AMINO ACID DIGESTIBILITY AND CONCENTRATION OF ENERGY IN PROCESSED SOYBEAN AND RAPESEED PRODUCTS FED TO PIGS

BY

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THESIS

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ABSTRACT

Two experiments were conducted to determine the AA and energy digestibility in 2 sources of enzyme-treated soybean meal (**ESBM-1** and **ESBM-2**), in extruded soybean meal (**SBM-EX**), in soy protein concentrate (**SPC**), in conventional dehulled soybean meal (**SBM-CV**), in conventional 00-rapeseed expellers (**RSE**), and in a fermented co-product mixture (**FCM**) that contained rapeseed meal, wheat, soy molasses, and potato peel fed to pigs. In Exp. 1, the objectives were to determine the standardized ileal digestibility (**SID**) of CP and AA in ESBM-1, ESBM-2, SBM-EX, SPC, SBM-CV, RSE, and FCM fed to weanling pigs. Seven cornstarch-based diets were prepared using each of the protein sources as the sole source of CP and AA. A N-free diet was prepared to calculate basal endogenous losses of CP and AA and this diet was fed to 2 groups of pigs. The SID of Arg, His, Ile, Leu, Met, and Phe were greater ($P < 0.05$) in ESBM-1 than in SPC, and the SID of Lys was greater ($P < 0.05$) in SBM-CV than in ESBM-2. The SID of total indispensable AA was not different among the SBM products. The SID of total dispensable AA in ESBM-1 was only greater ($P < 0.05$) than in SPC. Therefore, the SID of total AA was greater ($P < 0.05$) in ESBM-1 than in SPC, but no other differences were observed among SBM products. The SID of most AA in RSE and the SID of all AA in FCM were less ($P < 0.05$) than in all the SBM products, but the SID of all AA in RSE was greater ($P < 0.05$) than in FCM. In Exp. 2, the objectives were to determine the digestibility of energy and the concentrations of DE and ME in ESBM-1, ESBM-2, SBM-EX, SPC, SBM-CV, RSE, and FCM. A corn-based diet consisting of 96.65% corn with vitamins and minerals was formulated. Seven additional diets containing corn and each of the experimental ingredients were also formulated. The ATTD of GE in corn was not different from SBM-CV, but was greater ($P < 0.05$) than in the other ingredients. The concentration of DE in ESBM-1, ESBM-2, SBM-EX, SPC, and SBM-CV

was 4,272, 3,972, 4,432, 4,419, and 4,173 kcal/kg DM, respectively. The concentration of DE in RSE and FCM was 3,658 and 3,458 kcal/kg DM, respectively. The DE (DM basis) in corn (3,864 kcal/kg DM) was greater ($P < 0.05$) than in FCM, but less ($P < 0.05$) than in SBM-EX, SPC, ESBM-1, and SBM-CV. The DE (DM basis) in SBM-EX was greater ($P < 0.05$) than in SBM-CV, ESBM-2, RSE, and FCM, but not different from SPC and ESBM-1. The concentration of ME in ESBM-1, ESBM-2, SBM-EX, SPC, and SBM-CV was 4,158, 3,782, 4,240, 4,226, and 4,044 kcal/kg DM, respectively. The concentration of ME in RSE and FCM was 3,522 and 3,364 kcal/kg DM, respectively. The ME (DM basis) of ESBM-2 was less ($P < 0.05$) than in all other soybean products, but greater ($P < 0.05$) than in RSE and FCM. The ME (DM basis) of corn (3,780 kcal/kg DM) was less ($P < 0.05$) than in all soybean products except ESBM-2, but greater ($P < 0.05$) than in the rapeseed products. There was no difference in DE and ME (DM basis) between RSE and FCM, but the DE and ME for both ingredients were less ($P < 0.05$) than in all soybean products. In conclusion, although processing of soybean meal results in increased concentration of CP, processing may also reduce the digestibility of AA, which is likely due to heat damage during processing. There are, however, differences among processed soy products with some products having greater SID of AA, DE, and ME than others. Furthermore, the concentrations of DE and ME in all soybean products used in this experiment were greater than in rapeseed expellers and the fermented co-product mixture. Results also indicate that fermentation of a mixture of rapeseed meal, wheat, and relatively low quality co-products does not result in SID values that are similar to those of unfermented 00-rapeseed expellers or soybean products.

Key words: amino acid digestibility, energy, enzyme-treated soybean meal, extruded soybean meal, fermented rapeseed expellers, pigs, soy protein concentrate

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CHAPTER 1: INTRODUCTION

Soybean meal (**SBM**) is an ideal protein source for swine diets because of its desirable amino acid profile that complements the AA composition of cereal grains that are commonly included in swine diets (Stein et al., 2008). However, SBM contains antinutritional factors such as trypsin inhibitors, phytate, lectins, and oligosaccharides that elicit a transient hypersensitivity response that adversely affect nutrient digestibility and growth performance in young pigs (Li et al., 1991a; Baker, 2000; Hong et al., 2004). To overcome this response, processing of SBM made it suitable to be fed to young pigs without affecting growth performance (Li et al., 1991b). Plant-based protein sources generally cost less than animal proteins, but due to increasing prices of soybeans and SBM, producers are finding ways to improve the nutrient quality of SBM. Extrusion, enzyme treatment, and fermentation are processes that can improve the bioavailability of nutrients in SBM by breaking down nutrients into smaller constituents that are easier to absorb in the small intestine and by removing antinutritional factors and oligosaccharides (Hong et al., 2004; Cervantes-Pahm and Stein, 2010; Song et al., 2010; Rojas and Stein, 2013; Zhang et al., 2013).

Feed costs represent more than 60% of the total cost in swine production (Noblet and Milgen, 2013). Higher inclusion rates of alternative protein sources to replace SBM in swine diets may reduce the cost of feed (Landero et al., 2011). Canola and rapeseed products offer an alternate source of CP and AA in swine diets. However, the inclusion of canola or rapeseed is limited by the level of glucosinolates and the relatively higher concentrations of fiber in the meal (Bell, 1993; Arntfield and Hickling, 2011; Newkirk, 2011). Reducing the fiber content or increasing the digestibility of fiber may increase nutrient utilization in canola and rapeseed meals

(Landero et al., 2011). Solvent extraction, expeller pressing, and cold pressing procedures of oil extraction result in canola and rapeseed meals that vary in nutrient composition and digestibility, but offer alternative sources of CP, AA, and energy that can replace SBM in swine diets without affecting growth performance (Seneviratne et al, 2010; Landero et al., 2011). However, due to variability caused by different procedures of oil extraction, it is important to determine the nutrient composition of canola and rapeseed products from different sources. Therefore, the objectives of this thesis are:

1) To determine the apparent ileal digestibility and standardized ileal digestibility of CP and AA in 2 sources of enzyme-treated soybean meal (ESBM-1 and ESBM-2), SBM-EX, SPC, SBM-CV, RSE, and FCM and to test the hypothesis that processing of SBM increases the digestibility of CP and AA.
2) To determine the concentration of DE and ME in ESBM-1, ESBM-2, SBM-EX, SPC, SBM-CV, RSE, and FCM and to test the hypothesis that processing of SBM improves energy digestibility.

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CHAPTER 2: PROCESSED SOYBEAN AND RAPESEED PRODUCTS: A LITERATURE REVIEW

Soybean (*Glycine max)* is an annual oilseed legume that is grown extensively in the United States and around the world. It is produced for both human consumption and as an important protein source in livestock feeds in the form of soybean meal (**SBM**). The demand for soybeans is primarily driven by the demand for SBM. Most of the protein in soybeans is consumed as animal feed, with only about 2% being directly consumed by humans (Goldsmith, 2008).

Soybean production is encouraged by the increased demand by humans for animal proteins and by the demand for oil in the biodiesel industry. A total of 267 million metric tons of soybeans were produced in 2013 (Table 2.1), with the United States being the largest soybean producer in the world, followed by Brazil, Argentina, India, and China (USDA, 2014). In the United States, the harvested area for soybeans ranged from 29 million hectares in 2000 (USDA, 2003) to 31 million hectares in 2013, whereas production ranged from around 75 million metric tons in 2000 to 82 million metric tons in 2013.

SOYBEAN MEAL

Soybeans are processed to extract oil from the seeds to be used for human consumption, biodiesel, or other uses. In the United States, the solvent extraction procedure is the most common method used to separate the oil from the soybeans (Grieshop et al., 2003). This procedure allows for processing of larger volumes of soybeans, at least 2,700 metric tons per day, to be economically viable, and is more efficient in extracting oil compared with mechanical oil extraction (Johnson, 2008). There is demand for mechanically extracted oil in niche markets;

however, the efficiency of extraction has to be improved to be economically viable on a larger scale (Grieshop et al., 2003). The resulting byproduct after the removal of oil is SBM, which is widely used as a protein source in livestock diets. The AA composition of SBM complements that of many cereal grains, accounting for its popularity in swine diets (Stein et al., 2008). In soybeans, N and photosynthetic products are deposited as storage proteins, making its protein content higher than that of any other grain (Deak et al., 2008). The digestibility of Lys and concentration of ME in SBM is greater than in other commonly used oilseed meals (Stein et al., 2008). Lysine is the first-limiting AA in corn, which is also deficient in Trp, making SBM a good complement to corn because of its relatively high concentration of Lys and Trp (Baker, 2000; Stein et al., 2008).

Raw or improperly processed soybeans contain several antinutritional factors (**ANF**) such as phytate, lectins, oligosaccharides, and trypsin inhibitors (Baker, 2000; Hong et al., 2004). The major oligosaccharides in soybeans are raffinose, stachyose, and verbascose, composing approximately 5 to 8% of the DM (Middelbos and Fahey, Jr., 2008). Oligosaccharides interfere with digestion of nutrients in the small intestine by increasing the viscosity of the digesta and reducing the interaction between digestive enzymes and their substrates (Smiricky et al., 2002). Intake of oligosaccharides can cause flatulence, diarrhea, and reduced nutrient digestibility in pigs (Woyengo et al., 2014). Nonruminants lack the α-galactosidase enzyme resulting in poor digestion of oligosaccharides in the small intestine (Smiricky et al., 2002). Processing of soybeans into SBM does not eliminate oligosaccharides and the concentrations of raffinose, stachyose, and verbascose in SBM are affected by processing conditions (Grieshop et al., 2003). Trypsin inhibitors decrease the bioavailability and digestibility of protein by blocking the action of proteases in the gastrointestinal tract (Stein et al., 2008; Goebel and Stein, 2011a). The Kunitz

inhibitor and the Bowman-Birk inhibitor are the 2 types of trypsin inhibitors in soybeans (Baker, 2000; Deak et al., 2008). Heat treatment inactivates trypsin inhibitors and all soybean products need to be heat treated before being fed to pigs (Messerschmidt et al., 2012). However, processing of soybeans may also reduce the bioavailability of AA if SBM is overcooked (Song et al., 2010). Heat damage will result in Maillard reactions that destroy some of the Lys in the resulting product, making it unavailable to the animal and thus, reducing the standardized ileal digestibility of Lys (Cervantes-Pahm and Stein, 2010; Gonzalez-Vega et al., 2011).

Early-weaned pigs that are fed diets containing high levels of SBM may experience a transient hypersensitivity to antigenic soybean proteins, such as glycinin and β-conglycinin (Li et al., 1990). This response causes villi atrophy and an increase in crypt depth, hindering the ability of the small intestine to absorb nutrients, and thus, a reduction in growth performance (Li et al., 1991a; Li et al., 1991b). β-conglycinin is also more resistant to digestion by pepsin compared with glycinin, resulting in reduced ADG and feed efficiency in piglets fed diets containing purified β-conglycinin (Zhao et al., 2008). Damage to the villi may also be attributed to bacterial growth that is encouraged by the influx of undigested protein that reaches the small intestine (Li et al., 1990). To avoid this period of transient hypersensitivity that negatively affects growth performance during the first few days after weaning, highly digestible animal protein sources are commonly included in the diet to stimulate feed intake and weight gain in nursery pigs (Jones et al., 2010).

A combination of animal and plant protein sources can be used in diets for young pigs to meet the AA requirements of the animals. Animal proteins, such as fish meal, blood meal, spray-dried animal plasma, and milk products such as dried skim milk and dried whey, are most commonly used in nursery pig diets because they are highly digestible, palatable, and contain no

ANF (Hong et al., 2004, Kim et al, 2010). However, if soybean products that do not contain ANF can be produced, it may be possible to use such soybean products instead of animal protein. Soy protein concentrate (**SPC**) and soy protein isolate (**SPI**) are processed soybean products that contain more protein than SBM as a result of the removal of most water-soluble and non-protein constituents (Zhang et al., 2013). Soy protein concentrate may be included in nursery pig diets as an alternative to animal protein, whereas SPI is commonly produced for human consumption (Deak et al., 2008; Stein et al., 2008). Sucrose, raffinose, and stachyose are removed from defatted soy flakes to produce SPC (Lenehan et al., 2007). Soy protein isolate is produced by removing the sugars and the fiber content of dehulled and defatted soy flours (Deak et al., 2008). These products are believed to have less antigenic proteins compared with SBM, allowing them to be fed to young pigs (Stein et al., 2008). However, it is not always economical to feed SPC to growing-finishing pigs or sows because they are more expensive, and also because the protein in SPC and SBM has the same digestibility in growing pigs (Smiricky et al., 2002; Stein et al., 2008). High concentration of SPC may also decrease feed intake, indicating a palatability problem and thus, limiting its inclusion rate (Lenehan et al., 2007).

Fermented Soybean Meal

Microbial fermentation can improve the quality of SBM by breaking down nutrients into their constituents that are easily absorbed by the body (Zhang et al., 2013), resulting in a product called fermented SBM (**FSBM**). Hydrated SBM is cooked in steam, cooled to room temperature, and is subsequently inoculated with either a fungal or bacterial strain, or both, before it is mixed and fermented in an incubator (Feng et al., 2007a). *Aspergillus oryzae* and *Bacillus subtilis* have been used as inoculants in processing FSBM (Feng et al., 2007a; Rojas and Stein, 2012; 2013). These microbes secrete proteases that partially digest large peptides into smaller peptides that are

easily absorbed in the small intestine (Hong et al., 2004, Gilbert et al., 2008). The reduction in peptide size in FSBM may be beneficial to young pigs because of their potentially limited gastric HCl secretion to digest proteins (Kim et al., 2010). The bioavailability of nutrients in SBM is increased and ANF are reduced through fermentation (Song et al., 2010). Fermented SBM has a greater concentration of AA, CP, P, and other nutrients, including crude fiber, compared with SBM because of the disappearance of sucrose, stachyose, and raffinose (Cervantes-Pahm and Stein, 2010; Tables 2.2 and 2.3). The DE, ME, and NE in FSBM is often less than in SBM because of the removal of sucrose and oligosaccharides during the fermentation process (Rojas and Stein, 2013). The energy gained from the improved apparent total tract digestibility (**ATTD**) of ADF and NDF in FSBM compared with SBM does not compensate for the loss of energy from sucrose and oligosaccharides (Rojas and Stein, 2013). Dried skim milk that is commonly used in diets young pigs can be partially replaced by FSBM without adverse effects on growth performance if the diets are balanced for Lys, Thr, Trp, Met, and lactose (Kim et al., 2010).

An improvement in growth performance results from feeding nursery pigs diets containing FSBM compared with SBM due to the removal of oligosaccharides during fermentation (Jones et al., 2010; Kim et al., 2010). Fermented SBM has higher digestibility of DM, CP, and energy compared with SBM (Feng et al., 2007b). There is no difference in the AID and SID of most indispensable AA between FSBM and SBM (Tables 2.4 and 2.5), but FSBM contains more digestible AA than SBM because of its greater AA concentration (Cervantes-Pahm and Stein, 2010; Rojas and Stein, 2013; Tables 2.2 and 2.3). Total protease and trypsin activity in the small intestine of piglets increased after feeding FSBM (Feng et al., 2007b), but the main factor that positively affects the performance of early weaned-piglets is the lower concentrations of antigenic proteins and ANF in FSBM compared with SBM (Zhang et al.,

2013). Use of FSBM instead of SBM reduces the incidence of diarrhea in nursery pigs due to degradation of glycinin and β-conglycinin (Song et al., 2010). Glycinin and β-conglycinin content in SBM was reduced by approximately 40% when it was fermented with *A. oryzae* (Kim et al., 2010).

Enzyme-treated Soybean Meal

Enzyme-treated SBM (**ESBM**) is another processed soybean product that is now widely accepted as a protein source in diets fed to young pigs. To produce ESBM, SBM is treated with an enzyme preparation for several hours and is subsequently heated to inactivate all residual enzymes in the resulting meal (Cervantes-Pahm and Stein, 2010; Goebel and Stein, 2011b). Similar to FSBM, ESBM has a greater concentration of CP and AA and a reduced concentration of ANF compared with SBM (Cervantes-Pahm and Stein, 2010; Tables 2.2 and 2.3). Unlike FSBM, the concentration of DE and ME is not affected by the removal of sucrose and oligosaccharides by enzyme treatment (Goebel and Stein, 2011b; Rojas and Stein, 2013). Enzyme-treated SBM may be included in nursery pig diets because of the reduced concentration of oligosaccharides that otherwise limit the inclusion rate of SBM in these diets (Cervantes-Pahm and Stein, 2010). Digestibility of protein and dry matter improved as the inclusion rate of ESBM was increased in diets fed to nursery pigs, indicating that ESBM is highly digestible and contains low levels of ANF (Zhu et al., 1997). Most AA in ESBM have SID values that are similar to SPI and fish meal, and thus, growth performances that are similar to that of animal protein-based diets can be obtained when fed to nursery pigs (Stein et al., 2008; Cervantes-Pahm and Stein, 2010; Rojas and Stein, 2013). Moreover, a low concentration of free AA in blood serum indicates that AA are utilized in protein metabolism by the animal. Pigs fed ESBM have a decreased free AA concentration in blood serum, which signifies tissue synthesis and an

improvement in the balance of available AA compared with pigs fed a corn-SBM based diet (Zhu et al., 1997).

RAPESEED MEAL

Rapeseed belongs to the *Brassicaceae* plant family, which is composed of numerous oilseed crops that are cultivated for their seeds and used either as a spice or a source of oil (Daun, 2011). The total world production of rapeseed in 2013 was 63 million metric tons, harvesting a total area of 36 million hectares worldwide (USDA, 2014; Table 2.1). The European Union is the top producer of rapeseed with 21 million metric tons, followed by China and Canada (USDA, 2014). Rapeseed is the second largest oilseed crop that is grown for vegetable oil used for human consumption and for its resulting meal by-product used as a protein source in animal feed (Lennox and Beckman, 2011; Table 2.1). In recent years, the use of vegetable oil for the production of biodiesel is gaining popularity, driving the demand and the production of rapeseed worldwide (Friedt and Snowdon, 2009). The supply of canola meal (**CM**) continues to increase due to the increase in canola seed production, but price of CM remains competitive with other alternative co-products used as feed ingredients (Zhou et al., 2012).

Canola refers to the low erucic acid and low glucosinolate cultivars of rapeseed, also called 00-rapeseed or double-low rapeseed in Europe (Barthet and Daun, 2011). Canola is relative new to the United States, but the demand for canola oil is increasing because it has been recognized as a healthy oil by the American Heart Association (Daun, 2011). The cultivars that are currently used to produce canola oil in the United States and Canada include *B. napus, B. rapa*, and *B. juncea* (Przybylski and Eskin, 2011). Canola oil also contains high levels of tocopherols that have natural antioxidant properties (Przybylski and Eskin, 2011).

Canola meal, expeller-pressed CM (**EPCM**), cold-pressed canola cake (**CPCC**) 00-rapeseed meal (**RSM**), and 00-rapeseed expellers (**RSE**) are byproducts of the seed-crushing industry that are suitable protein sources in livestock feeding because of their desirable AA profile (Landero et al., 2012). All canola products contain high levels of Met and Cys, but are deficient in Lys (Newkirk, 2011). Canola and rapeseed also have higher levels of most of the B-vitamins and essential minerals than SBM (Bell, 1993; NRC, 2012). Canola meal contains 3 times more fiber than SBM (Bell, 1993; Landero et al., 2011; NRC, 2012; Table 2.2), which limits its use in diets for pigs.

Canola products are sold at a discounted rate relative to SBM because of their lower energy and AA content (Landero et al, 2011). The high fiber content in canola and rapeseed products may reduce the digestibility of CP and AA by trapping protein in the fiber structure, making them inaccessible to proteases (Kracht et al., 2004; Grageola et al., 2013; Table 2.2). The fiber fraction of CM and RSM includes cellulose and lignin from the hull and hemicellulose and pectin from the cell wall of cotyledons (Zhou et al., 2012). Reducing the fiber content or increasing fiber digestibility of CM can improve nutrient utilization when included in the diet (Landero et al., 2011). Higher AA digestibility in CPCC may be associated with the lower fiber concentration and greater fat compared with EPCM (Grageola et al., 2013). Dietary fat slows gastric emptying and reduces the passage rate of digesta in the small intestine, which provides a longer time for the animal to digest AA and peptides (Cervantes-Pahm and Stein, 2008). Partial substitution of SBM for CM or EPCM in diets fed to weaned pigs that were formulated to equal NE and SID AA content did not affect growth performance of weaned pigs (Landero et al., 2011; Seneviratne et al., 2011; Parr et al., 2014). Formulation of diets with increasing inclusion of CM

needs to account for the increased heat production due to higher fiber and protein intake (Smit et al., 2014).

The nutrient composition of the meal is influenced by several factors including the cultivar, growing conditions, environmental conditions at harvest, and differences in processing (Newkirk, 2011). The efficiency of the oil extraction process and the addition of gum dictate the oil content of the meal (Bell, 1993). Solvent extraction, expeller pressing, and cold pressing are the common types of oil extraction methods used to remove the oil from canola and rapeseed (Seneviratne et al., 2010). Large crushing plants most commonly use solvent extraction in processing of canola and rapeseed because of its higher oil extraction efficiency, resulting in CM or RSM with a relatively low DE content (Zijlstra and Beltranena, 2013). It involves an initial expeller extraction at approximately 110ºC to produce a seed cake that subsequently undergoes solvent extraction using hexane, after which it is desolventized and toasted at a temperature of up to 115ºC (Spragg and Mailer, 2007). Oil that is mechanically extracted from the seed results in production of EPCM, RSE, or CPCC. The double-press expeller process is most common in smaller oilseed crushing plants or in regions where seed availability is limited (Newkirk, 2011). The seed is heated to 110ºC using steam before passing through the press and reaching temperatures of up to 135ºC resulting in more than 75% oil extraction (Spragg and Mailer, 2007). Cold pressing is another form of mechanical extraction of oil that does not involve heating the seed prior to extraction and reaches up to 65ºC during the expeller process, resulting in approximately 60% oil extraction (Spragg and Mailer, 2007). Cold pressing is commonly done in small operations and results in the extraction of virgin canola oil that is higher priced because of the increase in the demand for natural, unprocessed food (Przybylski and Eskin, 2011). The meal resulting from mechanical extraction contains significantly more residual oil than solvent-

extracted meal, which results in greater energy values, but a reduced concentration of digestible AA in expeller pressed meals (Seneviratne et al., 2010; NRC, 2012; Zijlstra and Beltranena, 2013). Expeller pressed meals should be tested for fat and CP prior to use because of the variability in oil content of samples coming from different plants (Spragg and Mailer, 2007).

Antinutritional Factors

The inclusion rate of canola or rapeseed meals in diets fed to pigs is limited due to the concentration of ANF in the ingredient. Traditional cultivars of rapeseed contained oil that had high levels of erucic acid and a meal that had high levels of glucosinolates (Przybylski and Eskin, 2011). Glucosinolates are secondary metabolites that are present in all brassica oilseed species (Tripathi and Mishra, 2007; Diederichsen and McVetty, 2011). Hydrolysis of glucosinolates by myrosinases or non-enzymatically by heat or low pH produces harmful substances such as thiocyanate, isothiocyanate, oxazolidinethione, and nitriles that affect the thyroid, liver, and kidneys (Bell, 1993; Spragg and Mailer, 2007; Tripathi and Mishra, 2007; Seneviratne et al., 2010). Environmental factors such as sulfur content of the soil influences the glucosinolate content in canola and rapeseed (Barthet and Daun, 2011). A maximum glucosinolate content of 2 mmol/kg diet is considered acceptable in feed containing canola or rapeseed products (Zijlstra and Beltranena, 2013).

Sinapine has no significance in pig production, but its hydrolysis produces off-flavor or "fishy eggs" due to the absence of the enzyme trimethylamine oxidase in the liver of susceptible brown-egg-laying hens (Bell, 1993; Spragg and Mailer, 2007). It also has a bitter taste and thus, affects palatability and feed intake, but to a lesser extent compared with glucosinolates (Bell, 1993). Solvent-extracted CM contains less glucosinolates and sinapine compared with EPCM and CPCC, and EPCM containing less of both those ANF than CPCC, which indicates that heat

treatment reduces the concentration of glucosinolate and sinapine in the resulting meal (Spragg and Mailer, 2007).

Tannins are present in canola meal and rapeseed meal with levels of up to 3%, which results in reduced palatability and protein digestibility, but it is possible that the tannins in canola do not to have the same negative effects as tannins in other plants (Newkirk, 2011). The presence of tannins can decrease protein digestibility by reducing trypsin activity (McDonnell et al., 2010). Tannins are mainly present in the hull and are more dominant in dark seed coat than in yellow seed coat varieties (Bell, 1993).

Phytic acid, which is present mainly in the embryo, is the principal storage form of P in the seed and can also bind other essential minerals such as Mg, Ca, Mn, Zn, and Cu, reducing their digestibility (Bell, 1993). Phytate reduces P digestibility by binding P in grains and legumes, making it unavailable to the pig unless phytase is supplemented in the diet or the grain used is high in phytase such as wheat (Hill, 2013). Therefore, the negative effects of phytic acid may be alleviated by the inclusion of microbial phytase in the diet. The reduced concentration of phytate-bound P indicates that fermentation of SBM also results in hydrolysis of phytate bonds (Rojas and Stein, 2012).

CONCLUSIONS

Soybean meal has traditionally been the ideal protein source in swine diets. Young pigs experience a period of transient hypersensitivity when fed a diet with a high inclusion of SBM and thus, are fed diets with animal or milk proteins that are highly digestible, palatable, and contain no ANF. However, protein derived from animal and milk products are more expensive. Fermented SBM and ESBM are processed soybean products that provide alternative sources of CP and AA that can replace SBM in diets for young pigs without adverse effects on growth

performance. Digestibility of CP and AA in FSBM and ESBM are enhanced because the concentration of ANF such as trypsin inhibitors and oligosaccharides are reduced or eliminated. Canola and rapeseed products are also viable alternative protein sources for swine diets because of their desirable AA composition and reduced price. The nutrient composition of canola and rapeseed products is significantly affected by processing procedures. Expeller-pressed CM, CPCC, and RSE contain more residual oil than solvent-extracted meals, which results in increased concentrations of DE, ME, and NE compared with CM. However, the high fiber content in CM and RSM reduces the energy value and digestibility of CP and AA. Antinutritional factors such as glucosinolates, sinapine, tannins, and phytate limit the inclusion of canola and rapeseed products in swine diets. Due to the presence of ANF, swine diets must be formulated without having to sacrifice growth performance when canola and rapeseed are included in the diet.

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TABLES

Table 2.1. World production of major oilseeds[1] (million metric tons)

Item	2009/10	2010/11	2011/12	2012/13
Soybean	260.60	264.15	239.57	267.47
Rapeseed	61.06	60.58	61.48	63.02
Cottonseed	39.51	44.30	47.78	46.07
Peanut	36.18	39.85	38.27	40.11
Sunflower seed	32.14	33.63	40.64	36.39
Palm kernel	12.43	12.91	13.79	14.85
Copra	5.71	5.89	5.56	5.80
Total	447.63	461.29	447.10	473.72

[1]Adapted from USDA (2014).

Table 2.2. Chemical composition of soybean meal, fermented soybean meal, enzyme-treated soybean meal, canola meal, canola expellers, and cold-pressed canola cake, as-fed basis[1]

	Soybean meal, dehulled	Fermented soybean meal	Enzyme-treated soybean meal	Canola meal	Canola expellers	Cold-pressed canola cake
DM, %	89.98	92.88	92.70	91.33	93.11	87.31
DE, kcal/kg	3,619	3,975	3,914	3,273	3,779	-
ME, kcal/kg	3,294	3,607	3,536	3,013	3,540	-
NE, kcal/kg	2,087	-	-	1,890	2,351	-
CP, %	47.73	54.07	55.62	37.50	35.19	25.81
Ether extract, %	1.52	2.30	1.82	3.22	9.97	20.20
NDF, %	8.21	-	-	22.64	23.77	15.32
ADF, %	5.28	-	-	15.42	17.57	11.45
Crude fiber, %	3.89	3.46	4.06	10.50	9.77	5.84
Ca, %	0.33	0.29	0.31	0.69	0.69	0.48
Total P, %	0.71	0.80	0.75	1.08	1.15	0.88
Trypsin inhibitor, TIU/mg	4.00	<1.00	2.10	-	-	-
Glucosinolates (μmol/g)	-	-	-	3.84	11.88	5.63

[1]Adapted from Cervantes-Pahm and Stein (2010), NRC (2012), and Grageola et al. (2013).

Table 2.3. Amino acid composition of soybean meal, fermented soybean meal, enzyme-treated soybean meal, canola meal, and canola expellers, as-fed basis[1]

	Soybean meal, dehulled	Fermented soybean meal	Enzyme-treated soybean meal	Canola meal	Canola expellers	Cold-pressed canola cake
Indispensable AA, %						
Arg	3.45	3.70	3.95	2.28	1.76	1.59
His	1.28	1.37	1.41	1.07	0.82	0.67
Ile	2.14	2.55	2.48	1.42	1.67	1.05
Leu	3.62	4.25	4.09	2.45	1.95	1.83
Lys	2.96	3.14	3.20	2.07	1.58	1.52
Met	0.66	0.75	0.71	0.71	0.61	0.47
Phe	2.40	2.87	2.78	1.48	1.48	1.03
Thr	1.86	2.09	2.13	1.55	1.22	1.11
Trp	0.66	0.69	0.72	0.43	0.32	0.34
Val	2.23	2.67	2.57	1.78	1.63	1.33

[1]Adapted from NRC (2012) and Grageola et al. (2013).

Table 2.4. Apparent ileal digestibility of CP and AA in soybean meal, fermented soybean meal, enzyme-treated soybean meal, canola meal, and canola expellers, as-fed basis[1]

	Soybean meal, dehulled	Fermented soybean meal	Enzyme-treated soybean meal	Canola meal	Canola expellers	Cold-pressed canola cake
CP, %	82.0	72.0	82.0	68.0	70.0	-
Indispensable AA, %						
Arg	92.0	87.0	92.0	82.0	80.0	82.0
His	87.0	79.0	87.0	75.0	76.0	79.0
Ile	87.0	79.0	86.0	72.0	76.0	71.0
Leu	86.0	79.0	86.0	74.0	77.0	74.0
Lys	87.0	72.0	83.0	71.0	70.0	74.0
Met	88.0	85.0	88.0	82.0	82.0	80.0
Phe	86.0	77.0	83.0	74.0	79.0	74.0
Thr	80.0	68.0	78.0	65.0	67.0	65.0
Trp	88.0	75.0	80.0	66.0	72.0	80.0
Val	83.0	75.0	84.0	69.0	71.0	68.0

[1]Adapted from NRC (2012) and Grageola et al. (2013).

Table 2.5. Standardized ileal digestibility of CP and AA in soybean meal, fermented soybean meal, enzyme-treated soybean meal, canola meal, and canola expellers, as-fed basis[1]

	Soybean meal, dehulled	Fermented soybean meal	Enzyme-treated soybean meal	Canola meal	Canola expellers	Cold-pressed canola cake
CP, %	87.0	79.0	88.0	74.0	75.0	-
Indispensable AA, %						
Arg	94.0	90.0	96.0	85.0	83.0	88.0
His	90.0	81.0	90.0	78.0	78.0	84.0
Ile	89.0	82.0	89.0	76.0	78.0	75.0
Leu	88.0	82.0	89.0	78.0	78.0	78.0
Lys	89.0	75.0	86.0	74.0	71.0	79.0
Met	90.0	88.0	91.0	85.0	83.0	83.0
Phe	88.0	80.0	86.0	77.0	80.0	78.0
Thr	85.0	73.0	83.0	70.0	70.0	73.0
Trp	91.0	78.0	83.0	71.0	73.0	85.0
Val	87.0	80.0	89.0	74.0	73.0	73.0

[1]Adapted from NRC (2012) and Grageola et al. (2013).

CHAPTER 3: AMINO ACID DIGESTIBILITY IN PROCESSED SOYBEAN AND RAPESEED PRODUCTS FED TO WEANLING PIGS

ABSTRACT

An experiment was conducted to determine the apparent ileal digestibility (AID) and the standardized ileal digestibility (SID) of CP and AA in 4 sources of processed soybean products, in conventional dehulled soybean meal (SBM-CV), in conventional 00-rapeseed expellers (RSE), and in a fermented co-product mixture (FCM) that contained rapeseed meal, wheat, soy molasses, and potato peel fed to weanling pigs. The 4 processed soybean products included 2 sources of enzyme-treated soybean meal (ESBM-1 and ESBM-2), extruded soybean meal (SBM-EX), and soy protein concentrate (SPC). Twenty seven weanling barrows (initial BW: 9.29 ± 0.58 kg) were surgically equipped with a T-cannula in the distal ileum. Pigs were randomly allotted to three 9 × 5 Youden squares with 9 pigs and five 7-d periods in each square. Seven cornstarch-based diets were prepared using each of the protein sources as the sole source of CP and AA. A N-free diet was prepared to calculate basal endogenous losses of CP and AA and this diet was fed to 2 groups of pigs. Results indicate that the SID of CP was greater ($P < 0.05$) in ESBM-1 than in SPC, RSE, and FCM. The SID of Arg, His, Ile, Leu, Met, and Phe were greater ($P < 0.05$) in ESBM-1 than in SPC, and the SID of Lys was greater ($P < 0.05$) in SBM-CV than in ESBM-2. The SID of Thr, Trp, Val and total indispensable AA were not different among the soybean products. The SID of total indispensable AA was not different among the SBM products. However, the SID of total dispensable AA in ESBM-1 was only greater ($P < 0.05$) than in SPC. Therefore, the SID of total AA was greater ($P < 0.05$) in ESBM-1 than in SPC, but no other differences were observed among SBM products. The SID of most AA in RSE and the SID of all AA in FCM were less ($P < 0.05$) than in all the SBM products, but the SID of all AA in RSE were greater

($P < 0.05$) than in FCM. Results of this research indicate that although processing of soybean meal results in increased concentration of CP, processing may also reduce the digestibility of AA, which is likely due to heat damage during processing. There are, however, differences among processed soy products with some products having greater SID of AA than others. Results also indicate that fermentation of a mixture of rapeseed meal, wheat, and relatively low quality co-products does not result in SID values that are similar to those of unfermented 00-rapeseed expellers or soybean products.

Key words: amino acid digestibility, enzyme-treated soybean meal, extruded soybean meal fermented rapeseed expellers, soy protein concentrate, weanling pigs

INTRODUCTION

Soybean meal (**SBM**) is the most commonly used plant protein source in swine diets (Goerke et al., 2012). However, soybeans contain antinutritional factors including antigens, trypsin inhibitors, oligosaccharides, and lectins, which are unfavorable to younger pigs (Friesen et al, 1993; Mawson et al., 1993). To avoid providing these antinutritional factors, diets for weanling pigs usually contain potato protein concentrate and (or) animal protein sources such as fishmeal, poultry byproduct meal, blood proteins, or whey protein, which are more expensive than SBM. However, SBM can be processed to soy protein concentrate (**SPC**), fermented SBM, or enzyme-treated SBM by removing the soluble carbohydrates, primarily sucrose, raffinose, and stachyose, from the defatted meal. These processed soybean products are more tolerable to young pigs than conventional SBM (Lenehan et al., 2007; Jones et al., 2010; Kim et al., 2010). However, differences in starting material and processing methods may result in processed soybean products with different characteristics (Berk, 1992).

Rapeseeds that are low in erucic acid and glucosinolates are referred to as 00-rapeseeds and meal and expellers produced from 00-rapeseeds may be fed to older pigs.

However, these ingredients are usually not fed to weanling pigs because of the residual glucosinolates and the relatively high concentrations of fiber in these products (Mckinnon and Bowland, 1977). However, it is possible that fermentation can improve the nutritional value of these meals, which may allow them to be fed to weanling pigs. Therefore, the objective of this experiment was to determine the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of CP and AA in 4 sources of processed soybean products, in conventional dehulled SBM, in conventional 00-rapeseed expellers, and in a fermented co-product mixture (FCM) that contained rapeseed meal, wheat, soy molasses, and potato peel fed to weanling pigs.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for this experiment.

The pigs used were the offspring of G-Performer boars mated to Fertilis 25 females (Genetiporc, Alexandria, MN). The ingredients that were used in the experiment (Table 3.1) included 2 sources of enzyme-treated soybean meal (**ESBM-1;** HP 300, Hamlet Protein Inc., Horsens, Denmark) and (**ESBM-2;** Vilosoy, Dansk Vilomix, Mørke, Denmark) that were produced by the same company but different starting material and processing procedures may have been used, an extruded soybean meal that was subsequently treated with an enzyme preparation (**SBM-EX;** Alpha Soy Pig 530, Agro Korn, Videbæk, Denmark), a soy protein concentrate (**SPC;** SPC 60 Imcosoy, Imcopa, Paraná, Brazil), a conventional de-hulled soybean meal that was sourced from Brazil (**SBM-CV**), a conventional 00-rapeseed expellers (**RSE;** The Protein and Oilfabric Scanola Inc., Aarhus, Denmark) and a fermented co-product mixture containing fermented 00-rapeseed meal, wheat bran, soy molasses, and potato peel (**FCM;** EP 100, European Protein, Bække, Denmark).

Collection of Ingredients

Four samples of each ingredient (Table 3.1) were collected by the Danish Pig Research Centre at local swine production units or at feed mills in Denmark. Samples were collected over a period of 2 months during the fall of 2012 to ensure that the ingredients used in the experiment represented different production batches. The 4 samples of each ingredient were mixed thoroughly and then divided using a riffle type divider (Rationel Kornservice Inc., Esbjerg, Denmark) and a representative subsample was collected and used in the experiment.

Diets, Animals, Housing, and Experimental Design

Four sources of processed soy protein (i.e., ESBM-1, ESBM-2, SBM-EX, and SPC), SBM-CV, RSE, and FCM were used. Eight diets were prepared (Table 3.2). Seven diets contained 1 of the 7 AA containing ingredients as the sole source of AA. A N-free diet was also prepared and used to calculate basal endogenous losses of CP and AA. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998). Each diet also contained 0.4% chromic oxide as an indigestible marker. No antibiotic growth promoters were used in the diets.

Twenty seven weanling barrows (initial BW: 9.29 ± 0.58 kg) were surgically equipped with a T-cannula in the distal ileum using procedures adapted from Stein et al. (1998). Pigs were randomly allotted to three 9 × 5 Youden squares with 9 pigs and 5 periods in each square. Within each square, 2 pigs were assigned to the N-free diet and one pig was assigned to each of the remaining diets. As a consequence, there were a total of 15 replications for all the AA-containing diets and 30 replications for the N-free diet. Pigs were housed in individual pens (1.2 × 1.5 m) that had smooth side panels and fully slatted tri-bar stainless steel floors in an environmentally controlled room, and each pen equipped with a feeder and a nipple drinker.

All pigs were fed at a daily level of 3 times the estimated maintenance energy requirement (i.e., 197 kcal ME per $kg^{0.75}$; NRC, 2012) throughout the experiment. The daily allotments of feed were divided into 2 equal meals that were provided at 0700 and 1600 h. The pigs had access to water at all times.

Data Recording and Sample Collection

Pig weights were recorded at the beginning of each period and at the conclusion of the experiment. The amount of feed supplied each day was also recorded. The initial 5 d of each period was considered an adaptation period to the diet. Ileal digesta were collected for 8 h on d 6 and 7 as explained by Stein et al. (1999). In short, a plastic bag was attached to the cannula barrel and digesta flowing into the bag was collected. Bags were removed whenever they were filled with digesta, or at least once every 30 min, and were immediately stored at –20°C to prevent bacterial degradation of the AA in the digesta. On the completion of one experimental period, animals were deprived of feed overnight and the following morning, a new experimental diet was offered.

Chemical Analysis

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a sub-sample was collected for chemical analysis. Samples of each diet and of each AA-containing ingredient were collected as well. Digesta samples were lyophilized and ground through a 1-mm screen in a Wiley mill (Model 4; Thomas Scientific, Swedesboro, NJ) prior to chemical analysis. All samples of ingredients and ileal digesta were analyzed in duplicate, with the exception of ileal digesta from N-free fed pigs that were analyzed in duplicate in 2 separate samples. All diet samples were analyzed in duplicate in 4 separate samples. All samples were analyzed for DM by oven drying duplicate samples at 135°C for 2 h (Method 930.15; AOAC Int., 2007) and also analyzed for ash (Method 942.05; AOAC Int., 2007). The concentration of N in all samples was determined using the combustion procedure

(Method 990.03; AOAC Int., 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Aspartic acid was used as a calibration standard and crude protein was calculated as N × 6.25. Amino acids were analyzed in all samples on a Hitachi Amino Acid Analyzer (Model L8800, Hitachi High Technologies America Inc., Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before analysis, samples were hydrolyzed with 6*N* HCl for 24 h at 110°C [Method 982.30 E(a); AOAC Int., 2007]. Methionine and Cys were analyzed 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]. The Cr concentrations of diets and ileal digesta samples were measured using an inductive coupled plasma atomic emission spectrometric method (Method 990.08; AOAC Int., 2007) after nitric acid-perchloric acid wet ash sample preparation (Method 968.088D; AOAC Int., 2007). Diets and ingredient samples were also analyzed for ADF (Method 973.18; AOAC Int., 2007), and NDF (Holst, 1973). Ingredients were also analyzed for Ca and P (Method 975.03; AOAC Int., 2007) and concentration of acid hydrolyzed ether extract was measured in all 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 an automated analyzer (Soxtec 2050 FOSS; North America, Eden Prairie, MN). Ingredient samples were also analyzed for trypsin inhibitor activity (Method Ba 12-75; AOCS, 2006), and for sucrose, stachyose, and raffinose (Janauer and Englmaier, 1978). Rapeseed samples were also analyzed for glucosinolates (Method Ak 1-92; AOCS, 1998). Diets and ingredients were also analyzed for gross energy on an adiabatic bomb calorimeter (Model 6300, Parr Instruments, Moline, IL) using benzoic acid as the internal standard.

Calculations and Statistical Analysis

Apparent ileal digestibility values for OM, CP, and AA in the 7 diets were calculated. The values for OM represent the AID for the diet, but because the soybean products, RSE, or FCM contributed all CP and AA to the diets, the AID of CP and AA for the diets also represent the AID of CP and AA for each ingredient. Equation [1] (Stein et al., 2007) was used to calculate the AID:

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

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

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

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

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

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

$$SID = [(AID + IAA_{end})/AA_f] \quad \textbf{[3]}$$

where SID is the standardized ileal digestibility value (%). The SID of CP was also calculated using this equation.

Normality was verified and outliers were identified using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC). An observation was considered an outlier if the value was more than 3 standard deviations away from the grand mean. Data were analyzed by ANOVA using the PROC MIXED of SAS in a randomized complete block design with the pig as the experimental unit. The statistical model included diet as the fixed effect and pig and period as the random effect. When diet was a significant source of variation, treatment means were separated and multiple compared using the LSMEANS statement and Bonferroni correction of PROC MIXED. Statistical significance and tendency were considered at $P < 0.05$ and $0.05 \leq P < 0.10$, respectively.

RESULTS

The final BW of pigs was 19.53 ± 2.74 kg. The analyzed concentration of CP in the SBM products ranged from 47.81 to 62.05% and RSE and FCM contained 30.13 and 32.00 % CP, respectively (Table 3.1). The SBM products contained 4,140 to 4,555 kcal/kg GE, 0.29 to 0.33% Ca, 0.60 to 0.73% P, 0.70 to 1.81% AEE, 7.76 to 19.69% NDF, and 4.85 to 10.26% ADF, whereas RSE and FCM contained 4,533 and 4,154 kcal/kg GE, 0.78 and 0.66% Ca, 0.96 and 0.91% P, 10.22 and 4.31% AEE, 24.54 and 22.88% NDF, and 19.93 and 14.81% ADF, respectively. The trypsin inhibitor activity in the SBM products ranged from 1.60 to 2.70 TIA/mg and 1.40 TIA/mg of RSE, and less than 1.00 TIA/mg in FCM. The concentrations of glucosinolates were 16.11 μmol/g in RSE and 2.77 μmol/g in FCM. The SBM products contained 0.06 to 4.99% sucrose, 0.06 to 1.64% stachyose, and 0.03 to 0.50% raffinose, whereas the rapeseed products contained 1.51 to 5.45% sucrose, 0.38 to 0.62% stachyose, and 0.17 to 0.23% raffinose. The SBM products contained 21.28 to 28.03% indispensable AA and 24.24 to 31.87% dispensable AA, whereas RSE and FCM contained 12.36 to 12.55% indispensable AA and 13.67 to 14.93% dispensable AA.

Among the diets containing SBM products, the AID of ash in the SBM-CV diet was greater ($P < 0.05$) than in ESBM-1 diet, ESBM-2 diet, and SBM-EX diet, but not different from SPC diet (Table 3.4). No difference was observed in the AID of OM among diets containing SBM products, except that the SPC diet had greater ($P < 0.05$) AID of OM than the ESBM-2 diet. No differences were observed in the AID of ash and OM between the RSE diet and the FCM diet. The N-free diet had greater ($P < 0.05$) AID of ash than the SBM-EX diet, RSE diet, and FCM diet, and had greater ($P < 0.05$) AID of OM than all other diets.

Among the SBM products, the AID and SID of CP in ESBM-1 was greater ($P < 0.05$) than in SPC, but not different from ESBM-2, SBM-EX, and SBM-CV (Tables 3.5 and 3.6). No differences were observed in AID and SID of CP among ESBM-2, SBM-EX, SPC, and SBM-CV. The AID and SID of CP in the 2 rapeseed products was less ($P < 0.05$) than in all SBM products, except that no difference was observed in the SID of CP among ESBM-2, SPC, and RSE. However, the AID and SID of CP was greater ($P < 0.05$) in RSE than in FCM.

Among the SBM products, ESBM-1 had greater ($P < 0.05$) AID of Arg, His, Ile, Leu, Met, Phe, and Trp than SPC, greater ($P < 0.05$) AID of Arg, Thr, and Val than ESBM-2, and had greater ($P < 0.05$) AID of Val than SBM-EX. The AID of Lys was greater ($P < 0.05$) in SBM-CV than in ESBM-2, but not different from the other SBM products. Therefore, the AID of total indispensable was greater ($P < 0.05$) in ESBM-1 than in ESBM-2, but no differences were observed among the other SBM products. The AID of all indispensable AA was less ($P < 0.05$) in FCM than in all SBM products, and the AID of all AA in RSE was also less ($P < 0.05$) than in ESBM-1 and SBM-CV, and the AID of most AA in RSE was also less ($P < 0.05$) than in ESBM-2, SBM-EX, and SPC. The AID of all indispensable AA was greater ($P < 0.05$) in RSE than in FCM.

Among the SBM products, the AID of Ala were greater ($P < 0.05$) in ESBM-1 than in SPC, the AID of Cys was greater ($P < 0.05$) in SBM-CV than in ESBM-2, the AID of Pro was greater ($P < 0.05$) in ESBM-1 and SBM-CV than in SPC, and the AID of total dispensable AA was greater ($P < 0.05$) in ESBM-1 than in ESBM-2 and SPC. The AID of Ala, Glu, and total dispensable AA were less ($P < 0.05$) in RSE than in ESBM-2 and SPC, and the AID of Asp, Ser, and Tyr was less ($P < 0.05$) in RSE than in all SBM products.

The AID of all dispensable AA was less ($P < 0.05$) in FCM than in RSE and in all SBM products. The AID of total AA was greater ($P < 0.05$) in ESBM-1 than in SPC, but no difference was observed in the AID of total AA among the other SBM products. The AID of total AA was less ($P < 0.05$) in the 2 rapeseed products than in all SBM products, except that the AID of total AA was not different between RSE and SPC. However, the AID of total AA was greater ($P < 0.05$) in RSE than in FCM.

Among the SBM products, ESBM-1 had greater ($P < 0.05$) SID of Arg, His, Ile, Leu, Met, and Phe than SPC, the SID of Lys was greater ($P < 0.05$) in SBM-CV than in ESBM-2, but no other differences were observed among the SBM products. Therefore, no differences were observed in the SID of total indispensable AA among the SBM products. The SID of most indispensable AA was less ($P < 0.05$) in RSE than in the SBM products, with the exception that the SID of Arg, His, Lys, Met, and Trp in ESBM-2, the SID of His, Met, and Trp in SBM-EX, the SID of Arg, His, Leu, Met, and Trp in SPC, and the SID of His and Trp in SBM-CV were not different from the SID of these AA in RSE. However, the SID of total indispensable AA was less ($P < 0.05$) in RSE than in all SBM products. The SID of all indispensable AA was less ($P < 0.05$) in FCM than in RSE and all SBM products.

Among the SBM products, the SID of Ala was greater ($P < 0.05$) in ESBM-1 than in SPC, the SID of Cys was greater ($P < 0.05$) in SBM-CV than in ESBM-2, the SID of Pro was greater ($P < 0.05$) in ESBM-1, SBM-EX, and SBM-CV than in SPC, but no other differences

were observed among these SBM products. Therefore, the SID of total dispensable AA was greater ($P < 0.05$) in ESBM-1 than in SPC, but not different from other SBM products. Compared with the SBM products, RSE had less ($P < 0.05$) SID of Ala than ESBM-1, less ($P < 0.05$) SID of Cys than SBM-CV, and less ($P < 0.05$) SID of Asp, Ser, and Tyr than all SBM products. Therefore, the SID of total dispensable AA in RSE was not different from all SBM products. However, the SID of all dispensable AA in FCM were less ($P < 0.05$) than in RSE and all the SBM products. The SID of total AA was greater ($P < 0.05$) in ESBM-1 than in SPC and RSE, and FCM had the least ($P < 0.05$) SID of total AA compared with RSE and all SBM products.

DISCUSSION

Composition and Chemical Characteristics of Ingredients

The chemical composition of SBM-CV was close to expected values (Goebel and Stein, 2011; NRC, 2012; Rojas and Stein, 2013), except for concentrations of sucrose, stachyose and raffinose, which were less than previous values. In contrast, concentrations of ADF and NDF were slightly greater than values reported by NRC (2012), but in good agreement with Rojas and Stein (2013) and less than values reported by Goebel and Stein (2011).

The chemical composition of ESBM-1 was similar to what was reported by Goebel and Stein (2011), except for concentrations of sucrose, stachyose and raffinose, which were less than previously observed. However, the concentrations of CP and indispensable AA in ESBM-1 were less than the concentrations reported by Yang et al. (2007), which may have been a result of differences in the methods of analysis.

Concentrations of CP and AA in ESBM-2 were similar to the values for fermented soybean meal that were reported by Cervantes-Pahm and Stein (2010) and Rojas and Stein

(2013), but concentrations of sucrose, stachyose, and raffinose in ESBM-2 were greater than the values reported by Rojas and Stein (2013). This indicates that the fermentation process used to produce ESBM-2 was not completely efficient in removing the oligosaccharides from the product.

Concentrations of CP and AA in SBM-EX were close to those determined in ESBM-2, but unlike ESBM-2, SBM-EX is produced by extrusion of dehulled soybean meal with a subsequent enzyme treatment. Concentrations of sucrose, stachyose, and raffinose in SBM-EX were greater than the values reported by Rojas and Stein (2013) for fermented soybean meal, which is likely because SBM-EX has not been fermented.

The concentrations of CP and most indispensable AA of SPC were similar to the values of soy protein concentrate reported by Yang et al. (2007), but were less than the values reported by Lenehan et al. (2007) and NRC (2012). This may have been a result of different sources of SBM used during the production of the products. However, the very high concentrations of ADF and NDF in SPC indicate that soy hulls may have been added to this ingredient, which resulted in a reduction in the concentration of CP. It therefore appears that SPC is different from traditional sources of soy protein concentrate.

Ileal Digestibility of Ash and OM

The greater AID of OM in the N-free diet than in any of the other diets was expected because of the low fiber concentration in the N-free diet. The lack of a difference in the digestibility of OM among the diets containing ESBM-1, ESBM-2, and SBM-EX also was expected because the inclusion rate of soybean products was the same in all of these diets and these results, therefore, indicate that the AID of the intestinally digestible nutrients in these 3 ingredients is not different. The fact that the AID of OM in the SPC diet was greater than in the ESBM-2 diet is likely a consequence of the increased concentration of cornstarch in the diet containing SPC compared with the diet containing ESBM-2. However, the AID of OM

in the diet containing SBM-CV was expected to be less than in the diets containing the other soybean products because of the reduced inclusion of cornstarch in this diet, but the fact that this was not the case may indicate that the AID of nutrients in SBM-CV *per se* may be greater than in the other soybean products. However, the design of the experiment does not allow us to determine the actual AID of OM in the ingredients.

The reduced AID of OM in the diets containing RSE and FCM compared with that in all other ingredients mainly reflects the increased fiber concentration in these diets. The inclusion of cornstarch, sucrose, and soybean oil was similar to the inclusion in the diet containing SBM-CV, so the reduced AID of OM in the diets containing RSE and FCM indicate that the AID of OM in RSE and FCM is less than in SBM-CV.

The majority of the ash in all diets was from the minerals that were added to the diets, but between 30 and 45% of the ash in the diets originated from the ash in the protein-containing ingredients. The AID of ash that were calculated for the diets containing ESBM-1, ESBM-2, SBM-EX, or SPC is close to values reported for a corn-soybean meal diet fed to growing-finishing pigs (Urriola and Stein, 2012). However, the fact that the AID of ash in diets containing ESBM-1, ESBM-2, or SBM-EX was less than in the diet containing SBM-CV indicates that the ash fraction in these ingredients may have become less digestible due to the processing. It is also possible that the secretion of minerals into the intestinal tract was greater when diets containing some ingredients versus other ingredients were provided because the type of fiber in an ingredient influences the endogenous secretions of minerals into the digestive tract (Urriola and Stein, 2012). It is, however, not possible to distinguish between minerals in the ileal digesta of endogenous and of dietary origin. The reduced AID of ash in the diets containing RSE or FCM may also be a result of increased secretions of minerals into the digestive tract.

Ileal Digestibility of Amino Acids

Values for AID and SID of CP and AA for SBM-CV concur with previous estimates (Smiricky et al., 2002; Baker et al., 2010; NRC, 2012), but were slightly greater than the values reported by Urbaityte et al. (2009) and Cervantes-Pahm and Stein (2010). Thus the present values are within the range of previously reported values and the source of SBM-CV used in this experiment can be considered a normal source of dehulled soybean meal.

Values for the AID and SID of AA in ESBM-1 that were obtained in this experiment are very close to or slightly greater than previous values reported for this ingredient (Cervantes-Pahm and Stein, 2010; NRC, 2012). The fact that the SID of most AA in ESBM-1 was not different from values observed in SBM-CV is also in agreement with previous observations.

To our knowledge, no values for AID and SID of CP and AA in ESBM-2 have previously been reported. The observation that the SID of some AA is less in ESBM-2 than in ESBM-1 indicates that the enzyme treatment or the process used to produce ESBM-2 is less efficient in maintaining high AA digestibility compared with the process used to produce ESBM-1. Specifically, the low SID of Lys in ESBM-2 indicates that the heating applied during drying of this product is more severe compared with that used to dry ESBM-1. The fact that the Lys:CP ratio was less for ESBM-2 than in other soy proteins except for SBM-EX further indicates that this product was heat damaged because the Lys:CP ratio is an indication of heat damage in soy proteins (González-Vega et al., 2011). In most feed ingredients, the SID of Thr is the least among the indispensable AA because of relatively high concentrations of Thr in the endogenous protein that is lost at the end of the distal ileum. However, for ESBM-2, the SID of Lys was the least among the indispensable AA which also indicates that this ingredient was heat damaged.

We are not aware of any previous data for the SID of AA in SBM-EX, but the current data indicate that the extrusion process used to produce SBM-EX does not change the SID of AA compared with SBM-CV. The exception to this is that the SID for Lys is less in SBM-EX than in SBM-CV, which is likely a result of over-heating of this product during the extrusion process. The Lys:CP ratio for SBM-EX was also the least among all soy proteins.

There are also no values for AID and SID of CP and AA that have been reported for SPC, but values observed in this experiment for SPC are less than the values reported for soy protein concentrate by Smiricky et al. (2002) and by Cervantes-Pahm and Stein (2008) – but the latter 2 experiments were conducted with growing pigs rather than weanling pigs. However, Urbaityte et al. (2009) determined SID of AA in 4 sources of soy protein concentrate using weanling pigs and reported values that were slightly greater than the values observed in this experiment. It is generally assumed that SID values for AA in soy protein concentrate are greater than in SBM-CV because many of the carbohydrates and fibers have been removed during the production of soy protein concentrate. In previous experiments in which SID values for AA have been compared between soy protein concentrate and SBM-CV, values for soy protein concentrate were greater than for SBM-CV (Cervantes-Pahm and Stein, 2008; Urbaityte et al., 2009). However, in the present experiment, SID values for SPC were not greater than in SBM-CV. This observation indicates that the production processes used to produce SPC are less efficient in improving AA digestibility compared with what has been observed in previous research. It is also surprising that concentrations of ADF and NDF in SPC are twice as high as in SBM-CV and some of the other soy proteins used in this experiment. Usually, concentrations of ADF and NDF or crude fiber are comparable to or less than in SBM-CV (Cervantes-Pahm and Stein, 2008; Urbaityte et al., 2009; NRC, 2012). It is, therefore, likely that soy hulls or another source of fiber were added during the

production process of SPC, which make this ingredient different from traditional soy protein concentrates.

The values for AID and SID of CP and AA in the RSE used in this experiment are greater than values reported in previous experiments (Woyengo et al., 2010; NRC, 2012), which indicates that the RSE used in this experiment was of high quality although the concentration of CP was less than previously observed (NRC, 2012). It is usually not common to feed RSE to weanling pigs, but the present results indicate that weanling pigs have a relatively good digestibility of AA in RSE.

The AID and SID of CP and AA in FCM were less than in all other products. Based on currently available information, it is not possible to determine the reason for these low values. It is likely that because wheat bran, soy molasses, and potato peels are used in the production of FCM, the increased concentration of fiber has reduced the digestibility of AA in this ingredient compared with other ingredients. In addition, the extremely low digestibility of Lys in FCM indicates that this product may have been over-heated during processing. The low AID for OM also indicates that some of the ingredients used in the production of FCM may have had low digestibility. Based on the current data, it is concluded that use of FCM in diets fed to weanling pigs will result in more nitrogen being excreted from the pigs than if the other ingredients tested in this experiment are used.

CONCLUSIONS

To our knowledge, no values for AID and SID of CP and AA in ESBM-2, SBM-EX, SPC, and FCM have previously been reported. Results of this research indicate that although processing of soybean meal results in increased concentration of CP, processing may also reduce the digestibility of AA, which is likely due to heat damage during processing. There are, however, differences among processed soy products with some products having greater

AID and SID of AA than others. Results also indicate that fermentation of a mixture of rapeseed meal, wheat, and relatively low quality co-products does not result in AID and SID values that are similar to those of unfermented 00-rapeseed expellers or soybean products.

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TABLES

Table 3.1. Analyzed nutrient composition of two sources of enzyme-treated soybean meal, extruded soybean meal, soy protein concentrate, conventional soybean meal, conventional 00-rapeseed expellers, and a fermented co-product mixture containing fermented 00-rapeseed expellers, wheat, soy molasses, and potato peel, as-fed basis

	Ingredient[1]						
Item	ESBM-1	ESBM-2	SBM-EX	SPC	SBM-CV	RSE	FCM
GE, kcal/kg	4,555	4,380	4,454	4,499	4,140	4,533	4,154
DM, %	91.98	91.17	92.85	91.71	88.67	88.58	87.09
CP, %	56.82	52.07	53.28	62.05	47.81	30.13	32.00
Ca, %	0.31	0.33	0.29	0.32	0.30	0.78	0.66
P, %	0.70	0.73	0.64	0.63	0.60	0.96	0.91
Ash, %	6.47	6.85	6.36	5.97	6.09	6.52	6.85
OM, %	85.51	84.32	86.49	85.74	82.58	82.06	80.24
AEE[2], %	1.81	0.70	1.82	1.01	1.23	10.22	4.31
NDF, %	9.16	9.48	12.73	19.69	7.76	24.54	22.88
ADF, %	4.85	4.99	5.09	10.26	5.13	18.93	14.81
Trypsin inhibitor activity, TIU[3]/mg	2.00	1.60	2.50	1.60	2.70	1.40	<1.00
Glucosinolates, μmol/g	-	-	-	-	-	16.11	2.77
Carbohydrates, %							
Sucrose	0.06	4.35	0.89	0.97	4.99	5.45	1.51

Table 3.1 (cont.)

Stachyose	0.06	1.58	0.71	1.23	1.64	0.62	0.38
Raffinose	0.03	0.67	0.20	0.28	0.50	0.23	0.17
Indispensable AA, %							
Arg	4.00	3.64	3.75	4.54	3.44	1.73	1.80
His	1.43	1.31	1.30	1.57	1.22	0.79	0.75
Ile	2.63	2.38	2.40	2.93	2.18	1.21	1.11
Leu	4.31	3.89	4.02	4.85	3.60	1.96	2.12
Lys	3.64	3.14	3.17	3.90	3.02	1.78	1.65
Met	0.74	0.70	0.67	0.82	0.65	0.59	0.59
Phe	2.86	2.57	2.71	3.22	2.37	1.16	1.27
Thr	2.10	1.92	1.95	2.35	1.79	1.28	1.31
Trp	0.74	0.65	0.70	0.77	0.66	0.39	0.37
Val	2.82	2.57	2.49	3.08	2.35	1.47	1.58
Total	25.27	22.77	23.16	28.03	21.28	12.36	12.55
Dispensable AA, %							
Ala	2.43	2.22	2.20	2.66	2.03	1.26	1.43
Asp	6.28	5.72	5.94	7.08	5.35	2.10	2.27
Cys	0.74	0.70	0.65	0.77	0.62	0.65	0.68
Glu	9.54	8.65	8.96	10.69	8.17	4.47	4.93

Table 3.1 (cont.)

Gly	2.33	2.13	2.12	2.54	1.96	1.43	1.52
Pro	2.92	2.63	2.63	3.13	2.33	1.74	1.98
Ser	2.45	2.22	2.40	2.81	2.10	1.17	1.19
Tyr	1.99	1.81	1.88	2.19	1.68	0.85	0.93
Total	28.68	26.08	26.78	31.87	24.24	13.67	14.93
Total AA	53.95	48.85	49.94	59.90	45.52	26.03	27.48
Calculated values							
Lys:CP ratio[4], %	6.41	6.03	5.95	6.29	6.32	5.91	5.16

[1] ESBM-1 = HP 300; ESBM-2 = Vilosoy; SBM-EX = Alpha Soy Pig 530; SPC = SPC 60 Imcosoy; SBM-CV = conventional soybean meal; RSE = conventional 00-rapeseed expellers; FCM = EP 100.

[2]AEE = Acid hydrolyzed ether extract.

[3]TIU = Trypsin inhibitor units.

[4]The Lys:CP ratio was expressed as the concentration of Lys as a percentage of the concentration of CP in each sample (González-Vega et al., 2011).

Table 3.2. Ingredient composition of experimental diets containing enzyme-treated soybean meal, extruded soybean meal, soy protein concentrate, conventional soybean meal, conventional 00-rapeseed expellers, and a fermented co-product mixture containing fermented 00-rapeseed expellers, wheat, soy molasses, and potato peel, as-fed basis

	Diet[1]							
Ingredient, %	ESBM-1	ESBM-2	SBM-EX	SPC	SBM-CV	RSE	FCM	N-free
HP 300	35.00	-	-	-	-	-	-	-
Vilosoy	-	35.00	-	-	-	-	-	-
Alpha Soy Pig 530	-	-	35.00	-	-	-	-	-
SPC 60 Imcosoy	-	-	-	30.00	-	-	-	-
Soybean meal, 47.5% CP	-	-	-	-	40.00	-	-	-
00-rapeseed expellers	-	-	-	-	-	40.00	-	-
EP 100	-	-	-	-	-	-	40.00	-
Soybean oil	3.00	3.00	3.00	3.00	3.00	3.00	3.00	4.00
Solka floc[2]	-	-	-	-	-	-	-	4.00
Monocalcium phosphate	0.85	0.85	0.85	0.85	0.85	0.50	0.50	2.40
Limestone	1.45	1.45	1.45	1.45	1.45	1.50	1.50	0.50
Sucrose	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Cornstarch	38.60	38.60	38.60	43.60	33.60	33.90	33.90	67.50
Magnesium oxide	-	-	-	-	-	-	-	0.10
Potassium carbonate	-	-	-	-	-	-	-	0.40

Table 3.2 (cont.)

Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[3]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1] ESBM-1 = HP 300; ESBM-2 = Vilosoy; SBM-EX = Alpha Soy Pig 530; SPC = SPC 60 Imcosoy; SBM-CV = conventional soybean meal; RSE = conventional 00-rapeseed expellers; FCM = EP 100; N-free = nitrogen-free diet.

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

[3] The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 3.3. Analyzed nutrient composition of experimental diets containing enzyme-treated soybean meal, extruded soybean meal, soy protein concentrate, conventional soybean meal, conventional 00-rapeseed expellers, a fermented co-product mixture containing fermented 00-rapeseed expellers, wheat, soy molasses, and potato peel, as-fed basis

	Diet[1]							
Item	ESBM-1	ESBM-2	SBM-EX	SPC	SBM-CV	RSE	FCM	N-free
GE, kcal/kg	4,083	4,032	4,031	3,978	3,921	4,125	3,957	3,716
DM, %	92.93	94.59	92.82	92.49	90.56	91.84	90.91	91.51
CP, %	19.98	18.10	18.76	18.81	19.21	12.19	12.47	0.25
Ash, %	5.02	5.43	4.84	4.56	5.67	5.48	5.45	3.64
OM, %	87.91	89.16	87.98	87.92	84.88	86.37	85.46	87.87
NDF, %	3.80	3.38	4.49	6.08	4.07	11.59	10.13	4.82
ADF, %	1.96	1.86	1.98	2.46	2.48	8.54	6.22	3.24
Cr, %	0.21	0.22	0.22	0.22	0.21	0.21	0.22	0.19
Indispensable AA, %								
Arg	1.40	1.25	1.33	1.46	1.36	0.78	0.67	0.01
His	0.51	0.45	0.46	0.51	0.49	0.35	0.29	0.00
Ile	0.93	0.80	0.83	0.93	0.87	0.51	0.44	0.01
Leu	1.55	1.38	1.43	1.61	1.48	0.93	0.81	0.03
Lys	1.27	1.08	1.13	1.27	1.20	0.81	0.62	0.00
Met	0.26	0.25	0.24	0.26	0.26	0.26	0.22	0.00
Phe	1.01	0.90	0.98	1.06	0.97	0.53	0.47	0.02

Table 3.3 (cont.)

Thr	0.74	0.69	0.72	0.78	0.73	0.59	0.51	0.01
Trp	0.28	0.26	0.27	0.26	0.28	0.19	0.17	<0.04
Val	1.00	0.86	0.86	0.97	0.92	0.67	0.58	0.00
Total	8.95	7.92	8.25	9.11	8.56	5.62	4.78	0.12
Dispensable AA, %								
Ala	0.88	0.78	0.81	0.88	0.82	0.59	0.55	0.02
Asp	2.23	2.00	2.14	2.33	2.15	0.97	0.86	0.02
Cys	0.26	0.24	0.23	0.25	0.25	0.30	0.25	0.01
Glu	3.43	3.07	3.28	3.54	3.30	2.05	1.89	0.03
Gly	0.83	0.74	0.77	0.83	0.79	0.67	0.58	0.01
Pro	1.02	0.91	0.95	1.03	0.99	0.81	0.72	0.09
Ser	0.86	0.82	0.90	0.97	0.87	0.54	0.47	0.01
Tyr	0.65	0.58	0.62	0.66	0.63	0.37	0.32	0.01
Total	10.16	9.14	9.70	10.49	9.80	6.30	5.64	0.20
Total AA	19.11	17.06	17.95	19.60	18.36	11.92	10.42	0.32

[1] ESBM-1 = HP 300; ESBM-2 = Vilosoy; SBM-EX = Alpha Soy Pig 530; SPC = SPC 60 Imcosoy; SBM-CV = conventional soybean meal; RSE = conventional 00-rapeseed expellers; FCM = EP 100; N-free = nitrogen-free diet.

Table 3.4. Apparent ileal digestibility (AID) of ash and organic matter (OM) in diets containing enzyme-treated soybean meal, extruded soybean meal, soy protein concentrate, conventional soybean meal, conventional 00-rapeseed expellers, a fermented co-product mixture containing fermented 00-rapeseed expellers, wheat, soy molasses, and potato peel, and N-free diet fed to pigs[1, 2]

Item	Ingredients								Pooled SEM	*P*-value
	ESBM-1	ESBM-2	SBM-EX	SPC	SBM-CV	RSE	FCM	N-free		
Ash, %	37.86^{bcd}	37.15^{bcd}	31.70^{cde}	40.55^{abc}	52.87^{a}	22.54^{e}	26.10^{de}	48.32^{ab}	3.65	<0.01
OM, %	84.41^{bc}	82.52^{c}	83.31^{bc}	85.36^{b}	84.21^{bc}	76.89^{d}	75.71^{d}	91.39^{a}	0.70	<0.01

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

[1] ESBM-1 = HP 300; ESBM-2 = Vilosoy; SBM-EX = Alpha Soy Pig 530; SPC = SPC 60 Imcosoy; SBM-CV = conventional soybean meal; RSE = conventional 00-rapeseed expellers; FCM = EP 100; N-free = nitrogen-free diet.

[2]Data are least square means of 15 observations for all treatments; AID = 1 – (Ash or OM in digesta/Ash or OM in feed) × (Cr in feed/Cr in digesta) × 100%.

Table 3.5. Apparent ileal digestibility (AID) of CP and AA in enzyme-treated soybean meal, extruded soybean meal, soy protein concentrate, conventional soybean meal, conventional 00-rapeseed expellers, and a fermented co-product mixture containing fermented 00-rapeseed expellers, wheat, soy molasses, and potato peel fed to pigs[1, 2]

Item	Ingredients							Pooled SEM	*P*-value
	ESBM-1	ESBM-2	SBM-EX	SPC	SBM-CV	RSE	FCM		
CP, %	81.94[a]	75.11[ab]	76.64[ab]	72.70[b]	78.89[ab]	64.95[c]	56.52[d]	2.27	<0.01
Indispensable AA, %									
Arg	91.55[a]	87.40[b]	89.43[ab]	87.21[b]	90.09[ab]	80.68[c]	70.13[d]	1.23	<0.01
His	89.40[a]	86.08[abc]	85.90[abc]	84.95[bc]	87.46[ab]	82.13[c]	72.73[d]	1.47	<0.01
Ile	88.65[a]	85.27[ab]	86.47[ab]	84.29[b]	86.52[ab]	75.81[c]	68.00[d]	1.31	<0.01
Leu	88.54[a]	85.67[ab]	86.37[ab]	84.52[b]	86.48[ab]	79.80[c]	72.55[d]	1.33	<0.01
Lys	84.47[ab]	79.07[bc]	83.17[ab]	83.65[ab]	86.18[a]	75.74[c]	58.37[d]	1.69	<0.01
Met	90.25[a]	87.56[abc]	87.66[abc]	86.11[bc]	89.44[ab]	85.14[c]	80.60[d]	1.08	<0.01
Phe	89.61[a]	86.64[ab]	87.71[ab]	85.94[b]	86.86[ab]	79.70[c]	73.69[d]	1.30	<0.01
Thr	80.71[a]	76.45[b]	78.27[ab]	79.57[ab]	80.51[ab]	69.66[c]	60.80[d]	1.46	<0.01
Trp	89.53[a]	85.80[bc]	87.20[ab]	85.89[bc]	88.60[ab]	83.33[c]	79.18[d]	1.29	<0.01
Val	85.30[a]	80.66[b]	81.00[b]	81.59[ab]	83.29[ab]	72.00[c]	63.43[d]	1.46	<0.01
Mean	87.48[a]	83.71[b]	85.68[ab]	84.42[ab]	86.30[ab]	77.64[c]	67.99[d]	1.19	<0.01
Dispensable AA, %									
Ala	81.07[a]	75.75[abc]	77.62[ab]	74.15[bc]	79.51[ab]	70.92[c]	62.09[d]	2.10	<0.01
Asp	85.28[a]	82.64[a]	81.91[a]	82.71[a]	84.50[a]	73.74[b]	61.48[c]	1.38	<0.01
Cys	74.79[ab]	69.15[bc]	70.98[ab]	71.45[ab]	77.07[a]	74.15[ab]	62.53[c]	2.86	<0.01

Table 3.5 (cont.)

Glu	87.55[a]	84.27[ab]	85.28[ab]	85.64[ab]	87.62[a]	83.34[b]	77.33[c]	1.64	<0.01
Gly	64.56[a]	52.53[a]	57.36[a]	52.41[a]	63.45[a]	53.17[a]	30.98[b]	4.19	<0.01
Pro	30.97[a]	-0.21[abc]	16.08[abc]	-13.81[c]	26.36[ab]	-5.09[bc]	-74.74[d]	14.67	<0.01
Ser	86.73[a]	83.61[a]	86.30[a]	86.28[a]	86.85[a]	73.19[b]	65.56[c]	1.12	<0.01
Tyr	89.16[a]	85.72[a]	87.25[a]	86.22[a]	87.16[a]	75.39[b]	70.09[c]	1.24	<0.01
Mean	78.13[a]	70.37[bc]	73.15[ab]	69.83[bc]	76.89[ab]	64.69[c]	46.46[d]	2.78	<0.01
Total AA	82.47[a]	76.79[ab]	78.67[ab]	76.12[bc]	81.31[ab]	70.60[c]	56.42[d]	1.98	<0.01

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

[1]ESBM-1 = HP 300; ESBM-2 = Vilosoy; SBM-EX = Alpha Soy Pig 530; SPC = SPC 60 Imcosoy; SBM-CV = conventional soybean meal; RSE = conventional 00-rapeseed expellers; FCM = EP 100.

[2]Data are least square means of 15 observations for all treatments; AID = 1 – (CP or AA in digesta/CP or AA in feed) × (Cr in feed/Cr in digesta) × 100%.

Table 3.6. Standardized ileal digestibility (SID) of CP and AA in enzyme-treated soybean meal, extruded soybean meal, soy protein concentrate, conventional soybean meal, conventional 00-rapeseed expellers, and a fermented co-product mixture containing fermented 00-rapeseed expellers, wheat, soy molasses, and potato peel fed to pigs[1,2,3]

Item	Ingredient							Pooled SEM	*P*-value
	ESBM-1	ESBM-2	SBM-EX	SPC	SBM-CV	RSE	FCM		
CP, %	89.92[a]	85.20[abc]	86.19[ab]	82.19[bc]	87.99[ab]	79.50[c]	70.60[d]	2.27	<0.01
Indispensable AA, %									
Arg	96.88[a]	93.48[abc]	95.03[ab]	92.26[bc]	95.44[ab]	90.12[c]	81.06[d]	1.23	<0.01
His	93.41[a]	90.64[ab]	90.27[ab]	88.88[b]	91.51[ab]	87.93[b]	79.56[c]	1.47	<0.01
Ile	91.71[a]	88.90[ab]	89.90[ab]	87.34[b]	89.71[ab]	81.29[c]	74.35[d]	1.31	<0.01
Leu	91.65[a]	89.22[ab]	89.64[ab]	87.50[bc]	89.65[ab]	84.94[c]	78.36[d]	1.32	<0.01
Lys	87.34[ab]	82.51[bc]	86.39[ab]	86.52[ab]	89.15[a]	80.19[c]	64.17[d]	1.69	<0.01
Met	92.92[a]	90.47[abc]	90.63[abc]	88.82[bc]	92.06[ab]	87.77[c]	83.71[d]	1.10	<0.01
Phe	92.60[a]	90.07[ab]	90.80[ab]	88.78[b]	89.91[ab]	85.29[c]	79.93[d]	1.30	<0.01
Thr	87.51[a]	83.93[a]	85.28[a]	85.97[a]	87.25[a]	78.05[b]	70.55[c]	1.47	<0.01
Trp	93.33[a]	89.95[ab]	91.09[ab]	89.99[ab]	92.30[ab]	89.00[b]	85.29[c]	1.29	<0.01
Val	89.95[a]	86.18[a]	86.42[a]	86.40[a]	88.22[a]	78.85[b]	71.36[c]	1.46	<0.01
Mean	91.42[a]	88.25[a]	89.93[a]	88.28[a]	90.32[a]	83.84[b]	75.23[c]	1.19	<0.01
Dispensable AA, %									
Ala	88.25[a]	83.92[ab]	85.40[ab]	81.30[b]	86.95[ab]	81.53[b]	73.22[c]	2.10	<0.01
Asp	88.53[a]	86.32[a]	85.28[a]	85.81[a]	87.77[a]	81.10[b]	69.72[c]	1.38	<0.01
Cys	82.26[ab]	77.30[b]	79.33[ab]	79.03[ab]	84.64[a]	80.54[ab]	70.20[c]	2.88	<0.01

Table 3.6 (cont.)

Glu	90.05[a]	87.12[a]	87.89[a]	88.06[a]	90.15[a]	87.49[a]	81.78[b]	1.64	<0.01
Gly	86.59[a]	77.67[a]	81.07[a]	74.47[ab]	86.22[a]	80.22[a]	61.92[b]	4.19	<0.01
Pro	101.18[a]	80.32[ab]	91.56[a]	55.39[b]	97.21[a]	83.05[ab]	22.47[c]	14.67	<0.01
Ser	91.97[a]	89.16[a]	91.25[a]	90.41[a]	91.82[a]	81.41[b]	74.83[c]	1.14	<0.01
Tyr	92.43[a]	89.52[a]	90.85[a]	90.39[a]	90.61[a]	81.15[b]	76.67[c]	1.15	<0.01
Mean	90.04[a]	83.82[ab]	85.59[ab]	81.31[b]	88.91[ab]	83.69[ab]	67.41[c]	2.78	<0.01
Total AA	90.64[a]	86.11[abc]	87.34[abc]	84.05[bc]	89.60[ab]	83.56[c]	71.10[d]	2.06	<0.01

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

[1]ESBM-1 = HP 300; ESBM-2 = Vilosoy; SBM-EX = Alpha Soy Pig 530; SPC = SPC 60 Imcosoy; SBM-CV = conventional soybean meal; RSE = conventional 00-rapeseed expellers; FCM = EP 100.

[2]Data are least square means of 15 observations for all treatments.

[3]Standardized ileal digestibility values were calculated by correcting the values for apparent ileal digestibility for the basal ileal endogenous losses. Endogenous losses (g/kg of DMI) of CP and AA were as follows: CP, 18.92; Arg, 0.82; His, 0.22; Ile, 0.31; Leu, 0.52; Lys, 0.39; Met, 0.08; Phe, 0.32; Thr, 0.54; Trp, 0.12; Val, 0.50; Ala, 0.66; Asp, 0.78; Cys, 0.21; Glu, 0.92; Gly, 1.99; Pro, 7.33; Ser, 0.48; Tyr, 0.24.

CHAPTER 4: DIGESTIBILITY OF ENERGY AND CONCENTRATIONS OF DIGESTIBLE AND METABOLIZABLE ENERGY IN PROCESSED SOYBEAN AND RAPESEED PRODUCTS FED TO GROWING PIGS

ABSTRACT

An experiment was conducted to determine the digestibility of energy and the concentrations of DE and ME in 4 sources of processed soybean products, in conventional dehulled soybean meal (SBM-CV), in conventional 00-rapeseed expellers (RSE), and in a fermented co-product mixture (FCM) that contained rapeseed meal, wheat, soy molasses, and potato peel fed to weanling pigs. The 4 processed soybean products included 2 sources of enzyme-treated soybean meal (ESBM-1 and ESBM-2), extruded soybean meal (SBM-EX), and soy protein concentrate (SPC). Sixty four barrows (initial BW: 19.81 ± 0.90 kg) were placed in metabolism cages and were allotted into a randomized complete block design with 8 diets and 8 pigs per diet. A corn-based diet and 7 diets containing corn and each of the experimental ingredients were formulated. Feces and urine were collected for 5 d after a 5 d adaptation period. Results indicate that the ATTD of GE in corn was not different from SBM-CV, but was greater ($P < 0.05$) than in the other ingredients. The concentration of DE in ESBM-1, ESBM-2, SBM-EX, SPC, and SBM-CV was 4,272, 3,972, 4,432, 4,419, and 4,173 kcal/kg DM, respectively. The concentration of DE in RSE and FCM was 3,658 and 3,458 kcal/kg DM, respectively. The DE (DM basis) in corn (3,864 kcal/kg DM) was greater ($P < 0.05$) than in FCM, but less ($P < 0.05$) than in SBM-EX, SPC, ESBM-1, and SBM-CV. The DE (DM basis) in SBM-EX was greater ($P < 0.05$) than in SBM-CV, ESBM-2, RSE, and FCM, but not different from SPC and ESBM-1. The concentration of ME in ESBM-1,

ESBM-2, SBM-EX, SPC, and SBM-CV was 4,158, 3,782, 4,240, 4,226, and 4,044 kcal/kg DM, respectively. The concentration of ME in RSE and FCM was 3,522 and 3,364 kcal/kg DM, respectively. The ME (DM basis) of ESBM-2 was less ($P < 0.05$) than in all other soybean products, but greater ($P < 0.05$) than in RSE and FCM. The ME (DM basis) of corn (3,780 kcal/kg DM) was less ($P < 0.05$) than in all soybean products except ESBM-2, but greater ($P < 0.05$) than in the rapeseed products. There was no difference in DE and ME (DM basis) between RSE and FCM, but the DE and ME for both ingredients were less ($P < 0.05$) than in all soybean products. It is concluded that there are differences among processed soybean products with some having greater concentrations of DE and ME than others. However, the concentrations of DE and ME in all soybean products used in this experiment were greater than in rapeseed expellers and the fermented co-product mixture.

Key words: energy, enzyme-treated soybean meal, extruded soybean meal, fermented rapeseed expellers, pigs, soy protein concentrate

INTRODUCTION

Soybean meal (**SBM**) is widely used as a protein source in swine diets because of its availability and its desirable AA profile (Lallès, 2000). However, inclusion of SBM is limited in nursery diets due to the presence of antinutritional factors (**ANF**), which cause a transient hypersensitivity response and a reduction in growth performance in young pigs (Li et al., 1991). Processing of SBM may reduce or eliminate ANF allowing them to be included in nursery pig diets without negatively affecting growth performance (Cervantes-Pahm and Stein, 2010; Song et al., 2010; Rojas and Stein, 2013a). Fermentation, enzyme treatment, and extrusion are procedures that can possibly improve the digestibility of energy by eliminating oligosaccharides

that cannot be digested by young pigs, and may induce diarrhea (Woyengo et al., 2014). However, the bioavailability of nutrients in SBM may be compromised during processing (Song et al., 2010), resulting in differences in the digestibility of AA and energy among processed soybean products.

Traditionally, inclusion of rapeseed products in swine diets is limited due to the negative effects of glucosinolates on growth performance (Przybylski and Eskin, 2011), although most varieties of canola and 00-rapeseed meals that are currently grown are low in erucic acid and glucosinolates. The efficiency of solvent extraction results in a low DE content in solvent-extracted 00-rapeseed meal (Zijlstra and Beltranena, 2013). On the other hand, 00-rapeseed expellers are mechanically pressed to extract oil, which results in higher residual oil content in the meal compared with solvent-extracted 00-rapeseed meal (Newkirk, 2011). However, the digestibility of energy and other nutrients are reduced in 00-rapeseed meal and 00-rapeseed expellers due to relatively high concentrations of fiber (Landero et al., 2011). It is possible that fermentation can increase the digestibility of energy in 00-rapeseed products by reducing the concentration of ANF and eliminating oligosaccharides in the final product (Xu et al., 2012). Therefore, the objective of this experiment was to determine the apparent total tract digestibility (**ATTD**) of GE and the concentration of DE and ME in 4 sources of processed soybean products, in conventional dehulled SBM, in conventional 00-rapeseed expellers, and in a fermented co-product mixture (**FCM**).

MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois.

The pigs used were the offspring of G-Performer boars × Fertilis 25 females (Genetiporc, Alexandria, MN). The ingredients that were used in the experiment (Table 4.1) included 2 sources of enzyme-treated soybean meal (**ESBM-1;** HP 300, Hamlet Protein Inc., Horsens, Denmark) and (**ESBM-2;** Vilosoy, Dansk Vilomix, Mørke, Denmark), extruded soybean meal (**SBM-EX;** Alpha Soy Pig 530, Agro Korn, Videbæk, Denmark), soy protein concentrate (**SPC;** Imcosoy, Imcopa, Paraná, Brazil), conventional de-hulled soybean meal (**SBM-CV**), conventional 00-rapeseed expellers (**RSE;** The Protein and Oilfabric Scanola Inc., Aarhus, Denmark) and FCM containing fermented 00-rapeseed meal, wheat, soy molasses, and potato peel (EP 100, European Protein, Bække, Denmark). The SBM-CV used in this experiment was from a commercial source provided by the Danish Pig Research Centre.

Diets, Animals, and Experimental Design

Sixty four barrows (initial BW: 19.81 ± 0.90 kg) were placed individually in metabolism cages equipped with a feeder and a nipple waterer and were allotted to a randomized complete block design with 8 diets and 8 pigs per diet. The BW of each pig was used as the blocking factor.

A corn-based diet and 7 diets containing corn and each of the experimental ingredients were formulated (Table 4.2). Four sources of processed soy products (i.e., ESBM-1, ESBM-2, SBM-EX, and SPC), SBM-CV, RSE, and FCM were used. On an as-fed basis, the basal diet contained 96.65% corn, the ESBM-1 diet contained 76.00% corn and 21.00% ESBM-1, the ESBM-2 diet contained 73.75% corn and 23.25% ESBM-2, the SBM-EX diet contained 74.25% corn and 22.75% SBM-EX, the SPC diet contained 78.00% corn and 19.00% SPC, the SBM-CV diet contained 71.25% corn and 25.75% SBM-CV, the RSE diet contained 62.55% corn and 35.00% RSE, and the FCM diet contained 62.40% corn and 35.00% FCM. Vitamins and

minerals were included in the diets to meet or exceed current requirement estimates (NRC, 2012). Corn and the test ingredients were the only sources of energy in the diets. The inclusion rate of the test ingredients in their respective diets were at levels that were expected to result in isonitrogenous diets.

Feeding and Sample Collection

All pigs were fed at a daily level of 2.5 times the estimated maintenance energy requirement (i.e., 197 kcal ME per $kg^{0.75}$; NRC, 2012) and were divided into 2 equal meals that were provided at 0800 and 1700h. Pig had access to water at all times.

Pigs were fed the experimental diets for 12 d including a 5 d adaptation period and 5 d for fecal sampling. Nondigestible fecal markers were included in the morning meal on d 6 (chromic oxide) and on d 11 (ferric oxide) to mark the beginning and the end of fecal collections, respectively (Adeola, 2001). Feces were collected twice daily and were stored at –20ºC immediately after collection. Urine collections were initiated on d 6 at 0800 h and ceased on d 11 at 0800 h. Urine buckets were placed under the metabolism cages to permit total collection and were emptied in the morning. A preservative of 50mL of 3N HCL was added to each bucket when they were emptied. The collected urine was weighed and a 10% subsample was stored at –20ºC.

Chemical Analysis

At the conclusion of the experiment, fecal samples were dried at 65ºC in a forced-air oven and ground before analyses. Urine samples were thawed and mixed within animal and diet, and a subsample was collected and lyophilized before analyzing for GE as previously described (Kim et al., 2009). All samples were analyzed in duplicates. Diets and ingredients were analyzed for DM by oven drying at 135°C for 2 h (Method 930.15; AOAC Int., 2007), ash (Method

975.03; AOAC Int., 2007) and CP by combustion (Method 999.03; AOAC Int., 2007). Diets, ingredients, fecal samples, and urine samples were analyzed for GE by adiabatic bomb calorimetry (Model 6300; Parr Instruments, Moline, IL). Ingredient samples were also analyzed for ADF (Method 973.18; AOAC Int., 2007), and NDF (Holst, 1973). Ingredient samples were also analyzed for trypsin inhibitor activity (Method Ba 12-75; AOCS, 2006), for sucrose, stachyose, and raffinose (Janauer and Englmaier, 1978), and rapeseed samples for glucosinolates (Method Ak 1-92; AOCS, 1998).

Calculations and Statistical Analysis

The DE and ME for each diet were calculated by subtracting the GE excreted in the feces and in the urine from the intake of GE (Adeola, 2001). The DE and ME in the corn diet were divided by the inclusion rate of corn to calculate the DE and ME in corn. The contributions of DE and ME from corn to the diets containing ESBM-1, ESBM-2, SBM-EX, SPC, SBM-CV, RSE, and FCM were calculated and subtracted from the total DE and ME of these diets, and the concentrations of DE and ME in the ingredients were calculated by difference (Adeola, 2001). The DE and ME in all ingredients were calculated on both an as-fed and a DM basis. The ATTD of GE was calculated for each ingredient and for all diets (Adeola, 2001).

Data were analyzed by ANOVA using the Proc 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 identify outliers, but no outliers were observed. The fixed effect was the diet and replicate was the random effect. 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 α level of 0.05 was used to assess significance among means.

RESULTS

Chemical Characteristics of Ingredients

The GE concentration was 3,837 kcal/kg (as-fed basis) in corn and 4,555, 4,380, 4,454, 4,499, 4,140, 4,533, and 4,154 kcal/kg in ESBM-1, ESBM-2, SBM-EX, SPC, SBM-CV, RSE, and FCM, respectively (Table 4.1). The analyzed concentration of CP in ESBM-1, ESBM-2, SBM-EX, SPC, and SBM-CV were 56.82, 52.07, 53.28, 62.05, and 47.81%, respectively. The analyzed concentration of CP in the rapeseed products were 30.13 and 32.00% for RSE and FCM, respectively. The ash content in corn was 1.24% and ranged from 5.97 to 6.85% in the test ingredients. The concentration of trypsin inhibitors in the soybean products ranged from 1.60 to 2.70 TIU^3/mg and was 1.40 and <1.00 TIU^3/mg for RSE and FCM, respectively. The glucosinolate concentration in the rapeseed products were 16.11 and 2.77 μmol/g for RSE and FCM, respectively.

Energy Digestibility

Pigs fed the corn diet had less ($P < 0.05$) gross energy intake compared with pigs fed the ESBM-1, ESBM-2, FSBM, RSE, or FCM diets, but did not differ from pigs fed the SBM-CV diet (Table 4.3). The fecal excretion of GE was less ($P < 0.05$) from pigs fed diets with soybean products than from pigs fed diets with rapeseed products, but was not different between pigs fed the RSE and the FCM diets. Pigs fed the ESBM-2 diet had greater ($P < 0.05$) fecal excretion of GE than pigs fed the corn and SBM-CV diet, but not different from the fecal excretion of GE from pigs fed the ESBM-1, SBM-EX, or SPC diets. The urine excretion of GE was less ($P < 0.05$) for pigs fed the corn diet than for pigs fed diets containing ESBM-2, SBM-CV, RSE, or FCM, but not different from pigs fed diets containing ESBM-1, SBM-EX, or SPC. The ATTD of

GE was greater ($P < 0.05$) in the SBM-CV diet than in ESBM-1, ESBM-2, SBM-EX, SPC, RSE, and FCM diets, but not different from the corn diet. The ATTD of GE was not different between the diets containing rapeseed products, but the ATTD of GE in these diets was less ($P < 0.05$) than in all diets containing soybean products. The concentration of DE in the SBM-EX diet was greater ($P < 0.05$) than in the corn, ESBM-2, SBM-CV, RSE, and FCM diets, but not different from the ESBM-1 and SPC diets. The DE in the ESBM-2 diet was also greater ($P < 0.05$) than in diets containing corn, RSE, or FCM. The DE of the corn diet was less ($P < 0.05$) than the DE of all the diets containing soybean products, but not different from the ME of the RSE and FCM diets.

The ATTD of GE was greater ($P < 0.05$) in SBM-CV than in all other ingredients except corn, and the ATTD of GE among the processed soybean products was not different, but greater ($P < 0.05$) than in the rapeseed products. The DE and ME (as-fed basis) in ESBM-1, SBM-EX, and SPC were greater ($P < 0.05$) than in corn, ESBM-2, SBM-CV, RSE, and FCM. The DE (DM basis) in corn was less ($P < 0.05$) than in all soybean products, but greater ($P < 0.05$) than in FCM. The DE (DM basis) in SBM-EX was greater ($P < 0.05$) than in ESBM-2, RSE, and FCM, but not different from SPC, ESBM-1, and SBM-CV. The DE (DM basis) in ESBM-2 was also less ($P < 0.05$) than in ESBM-1, SBM-EX, and SPC, but not different from SBM-CV. The ME (DM basis) of ESBM-2 was less ($P < 0.05$) than in all other soybean products, but greater ($P < 0.05$) than in RSE and FCM. The ME (DM basis) of corn was less ($P < 0.05$) than in all soybean products except ESBM-2, but greater ($P < 0.05$) than in the rapeseed products. There was no difference in DE and ME (DM basis) between RSE and FCM, but the DE and ME for both ingredients were less ($P < 0.05$) than in all soybean products.

DISCUSSION

The values for GE, DE, ME, and ATTD of GE in corn that were determined in this experiment are in close agreement with values that were previously reported (Zhang et al., 2013; Rojas and Stein, 2013a), but were slightly less than the values reported by Pedersen et al. (2007), Rojas and Stein (2013b) and the NRC (2012). The values for GE, DE, ME and ATTD of GE determined for SBM-CV were in agreement with data from Goebel and Stein (2011), but slightly greater than the values reported by Baker and Stein (2009).

The value for DE in ESBM-1 was in close agreement with values reported by Goebel and Stein (2011), but the value for ME was greater in ESBM-1 than the values reported by Goebel and Stein (2011). The concentration of DE and ME in ESBM-1 is not different from SBM-CV because the removal of sucrose and oligosaccharides by enzyme treatment does not affect DE and ME (Goebel and Stein, 2011).

To our knowledge, no values for DE and ME in ESBM-2 have previously been reported. The value for DE was lower but the concentration of GE and ME were similar to the values reported by Rojas and Stein (2013a) for FSBM. The concentration of DE in ESBM-2 was not different from SBM-CV, but ME in ESBM-2 was less than in SBM-CV, indicating that the enzyme treatment or the process used to produce ESBM-2 was different and less effective compared with the process used to produce ESBM-1. The concentrations of sucrose, stachyose, and raffinose in ESBM-2 were greater than the values reported for FSBM by Rojas and Stein (2013a), indicating that the process used to produce ESBM-2 was not completely efficient in removing oligosaccharides. The lower DE and ME values in ESBM-2 may be attributed to its higher concentrations of oligosaccharides compared with ESBM-1.

We are not aware of any previous data for DE and ME in SBM-EX but the values were higher than previously reported for FSBM (Rojas and Stein, 2013a). The current data from this experiment indicate that the extrusion process used to produce SBM-EX did not change the DE and ME on a DM basis, but increased the DE and ME on an as-fed basis compared with SBM-CV because of the increased concentration of DM in SBM-EX. The concentrations of DE and ME in SBM-EX were close to those determined in ESBM-1, but unlike the treatment of SBM using a propriety blend of enzymes to produce ESBM-1 (Cervantes-Pahm and Stein, 2010), SBM-EX is produced by extrusion of dehulled soybean meal with a subsequent enzyme treatment.

Values for DE and ME in SPC observed in this experiment for SPC concur with previously reported data for soy protein concentrate by Zhang et al. (2013). Concentrations of ADF and NDF in SPC are usually less than in SBM-CV (Cervantes-Pahm and Stein, 2008; Urbaityte et al., 2009; NRC, 2012), but values of ADF and NDF in SPC for this experiment were twice as high as in SBM-CV. The greater concentration of DE and ME in SPC compared with SBM-CV indicates that the process used to produce SPC may have increased the digestibility of fiber in SPC.

The values for DE and ME in RSE are lower than in all soybean products and lower than the values previously reported (Woyengo et al., 2010; NRC, 2012), possibly due to a combination of a higher fiber concentration and lower fat content in the expellers used in this experiment. The reason for this observation most likely is that the process used to produce the RSE used in this experiment is more efficient in extracting oil from the seed than the process used in previous experiments. Increased concentration of fiber in the diet reduces energy digestibility (Urriola et al., 2013). The concentration of AEE in RSE was significantly higher

than in all the soybean products, but the lower concentration of DE and ME indicates that the higher fiber content reduced the digestibility of energy in RSE. It is not common to dehull rapeseed prior to expeller processing, resulting in a meal that has a high concentration of fiber (Newkirk, 2011).

There are no values for DE and ME in FCM that have previously been reported, but the values determined in this experiment were less than in all the soybean products. The values for DE and ME determined for FCM indicate that the combination of fermented 00-rapeseed meal, wheat bran, soy molasses, and potato peel did not increase the energy value of the final product. If FCM is included in diets fed to weanling pigs, the energy concentration will, therefore, be reduced.

CONCLUSIONS

There are differences among processed soybean products with some having greater concentrations of DE and ME than others. Extrusion and enzyme treatment of SBM may increase the energy digestibility of the final product, and the concentrations of DE and ME in all soybean products are greater than in RSE and FCM. The lower energy digestibility in RSE and FCM can be attributed to the higher fiber content in these ingredients compared with the soybean products.

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TABLES

Table 4.1. Analyzed nutrient composition of corn, enzyme-treated soybean meal, extruded soybean meal, soy protein concentrate, conventional soybean meal, conventional 00-rapeseed expellers, and a fermented co-product mixture containing fermented 00-rapeseed expellers, wheat, soy molasses, and potato peel (as-fed basis)

	Ingredient[1]							
Item	Corn	ESBM-1	ESBM-2	SBM-EX	SPC	SBM-CV	RSE	FCM
GE, kcal/kg	3,837	4,555	4,380	4,454	4,499	4,140	4,533	4,154
DM, %	85.85	91.98	91.17	92.85	91.71	88.67	88.58	87.09
CP, %	6.92	56.82	52.07	53.28	62.05	47.81	30.13	32.00
Ca, %	-	0.31	0.33	0.29	0.32	0.30	0.78	0.66
P, %	-	0.70	0.73	0.64	0.63	0.60	0.96	0.91
Ash, %	1.03	6.47	6.85	6.36	5.97	6.09	6.52	6.85
OM, %	-	85.51	84.32	86.49	85.74	82.58	82.06	80.24
AEE[2], %	-	1.81	0.70	1.82	1.01	1.23	10.22	4.31
NDF, %	-	9.16	9.48	12.73	19.69	7.76	24.54	22.88
ADF, %	-	4.85	4.99	5.09	10.26	5.13	18.93	14.81
Trypsin inhibitor activity, TIU[3]/mg	-	2.00	1.60	2.50	1.60	2.70	1.40	<1.00

Table 4.1 (cont.)

Glucosinolates, μmol/g	-	-	-	-	-	-	16.11	2.77
Carbohydrates, %								
Sucrose	-	0.06	4.35	0.89	0.97	4.99	5.45	1.51
Stachyose	-	0.06	1.58	0.71	1.23	1.64	0.62	0.38
Raffinose	-	0.03	0.67	0.20	0.28	0.50	0.23	0.17

[1] ESBM-1 = HP 300; ESBM-2 = Vilosoy; SBM-EX = Alpha Soy Pig 530; SPC = SPC 60 Imcosoy; SBM-CV = conventional soybean meal; RSE = conventional 00-rapeseed expellers; FCM = EP 100.

[2]AEE = Acid hydrolyzed ether extract.

[3]TIU = Trypsin inhibitor units.

Table 4.2. Composition of experimental diets containing corn, enzyme-treated soybean meal, extruded soybean meal, soy protein concentrate, conventional soybean meal, conventional 00-rapeseed expellers, and a fermented co-product mixture containing fermented 00-rapeseed expellers, wheat, soy molasses, and potato peel (as-fed basis)

	Diet[1]							
Item	Corn	ESBM-1	ESBM-2	SBM-EX	SPC	SBM-CV	RSE	FCM
Ingredients, %								
Corn	96.65	76.00	73.75	74.25	78.00	71.25	62.55	62.40
HP 300	-	21.00	-	-	-	-	-	-
Vilosoy	-	-	23.25	-	-	-	-	-
Alpha Soy Pig 530	-	-	-	22.75	-	-	-	-
SPC 60 Imcosoy	-	-	-	-	19.00	-	-	-
Soybean meal, 47.5% CP	-	-	-	-	-	25.75	-	-
00-rapeseed expellers	-	-	-	-	-	-	35.00	-
EP 100	-	-	-	-	-	-	-	35.00
Limestone	1.25	1.20	1.20	1.20	1.20	1.20	0.65	0.80
Monocalcium phosphate	1.40	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Table 4.2 (cont.)

Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed Composition								
GE, kcal/kg	3,635	3,829	3,803	3,865	3,824	3,731	3,959	3,868
DM, %	86.74	87.98	87.84	88.18	87.89	86.95	87.29	86.86
CP, %	6.52	17.09	17.85	17.35	16.91	17.94	14.81	15.08
Ash, %	3.76	4.52	4.84	4.26	4.07	4.49	4.74	5.40

[1] ESBM-1 = HP 300; ESBM-2 = Vilosoy; SBM-EX = Alpha Soy Pig 530; SPC = SPC 60 Imcosoy; SBM-CV = conventional soybean meal; RSE = conventional 00-rapeseed expellers; FCM = EP 100; Corn = corn basal diet.

[2] The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 4.3. Concentration of digestible and metabolizable energy and apparent total tract digestibility (ATTD) of GE in corn, enzyme-treated soybean meal, extruded soybean meal, soy protein concentrate, conventional soybean meal, conventional 00-rapeseed expellers, and a fermented co-product mixture containing fermented 00-rapeseed expellers, wheat, soy molasses, and potato peel, as-fed basis[1]

	Diet									
Item	Corn	ESBM-1	ESBM-2	SBM-EX	SPC	SBM-CV	RSE	FCM	SEM	*P*-value
Diets										
GE intake, kcal/d	3,179^{b}	3,369^{a}	3,331^{a}	3,417^{a}	3,399^{a}	3,303^{ab}	3,376^{a}	3,321^{a}	45.3	<0.01
GE in feces, kcal/d	374.5^{cd}	412.5^{bc}	424.5^{b}	411.4^{bc}	408.8^{bc}	351.1^{d}	604.4^{a}	599.5^{a}	20.4	<0.01
GE in urine, kcal/d	60.8^{b}	80.7^{ab}	109.4^{a}	82.6^{ab}	86.0^{ab}	97.0^{a}	108.9^{a}	102.7^{a}	14.8	0.12
ATTD of GE, %	88.2^{ab}	87.8^{b}	87.3^{b}	87.9^{b}	88.0^{b}	89.4^{a}	82.1^{c}	82.0^{c}	0.6	<0.01
DE, kcal/kg	3,206^{cd}	3,361^{ab}	3,320^{b}	3,399^{a}	3,364^{ab}	3,335^{b}	3,251^{c}	3,170^{d}	22.4	<0.01
ME, kcal/kg	3,136^{de}	3,270^{ab}	3,195^{cd}	3,305^{a}	3,268^{ab}	3,225^{bc}	3,122^{e}	3,050^{f}	33.3	<0.01
Ingredients										
ATTD of GE, %	88.2^{ab}	86.9^{b}	85.1^{b}	87.2^{b}	87.2^{b}	92.4^{a}	72.6^{c}	71.7^{c}	1.9	<0.01
DE, kcal/kg	3,317^{cd}	4,000^{a}	3,757^{b}	4,115^{a}	4,090^{a}	3,772^{b}	3,360^{c}	3,144^{d}	82.4	<0.01
DE, kcal/kg of DM	3,864^{c}	4,349^{a}	4,121^{b}	4,432^{a}	4,460^{a}	4,303^{ab}	3,793^{cd}	3,610^{d}	90.9	<0.01
ME, kcal/kg	3,245^{cd}	3,825^{a}	3,448^{bc}	3,937^{a}	3,876^{a}	3,545^{b}	3,120^{de}	2,930^{e}	122.0	<0.01
ME, kcal/kg of DM	3,780^{b}	4,158^{a}	3,782^{b}	4,240^{a}	4,226^{a}	4,044^{a}	3,522^{c}	3,364^{c}	135.3	<0.01

Table 4.3 (cont.)

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

CHAPTER 5: CONCLUSIONS

Results of this research indicate that although processing of soybean meal (**SBM**) results in increased concentration of CP, processing may also reduce the digestibility of AA, which is likely due to heat damage during processing. There are, however, differences among processed soy products with some products having greater apparent ileal digestibility (**AID**) and standardized ileal digestibility (**SID**) of AA than others. Results also indicate that fermentation of a mixture of rapeseed meal, wheat, and relatively low quality co-products does not result in AID and SID values that are similar to those of unfermented 00-rapeseed expellers or soybean products.

There are differences among processed soybean products with some having greater concentrations of digestible (**DE**) and metabolizable energy (**ME**) than others. Extrusion and enzyme treatment of SBM may increase the energy digestibility of the final product, and the concentrations of DE and ME in all soybean products used in this experiment are greater than in conventional 00-rapeseed expellers (**RSE**) and the fermented co-product mixture (**FCM**). The lower energy digestibility in RSE and FCM can be attributed to the higher fiber content in these ingredients compared with the soybean products.

Rising prices of feed ingredients call for alternative sources of protein and energy in swine diets. It is important to determine the digestibility of AA and concentration of energy among soybean and rapeseed meals coming from different sources because of the variability in nutrient composition of the final product. Cost of feed comprises the majority of the costs of a swine production system, thus, an accurate determination of nutrient availability in feed ingredients and subsequent feed formulation will result in an economical and viable enterprise.