]	40.6[b]	37.9[b]	2.5	< 0.01
ATTD of ash, %	60.3[c]	64.6[b]	72.9[a]	62.5[bc]	1.2	< 0.01

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

[1]Data are means of 9 observations per treatment.

[2]AEE = acid hydrolyzed ether extract.

Table 4.6. Concentration of digestible and metabolizable energy, daily energy and nitrogen balance, and apparent total tract digestibility (ATTD) of energy, DM, and nutrients in corn, fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), and fish meal, as-fed basis, Exp. 1[1]

Item	Corn	FSBM	SBM-CV	Fish meal	SEM	*P*-value
GE intake, kcal	3,388[a]	1,275[c]	1,546[b]	1,112[d]	124.3	< 0.01
GE in feces, kcal	388.5[a]	148.8[b]	150.1[b]	172.2[b]	23.8	< 0.01
GE in urine, kcal	100.1	123.3	115.8	93.5	18.1	0.63
DE, kcal/kg	3,439[c]	3,910[b]	4,069[a]	3,513[c]	48.9	< 0.01
DE, kcal/kg DM	3,951[c]	4,296[b]	4,553[a]	3,827[c]	52.2	< 0.01
ME, kcal/kg	3,324[bc]	3,441[b]	3,698[a]	3,132[c]	73.6	< 0.01
ME, kcal/kg DM	3,819[b]	3,781[b]	4,137[a]	3,412[c]	80.9	< 0.01
NE, kcal/kg	2,469[c]	2,666[b]	2,832[a]	2,394[c]	42.0	< 0.01
NE, kcal/kg DM	2,864[b]	2,951[b]	3,193[a]	2,626[c]	46.1	< 0.01
N intake, g	6.2[c]	14.5[b]	15.3[a]	15.1[a]	0.5	< 0.01
N in feces, g	1.5	1.3	1.2	1.3	0.1	0.37
N in urine, g	3.1	5.0	4.7	3.5	0.6	0.09

Table 4.6 (cont.)

N retention, g	1.6[c]	8.3[b]	9.4[ab]	10.3[a]	0.5	< 0.01
Biological value, %	34.8[c]	62.8[b]	67.1[ab]	75.4[a]	4.3	< 0.01
ATTD of GE, %	88.6[a]	88.2[a]	90.3[a]	84.0[b]	1.1	< 0.01
ATTD of DM, %	89.1[a]	86.9[a]	89.5[a]	81.6[b]	1.3	< 0.01
ATTD of N, %	76.0[b]	91.3[a]	91.8[a]	91.6[a]	1.0	< 0.01
ATTD of AEE[2], %	28.5[c]	71.9[a]	56.9[b]	49.9[b]	4.7	< 0.01
ATTD of ash, %	60.3[c]	68.3[b]	78.7[a]	64.3[bc]	1.8	< 0.01

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

[1]Data are means of 9 observations per treatment.

[2]AEE = acid hydrolyzed ether extract.

Table 4.7. Apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of CP and AA in fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), and fish meal by weanling pigs, Exp. 2[1]

	AID					SID[2]				
	Ingredient					Ingredient				
Item	FSBM	SBM-CV	Fish meal	SEM	*P*-value	FSBM	SBM-CV	Fish meal	SEM	*P*-value
CP, %	64.5	59.7	61.9	2.7	0.50	79.9	79.6	76.1	2.7	0.54
Indispensable AA, %										
Arg	87.6[a]	86.1[a]	77.4[b]	1.2	< 0.01	94.2[a]	94.2[a]	86.1[b]	1.2	< 0.01
His	83.6[a]	81.9[a]	75.4[b]	1.2	< 0.01	89.3[a]	89.1[a]	82.3[b]	1.2	0.01
Ile	82.1[a]	77.7[b]	75.1[b]	1.2	< 0.01	87.5[a]	84.7[ab]	81.7[b]	1.2	< 0.01
Leu	82.1[a]	76.8[b]	75.5[b]	1.2	< 0.01	87.6[a]	84.3[ab]	82.2[b]	1.2	0.02
Lys	76.2	77.0	76.0	1.3	0.86	82.2	84.2	81.1	1.3	0.24
Met	85.6[a]	79.2[b]	79.9[b]	1.4	< 0.01	90.6[a]	85.7[b]	82.8[b]	1.4	< 0.01
Phe	83.4[a]	78.9[b]	72.3[c]	1.2	< 0.01	88.6[a]	85.8[a]	79.7[b]	1.2	< 0.01
Thr	72.0[a]	64.5[b]	66.7[b]	1.6	0.01	83.4	79.6	79.0	1.6	0.14

Table 4.7 (cont.)

Trp	82.7[a]	81.9[a]	77.7[b]	1.3	0.02	89.4	89.6	86.8	1.3	0.25
Val	77.7[a]	69.4[b]	69.4[b]	1.5	< 0.01	85.6[a]	80.5[b]	78.4[b]	1.5	< 0.01
Mean	81.1[a]	77.4[b]	74.4[b]	1.2	< 0.01	87.6[a]	85.8[a]	81.7[b]	1.2	< 0.01
Dispensable AA, %										
Ala	71.6[a]	61.5[b]	66.6[a]	1.9	< 0.01	81.9[a]	75.5[b]	74.8[b]	1.9	0.02
Asp	81.5[a]	77.5[b]	65.5[c]	1.5	< 0.01	86.6[a]	84.3[a]	72.8[b]	1.5	< 0.01
Cys	64.4[a]	64.7[a]	46.4[b]	2.5	< 0.01	75.2[a]	79.2[a]	67.0[b]	2.5	< 0.01
Glu	77.0[b]	82.9[a]	74.1[b]	1.6	< 0.01	81.3[b]	88.5[a]	80.7[b]	1.6	0.01
Gly	47.1	38.8	47.5	5.4	0.40	77.7	80.1	69.2	5.4	0.29
Pro	3.1	-36.1	-50.2	26.3	0.18	100.1	93.0	71.3	26.3	0.57
Ser	80.3[a]	74.2[b]	64.5[c]	1.6	< 0.01	88.4[a]	85.3[a]	76.7[b]	1.6	< 0.01
Tyr	82.1[a]	77.4[b]	71.6[c]	1.2	< 0.01	88.4[a]	85.8[a]	80.7[b]	1.2	< 0.01
Mean	68.0[a]	63.1[a]	54.0[b]	3.5	0.02	85.0[a]	85.6[a]	75.2[b]	3.5	0.05
All AA	74.1[a]	69.8[ab]	64.0[b]	2.2	0.01	86.2[a]	85.7[a]	78.4[b]	2.2	0.03

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

[1]Data are least squares means of 8 observations.

[2]Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of DMI) as CP, 25.55; Arg, 0.78; His, 0.27; Ile, 0.45; Leu, 0.78; Lys, 0.64; Met, 0.13; Phe, 0.46; Thr, 0.79; Trp, 0.16; Val, 0.71; Ala, 0.82.

CHAPTER 5

EFFECTS OF REPLACING FISH MEAL, CHICKEN MEAL, OR POULTRY BY-PRODUCT MEAL WITH FERMENTED SOYBEAN MEAL IN PHASE 1, PHASE 2, AND PHASE 3 DIETS FED TO WEANLING PIGS

ABSTRACT

Three experiments were conducted to test the hypothesis that fermented soybean meal (FSBM), may replace fish meal, chicken meal (CM), or poultry by-product meal (PBM) in diets fed to weanling pigs during the initial 28 d post-weaning. In all experiments, newly weaned pigs (21 d) were randomly allotted to a randomized complete block design. In Exp. 1, 192 pigs (initial BW: 6.88 ± 2.48 kg) were allotted to 4 dietary treatments with 2 phases (14 and 12 d, respectively). In phase 1, a positive control diet contained fish meal, whey powder, and protein plasma. A negative control diet (without animal protein) and 2 additional diets in which FSBM replaced fish meal or fish meal and protein plasma were also formulated. In phase 2 diets, a positive control, a negative control diet, and 2 diets in which FSBM replaced fish meal or fish meal and whey powder were formulated. In Exp. 2, 175 pigs (initial BW: 6.86 ± 2.86 kg) were allotted to 5 dietary treatments with 3 phases (7, 7, and 14 d, respectively). The positive control diet contained fish meal, whey powder, and protein plasma in phase 1 and 2, and fish meal and whey powder in phase 3, but no animal ingredients were included in the negative control diets. Three additional diets were formulated within each phase in which FSBM replaced fish meal, fish meal and protein plasma, or fish meal, protein plasma, and whey powder. In Exp. 3, 175 pigs (initial BW: 6.97 ± 2.1 kg) were allotted to 5 dietary treatments with 3 phases (7, 7, and 14 d, respectively). Three positive control diets contained fish meal, CM, or PBM whereas none of

these ingredients were included in the negative control diets. An additional diet in which fish meal, CM, or PBM was replaced by FSBM was also formulated. The final BW of the pigs in each experiment was not different among treatments. Likewise, the G:F ratio for the overall experiment were not difference among treatments in Exp. 1 and Exp. 2. However, in Exp. 3, G:F was greater for pigs fed the fish meal diets than for pigs on the other treatments, but it was not different among pigs fed CM, PBM, or FSBM. In conclusion, FSBM may replace FM, CM, and PBM in diets fed to pigs during the initial 28 d post-weaning without affecting pig growth performance except that G:F may be reduced.

Key Words: chicken meal, fermented soybean meal, fish meal, pig, poultry by-product meal.

INTRODUCTION

Use of conventional soybean meal (**SBM-CV**) as the sole source of AA in weanling pig diets is not recommended because SBM-CV contains anti-nutritional factors such as oligosaccharides and antigens (Li et al., 1991; Jezierny et al., 2010). Antigens may produce transient hypersensitivity in the small intestine, which affects the digestion and absorption of nutrients (Li et al., 1991).

Instead of SBM-CV, animal proteins such as fish meal, chicken meal (**CM**), and poultry by-product meal (**PBM**) are usually used as AA sources in diets for weanling pigs because these ingredients have a high digestibility of nutrients and are free of anti-nutritional factors (Kim and Easter, 2001; Pierce et al., 2005). However, production of fermented soybean meal (**FSBM**) was recently initiated in the US. During fermentation, most of the oligosaccharides and the antigens are removed (Cervantes-Pahm and Stein, 2010), and it is, therefore, believed that FSBM is

tolerated by weanling pigs. The digestibility of P, AA, and energy in US-produced FSBM has been reported (Rojas and Stein, 2012a; b).

Between 3 and 9% of FSBM may be used in weanling pig diets to replace dried skim milk powder and protein plasma (Kim et al., 2010), and 1.5 to 3.75% of FSBM in combination with dried porcine solubles may replace fish meal in diets fed to pigs from d 7 to 21 post-weaning (Jones et al., 2010). However, it is not known if FSBM can replace CM and PBM and there are no data on inclusion of more than 10%FSBM in diets fed to weanling pigs. There are also no data on effects of replacing fish meal, CM, or PBM by FSBM during the initial 7 d post-weaning. Therefore, the objectives of these experiments were to test the hypothesis that FSBM can replace all animal proteins in diets fed to weanling pigs during the initial 28 d post-weaning.

MATERIALS AND METHODS

Three experiments were conducted, and the Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for all experiments. Pigs used in the experiments were the offspring of G-performer boars mated to F-25 gilts (Genetiporc, Alexandria, MN). Pigs were weaned at approximately 21 d of age. Ingredients used in the experiments included FSBM, SBM-CV, fish meal, whey powder, protein plasma, CM, and PBM (Table 1). The FSBM (PepSoyGen®) was sourced from Nutra Ferma, Sioux City, SD, and is produced by fermentation of SBM in the presence of *Aspergillus oryzae* and *Lactobacillus subtilis*. The SBM-CV that was used was sourced locally (Solae, Gibson City, IL). The fish meal was prepared from menhaden fish (Menhaden Select, Omega Protein, Houston, TX). Chicken meal and PBM were prepared from rendered parts of chickens (The Scoular Company, Minneapolis, MN).

In all 3 experiments, pigs were housed in 1.2 x 1.4 m pens that have fully slatted floors. A feeder and a nipple drinker were provided in each pen. Feed and water were provided on an ad libitum basis throughout the experiment.

Corn was the only source of cereal grain that was used in all diets used in the 3 experiments. In Exp. 1, diets were formulated to contain 1.35 and 1.25% standardized ileal digestible Lys in phase 1 and phase 2, respectively. In Exp. 2 and 3, diets were formulated to contain 1.40, 1.35, and 1.25% standardized ileal digestible Lys in phase 1, phase 2, and phase 3, respectively. All other AA were included in the diets according to the ideal protein concept (Baker, 1997).

Exp. 1: Fermented Soybean Meal in Phase 1 and Phase 2 Diets

Experiment 1 was designed to test the hypothesis that FSBM can replace fish meal in phase 1 and phase 2 diets fed to weanling pigs during the initial 26 d post-weaning without negatively impacting growth performance. A total of 192 weaned pigs with an average initial BW of 6.88 ± 2.48 kg were used. On the day of weaning, pigs were randomly allotted to 4 dietary treatments in a randomized complete block design based on BW and sex. Phase 1 diets were fed for 14 d and phase 2 diets were provided during the following 12 d. There were 6 pigs per pen and 8 replicate pens per treatment. Four phase 1 diets were formulated (Tables 2 and 3). The positive control diet contained 8% fish meal, 15% whey powder, and 3.5% protein plasma, but in the negative control diet, fish meal and protein plasma were replaced by corn and SBM-CV. Two additional diets in which FSBM replaced fish meal (**FSBM-Low**) or fish meal and protein plasma (**FSBM-High**) were also formulated. In the phase 2 diets the positive control diet contained 8% fish meal and 5% whey powder, but fish meal and whey powder were replaced by

corn and SBM-CV in the negative control diet, and FSBM replaced fish meal or fish meal and whey powder in the FSBM-Low and the FSBM-High diets, respectively.

Diets and ingredients were analyzed for GE using bomb calorimetry (Model 6300 Parr Instruments, Moline, IL), DM (method 930.15; AOAC Int., 2007), CP by combustion (method 999.03; AOAC Int., 2007) using a Rapid N cube (Elementar Americas Inc, Mt Laurel, NJ), ADF (method 973.18; AOAC Int., 2007), and NDF (Holst, 1973). Ash (method 975.03; AOAC Int., 2007) was also analyzed in the ingredients. Phosphorus and Ca were analyzed in all diets and ingredients by the inductively coupled plasma spectroscopy procedure (method 975.03; AOAC Int., 2007) after wet ash sample preparation (method 975.03; AOAC Int., 2007). Total fat concentration was measured in ingredients by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (method 2003.06, AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN) and AA were analyzed in all samples of diets and ingredients (method 982.30 E [a, b, c]; AOAC Int., 2007).All diets and ingredients were ground through a 1-mm screen in a Wiley mill (model 4; Thomas Scientific, Swedesboro, NJ) before analysis. All samples were analyzed in duplicate.

Individual pig BW was recorded at the start of the experiment, on d 14, and at the conclusion of the experiment. Daily feed allotments were recorded as well and feed left in the feeders was recorded on the same days as pigs were weighed. At the conclusion of the experiment, data were summarized to calculate ADG, ADFI, and G:F for each pen and treatment group. Data were analyzed using the MIXED Procedure (SAS Institute Inc., Cary, NC). Homogeneity of the variances among treatments was confirmed using the UNIVARIATE procedure and this procedure was also used to identify outliers, but no outliers were observed. Diet was the fixed effect and replicate was the random effect. The LS Means statement was used

to calculate treatment means and the PDIFF option was used to separate means if differences were detected. The pen was the experimental unit for all calculations and anα-level of 0.05 was used to assess significance among means.

Exp. 2: Fermented Soybean Meal in Phase 1, Phase 2, and Phase 3 Diets

Experiment 2 was designed to test the hypothesis that FSBM can replace fish meal, whey powder, and protein plasma in phase 1, phase 2, and phase 3 diets fed to weanling pigs without negatively impacting growth performance. A total of 175 pigs with an initial BW of 6.86 ± 2.86 kg were used. On the day of weaning, pigs were randomly allotted to 5 dietary treatments as described for Exp. 1. Phase 1, phase 2, and phase 3 diets were fed for 7, 7, and 14 d post-weaning, respectively. There were 5 pigs per pen and 7 replicate pens per treatment. Five phase 1 diets and 5 phase 2 diets were formulated (Tables 4 and 5). The positive control diets contained fish meal, whey powder, and protein plasma. In the negative control diets, all whey powder, fish meal, and protein plasma were replaced by corn and SBM-CV. Three additional diets in which FSBM replaced fish meal (FSBM-Low), fish meal and protein plasma (**FSBM-Medium**), or fish meal, protein plasma, and whey powder (FSBM-High), respectively, were also formulated within each phase. In phase 3 diets (Tables 6 and 7), the positive control diet contained fish meal and whey powder, whereas those ingredients were not included in the negative control diet. Fermented soybean meal replaced whey powder in the diet fed to FSBM-Low and FSBM-Medium treatments, but FSBM replaced both fish meal and whey powder in the diet fed to FSBM-High pigs. All diets and ingredients were ground as explained for Exp. 1 before chemical analysis and analyzed as described for Exp. 1.

Individual pig BW was recorded at the start of the experiment and on d 7, 14, and 28 post-weaning. Daily feed allotments were recorded as described for Exp. 1 and data were summarized and analyzed as described for Exp. 1.

Exp. 3: Fermented Soybean Meal, Chicken Meal, or Poultry By-product Meal in Phase 1, Phase 2, and Phase 3 Diets

Experiment 3 was designed to test the hypothesis that FSBM can replace CM, PBM, or fish meal in phase 1, phase 2, and phase 3 diets fed to weanling pigs without negatively impacting growth performance. A total of 175 pigs with an initial BW of 6.97 ± 2.1 kg were used. On the d of weaning, pigs were randomly allotted to 5 treatment groups that were fed a 3-phase feeding program as explained for Exp. 2. There were 5 pigs per pen and 7 replicate pens per treatment. Five phase 1 diets were formulated (Tables 8 and 9). Three of these diets contained fish meal, CM, or PBM, and 15% whey powder and 3% protein plasma, but the negative control diet did not contain any ingredients of animal origin. The last diet was formulated by using 10% FSBM in addition to whey powder and protein plasma, but no fish meal, CM, or PBM. Phase 2 and phase 3 diets were formulated as the phase 1 diets with the exception that no protein plasma was used in these diets and whey powder was included by only 10 and 5% in phase 2 and phase 3 diets, respectively (Tables 10 and 11). All diets and ingredients were ground and analyzed as explained for Exp. 1. Individual pig BW and daily feed allotments were also recorded as described for Exp. 2, and data were summarized and analyzed as described for Exp. 1.

RESULTS

Exp. 1: Fermented Soybean Meal in Phase 1 and Phase 2

The initial and final BW was not different among treatments (Table 12). However, the BW at the end of phase 1 was greater ($P < 0.01$) in pigs fed the PC or FSBM-Low diets than for pigs fed the FSBM-High diet, but no difference was observed between pigs fed the FSBM-High or the NC diets. The ADG in phase 1 was greater ($P < 0.05$) for pigs fed the FSBM-Low diet diet than for pigs fed the NC or FSBM-High diets, but no difference was observed between pigs fed the NC and the FSBM-High diets. However, during phase 2 and for the overall experiment, ADG was not different among treatments. The ADFI was not different during phase 1, phase 2, or the overall experiment among diets. However, during phase 1, ADFI tended to be greater ($P = 0.08$) for pigs fed the FSBM-Low diet than for pigs fed the other diets. The G:F ratio was not different among treatments during phase 1 or for the overall experiment, but the G:F ratio during phase 2 was less ($P < 0.01$) for pigs fed the FSBM-Low diet than for pigs fed PC or FSBM-High diets.

Exp. 2: Fermented Soybean Meal in Phase 1, Phase 2, and Phase 3 Diets

The initial BW was not different among treatments (Table 13), but the BW at the end of phase 1 was greater ($P < 0.01$) for pigs fed the PC or FSBM-Low diets than for pigs fed the NC, FSBM-Medium, or FSBM-High diets. Pigs fed the FSBM-High diet had less ($P < 0.01$) BW than pigs fed the PC and FSBM-Low diets at the end of each phase, but the BW for pigs fed the FSBM-Medium diet was not different from that of pigs on any of the other treatments. The ADG during phase 1 was greater ($P< 0.01$) for pigs fed the PC or FSBM-Low diets than for pigs fed the other diets, but during phase 2 and phase 3, ADG was not different among treatments. However, ADG for the overall experiment was greater ($P < 0.01$) for pigs fed the PC diets than for pigs fed the NC or the FSBM-High diets, but there was no difference among pigs fed PC,

FSBM-Low, or FSBM-Medium diets. The ADFI during phase 1 was greater ($P < 0.01$) for pigs fed PC or FSBM-Low diets than for pigs fed the other diets, but for phase 2, phase 3, and the overall experimental period, no difference among treatments were observed for ADFI. The G:F ratio during phase 1 was not different among pigs fed the PC or FSBM-Low diets. However, pigs fed the NC, FSBM-Medium, and FSBM-High diets had negative values for G:F, and, therefore, these treatments were not included in the statistical analysis for G:F during phase 1. The G:F was not different among diets fed to pigs during phase 2, phase 3, or for the overall experimental period, but in phase 3 there was a tendency ($P = 0.08$) for pigs fed the FSBM-Low diet to have less G:F than pigs fed the other experimental diets.

Exp. 3: Fermented Soybean Meal, Chicken Meal, or Poultry By-product Meal in Phase 1, Phase 2, and Phase 3 Diets

The initial BW was not different among treatments (Table 14). Likewise, the BW at the end of phase 1 and at the end of phase 3 were not different among treatments although pigs fed the PC diet tended ($P = 0.08$) to be heavier at the end of phase 3 than pigs fed the NC diets. However, the BW at the end of phase 2 was less ($P < 0.01$) for pigs fed the NC diet than for pigs fed the other diets. The ADG during phase 1 and phase 3 were not different among treatments. However, during phase 2, ADG was less ($P < 0.01$) for pigs fed the NC diet than for pigs fed the other diets, but no differences were observed among the other diets. For the entire experiment, there was a tendency ($P = 0.07$) for ADG to be greater for pigs fed the PC diet than for pigs fed the NC diet. The ADFI for all phases and for the overall experiment was not different among diets. The G:F ratio was not different among treatments during phase 1 and phase 3. However, G:F was less ($P < 0.01$) during phase 2 for pigs fed the NC diet than for pigs fed the other diets,

but no differences among the other diets were observed. The G:F ratio for the overall experiment was greater ($P < 0.05$) for pigs fed the PC diets than for pigs fed the other diets.

DISCUSSION

In Exp. 1, pigs fed either low or high levels of FSBM in the diets had a BW at the end of the experiment that was not different from that of pigs fed the positive control diet. This observation is in agreement with Jones et al., 2010, who reported that fish meal may be replaced by 6% FSBM in a diet fed from 7 d to 28 d post-weaning. The FSBM-High diet was formulated to replace fish meal and protein plasma by FSBM, and results indicated that high levels of FSBM may replace fish meal. The fact that ADG during phase 1 was greater for pigs fed the FSBM-Low diet than for pigs fed the NC and FSBM-High diets indicate that FSBM can replace fish meal and SBM-CV in diets fed to weanling pigs, but it cannot replace whey powder or plasma protein. The reason for this observation is most likely that whey powder provides both lactose and AA to the diet, but no lactose is provided by FSBM. Weanling pigs easily digest lactose and inclusion of 15 to 30% lactose during the initial weeks post-weaning usually results in improved performance (Mahan et al., 1993; Tang et al., 1999; Mahan et al., 2004; Kim et al., 2010). Protein plasma is an ingredient that is used not only to supply AA to the diet; it also contains immunoglobulins that may enhance the immune system of newly weaned pigs, which may result in a reduction in post-weaning diarrhea (Van Dijk et al., 2001). It is, therefore, likely that when FSBM replaced whey powder and protein plasma, pigs did not get sufficient quantities of lactose and immunoglobulins, which was the reason for the reduction in performance for the FSBM fed pigs.

During the first week post-weaning pigs experience many changes (Pluske et al., 1997) and usually pigs during this phase have low ADG and ADFI. Therefore, the main objective during the first week post-weaning is to avoid loss of BW and to stimulate feed intake. In the second experiment, results indicated that FSBM may replace fish meal without negatively impacting pig growth performance. In agreement with the results of Exp. 1, it was not possible to replace whey powder and protein plasma during the first week post-weaning without negatively impacting pig growth performance. However, the fact that ADG and ADFI were not different among treatments in the second week post-weaning indicates that FSBM may replace whey powder in diets after 1 week post-weaning. The reason for this observation is most likely that lactase activity in the small intestine starts decreasing at 3 d after weaning and continues to decrease as pigs get older (Tang et al., 1999). Kim et al. (2007) and Jones et al. (2010) reported that increasing levels of FSBM improved G:F and ADG. However, results from Exp. 1 and 2 indicated that increasing the concentration of FSBM beyond 9 and 15% during the first and the second week post-weaning, respectively, tend to decrease ADFI, ADG, and G:F.

Overall, the results of Exp. 1 and 2 indicated that whey powder and protein plasma improved growth performance of weanling pigs and that these ingredients cannot be replace by FSBM. In Exp. 3, therefore, the inclusions of whey powder and protein plasma were kept constant among treatments and only effects of replacing fish meal, CM, and PBM with FSBM were evaluated. As was the case in Exp. 1 and 2, it was possible to replace fish meal with FSBM without impacting ADG and ADFI, but unlike the situation in Exp. 1 and 2, G:F was slightly less for pigs fed FSBM compared with pigs fed fish meal. We do not have an explanation for this observation. It was previously reported that CM and PBM may replace fish meal during the first 28 d after weaning (Keegan et al., 2004; Zier et al., 2004). However, Keegan et al. (2004)

reported that pigs fed CM with high levels of ash had a reduction in G:F compared with pigs fed CM with low levels of ash. In the present experiment, we only had 1 source of CM, and the ash value was close to the ash value reported by Keegan et al. (2004) for CM with low levels of ash. Likewise, the ash in PBM used in this experiment is close to the value of ash for CM with high ash reported by Keegan et al. (2004). We did not observe any difference in ADG, ADFI, or G:F between CM and PBM. However, the fact that the final BW at the end of the experiment was not different among treatments indicates that FSBM can replace not only fish meal, but also CM and PBM in diets fed to weanling pigs. We are not aware of any previous data that have demonstrated this effect.

In conclusion, FSBM may replace FM, CM, and PBM in diets fed to pigs during the initial 28 d post-weaning without affecting pig growth performance except that G:F may be reduced. However, FSBM cannot replace protein plasma and whey powder during the first week after weaning without negatively impacting pig growth performance, but during the second and third week after weaning, it is possible to use FSBM rather than protein plasma and whey powder.

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Table 5.1. Analyzed nutrient composition of fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), fish meal, protein plasma (PP), chicken meal (CM), poultry by-product meal (PBM), whey dried, and corn, as-fed basis

	Ingredient							
Item	FSBM	SBM-CV	Fish meal	PP	CM	PBM	Whey dried	Corn
GE, kcal/kg	4,328	4,283	4,337	4,620	4,907	5,226	3,593	3,924
Ash, %	7.06	5.70	20.20	8.06	14.19	11.33	7.29	1.26
DM, %	92.97	90.69	93.70	89.57	96.80	94.80	84.15	89.11
CP, %	52.96	44.93	61.47	73.14	66.04	62.25	13.53	7.61
ADF, %	5.37	6.15	-	-	-	-	-	2.29
NDF, %	8.30	9.51	-	-	-	-	-	8.98
P, %	0.81	0.62	3.09	1.31	2.43	1.87	0.65	0.27
Ca, %	0.36	0.35	5.23	0.11	4.43	2.69	0.42	0.02
AEE[1], %	1.4	1.4	10.17	0.32	11.03	14.29	0.84	4.08
Indispensable, AA %								
Arg	3.53	3.12	3.69	4.23	4.05	4.05	0.26	0.37
His	1.37	1.18	1.47	2.56	1.25	1.32	0.21	0.21
Ile	2.44	2.01	2.53	2.35	2.43	2.35	0.65	0.24

Table 5.1 (cont.)

Leu	4.05	3.35	4.37	7.36	4.27	4.25	1.11	0.75
Lys	3.24	2.75	4.85	6.64	3.49	3.96	0.93	0.27
Met	0.70	0.57	1.66	0.71	1.09	1.26	0.15	0.15
Phe	2.71	2.26	2.45	4.17	2.42	2.41	0.35	0.33
Thr	1.96	1.65	2.45	4.24	2.27	2.37	0.68	0.26
Trp	0.74	0.67	0.66	1.40	0.58	0.60	0.23	0.07
Val	2.61	2.11	2.96	5.04	3.15	2.92	0.62	0.33
Dispensable, AA %								
Ala	2.24	1.86	3.81	4.03	3.78	3.92	0.52	0.48
Asp	5.58	4.65	5.38	7.06	4.67	4.84	1.09	0.45
Cys	0.68	0.59	0.48	2.07	0.96	0.59	0.22	0.15
Glu	8.95	7.60	7.90	10.14	7.56	7.68	1.81	1.17
Gly	2.22	1.86	4.43	2.63	5.56	5.63	0.21	0.30
Pro	2.40	2.25	2.83	4.29	4.06	3.52	0.59	0.55
Ser	2.22	1.84	2.07	4.23	2.65	2.38	0.43	0.30
Tyr	1.96	1.65	2.00	3.72	1.92	2.08	0.26	0.23
Total AA	49.60	41.97	55.99	76.87	56.16	56.13	10.32	6.61

[1]AEE = acid hydrolyzed ether extract.

Table 5.2. Composition of experimental diets, as-fed basis, Exp. 1

Item	Diet							
	Phase 1				Phase 2			
	Positive control	Negative Control	FSBM Low	FSBM High	Positive control	Negative Control	FSBM Low	FSBM High
Ingredient, %								
Corn	50.57	45.16	47.81	40.61	55.16	59.25	52.45	55.43
FSBM[1]	-	-	10.00	19.00	-	-	9.00	11.00
Whey powder, dried	15.00	15.00	15.00	15.00	5.00	-	5.00	-
Soybean meal, 48% CP	18.00	34.00	17.00	19.75	28.00	35.00	28.00	28.00
Fish meal	8.00	-	-	-	8.00	-	-	-
Protein plasma	3.50	-	3.50	-	-	-	-	-
Soybean oil	3.10	2.55	3.45	2.75	2.35	2.50	2.65	2.55
Ground limestone	0.35	0.75	1.00	0.95	0.35	0.75	0.95	0.95
Dicalcium phosphate	0.30	1.10	0.95	0.80	0.10	1.15	0.80	0.95
L-lysine HCL	0.19	0.32	0.29	0.19	0.07	0.26	0.17	0.15

Table 5.2 (cont.)

DL-methionine	0.16	0.21	0.17	0.14	0.14	0.21	0.16	0.16
L-threonine	0.13	0.21	0.13	0.11	0.13	0.18	0.12	0.11
Sodium chloride	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]FSBM = fermented soybean meal.

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

Table 5.3. Analyzed nutrient composition of experimental diets, as-fed basis, Exp. 1

Item	Diet							
	Phase 1				Phase 2			
	Positive control	Negative Control	FSBM Low	FSBM High	Positive control	Negative Control	FSBM Low	FSBM High
GE, kcal/kg	4,113	4,048	4,092	4,091	4,100	4,065	4,091	4,107
DM, %	90.27	90.40	89.63	90.58	89.39	89.89	89.98	90.52
CP, %	22.70	24.72	22.53	25.79	24.29	24.18	24.20	25.67
ADF, %	2.31	2.68	2.50	3.00	2.73	2.91	3.07	3.21
NDF, %	8.32	7.98	7.20	6.83	8.81	8.57	8.41	8.39
P, %	0.71	0.67	0.64	0.63	0.61	0.58	0.59	0.59
Ca, %	0.81	0.82	0.81	0.82	0.81	0.74	0.75	0.77
Indispensable, AA %								
Arg	1.30	1.45	1.29	1.51	1.40	1.38	1.54	1.49
His	0.57	0.59	0.57	0.61	0.57	0.56	0.62	0.60
Ile	0.89	0.98	0.88	1.00	0.93	0.89	0.99	0.99

Table 5.3 (cont.)

Leu	1.84	1.87	1.83	1.96	1.83	1.76	1.95	1.89
Lys	1.58	1.62	1.53	1.59	1.39	1.40	1.46	1.40
Met	0.51	0.50	0.42	0.45	0.50	0.53	0.44	0.48
Phe	0.99	1.11	1.05	1.12	1.03	1.06	1.18	1.15
Thr	1.04	1.12	1.00	1.10	0.96	0.97	0.99	0.95
Trp	0.30	0.31	0.31	0.32	0.28	0.27	0.30	0.30
Val	1.09	1.06	1.05	1.09	1.05	0.97	1.08	1.09

[1]FSBM = fermented soybean meal.

Table 5.4. Composition of experimental phase 1 and phase 2 diets, as-fed basis, Exp. 2

Item	Diet									
	Phase 1					Phase 2				
	Positive control	Negative control	FSBM Low	FSBM Medium	FSBM High	Positive control	Negative control	FSBM Low	FSBM Medium	FSBM High
Ingredient. %										
Corn	47.35	54.8	44.07	39.07	56.05	54.68	54.99	51.42	48.84	55.66
FSBM[1]	-	-	9.00	20.00	22.00	-	-	9.00	15.00	18.00
Whey powder, dried	20.00	-	20.00	20.00	-	10.00	-	10.00	10.00	-
Soybean meal, 48% CP	15.00	40.00	15.00	15.00	15.00	20.00	40.00	20.00	20.00	20.00
Fish meal	7.00	-	-	-	-	7.00	-	-	-	-
Protein plasma	6.00	-	6.00	-	-	3.50	-	3.50	-	-
Soybean oil	3.00	1.70	3.15	3.00	3.15	2.75	1.60	2.88	2.85	2.74
Ground limestone	0.47	0.57	1.00	0.95	0.90	0.35	0.54	0.88	0.85	0.83
Dicalcium phosphate	0.12	1.60	0.67	0.65	1.36	0.55	1.65	1.12	1.10	1.43
L-lysine HCL	0.16	0.27	0.22	0.33	0.41	0.19	0.21	0.25	0.33	0.30

Table 5.4 (cont.)

DL-methionine	0.12	0.20	0.13	0.15	0.23	0.15	0.17	0.15	0.17	0.19
L-threonine	0.07	0.16	0.06	0.15	0.20	0.12	0.14	0.10	0.16	0.15
L-tryptophan	0.01	-	-	-	-	0.01	-	-	-	-
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral	0.30	0.30	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	100.00	100.00

[1]FSBM = fermented soybean meal.

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

Table 5.5. Analyzed nutrient composition of experimental phase 1 and phase 2 diets, as-fed basis, Exp. 2

	Diet[1]									
	Phase 1					Phase 2				
Item	Positive control	Negative control	FSBM Low	FSBM Medium	FSBM High	Positive control	Negative control	FSBM Low	FSBM Medium	FSBM High
GE, kcal/kg	4,104	4,049	4,074	4,095	4,121	4,114	4,041	4,087	4,077	4,093
DM, %	89.38	90.28	89.85	90.56	90.96	90.40	90.40	90.37	91.01	90.85
CP, %	23.56	24.40	23.32	25.26	24.62	23.92	24.44	23.75	23.56	24.09
ADF, %	1.80	3.48	2.38	2.87	3.33	2.51	3.55	2.79	3.32	3.45
NDF, %	6.75	8.33	5.02	5.78	8.21	7.44	9.07	7.73	8.11	8.80
P, %	0.63	0.71	0.59	0.63	0.68	0.69	0.72	0.63	0.64	0.69
Ca, %	0.76	0.80	0.78	0.82	0.85	0.81	0.80	0.78	0.75	0.82
Indispensable, AA %										
Arg	1.25	1.59	1.27	1.33	1.40	1.31	1.53	1.31	1.44	1.55
His	0.58	0.63	0.58	0.56	0.58	0.58	0.61	0.57	0.59	0.62
Ile	0.90	1.04	0.93	1.00	0.95	0.90	0.96	0.91	1.00	1.01

Table 5.5 (cont.)

Leu	1.93	1.95	1.93	1.82	1.80	1.84	1.86	1.85	1.88	1.93
Lys	1.67	1.55	1.64	1.63	1.54	1.59	1.49	1.48	1.59	1.58
Met	0.47	0.47	0.41	0.45	0.51	0.50	0.51	0.43	0.46	0.49
Phe	1.02	1.19	1.06	1.06	1.08	0.99	1.14	1.06	1.11	1.15
Thr	1.06	0.98	1.01	1.00	0.99	1.01	0.99	0.95	0.98	1.00
Trp	0.32	0.29	0.32	0.31	0.28	0.30	0.29	0.30	0.32	0.30
Val	1.16	1.14	1.17	1.08	1.06	1.12	1.06	1.08	1.09	1.12

[1]FSBM = fermented soybean meal.

Table 5.6. Composition of experimental phase 3 diets, as-fed basis, Exp. 2

Item	Diet				
	Positive control	Negative Control	FSBM Low	FSBM Medium	FSBM High
Ingredient, %					
Corn	54.25	58.43	51.01	51.01	57.78
FSBM[1]	-	-	9.00	9.00	12.00
Whey powder, dried	10.00	-	10.00	10.00	-
Soybean meal, 48% CP	25.00	37.00	25.00	25.00	25.00
Fish meal	7.00	-	-	-	-
Protein plasma	-	-	-	-	-
Soybean oil	2.14	1.58	2.27	2.27	2.18
Ground limestone	0.42	0.77	0.95	0.95	0.97
Dicalcium phosphate	0.09	1.10	0.63	0.63	0.94
L-lysine HCL	0.16	0.17	0.21	0.21	0.19
DL-methionine	0.12	0.14	0.12	0.12	0.14
L-threonine	0.12	0.11	0.11	0.11	0.10
L-tryptophan	-	-	-	-	-
Sodium chloride	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[2]	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00

[1]FSBM = fermented soybean meal.

[2]Provide the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite,

1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 5.7. Analyzed nutrient composition of experimental phase 3 diets, as-fed basis, Exp. 2

Item	Diet[1]				
	Positive control	Negative control	FSBMLow	FSBM Medium	FSBM High
GE, kcal/kg	4,046	3,993	4,047	4,047	4,040
DM, %	89.83	89.80	89.97	90.17	90.32
CP, %	22.56	24.46	23.98	24.03	24.82
ADF, %	2.98	3.20	3.18	2.99	3.19
NDF, %	8.26	7.24	6.81	6.95	9.22
P, %	0.60	0.60	0.56	0.55	0.61
Ca, %	0.73	0.79	0.72	0.77	0.83
Indispensable, AA %					
Arg	1.29	1.44	1.35	1.34	1.43
His	0.53	0.58	0.55	0.55	0.58
Ile	0.85	0.90	0.93	0.91	0.92
Leu	1.75	1.79	1.77	1.75	1.80
Lys	1.38	1.36	1.38	1.38	1.40
Met	0.45	0.44	0.40	0.40	0.45
Phe	0.95	1.08	1.04	1.03	1.09
Thr	0.92	0.90	0.90	0.92	0.92
Trp	0.27	0.28	0.29	0.29	0.28
Val	0.95	0.99	1.02	1.00	1.02

[1]FSBM = fermented soybean meal.

Table 5.8. Composition of experimental phase 1 diets, as-fed basis, Exp. 3

Item	Diet[1]				
	Phase 1				
	Positive control	Negative control	CM	PBM	FSBM
Ingredient, %					
Corn	48.30	46.13	46.22	46.22	44.86
Soybean meal, 48% CP	21.00	30.00	21.00	21.00	21.00
Fish meal	8.00	-	-	-	-
Chicken meal	-	-	9.00	-	-
Poultry by-product meal	-	-	-	9.00	-
FSBM	-	-	-	-	10.00
Whey powder, dried	15.00	15.00	15.00	15.00	15.00
Protein plasma	3.00	3.00	3.00	3.00	3.00
Soybean oil	3.00	2.82	3.69	3.69	3.16
Ground limestone	0.30	0.75	0.54	0.54	0.88
Dicalcium phosphate	0.25	1.05	0.25	0.25	0.90
L-lysine HCL	0.18	0.27	0.27	0.27	0.25
DL-methionine	0.14	0.16	0.18	0.18	0.15
L-threonine	0.12	0.12	0.13	0.13	0.10
L-tryptophan	0.01	-	0.02	0.02	-
Sodium chloride	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[2]	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00

[1]CM = chicken meal; PBM = poultry by-product meal; FSBM = fermented soybean meal.

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

Table 5.9. Analyzed nutrient composition of experimental phase 1 diets, as-fed basis, Exp. 3

	Diet[1]				
	Phase 1				
Item	Positive control	Negative control	CM	PBM	FSBM
GE, kcal/kg	4,110	3,997	4,182	4,246	4,067
DM, %	90.00	89.53	90.24	89.34	88.71
CP, %	23.97	20.60	25.78	24.74	23.96
ADF, %	2.39	2.46	2.43	2.53	2.78
NDF, %	6.83	6.34	7.70	8.29	6.37
P, %	0.75	0.69	0.73	0.61	0.67
Ca, %	0.92	0.93	0.95	0.72	0.83
Indispensable, AA %					
Arg	1.44	1.19	1.45	1.40	1.42
His	0.62	0.52	0.59	0.57	0.60
Ile	0.99	0.81	0.96	0.91	0.97
Leu	1.99	1.66	1.94	1.86	1.91
Lys	1.74	1.43	1.66	1.63	1.60
Met	0.52	0.40	0.47	0.48	0.45
Phe	1.12	0.94	1.05	1.01	1.08
Thr	1.09	0.93	1.09	1.01	1.03
Trp	0.31	0.28	0.32	0.33	0.32
Val	1.19	0.97	1.17	1.11	1.13

[1]CM = chicken meal; PBM = poultry by-product meal; FSBM = fermented soybean meal.

Table 5.10. Composition of experimental phase 2 and phase 3 diets, as-fed basis, Exp. 3

Item	Diet[1]									
	Phase 2					Phase 3				
	Positive control	Negative control	CM	PBM	FSBM	Positive control	Negative control	CM	PBM	FSBM
Ingredient, %										
Corn	52.16	49.98	50.58	50.58	48.7	55.76	53.31	54.20	54.20	52.95
Soybean meal, 48% CP	25.00	34.00	25.00	25.00	25.00	30.00	37.00	30.00	30.00	30.00
Fish meal	8.00	-	-	-	-	5.00	-	-	-	-
Chicken meal	-	-	9.00	-	-	-	-	6.00	-	-
Poultry by-product meal	-	-	-	9.00	-	-	-	-	6.00	-
FSBM	-	-	-	-	10.00	-	-	-	-	7.00
Whey powder, dried	10.00	10.00	10.00	10.00	10.00	5.00	5.00	5.00	5.00	5.00
Protein plasma	-	-	-	-	-	-	-	-	-	-
Soybean oil	2.85	2.67	3.32	3.32	3.02	2.24	1.95	2.64	2.64	2.29
Ground limestone	0.21	0.66	0.47	0.47	0.8	0.52	0.79	0.65	0.65	0.91
Dicalcium phosphate	0.48	1.28	0.42	0.42	1.13	0.43	0.90	0.39	0.39	0.80

Table 5.10 (cont.)

L-lysine HCL	0.24	0.33	0.22	0.22	0.32	0.13	0.14	0.17	0.17	0.15
DL-methionine	0.17	0.19	0.16	0.16	0.17	0.12	0.12	0.14	0.14	0.11
L-threonine	0.17	0.18	0.12	0.12	0.16	0.10	0.09	0.11	0.11	0.09
L-tryptophan	0.02	0.01	0.01	0.01	-	-	-	-	-	-
Sodium chloride	0.40	0.40	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	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1]CM = chicken meal; PBM = poultry by-product meal; FSBM = fermented soybean meal.

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

Table 5.11. Analyzed nutrient composition of experimental phase 2 and phase 3 diets, as-fed basis, Exp. 3

Item	Diet[1]									
	Phase 1					Phase 2				
	Positive control	Negative control	CM	PBM	FSBM	Positive control	Negative control	CM	PBM	FSBM
GE, kcal/kg	4,078	4,030	4,139	4,213	4,043	4,029	4,005	4,091	4,110	4,072
DM, %	88.56	88.98	89.50	90.66	90.09	89.51	88.93	89.69	88.99	89.47
CP, %	24.32	24.34	26.67	25.18	25.10	23.98	24.01	25.16	25.53	25.79
ADF, %	2.74	3.12	2.84	3.14	3.31	2.65	3.07	2.95	2.39	2.90
NDF, %	8.69	6.99	8.64	9.60	6.88	8.17	7.71	8.67	8.12	6.70
P, %	0.72	0.70	0.71	0.65	0.71	0.60	0.58	0.61	0.55	0.57
Ca, %	0.82	0.71	0.89	0.69	0.84	0.75	0.62	0.80	0.68	0.72
Indispensable, AA %										
Arg	1.42	1.53	1.56	1.55	1.58	1.44	1.63	1.47	1.54	1.40
His	0.58	0.61	0.59	0.60	0.63	0.59	0.65	0.58	0.61	0.57
Ile	0.97	0.98	1.04	1.01	1.06	0.98	1.10	0.99	1.01	0.97

Table 5.11 (cont.)

Leu	1.84	1.91	1.92	1.91	1.96	1.85	2.05	1.85	1.94	1.79
Lys	1.48	1.56	1.54	1.57	1.57	1.46	1.52	1.42	1.52	1.36
Met	0.48	0.46	0.53	0.53	0.42	0.47	0.45	0.45	0.53	0.41
Phe	1.03	1.11	1.09	1.09	1.16	1.06	1.21	1.06	1.10	1.04
Thr	0.96	1.03	1.02	1.00	1.00	0.94	0.96	0.92	0.99	0.88
Trp	0.29	0.30	0.31	0.32	0.34	0.28	0.31	0.29	0.30	0.29
Val	1.08	1.07	1.18	1.14	1.16	1.10	1.22	1.12	1.14	1.07

[1]CM = chicken meal; PBM = poultry by-product meal; FSBM = fermented soybean meal.

Table 5.12. Growth performance of nursery pigs fed experimental diets, Exp 1[1]

Item	Positive control	Negative control	FSBM[2] Low	FSBM High	SEM	*P*-value
BW, kg						
Day 0	6.97	6.93	6.99	6.99	0.349	0.22
Day 14	9.54[a]	9.46[ab]	9.74[a]	9.15[b]	0.388	0.01
Day 26	14.90	14.42	14.38	14.09	0.573	0.27
ADG, g/d						
Day 14	184[ab]	165[b]	197[a]	154[b]	10.71	0.04
Day 26	446	414	387	412	21.02	0.18
Day 0 to 26	305	278	284	273	12.58	0.33
ADFI, g/d						
Day 14	260	254	276	236	12.64	0.08
Day 26	655	647	644	625	25.24	0.75
Day 0 to 26	442	433	446	416	17.42	0.42
G:F						
Day 14	0.71	0.65	0.72	0.66	0.04	0.26
Day 26	0.68[a]	0.64[ab]	0.60[b]	0.66[a]	0.01	0.01
Day 0 to 26	0.69	0.64	0.64	0.66	0.02	0.14

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

[1]Each least squares mean represents 8 pens of 6 pigs/pen.

[2]FSBM = fermented soybean meal.

Table 5.13. Growth performance of nursery pigs fed experimental diets, Exp 2[1]

Item	Positive control	Negative control	FSBM[2] Low	FSBM Medium	FSBM High	SEM	*P*-value
BW, kg							
Day 0	7.08	7.04	7.07	7.10	7.13	0.42	0.35
Day 7	7.44[a]	6.94[bc]	7.41[a]	7.14[b]	6.86[c]	0.41	< 0.01
Day 14	9.09[a]	8.44[bc]	8.84[ab]	8.53[abc]	7.97[c]	0.43	< 0.01
Day 28	16.34[a]	14.99[bc]	15.94[ab]	15.37[abc]	14.43[c]	0.61	< 0.01
ADG, g/d							
Day 7	51[a]	-16[bc]	50[a]	4[b]	-37[c]	11.50	< 0.01
Day 14	232	214	205	200	158	23.29	0.27
Day 28	521	467	465	489	461	24.90	0.26
Day 0 - 28	331[a]	282[b]	292[ab]	295[ab]	260[b]	16.60	0.05
ADFI, g/d							
Day 7	126[a]	88[b]	127[a]	93[b]	67[b]	10.20	< 0.01
Day 14	301	282	285	282	234	19.70	0.20
Day 28	724	668	722	681	646	29.49	0.14
Day 0 - 28	469	427	455	434	398	20.81	0.11
G:F							
Day 7	0.29	-	0.41	-	-	0.15	0.56
Day 14	0.78	0.75	0.69	0.70	0.67	0.06	0.75
Day 28	0.72	0.70	0.64	0.72	0.71	0.02	0.08
Day 0 - 28	0.71	0.67	0.63	0.68	0.66	0.20	0.14

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

[1]Each least squares mean represents 7 pens of 5 pigs/pen.

[2]FSBM = fermented soybean meal.

Table 5.14. Growth performance of nursery pigs fed experimental diets, Exp 3[1]

Item	Positive control	Negative control	CM[2]	PBM[3]	FSBM[4]	SEM	*P*-value
BW, kg							
Day 0	7.06	7.09	7.07	7.10	7.05	0.34	0.53
Day 7	7.49	7.41	7.41	7.38	7.33	0.36	0.68
Day 14	9.12[a]	8.34[b]	8.94[a]	9.05[a]	8.87[a]	0.41	< 0.01
Day 28	17.49	16.16	16.62	16.65	16.36	0.73	0.08
ADG, g/d							
Day 0	61	45	49	40	40	10.47	0.59
Day 7	233[a]	132[b]	217[a]	239[a]	220[a]	14.17	< 0.01
Day 14	598	559	549	543	535	26.08	0.16
Day 0 - 28	372	324	341	341	333	16.04	0.07
ADFI, g/d							
Day 0	135	124	133	119	114	8.69	0.31
Day 7	308	275	297	315	300	18.96	0.44
Day 14	791	744	759	762	749	41.27	0.86
Day 0 - 28	506	471	487	490	478	26.09	0.80
G:F							
Day 0	0.44	0.34	0.34	0.32	0.34	0.06	0.69
Day 7	0.75[a]	0.48[b]	0.73[a]	0.76[a]	0.73[a]	0.03	< 0.01
Day 14	0.76	0.75	0.72	0.71	0.71	0.02	0.13
Day 0 - 28	0.74[a]	0.69[b]	0.70[b]	0.70[b]	0.70[b]	0.01	0.03

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

[1]Each least squares mean represents 7 pens of 5 pigs/pen.

[2]CM = chicken meal.

[3]PBM = poultry by-product meal.

[4]FSBM = fermented soybean meal.

CHAPTER 6

CONCLUSIONS

From the first 3 experiments that are reported in this thesis, it is concluded that apparent total tract digestibility (**ATTD**) and standardized total tract digestibility (**STTD**) of P in conventional soybean meal (**SBM-CV**) is less than in fermented soybean meal (**FSBM**), when no microbial phytase is added to the diet, but if phytase is used, no differences in ATTD and STTD of P between FSBM and SBM-CV are observed. It was also demonstrated that SBM-CV contains less digestible P than FSBM. This indicates that diets formulated with FSBM need less inorganic P than diets formulated with SBM-CV. It was also concluded that concentrations of DE, ME, and NE is greater in SBM-CV than in FSBM, but DE, ME, and NE are greater in FSBM than in fish meal. Fermentation of SBM seems to reduce the concentration of energy, but at the same time increases the concentration of DM, CP, acid hydrolyzed ether extraction, NDF, and ADF compared with SBM-CV. The reason for the reduced DE, ME, and NE in FSBM compared with SBM-CV is most likely that fermentation eliminates sugar and soluble carbohydrates in FSBM. The standardized ileal digestibility of most AA is not different between FSBM and SBM-CV, but they are greater in FSBM than in fish meal. It was also observed that the biological value of protein in fish meal is greater than in FSBM and SBM-CV, but the biological value of corn protein is less than in fish meal, FSBM, and SBM-CV.

From the growth performance experiments, it was concluded that FSBM may replace fish meal, chicken meal, and poultry by-product meal in diets fed to pigs during the initial 28 d post-weaning without affecting pig growth performance except that G:F may be reduced. It was also concluded that protein plasma and whey powder cannot be replaced by FSBM during the first

week after weaning without negatively affecting pig growth performance. However, during the second and third week after weaning, it is possible to use FSBM rather than protein plasma and whey powder. Overall results indicate that it may be possible to reduce diet costs without compromising pig growth performance if FSBM is included in diets fed to weanling pigs at the expense of animal protein sources.