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Concentration of digestible, metabolizable, and net energy and digestibility of energy and nutrients in fermented soybean meal, conventional soybean meal, and fish meal fed to weanling pigs

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Concentration of digestible, metabolizable, and net energy and digestibility of energy and nutrients in fermented soybean meal, conventional soybean meal, and fish meal fed to weanling pigs[1]

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ABSTRACT: Two experiments were conducted to determine the digestibility of energy and nutrients and the concentration of DE, ME, and NE in fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), and fish meal fed to weanling pigs. In Exp. 1, 36 barrows (initial BW: 22.0 ± 3.85 kg) were placed in metabolism cages and allotted to a randomized complete block design with 4 diets and 9 pigs per diet. Feces and urine were collected for 5 d after a 5 d adaptation period. Four diets including a corn-based diet and 3 diets consisting of corn and each of the experimental ingredients (FSBM, SBM-CV, and fish meal) were formulated. Results indicated that the apparent total tract digestibility (ATTD) of GE in corn, FSBM, and SBM-CV was 88.6, 88.2, and 90.3%, respectively, but the ATTD of GE in fish meal (84.0%) was less ($P <$ 0.01) than in the other ingredients. The concentrations of DE, ME, and NE in SBM-CV were 4,553, 4,137, and 2,972 kcal/kg DM. These values were greater ($P <$ 0.01) than the DE, ME, and NE in FSBM (4,296, 3,781, and 2,710 kcal/kg DM), corn (3,951, 3,819, and 2,791 kcal/kg DM), and fish meal (3,827, 3,412, and 2,450 kcal/kg DM). However, FSBM contained more ($P <$ 0.01) DE, ME, and NE than fish meal and more ($P <$ 0.01) DE than corn. The biological value of the protein in fish meal (75.4%) was greater ($P < 0.05$) than in corn (34.8%) and FSBM (62.8%), and the biological value of protein in SBM-CV (67.1%) was greater (P < 0.05) than in corn but not different from FSBM and fish meal. In Exp. 2, 8 barrows (initial BW: 10.4 ± 0.47 kg) were equipped with a T-cannula in the distal ileum and randomly allotted to a replicated 4 × 4 Latin square design with 4 diets and 4 periods per square. Three diets containing FSBM, SBM-CV, or fish meal as the sole source of AA and a N-free diet were formulated. The standardized ileal digestibility (SID) of all indispensable AA except Lys, Thr, and Trp was greater ($P < 0.01$) in FSBM than in fish meal. The SID of Met and Val was also greater ($P < 0.05$) in FSBM than in SBM-CV, but for the remaining indispensable AA, no difference between FSBM and SBM-CV was observed. In conclusion, the concentration of DE, ME, and NE is less in FSBM than in SBM-CV. However, DE, ME, and NE are greater in FSBM than in fish meal, but the SID of most AA is not different between FSBM and SBM-CV although they are greater than in fish meal.

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

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INTRODUCTION

Protein from conventional soybean meal (**SBM-CV**) contains antinutritional factors such as antigens, oligosaccharides, lectins, and trypsin inhibitors that may decrease nutrient availability and reduce growth performance of young pigs (Li et al., 1991; Hong et al., 2004). Therefore, inclusion of SBM-CV is restricted in diets fed to weanling pigs (Dunsford et al., 1989). Animal protein such as fish meal is often used in these diets (Kim and Easter, 2001) although animal protein is more expensive than soy protein. However, many of the antinutritional factors in SBM-CV may be eliminated if SBM-CV is fermented (Kaankuka et al., 1996; Hong et al., 2004; Cervantes-Pahm and Stein, 2010) and fermented soybean meal (**FSBM**) is better tolerated by

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young pigs than SBM-CV (Liu et al., 2007; Yang et al., 2007). Therefore, it is believed that FSBM may replace fish meal in diets fed to weanling pigs without reducing growth performance (Jones et al., 2010; Kim et al., 2010), and FSBM may have a positive effect on intestinal health and gut morphology of weaned pigs compared with SBM-CV (Kim et al., 2007). An increase in the apparent ileal digestibility (**AID**) of DM and most AA may also be observed in FSBM compared with SBM-CV (Min et al., 2004) although that is not always the case (Cervantes-Pahm and Stein, 2010).

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

MATERIALS AND METHODS

Two experiments were conducted, and the Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for both experiments.

Pigs used in the experiments were the offspring of G-performer boars mated to F-25 gilts (Genetiporc, Alexandria, MN). The ingredients that were used in the experiments included FSBM, SBM-CV, and fish meal (Table 1) and the same batches of these ingredients were used in both experiments. The source of FSBM that was used was PepSoyGen (Nutra Ferma, North Sioux City, SD), which is produced by fermentation of SBM in the presence of *Aspergillus oryzae* and *Bacillus subtilis*. The SBM-CV was sourced from Rose Acre Farms (Seymour, IN) and produced by cracking and dehulling fullfat soybeans that were subsequently defatted using a solvent, desolventized, toasted, and ground. The fish meal that was used in the experiment was prepared from menhaden fish (Menhaden Select; Omega Protein, Houston, TX).

Table 1. Analyzed nutrient composition of fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), fish meal, and corn, as-fed basis

	Ingredient			
Item	FSBM	SBM-CV	Fish meal	Corn
GE, kcal/kg	4,533	4,281	4,589	3,938
DM, %	91.0	89.39	91.80	87.04
CP, %	53.91	50.20	63.98	7.44
Ca, %	0.27	0.23	4.96	0.01
P, %	0.83	0.69	3.05	0.24
Ash, %	7.10	5.85	17.86	1.20
AEE,[1] %	1.50	1.39	9.33	2.20
NDF, %	8.45	5.40	–	6.56
ADF, %	4.97	3.42	–	1.76
TIU[2]/mg/kg	<1.00	4.20	–	–
Starch, %	0.90	0.61	–	55.77
Carbohydrates, %				
Glucose	0.33	0.00	–	–
Sucrose	0.00	8.77	–	–
Maltose	0.00	0.20	–	–
Fructose	0.54	0.00	–	–
Stachyose	0.06	6.23	–	–
Raffinose	0.00	1.29	–	–
Indispensable, AA %				
Arg	3.59	3.61	3.58	0.33
His	1.34	1.33	1.41	0.19
Ile	2.45	2.35	2.54	0.24
Leu	4.11	3.79	4.17	0.75
Lys	3.15	3.17	4.76	0.24
Met	0.73	0.69	1.66	0.14
Phe	2.64	2.46	2.35	0.31
Thr	2.00	1.85	2.34	0.23
Trp	0.71	0.66	0.59	0.05
Val	2.60	2.50	3.03	0.33
Dispensable, AA %				
Ala	2.26	2.12	3.71	0.46
Asp	5.82	5.37	5.32	0.44
Cys	0.82	0.66	0.49	0.15
Glu	9.31	8.69	7.72	1.14
Gly	2.24	2.06	4.13	0.28
Pro	2.87	2.41	2.91	0.56
Ser	2.33	2.12	2.03	0.27
Tyr	1.89	1.71	1.82	0.20
Total AA	50.86	47.55	54.56	6.31

[1]AEE = acid hydrolyzed ether extract.

[2]TIU = trypsin inhibitor units.

Experiment 1: Energy Concentration and Total Tract Digestibility

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

Four corn-based diets were formulated (Table 2). The basal diet contained 96.4% corn (as-fed basis), the FSBM diet contained 69.3% corn and 28.0% FSBM (as-fed basis), the SBM-CV diet contained 65.2% corn and 31.0% SBM-CV (as-fed basis), and the fish meal diet contained 75.3% corn and 24.0% fish meal (as-fed basis). Vitamins

Table 2. Composition of experimental diets containing corn, fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), or fish meal, as-fed basis, Exp. 1

Item	Diet			
	Corn	FSBM	SBM-CV	Fish meal
Ingredients, %				
Ground corn	96.40	69.30	65.20	75.30
FSBM	–	28.00	–	–
SBM-CV	–	–	31.00	–
Fish meal	–	–	–	24.00
Monocalcium phosphate	1.70	–	2.00	–
Ground limestone	1.20	2.00	1.10	–
Sodium chloride	0.40	0.40	0.40	0.40
Vitamin mineral premix[1]	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Analyzed composition				
GE, kcal/kg	3,740	3,932	3,931	3,926
DM, %	86.86	89.80	88.30	88.53
CP, %	6.87	20.49	20.30	21.30
ADF, %	1.86	3.02	2.67	2.04
NDF, %	9.92	11.49	9.92	15.59
AEE,[2] %	1.16	2.55	2.17	2.58
Ash, %	3.44	5.06	7.03	6.09
Starch, %	56.11	40.97	39.75	46.06

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

[2]AEE = acid hydrolyzed ether extract.

and minerals were included in the diets to meet or exceed the requirements for weanling pigs (NRC, 1998).

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

Pigs were fed experimental diets for 12 d including 5 d for adaptation and 5 d for fecal sampling. Fecal markers (10 g/kg) were included in the morning meal on d 6 (chromic oxide) and in the morning meal on d 11 (ferric oxide), to mark the beginning and the end, respectively, of fecal collections (Adeola, 2001). Feces were collected quantitatively twice daily and stored at –20°C immediately after collection. Urine collections were initiated on d 6 at 1700 h and ceased on d 11 at 1700 h. Urine buckets were placed under the metabolism cages to permit total collection. They were emptied in the morning and afternoon and a preservative of 50 mL of sulfuric acid was added to each bucket when they were emptied. The collected urine was weighed and a 10% subsample was stored at –20°C.

Chemical Analyses. After completing sample collections, urine samples were thawed and mixed, and a subsample was collected for chemical analysis. Fecal samples were dried at 65°C in a forced-air oven and ground through a 1-mm screen in a Wiley mill (model 4; Thomas Scientific, Swedesboro, NJ) before analyses. Urine samples were prepared and lyophilized before GE analysis as previously described (Kim et al., 2009). All samples were analyzed in duplicate with the exception that GE was analyzed in urine in triplicate samples. Diets, ingredients, and fecal samples were analyzed for DM (Method 930.15; AOAC Int., 2007), ash (Method 975.03; AOAC Int., 2007), and acid hydrolyzed ether extraction (**AEE**), which was determined by acid hydrolysis using 3 *N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (Method 2003.06; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Diets, ingredients, fecal samples, and urine samples were also analyzed for CP by combustion (Method 999.03; AOAC Int., 2007) using a Rapid N cube apparatus (Elementar Americas Inc., Mt. Laurel, NJ) and for GE using bomb calorimetry (Model 6300; Parr Instruments, Moline, IL). Ingredients were analyzed for AA [Method 982.30 E (a, b, c); AOAC Int., 2007], and diets and ingredients were analyzed for ADF (Method 973.18; AOAC Int., 2007), NDF (Holst, 1973), and for total starch using the glucoamylase procedure (Method 979.10; AOAC Int., 2007). Phosphorus and Ca were analyzed in all ingredients by inductively coupled plasma spectroscopy (Method 975.03; AOAC Int., 2007) after wet ash sample preparation (Method 975.03; AOAC Int., 2007). Samples of FSBM and SBM-CV were also analyzed for trypsin inhibitor concentration (Method Ba 12-75; AOCS, 2006), phytic acid (Ellis et al., 1977), and monosaccharides, sucrose, and oligosaccharides as described by Cervantes-Pahm and Stein (2010).

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

Data were analyzed by ANOVA using the Mixed Procedure (SAS Inst. Inc., Cary, NC). Homogeneity of the variances among treatments was confirmed using the UNIVARIATE procedure and this procedure was also used to identify outliers, but no outliers were observed. Diet was the fixed effect 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.

Experiment 2: Amino Acid Digestibility

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

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

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

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

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

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

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

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

Bags were removed whenever they were filled with digesta, or at least once every 30 min, and stored at –20°C to prevent bacterial degradation of AA in the digesta.

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

Calculations and Statistical Analysis. Values for AID, endogenous losses, and SID of CP and AA in the diets containing FSBM, SBM-CV, and fish meal were calculated (Stein et al., 2007). Data were analyzed by ANOVA using the MIXED procedure of SAS with diet as fixed effect and pig and replicate as random effects. An α value of 0.05 was used to assess significance among means.

Table 4. Analyzed nutrient composition of experimental diets, as-fed basis, Exp. 2

	Diet[1]			
Item	FSBM	SBM-CV	Fish meal	N free
GE, kcal/kg	4,034	3,937	3,857	3,788
Ash, %	5.90	4.16	6.76	3.87
DM, %	94.42	93.96	93.96	94.34
CP, %	15.43	12.07	16.91	0.32
ADF, %	1.75	1.73	0.28	3.19
NDF, %	3.70	2.60	5.44	2.84
AEE,[2] %	2.44	2.39	2.46	1.54
Indispensable, AA %				
Arg	1.12	0.91	0.85	0.01
His	0.45	0.35	0.37	–
Ile	0.79	0.60	0.64	0.02
Leu	1.32	0.98	1.08	0.03
Lys	1.00	0.82	1.18	0.01
Met	0.24	0.18	0.41	–
Phe	0.83	0.63	0.58	0.01
Thr	0.65	0.49	0.60	0.01
Trp	0.22	0.19	0.16	<0.04
Val	0.84	0.60	0.74	0.01
Dispensable, AA %				
Ala	0.75	0.55	0.74	0.02
Asp	1.82	1.38	1.30	0.02
Cys	0.23	0.17	0.12	0.01
Glu	2.96	2.27	1.93	0.03
Gly	0.73	0.54	1.03	0.01
Pro	0.84	0.63	0.67	0.02
Ser	0.76	0.55	0.50	0.01
Tyr	0.52	0.39	0.36	0.01
Total AA	16.07	12.23	13.46	0.25

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

[2]AEE = acid hydrolyzed ether extract.

Table 5. Concentrations of DE, ME and NE, daily N balance, and apparent total tract digestibility (ATTD) of GE and nutrients in experimental diets containing corn, fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), or fish meal, as-fed basis, Exp. 1[1]

Item	Corn	FSBM	SBM-CV	Fish meal	SEM	P-value
GE intake, kcal	3,266^{b}	3,623^{a}	3,755^{a}	3,664^{a}	122.2	<0.01
GE in feces, kcal	374.5^{b}	418.0^{ab}	403.4^{b}	464.8^{a}	23.3	0.02
GE in urine, kcal	96.5^{b}	192.6^{a}	181.0^{a}	168.8^{a}	18.1	<0.01
DE in diet kcal/kg	3,315^{c}	3,478^{ab}	3,504^{a}	3,433^{b}	16.6	<0.01
ME in diet kcal/kg	3,204^{b}	3,267^{a}	3,314^{a}	3,255^{ab}	21.4	<0.01
NE in diet kcal/kg	2,344^{b}	2,376^{ab}	2,409^{a}	2,369^{ab}	15.5	0.04
N intake, g	6.0^{c}	18.9^{b}	19.4^{ab}	19.8^{a}	0.5	<0.01
N in feces, g	1.4^{b}	2.3^{a}	2.2^{a}	2.4^{a}	0.1	<0.01
N in urine, g	3.0^{b}	7.1^{a}	6.8^{a}	5.9^{a}	0.6	<0.01
ATTD of GE, %	88.6^{a}	88.4^{ab}	89.2^{a}	87.3^{b}	0.4	0.02
ATTD of N, %	76.0^{b}	87.8^{a}	88.5^{a}	87.9^{a}	1.0	<0.01
ATTD of AEE,[2] %	28.5^{c}	48.6^{a}	40.6^{b}	37.9^{b}	2.5	<0.01

[a–c]Least squares means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data expressed as least squares mean values ($n = 9$) with pooled SEM.

[2]AEE = acid hydrolyzed ether extract.

RESULTS

Experiment 1: Energy Concentration and Total Tract Digestibility

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

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

Pigs fed corn had a greater ($P < 0.05$) fecal excretion of GE than pigs fed FSBM, SBM-CV, or fish meal (Table 6). There was no difference in urinary excretion of GE among ingredients. The DE, ME, and NE were greater ($P < 0.05$) in SBM-CV than in the other ingredients on an as-fed as well as on a DM basis, but FSBM contained more ($P < 0.05$) DE (as-fed and DM basis) than corn and fish meal and more ($P < 0.05$) ME and NE (as-is and DM basis) than fish meal. Nitrogen intake was less ($P < 0.05$) from corn than from FSBM, SBM-CV, or fish meal, but there was no difference in N intake between SBM-CV and fish meal. There were no differences among ingredients in fecal and urinary excretion of N. The retention of N was

Table 6. Concentrations of DE, ME and NE, daily N balance, and apparent total tract digestibility (ATTD) of GE, DM, and nutrients in corn, fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), and fish meal, as-fed basis, Exp. 1[1]

Item	Corn	FSBM	SBM-CV	Fish meal	SEM	*P*-value
GE intake, kcal	3,388[a]	1,275[c]	1,546[b]	1,112[d]	124.3	<0.01
GE in feces, kcal	388.5[a]	148.8[b]	150.1[b]	172.2[b]	23.8	<0.01
GE in urine, kcal	100.1	123.3	115.8	93.5	18.1	0.63
DE, kcal/kg	3,439[c]	3,910[b]	4,069[a]	3,513[c]	48.9	<0.01
DE, kcal/kg DM	3,951[c]	4,296[b]	4,553[a]	3,827[c]	52.2	<0.01
ME, kcal/kg	3,324[bc]	3,441[b]	3,698[a]	3,132[c]	73.6	<0.01
ME, kcal/kg DM	3,819[b]	3,781[b]	4,137[a]	3,412[c]	80.9	<0.01
NE, kcal/kg	2,431[b]	2,463[b]	2,653[a]	2,247[c]	53.5	<0.01
NE, kcal/kg DM	2,791[b]	2,710[b]	2,972[a]	2,450[c]	58.7	<0.01
N intake, g	6.2[c]	14.5[b]	15.3[a]	15.1[a]	0.5	<0.01
N in feces, g	1.5	1.3	1.2	1.3	0.1	0.37
N in urine, g	3.1	5.0	4.7	3.5	0.6	0.09
N retention, g	1.6[c]	8.3[b]	9.4[ab]	10.3[a]	0.5	<0.01
Biological value,[2] %	34.8[c]	62.8[b]	67.1[ab]	75.4[a]	4.3	<0.01
ATTD of GE, %	88.6[a]	88.2[a]	90.3[a]	84.0[b]	1.1	<0.01
ATTD of N, %	76.0[b]	91.3[a]	91.8[a]	91.6[a]	1.0	<0.01
ATTD of AEE,[3] %	28.5[c]	71.9[a]	56.9[b]	49.9[b]	4.7	<0.01

[a–d]Least squares means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data expressed as least squares mean values ($n = 9$) with pooled SEM.

[2]Biological value was calculated as [N retained/(N intake – N in feces)] × 100.

[3]AEE = acid hydrolyzed ether extract.

less ($P < 0.05$) from corn than from FSBM, SBM-CV, and fish meal. The retention of N was also less ($P < 0.05$) from FSBM than from fish meal, but there was no difference in N retention between FSBM and SBM-CV.

The biological value of the protein in corn was less ($P < 0.05$) than in all other ingredients and there was no difference in the biological value between FSBM and SBM-CV, but the biological value of protein was less ($P < 0.05$) in FSBM than in fish meal. The ATTD of GE was less ($P < 0.05$) in fish meal than in corn, FSBM, and SBM-CV, and there was no difference in the ATTD of GE among corn, FSBM, and SBM-CV. The ATTD of N was less ($P < 0.05$) in corn than in the other ingredients, but there was no difference among FSBM, SBM-CV, and fish meal. The ATTD of AEE was greater ($P < 0.05$) in FSBM than in the other ingredients, but there was no difference between SBM-CV and fish meal in the ATTD of AEE whereas corn had the least ($P < 0.05$) ATTD of AEE.

Experiment 2: Amino Acid Digestibility

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

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

DISCUSSION

It was not possible to obtain FSBM and SBM-CV from the same batch and the 2 sources of soybean meal were, therefore, obtained from different sources. As a consequence, it is possible that some of the differences between FSBM and SBM-CV that were observed in these experiments were a result of differences between the 2 sources of SBM rather than a result of fermentation per se.

Experiment 1: Energy Concentration and Total Tract Digestibility

Corn was used in the basal diet in this experiment because it is well tolerated by pigs and therefore is an ideal ingredient to use in experiments where DE and ME values of test ingredients are determined using the difference procedure. Values for GE, DE, ME, and ATTD of GE in corn that were determined in this experiment are in close agreement with previously reported values (Pedersen et al., 2007; Widmer et al., 2007; Baker and Stein, 2009; NRC, 2012). Likewise, the DE and ME that were determined for SBM-CV concur with data from Baker and Stein (2009). To our knowledge, DE, ME, and NE have never been reported for FSBM, but the reason for the reduced DE, ME, and NE in FSBM compared with SBM-CV is most likely that during fermentation of soy-

Table 7. Apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of CP and AA in fermented soybean meal (FSBM), conventional soybean meal (SBM-CV), and fish meal by weanling pigs, Exp. 2[1]

	AID					SID[2]				
	Ingredient					Ingredient				
Item	FSBM	SBM-CV	Fish meal	SEM	*P*-value	FSBM	SBM-CV	Fish meal	SEM	*P*-value
CP, %	65	60	62	2.7	0.50	80	80	76	2.7	0.54
Indispensable AA, %										
Arg	88[a]	86[a]	77[b]	1.2	<0.01	94[a]	94[a]	86[b]	1.2	<0.01
His	84[a]	82[a]	75[b]	1.2	<0.01	89[a]	89[a]	82[b]	1.2	0.01
Ile	82[a]	78[b]	75[b]	1.2	<0.01	88[a]	85[b]	82[b]	1.2	<0.01
Leu	82[a]	77[b]	76[b]	1.2	<0.01	88[a]	84[ab]	82[b]	1.2	0.02
Lys	76	77	76	1.3	0.86	82	84	81	1.3	0.24
Met	86[a]	79[b]	80[b]	1.4	<0.01	91[a]	86[b]	83[b]	1.4	<0.01
Phe	83[a]	79[b]	72[c]	1.2	<0.01	89[a]	86[a]	80[b]	1.2	<0.01
Thr	72[a]	65[b]	67[b]	1.6	0.01	83	80	79	1.6	0.14
Trp	83[a]	82[a]	78[b]	1.3	0.02	89	90	87	1.3	0.25
Val	78[a]	69[b]	69[b]	1.5	<0.01	86[a]	81[b]	78[b]	1.5	<0.01
Mean	81[a]	77[b]	74[b]	1.2	<0.01	88[a]	86[a]	82[b]	1.2	<0.01
Dispensable AA, %										
Ala	72[a]	62[b]	67[a]	1.9	<0.01	82[a]	76[b]	75[b]	1.9	0.02
Asp	82[a]	78[b]	66[c]	1.5	<0.01	87[a]	84[a]	73[b]	1.5	<0.01
Cys	64[a]	65[a]	46[b]	2.5	<0.01	75[a]	79[a]	67[b]	2.5	<0.01
Glu	77[b]	83[a]	74[b]	1.6	<0.01	81[b]	89[a]	81[b]	1.6	0.01
Gly	47	39	48	5.4	0.40	78	80	69	5.4	0.29
Pro	3	–36	–50	26.3	0.18	100	93	71	26.3	0.57
Ser	80[a]	74[b]	65[c]	1.6	<0.01	88[a]	85[a]	77[b]	1.6	<0.01
Tyr	82[a]	77[b]	72[c]	1.2	<0.01	88[a]	86[a]	81[b]	1.2	<0.01
Mean	68[a]	63[a]	54[b]	3.5	0.02	85[a]	86[a]	75[b]	3.5	0.05
All AA	74[a]	70[ab]	64[b]	2.2	0.01	86[a]	86[a]	78[b]	2.2	0.03

[a–c]Least squares means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data expressed as least squares mean values ($n = 8$) with pooled SEM.

[2]Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of DMI) as CP, 25.55; Arg, 0.78; His, 0.27; Ile, 0.45; Leu, 0.78; Lys, 0.64; Met, 0.13; Phe, 0.46; Thr, 0.79; Trp, 0.16; Val, 0.71; Ala, 0.82; Asp, 1.0; Cys, 0.26; Glu, 1.35; Gly, 2.37; Pro, 8.66; Ser, 0.65; and Tyr, 0.35.

bean meal, the oligosaccharides and sucrose are removed. Sucrose is easily digested by pigs and oligosaccharides are almost completely fermented (Smiricky et al., 2002). If oligosaccharides and sucrose in soybean meal are removed by enzyme treatment, the concentration of DE and ME are not affected (Goebel and Stein, 2011), but results of this experiment indicate that fermentation of soybean meal in the presence of *Bacillus subtillis* and *Aspergillus oryzae* may have a different impact on the concentration of DE and ME than enzyme treatment. Removal of sucrose and oligosaccharides from soybean meal results in a greater concentration of CP, ADF, and NDF, which is the reason the concentration of these nutrients is greater in FSBM than in SBM-CV. These changes in nutrient concentration in FSBM compared with SBM-CV were also reported by Cervantes-Pahm and Stein (2010). However, ADF and NDF are not completely fermented in the intestinal tract of pigs, and greater concentrations of ADF and NDF result in reduced values for DE and ME (NRC, 2012).

The DE and ME values that were calculated for corn concur with previous values (NRC, 2012), but the DE and ME in fish meal that were determined in this experiment are less than previous values (NRC, 2012), which may be a consequence of more ash and less DM in the fish meal used in this experiment. The greater concentration of GE in fish meal compared with FSBM and SBM-CV is most likely a result of the greater concentration of AEE in fish meal than in FSBM and SBM-CV. However, results of this experiment indicate that AEE and GE in fish meal is poorly digested, which is the reason DE, ME, and NE were less in fish meal than in FSBM. The fact that NE in FSBM is greater than in fish meal indicates that if FSBM is included in a diet rather than fish meal, the NE of the diet may increase.

The increased ATTD of ADF and NDF in FSBM compared with SBM-CV may be a result of fermentation indicating that fermentation may make it easier for microbes to gain access to the fiber in the ingredient. A similar observation was reported for ATTD of ADF and NDF in corn distillers dried grain with solubles compared with corn (Urriola et al., 2010). However, the observation that the DE in FSBM is less than in SBM-CV indicates that the increase in ATTD of ADF and NDF does not contribute enough energy to offset the loss of energy from sucrose and oligosaccharides in FSBM compared with SBM-CV.

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

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

Experiment 2: Amino Acid Digestibility

The present data are the first to report AID and SID for FSBM produced using *Aspergillus oryzae* and *Bacillus subtilis*, and this is also the first experiment in which AID and SID of AA in U.S.-produced FSBM is reported. The AA composition of the FSBM used in this experiment is in agreement with values reported by Hong et al. (2004) and Cervantes-Pahm and Stein (2010), who evaluated a different source of FSBM that was produced in the presence of *Aspergillus oryzae*, but without *Bacillus subtilis*. The fact that the AID of most indispensable AA is greater in FSBM than in SBM-CV is in agreement with Yang et al. (2007). The reason for the greater AID of indispensable AA in FSBM than in SBM-CV may be that during fermentation, the concentration of small peptides may increase (Hong et al., 2004) and small peptides may be better absorbed in the small intestine than AA (Gilbert et al., 2008). The present data indicate that AA in FSMB are well digested by weanling pigs and FSBM may, therefore, be used as a source of digestible AA in diets fed to weanling pigs. Cervantes-Pahm and Stein (2010) reported that the SID of Lys in FSBM is less than in SBM-CV, but that was not observed in this experiment. It is possible that the reason for the low SID of Lys in the experiment by Cervantes-Pahm and Stein (2010) is that the FSBM used in that experiment was heat damaged because heat damage of soybean meal will reduce the SID of Lys (Gonzales-Vega et al., 2011).

The AID and SID of indispensable AA in fish meal that were determined in this experiment were less than the values reported from previous experiments (Urbaityte et al., 2009; Cervantes-Pahm and Stein, 2010; NRC, 2012). The reason for this observation may be that the quality of fish meal that was used in this experiment was reduced compared with that used in previous experiments. The quality of fish meal may vary due to the species used and to the type of processing that is used to produce the meal (Wiseman et al., 1991; Kim and Easter, 2001; Cho and Kim, 2011). The relatively high concentration of ash in the fish meal used in this experiment indicates that a large proportion of the fish meal was bone, which may have been obtained from the fish filet industry. The protein in bones is more difficult to digest than protein in soft tissue, which may also have contributed to the reduced AID and SID of AA in the fish meal used in this experiment compared with previous data.

Conclusions

Results of the present experiments provide for the first time data for DE, ME, and NE and AID and SID of AA in soybean meal fermented in the presence of *Aspergillus oryzae* and *Bacillus subtilis*. Results indicate that fermentation of soybean meal increases the concentration of DM, CP, AEE, NDF, and ADF compared with SBM-CV, but oligosaccharides that are not tolerated by young pigs are eliminated in the fermentation process. The concentration of DE, ME, and NE are greater in FSBM than in fish meal but less than in SBM-CV. The SID of most AA is not different between SBM-CV and FSBM, but these values are greater than in fish meal. The biological value of protein in FSBM is also not different from that in SBM-CV. These results indicate that soybean meal fermented in the presence of *Aspergillus oryzae* and *Bacillus subtilis* may be used in diets fed to weanling pigs instead of fish meal without negatively affecting ME or NE of the diet or the SID of AA.

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