Energy concentration and phosphorus digestibility in canola, cottonseed, and sunflower products fed to growing pigs

D. A. Rodríguez, R. C. Sulabo, J. C. González-Vega, and H. H. Stein[1]

Department of Animal Sciences, University of Illinois, Urbana, 61801, USA.
Received 1 February 2013, accepted 8 July 2013. Published on the web 1 August 2013.

Rodríguez, D. A., Sulabo, R. C., González-Vega, J. C. and Stein, H. H. 2013. **Energy concentration and phosphorus digestibility in canola, cottonseed, and sunflower products fed to growing pigs**. Can. J. Anim. Sci. **93**: 493–503. Many protein sources are available to the swine feed industry, but accurate data for the energy concentration and the standardized total tract digestibility (STTD) of P in these ingredients are lacking. Therefore, two experiments were conducted to determine the concentration of digestible energy (DE), metabolizable energy (ME) and the STTD of P in oilseed products. In exp. 1, 48 barrows (44.8 ± 3.9 kg) were fed a basal diet containing 97.15% corn or seven diets containing corn and canola seed (CS), canola meal (CM), cottonseed meal (CSM), sunflower seed (SFS), sunflower meal (SFM), de-hulled sunflower meal (SFM-DH), or soybean meal (SBM). Six pigs were allotted to each treatment. Sunflower seeds contained 5492 kcal kg^{-1}, at least 689 kcal kg^{-1} more ($P < 0.05$) ME than all other feed ingredients. Likewise, CS (4803 kcal kg^{-1}) had greater ($P < 0.05$) ME than SBM (3676 kcal kg^{-1}), and both CS and SBM had greater ($P < 0.05$) ME than CM, SFM, SFM-DH, and CSM (2998, 2725, 2631, and 2459 kcal kg^{-1}, respectively). In exp. 2, 84 barrows (13.7 ± 1.5 kg) were allotted to 14 diets, which contained each of the oilseed products without or with phytase, in a randomized complete block design with six pigs per dietary treatment. The STTD of P in SBM was at least 4 percentage units greater ($P < 0.05$) than the STTD of P in the other ingredients. Adding phytase to the diets reduced fecal output of P from all ingredients and increased ($P < 0.05$) the STTD of P for all ingredients except SFM-DH. The ME concentration in SFS and CS is greater than that of SBM and the STTD of P among these ingredients is comparable, which indicates that SFS and CS may be fed to growing pigs at the expense of SBM.

Key words: Canola, cottonseed, energy, phosphorus, pigs, sunflower

Rodríguez, D. A., Sulabo, R. C., González-Vega, J. C. et Stein, H. H. 2013. **Concentration d'énergie et coefficient d'utilisation digestive du phosphore dans les produits à base de canola, graines de coton et tournesol donnés aux porcs en croissance**. Can. J. Anim. Sci. **93**: 493–503. Plusieurs sources de protéines sont disponibles pour l'industrie des aliments pour porcs, mais il n'y a pas suffisamment de données précises sur la concentration d'énergie et le coefficient normalisé d'utilisation du phosphore dans le tube digestif complet (STTD – « standardized total tract digestibility ») dans ces ingrédients. Deux expériences ont donc été effectuées pour déterminer la concentration d'énergie digestible (DE — « digestible energy »), d'énergie métabolisable (ME — « metabolisable energy ») et le STTD du P dans les produits oléagineux. Dans la première expérience, 48 castrats (44,8 ± 3,9 kg) ont reçu une diète de base contenant 97,15 % de maïs ou 7 diètes qui contenaient, maïs et graines de canola (CS – « canola seed »), tourteau de canola (CM – « canola meal »), tourteau de graines de coton (CSM – « cottonseed meal »), graines de tournesol (SFS – « sunflower seed »), tourteau de tournesol (SFM – « sunflower meal »), tourteau de tournesol décortiqué (SFM-DH – « de-hulled sunflower meal »), ou tourteau de soya (SBM – « soybean meal »). Six porcs ont été attribués à chacun des traitements. Les graines de tournesol contiennent 5492 kcal kg^{-1}, soit au moins 689 kcal kg^{-1} de plus de ($P < 0{,}05$) ME que tous les autres ingrédients des diètes. De même, la diète CS (4803 kcal kg^{-1}) avait une plus grande ($P < 0{,}05$) ME que la diète SBM (3676 kcal kg^{-1}), et les diètes CS et SBM avaient des ME plus grandes ($P < 0{,}05$) que les diètes CM, SFM, SFM-DH, et CSM (2998, 2725, 2631, et 2459 kcal kg^{-1}, respectivement). Dans la deuxième expérience, 84 castrats (13,7 ± 1,5 kg) ont été attribués à 14 diètes, qui contenaient chacun des produits oléagineux avec ou sans phytase, selon un dispositif aléatoire en blocs complets avec 6 porcs par traitement alimentaire. Le STTD du P dans la diète SBM était au moins 4 unités de pourcentage plus élevé ($P < 0{,}05$) que le STTD du P dans les diètes contenant les autres ingrédients. L'ajout de la phytase aux diètes a réduit la quantité de P dans les fèces pour toutes les diètes et a augmenté ($P < 0{,}05$) le STTD du P pour toutes les diètes, sauf la diète

Abbreviations: **AA**, amino acids; **ADF**, acid detergent fiber; **ADFI**, average daily feed intake; **ATTD**, apparent total tract digestibility; **BW**, body weight; **CM**, canola meal; **CP**, crude protein; **CS**, canola seeds; **CSM**, cotton seed meal; **DE**, digestible energy; **EPL**, endogenous phosphorus loss; **FTU**, phytase unit; **GE**, gross energy; **ME**, metabolizable energy; **NDF**, neutral detergent fiber; **SBM**, soybean meal; **SFM**, sunflower meal; **SFM-DH**, de-hulled sunflower meal; **SFS**, sunflower seeds; **STTD**, standardized total tract digestibility

[1]*Corresponding author (email: hstein@illinois.edu).*

SFM-DH. La concentration de ME dans les diètes SFS et CS est plus grande que celle de la diète SBM et le STTD du P parmi ces diètes est comparable, ce qui indique que les diètes SFS et CS peuvent être données aux porcs en croissance en remplacement de la diète SBM.

Mots clés: Canola, graine de coton, énergie, phosphore, porcs, tournesol

The principal oilseed produced in the world is soybean and due to the rapidly increasing demand for oil and amino acids (AA), the global production of soybeans is increasing faster than the production of any other agricultural crop (Goldsmith 2008). Canola and cotton are the two oilseed crops that are produced in the greatest quantities after soybeans and sunflower is the fifth most produced oilseed in the world [US Department of Agriculture (USDA) 2010]. Canola seeds (CS) and sunflower seeds (SFS) may be included in diets for pigs (Adams and Jensen 1985; Shaw et al. 1990), and the de-oiled meals from canola, cotton, and SFS may also be included as protein sources in swine diets (Thacker 1990; Wahlstrom 1990; Chiba 2001). The standardized ileal digestibility of AA in canola, cottonseed, and sunflower products fed to growing pigs was recently reported (González-Vega and Stein 2012). However, in addition to AA, oilseeds and oilseed meals also provide digestible energy (DE) and metabolizable energy (ME) to the diets, but there are no recent data for the DE and ME in canola, cotton, and sunflower products. The apparent total tract digestibility (ATTD) of P has been reported for canola, cotton, and sunflower products, but it is believed that values for the standardized total tract digestibility (STTD) of P are more accurate than values for ATTD of P (National Research Council (NRC) 2012). There are, however, no reports on values for the STTD of P in these ingredients, and it is not known how microbial phytase influences the STTD of P. Therefore, the objectives of the present experiments were to determine the DE and ME and the ATTD and STTD of P in CS and canola meal (CM), cotton seed meal (CSM), SFS, sunflower meal (SFM), de-hulled sunflower meal (SFM-DH), and soybean meal (SBM) when fed to growing pigs. The second objective was to test the hypothesis that the ATTD and STTD of P in these ingredients are increased by addition of microbial phytase to the diets.

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 the experiments. Pigs used in both experiments were the offspring of G-Performer boars that were mated to Fertilium 25 females (Genetiporc, Alexandria, MN). Canola seeds and CM were obtained from Specialty Commodities, Burnsville, MN, and CP Feeds L. L. C., Valders, WI, respectively. Cottonseed meal was purchased from Delta Oil Mill, Jonestown, MS. Sunflower seeds, SFM, and SFM-DH were sourced from Anderson Seed Company, Mentor, MN, ADM Milling Co., Kansas City, MO, and ADM Northern Sun Division, Enderlin, ND, respectively. De-hulled SBM was procured from Solae L. L. C., Gibson City, IL. The same batches of these ingredients were used in both experiments (Table 1). These batches were also identical to those used by González-Vega and Stein (2012).

Energy Measurements (Exp. 1)

Experiment 1 was conducted to compare the DE and ME values in CS, CM, CSM, SFS, SFM, and SFM-DH with values obtained for SBM. Forty-eight growing barrows (initial BW: 44.8 ± 3.9 kg) were randomly allotted to eight diets with six replicate pigs per diet. Pigs were housed in metabolism cages (0.9×1.6 m) that were equipped with a feeder and a nipple drinker, a fully slatted floor, a screen floor, and a urine tray. The latter allowed for the total, but separate, collection of urine and fecal materials from each pig.

A corn diet consisting of 97.15% (as-fed basis) corn and vitamins and minerals was formulated (Table 2). Seven additional diets were formulated by mixing corn with CS, CM, CSM, SFS, SFM, SFM-DH, or SBM. In these diets, the inclusion levels of each feed ingredient as well as the inclusion levels of dicalcium phosphate and limestone were adjusted to maintain a CP level of approximately 16% and a Ca:P ratio of 1.2:1. The quantity of feed provided per pig daily was calculated as three times the estimated requirement for maintenance energy (i.e., 106 kcal metabolizable energy per $kg^{0.75}$ of BW; NRC 1998) for the smallest pig in each replicate and divided into two equal meals that were fed at 0700 and 1600. Water was available at all times. The experiment lasted 14 d. The initial 7 d were considered an adaptation period to the diet, while urine and fecal materials were collected during the following 5 d according to the marker-to-marker approach (Adeola 2001). Chromic oxide was used as marker. Urine was collected in urine buckets over a preservative of 50 mL of 6 N HCl to prevent loss of N. Fecal samples and 20% of the collected urine were stored at $-20^{\circ}C$ immediately after collection.

At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a sub-sample was lyophilized and used for analysis (Kim et al. 2009). Fecal samples were dried in a forced-air oven and ground through a 1-mm screen in a Wiley mill (Model 4; Thomas Scientific, Swedesboro, NJ) prior to analysis. Fecal, diet, and ingredient samples were analyzed in duplicate for dry matter (method 985.05; AOAC International 2007). Gross energy was analyzed

Table 1. Analyzed chemical composition (as-fed basis) of test ingredients

	Ingredients[z]						
Item	CS	CM	CSM	SFS	SFM	SFM-DH	SBM
Dry matter (%)	93.5	89.6	89.3	95.8	89.9	91.1	89.2
Gross energy (kcal kg^{-1})	6375	4362	4348	7122	4290	4270	4293
Crude protein (N × 6.25) (%)	24.6	39.0	42.3	22.1	29.4	37.3	49.8
Acid hydrolyzed ether extract,[y] (%)	41.2	4.1	3.8	54.5	1.6	2.1	1.3
Acid detergent fiber (%)	16.6	18.6	17.1	7.6	29.2	21.9	5.4
Neutral detergent fiber (%)	21.3	32.2	24.6	8.1	39.3	30.3	9.1
Ash (%)	3.4	7.6	8.1	3.1	6.3	7.6	5.8
Calcium (%)	0.31	0.69	0.22	0.10	0.39	0.36	1.30
Total phosphorus (%)	0.58	1.07	1.30	0.70	1.19	1.27	0.68
Phytate (%)	1.5	2.6	3.2	1.8	2.8	3.0	1.4
Phytate P[y] (%)	0.42	0.73	0.90	0.51	0.79	0.85	0.39
Phytate P (% of total P)	73	69	69	73	66	67	58
Non-phytate P[x] (%)	0.16	0.34	0.40	0.19	0.40	0.42	0.29
Non-phytate P (% of total P)	27	31	31	27	34	33	42
Phytase (FTU[w] kg^{-1})	<70	<70	<70	<70	88	90	<70

[z]CS, canola seeds; CM, canola meal; CSM, cottonseed meal; SFS, sunflower seeds; SFM, sunflower meal; SFM-DH, dDe-hulled sunflower meal; SBM, soybean meal.
[y]Phytate P was calculated as 28.2% of phytate (Tran and Sauvant 2004).
[x]Non-phytate P was calculated as the difference between total P and phytate P.
[w]FTU, phytase units.

in all samples of ingredients, diets, feces, and urine using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Benzoic acid was used as the internal standard. All ingredient samples were also analyzed for crude protein (N × 6.25; method 990.03; AOAC International 2007), acid-hydrolyzed ether extract (method 2003.06; AOAC International 2007), ADF (method 973.18, AOAC International 2007), NDF (Holst 1973), and ash (method 975.03, AOAC International 2007). Calcium and total P in ingredients, diets, and fecal samples were analyzed by the inductively coupled plasma (ICP) spectroscopy method (method 985.01 A, B, and C; AOAC International 2007) after wet ash sample preparation [method 975.03 B(b); AOAC

Table 2. Composition of experimental diets (as-fed basis)[z], exp. 1

	Diets							
Ingredient (%)	Corn	CS	CM	CSM	SFS	SFM	SFM-DH	SBM
Corn	97.15	48.10	68.15	70.80	47.95	56.10	67.00	74.80
CS	–	50.00	–	–	–	–	–	–
CM	–	–	30.00	–	–	–	–	–
CSM	–	–	–	27.00	–	–	–	–
SFS	–	–	–	–	50.00	–	–	–
SFM	–	–	–	–	–	42.00	–	–
SFM-DH	–	–	–	–	–	–	31.00	–
SBM (48% CP)	–	–	–	–	–	–	–	23.00
Limestone	0.85	0.90	1.05	1.35	1.10	1.20	1.25	0.95
Dicalcium phosphate	1.30	0.30	0.10	0.15	0.25	–	0.05	0.55
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin–mineral premix[y]	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
Analyzed composition								
Dry matter (%)	87.4	90.4	88.3	88.0	91.6	88.7	88.9	88.6
Gross energy (kcal kg^{-1})	4,320	6,571	4,586	4,560	7,282	4,505	4,455	4,502

[z]CS, canola seeds; CM, canola meal; CSM, cottonseed meal; SFS, sunflower seeds; SFM, sunflower meal; SFM-DH, de-hulled sunflower meal; SBM, soybean meal.
[y]The vitamin–mineral premix provided the following quantities of vitamins and minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11 128 IU; vitamin D_3 as cholecalciferol, 2204 IU; vitamin E as DL-a-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamine 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, 1.0 mg, and nicotinic acid, 43.0 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.

International 2007]. Ingredients were analyzed for phytic acid (Ellis et al. 1977), and ingredients and diets were analyzed for phytase activity (Phytex Method, version 1, Eurofins, Des Moines, IA).

Following analysis, total tract digestibility values were calculated for energy in each diet (Widmer et al. 2007). The concentration of energy lost in the feces and in the urine, respectively, was calculated as well, and the quantities of DE and ME in each of the 8 diets were calculated using the direct method and in each ingredient using the difference method (Widmer et al. 2007).

The presence of outliers and the normality of the data were assessed using the UNIVARIATE procedure of SAS software (SAS Institute Inc., Cary, NC). Data were analyzed using the MIXED procedure with diet as the fixed effect and pig as the random effect. Least square means were calculated for each independent variable using the LSMeans procedure and when diet was a significant source of variation, means were separated using the PDIFF option of SAS software. The pig was the experimental unit for all calculations. An α level of 0.05 was used to determine significance among means.

Phosphorus Digestibility (Exp. 2)

Experiment 2 was conducted to determine the ATTD and STTD of P in the ingredients that were used in exp. 1. A total of 84 growing barrows (average initial BW: 13.7 ± 1.5 kg) were randomly allotted to 14 diets with six replicate pigs per diet in a randomized complete block design. Pigs were housed in metabolism cages as explained for exp. 1, but only feces, and not urine, were collected in this experiment.

Seven diets were formulated to contain similar concentrations of CP and to maintain a Ca:P ratio of 1.3:1. Diets were prepared by mixing cornstarch and sucrose with CS, CM, CSM, SFS, SFM, SFM-DH, or SBM (Tables 3 and 4). Seven additional diets that were identical to the initial seven diets with the exception that 500 units of phytase (OptiPhos 2000, Enzyvia, Sheridan, IN) was added to each diet were also formulated. No inorganic P was included in the diets and each test ingredient, therefore, provided all the P in each diet. Vitamins and all minerals except P were included in the diets according to current requirements (NRC 1998). Feed was provided in a daily amount equivalent to three times the maintenance energy requirement and was divided into two daily meals that were provided at 0700 and 1600. Water was available at all times. Pigs were fed their experimental diets for 14 d. The initial 7 d was considered an adaptation period to the diet, but fecal materials were collected during the following 5 d as explained for exp. 1. Fecal samples were stored at -20°C immediately after collection.

At the conclusion of the experiment, fecal samples were dried in a forced-air oven and ground through a 1-mm screen in a Wiley mill (Model 4; Thomas Scientific, Swedesboro, NJ) prior to analysis. Fecal samples and diets were analyzed in duplicate for DM, P, and Ca as outlined for exp. 1. The concentration of phytate bound P was calculated as 28.2% of phytate (Tran and Sauvant 2004), and non-phytate P was calculated as the difference between the concentration of total P and phytate bound P. The ATTD of P in each diet were calculated as previously described (Almeida and Stein 2010) and the STTD of P were calculated by

Table 3. Composition of experimental diets (as-fed basis)[z,y], exp. 2

	Diets						
Ingredient (%)	CS	CM	CSM	SFS	SFM	SFM-DH	SBM
CS	50.00	–	–	–	–	–	–
CM	–	35.00	–	–	–	–	–
CSM	–	–	33.00	–	–	–	–
SFS	–	–	–	50.00	–	–	–
SFM	–	–	–	–	40.00	–	–
SFM-DH	–	–	–	–	–	34.00	–
SBM	–	–	–	–	–	–	45.00
Cornstarch	38.75	53.70	55.30	38.60	47.50	54.45	43.65
Sucrose	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Ground limestone	0.55	0.60	1.00	0.70	1.80	0.85	0.65
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin–mineral premix[x]	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

[z]CS, canola seeds; CM, canola meal; CSM, cottonseed meal; SFS, sunflower seeds; SFM, sunflower meal; SFM-DH, de-hulled sunflower meal; SBM, soybean meal.

[y]Seven additional diets were formulated by adding 0.03% phytase to the diets at the expense of cornstarch. FTU, phytase units. OptiPhos 2000 (2000 FTU g^{-1}; Enzyvia, Sheridan, IN).

[x]The vitamin–micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A, 11 128 IU; vitamin D_3, 2204 IU; vitamin E, 66 IU; vitamin K, 1.42 mg; thiamine, 0.24 mg; riboflavin, 6.58 mg; pyridoxine, 0.24 mg; vitamin B_{12}, 0.03 mg; d-pantothenic acid, 23.5 mg; niacin, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 4. Analyzed composition (as-fed basis) of experimental diets[z], exp. 2

	No phytase						With phytase					
Item	CS	CM	CSM	SFS	SFM	SFM-DH	SBM	CS	CM	CSM	SFS	SFM	SFM-DH	SBM
Dry matter (%)	94.6	91.4	92.0	94.5	91.9	92.3	92.1	93.8	91.7	91.9	94.7	92.8	92.8	92.1
Calcium (%)	0.41	0.50	0.54	0.33	0.90	0.63	0.77	0.43	0.50	0.52	0.38	0.95	0.49	0.88
Phosphorus (%)	0.33	0.38	0.49	0.35	0.42	0.49	0.32	0.33	0.39	0.47	0.36	0.43	0.37	0.33
Phytase[y] (FTU kg^{-1})	<70	<70	96	<70	80	85	<70	450	600	610	540	620	480	570

[z]CS, canola seeds; CM, canola meal; CSM, cottonseed meal; SFS, sunflower seeds; SFM, sunflower meal; SFM-DH, de-hulled sunflower meal; SBM, soybean meal.
[y]FTU, phytase units.

correcting ATTD for the endogenous loss of P, which was assumed to be 200 mg kg^{-1} DMI (Stein 2011). Because the oilseeds or oilseed meals were the only P-contributing sources in the diets, the ATTD and STTD for each diet also represented the ATTD and STTD of P in each ingredient. Data were analyzed as outlined for exp. 1, except that the model included diet, phytase, and the diet × phytase interaction as fixed effects and pig as the random effect.

RESULTS

Energy Measurements (Exp. 1)

There were no differences in ADFI among pigs fed the different diets (Table 5). Daily GE intake was greatest ($P < 0.05$) for pigs fed the CS and SFS diets, whereas daily GE intake among pigs fed corn, CM, CSM, SFM, SFM-DH, or SBM diets were not different. Pigs fed the CS diet had the greatest ($P < 0.05$) fecal energy loss, whereas the least ($P < 0.05$) fecal energy was excreted by pigs fed the corn or SBM diets. Pigs fed the SFS and SFM diets excreted more ($P < 0.05$) fecal energy than pigs fed the CM diet. Pigs fed the SFS diet also excreted more ($P < 0.05$) urinary energy than pigs fed the other diets except for pigs fed the CS diet. In contrast, pigs fed the corn diet had the least ($P < 0.05$) urinary energy loss. The ATTD of GE was greatest ($P < 0.05$) in the corn and SBM diets. The SFS diet also had greater ($P < 0.05$) ATTD of GE than the CS, CSM, SFM, and SFM-DH diets, and the ATTD of GE was greater ($P < 0.05$) in the CM diet than in the CSM and SFM diets. No difference in ATTD of GE was observed between the CS and CM diets or between the SFM and SFM-DH diets.

The SFS diet had the greatest ($P < 0.05$) DE and ME among all experimental diets, followed by the CS and SBM diets. The DE and ME of the CM diet were not different from the DE and ME in the corn diet, but greater ($P < 0.05$) than in the CSM and SFM diets. The DE in the CM was also greater ($P < 0.05$) than the DE in the SFM-DH diet. No differences between SFM and SFM-DH diets in DE and ME were observed.

When calculated on an as-fed or a DM basis, SFS had the greatest ($P < 0.05$) DE and ME among all ingredients (Table 6). Canola seeds also contained more ($P < 0.05$) DE and ME than SBM, but SBM had greater ($P < 0.05$) DE and ME than CM, CSM, SFM, and SFM-DH. The DE of CM was greater ($P < 0.05$) than in CSM, SFM, and SFM-DH, and CM had greater ($P < 0.05$) ME than CSM and SFM-DH. Soybean meal had greater ($P < 0.05$) DE than corn, but there was no difference between corn and SBM in the calculated value for ME.

Phosphorus Digestibility (Exp. 2)

There were no differences ($P > 0.05$) in ADFI among pigs fed the experimental diets (Table 7). However, pigs fed the diet containing SFM-DH with phytase had less ($P < 0.05$) daily P intake compared with pigs fed the diet

Table 5. Daily energy balance (as-fed basis) for pigs fed diets containing corn, canola seeds, canola meal, cottonseed meal, sunflower seeds, sunflower meal, de-hulled sunflower meal, and soybean meal fed to growing pigs[z], exp. 1

	Diets[y]									
Item	Corn	CS	CM	CSM	SFS	SFM	SFM-DH	SBM	SEM	*P* value
ADFI[x] (kg)	1.32	1.32	1.30	1.29	1.28	1.28	1.31	1.21	0.04	0.57
GE intake (kcal)	5114*b*	6855*a*	5273*b*	5184*b*	6962*a*	5229*b*	5237*b*	4909*b*	160	<0.001
GE in feces (kcal)	556*d*	1267*a*	827*c*	952*bc*	1018*b*	1077*b*	944*bc*	524*d*	52	<0.001
GE in urine (kcal)	111*c*	227*ab*	198*b*	181*b*	275*a*	181*b*	163*bc*	200*b*	22	<0.001
ATTD[w] of GE (%)	89.1*a*	81.5*cd*	84.2*bc*	78.9*d*	85.4*b*	79.4*d*	82.0*cd*	89.3*a*	1.1	<0.001
DE in diet (kcal kg^{-1})	3466*d*	4248*b*	3425*d*	3165*e*	4632*a*	3238*e*	3273*e*	3615*c*	49	<0.001
ME in diet (kcal kg^{-1})	3382*cd*	4076*b*	3272*de*	3026*f*	4415*a*	3097*f*	3148*ef*	3449*c*	53	<0.001

[z]Data are least squares means of six observations per dietary treatment.
[y]CS, canola seeds; CM, canola meal; CSM, cottonseed meal; SFS, sunflower seeds; SFM, sunflower meal; SFM-DH, de-hulled sunflower meal; SBM, soybean meal.
[x]ADFI, average daily feed intake.
[w]ATTD, apparent total tract digestibility.
a–f Means within a row lacking a common letter differ ($P < 0.05$).

containing SFM-DH without phytase, because of a reduced P concentration in the SFM-DH diet with phytase. In contrast, adding phytase to the other ingredients did not affect daily P intake of pigs, which resulted in an ingredient × phytase interaction ($P < 0.001$).

There was less ($P < 0.05$) fecal P output from pigs fed the diets containing SBM, CM, or SFS than from pigs fed diets containing CS, CSM, SFM, or SFM-DH. Likewise, pigs fed the CS diets had less ($P < 0.05$) fecal P output than pigs fed SFM-DH, SFM, or CSM diets. Phytase inclusion also reduced ($P < 0.05$) daily P output and phytase increased ($P < 0.05$) the amount of P absorbed when added to all diets except for P absorption in pigs fed SFM-DH (ingredient × phytase interaction, $P < 0.05$).

There was no diet × phytase interaction for the ATTD and STTD of P. If no phytase was included, the ATTD of P in SBM (56.3%) was greater ($P < 0.05$) than in CS, CSM, and SFM (40.8, 41.8, and 33.0%, respectively), but not different from CM, SFS, and SFM-DH (52.2, 46.3, and 46.2%, respectively). If microbial phytase was included in the diet, the ATTD of P in SBM (72.5%) was greater ($P < 0.05$) than in CSM, SFM, and SFM-DH (56.0, 55.4, and 49.9%, respectively), but not different from CS, CM, and SFS (66.0, 68.9, and 68.5%, respectively). Inclusion of phytase in the diets increased ($P < 0.05$) the ATTD of P for all ingredients except SFM-DH. The STTD of P in SBM without phytase (62.0%) was greater than in CS, CSM, SFM, and SFM-DH (45.6, 45.6, 37.4, and 50.0%, respectively), but not different from CM and SFS (58.0 and 51.7%, respectively). If microbial phytase was added to the diets, the STTD of SBM (78.0%) was greater than in CSM, SFM, and SFM-DH (60.0, 59.8, and 54.9%, respectively), but not different from the STTD of P in CS, CM, and SFS (70.7, 74.6, and 73.8%, respectively). Adding phytase to the diets increased ($P < 0.05$) the STTD of P of all ingredients except SFM-DH.

Addition of microbial phytase to the ingredients increased ($P < 0.05$) daily Ca intake for pigs fed SFM

Table 6. Digestible and metabolizable energy concentration in corn, canola seeds, canola meal, cottonseed meal, sunflower seeds, sunflower meal, de-hulled sunflower meal, and soybean meal fed to growing pigs[z], exp. 1

	Ingredients[y]									
Item	Corn	CS	CM	CSM	SFS	SFM	SFM-DH	SBM	SEM	*P* value
As-fed basis										
GE (kcal kg^{-1})	4051	6375	4362	4348	7122	4290	4270	4293	–	–
DE (kcal kg^{-1})	3567*d*	5064*b*	3313*e*	2745*f*	5842*a*	2944*f*	2848*f*	4115*c*	85	<0.001
ME (kcal kg^{-1})	3481*c*	4803*b*	2998*d*	2459*e*	5492*a*	2725*de*	2631*e*	3676*c*	102	<0.001
DM basis										
GE (kcal kg^{-1})	4588	6767	4809	4772	7442	4720	4641	4712	–	–
DE (kcal kg^{-1})	4040*d*	5375*b*	3652*e*	3016*f*	6105*a*	3238*f*	3095*f*	4518*c*	92	<0.001
ME (kcal kg^{-1})	3942*c*	5098*b*	3306*d*	2700*e*	5739*a*	2998*de*	2860*e*	4035*c*	110	<0.001

[z]Data are least squares means of six observations per dietary treatment.
[y]CS, canola seeds; CM, canola meal; CSM, cottonseed meal; SFS, sunflower seeds; SFM, sunflower meal; SFM-DH, de-hulled sunflower meal; SBM, soybean meal.
a–f Means within a row lacking a common letter differ ($P < 0.05$).

Table 7. Phosphorus balance, apparent total tract digestibility (%), and standardized total tract digestibility (%) of P in pigs fed diets containing canola seeds, canola meal, cottonseed meal, sunflower seeds, sunflower meal, de-hulled sunflower meal, and soybean meal with and without microbial phytase[z,y], exp. 2

Item	ADFI[x] (g d^{-1})	P intake (g d^{-1})	P output (g d^{-1})	P absorbed (g d^{-1})	ATTD[w] of P (%)	Basal EPL[v] (mg d^{-1})	STTD of P[u] (%)
No phytase							
Canola seeds	474	1.97*de*	1.16*bc*	0.81*ef*	40.8*de*	94.8	45.6*ef*
Canola meal	457	1.60*g*	0.76*ef*	0.84*ef*	52.2*c*	91.5	58.0*cd*
Cotton seed meal	462	2.46*a*	1.43*a*	1.03*bcde*	41.8*de*	92.4	45.6*ef*
Sunflower seeds	432	1.60*g*	0.86*def*	0.74*f*	46.3*cd*	86.4	51.7*cde*
Sunflower meal	461	2.11*cd*	1.42*a*	0.69*f*	33.0*e*	92.2	37.4*f*
De-hulled sunflower meal	452	2.40*ab*	1.29*ab*	1.11*abcd*	46.2*cd*	90.4	50.0*de*
Soybean meal	458	1.59*g*	0.70*fg*	0.90*def*	56.3*bc*	91.7	62.0*bc*
With phytase							
Canola seeds	445	1.89*def*	0.64*fgh*	1.25*ab*	66.0*ab*	89.0	70.7*ab*
Canola meal	477	1.68*fg*	0.52*gh*	1.15*abc*	68.9*a*	95.3	74.6*a*
Cotton seed meal	460	2.35*ab*	1.05*cd*	1.33*a*	56.0*bc*	93.3	60.0*bcd*
Sunflower seeds	453	1.72*fg*	0.53*gh*	1.19*ab*	68.5*a*	90.5	73.8*a*
Sunflower meal	479	2.22*bc*	0.98*cd*	1.24*ab*	55.4*c*	95.9	59.8*cd*
De-hulled sunflower meal	467	1.86*ef*	0.93*de*	0.93*cdef*	49.9*cd*	93.4	54.9*cde*
Soybean meal	471	1.69*fg*	0.46*h*	1.23*ab*	72.5*a*	94.3	78.0*a*
SEM	18	0.08	0.08	0.09	3.7	3.7	3.7
P value							
Ingredient	0.82	<0.001	<0.001	0.21	<0.001	0.82	<0.001
Phytase	0.43	0.28	<0.001	<0.001	<0.001	0.38	<0.001
Ingredient × Phytase	0.82	<0.001	0.49	0.003	0.09	0.84	0.14

[z]OptiPhos 2000 (2000 FTU g^{-1}, Enzyvia, Sheridan, IN). FTU, phytase units.
[y]Data are means of six observations per dietary treatment.
[x]ADFI, average daily feed intake.
[w]ATTD, apparent total tract digestibility.
[v]EPL, endogenous P loss. The basal endogenous P losses (EPL) used was 200 mg kg^{-1} DMI, which is the average EPL of 10 experiments measured from pigs fed a P-free diet (Stein 2011). The daily basal EPL (mg d^{-1}) for each diet was calculated by multiplying the EPL (mg kg^{-1} DMI) by the daily DMI of each diet.
[u]STTD, standardized total tract digestibility. Values for STTD were calculated by correcting values of ATTD for basal EPL.
a–h Means within a row lacking a common letter differ ($P < 0.05$).

and SBM diets, reduced ($P < 0.05$) Ca intake for pigs fed SFM-DH diets, but had no effect on Ca intake for pigs fed diets containing the other ingredients (ingredient × phytase interaction, $P < 0.05$; Table 8).

Pigs fed the SFM diets had the greatest ($P < 0.05$) daily Ca output among all ingredients. Pigs fed the SBM or CSM diets also had greater ($P < 0.05$) daily Ca output than pigs fed the CS, SFS, or CM diets. Daily Ca output from pigs fed SFM-DH diets was less ($P < 0.05$) than from pigs fed the SBM diets. Adding phytase to the diet reduced ($P < 0.05$) daily Ca output from pigs fed diets containing CS and SFM. However, phytase only increased ($P < 0.05$) the amount of Ca absorbed by pigs when added to diets containing SBM, SFS, or SFM, but not to the other diets (diet × phytase interaction, $P < 0.05$). If no phytase was included in the diets, the ATTD of Ca was greater ($P < 0.05$) in the CM diet (68.3%) than in diets containing CSM, SFS, or SFM (57.6, 55.7, and 56.3%, respectively), but not different from diets containing CS, SFM-DH, or SBM (62.3, 65.4, and 65.9%, respectively). If microbial phytase was added to the diets, the ATTD of Ca was greater ($P < 0.05$) in the diet containing CM (79.9%) than in diets containing CSM, SFM, or SFM-DH (64.6, 67.9, and 67.5%, respectively), but not different from the ATTD of Ca in diets containing CS, SFS, or SBM (78.8, 76.4, and 74.1%, respectively). Adding phytase to the diet increased ($P < 0.05$) ATTD of Ca in all diets except the diet containing CSM, SFM-DH, or SBM.

DISCUSSION

Ingredient Composition

Concentrations of GE, Ca and total P in all ingredients were in agreement with values reported by Sauvant et al. (2004) and NRC (2012); however, concentration of Ca in SBM fed in this experiment was greater than reported values (Sauvant et al. 2004; NRC 2012). The concentration of acid-hydrolyzed ether extract in the SFS fed in this experiment was 54.5% (as-fed basis), whereas Sauvant et al. (2004) reported a value of 44.5% for crude fat in SFS. The concentration of phytate in the canola products fed in this experiment was greater than published values (Eeckhout and de Paepe 1994; Godoy et al. 2005), but there are limited data on the phytate concentration in CSM and SFS. Although, the concentration of phytate P in SFM, SFM-DH, and SBM that were fed in this experiment were in agreement with values reported by NRC (2012), the percentage of

Table 8. Calcium balance and apparent total tract digestibility (%) of Ca in pigs fed diets containing canola seeds, canola meal, cottonseed meal, sunflower seeds, sunflower meal, de-hulled sunflower meal, and soybean meal with and without microbial phytase[z,y], exp. 2

Item	Ca intake (g d^{-1})	Ca output (g d^{-1})	Ca absorbed (g d^{-1})	ATTD[x] of Ca (%)
No phytase				
Canola seeds	2.60*e*	0.96*de*	1.63*cd*	62.3*efg*
Canola meal	1.98*g*	0.63*fgh*	1.36*d*	68.3*bcde*
Cotton seed meal	2.71*e*	1.15*cd*	1.56*cd*	57.6*fg*
Sunflower seeds	1.51*i*	0.66*fgh*	0.85*e*	55.7*g*
Sunflower meal	4.52*b*	1.94*a*	2.58*b*	56.3*g*
De-hulled sunflower meal	3.08*d*	1.07*efg*	2.02*c*	65.4*defg*
Soybean meal	3.83*c*	1.31*bc*	2.52*b*	65.9*cdefg*
With phytase				
Canola seeds	2.43*ef*	0.51*gh*	1.92*c*	78.8*ab*
Canola meal	2.18*fg*	0.44*h*	1.74*cd*	79.9*a*
Cotton seed meal	2.64*e*	0.93*def*	1.71*cd*	64.6*defg*
Sunflower seeds	1.82*hi*	0.42*h*	1.39*d*	76.4*abc*
Sunflower meal	4.91*a*	1.56*b*	3.35*a*	67.9*cdef*
De-hulled sunflower meal	2.47*ef*	0.80*efg*	1.67*cd*	67.5*cdef*
Soybean meal	4.50*b*	1.15*cd*	3.35*a*	74.1*abcd*
SEM	0.13	0.11	0.16	3.7
P value				
Ingredient	<0.001	<0.001	<0.001	0.01
Phytase	0.14	<0.001	<0.001	<0.001
Ingredient × Phytase	<0.001	0.80	0.01	0.25

a–i Means within a column lacking a common superscript letter differ ($P < 0.05$).

phytate P as a percentage of total P in SFM and SFM-DH was relatively lower than the values reported by NRC (2012).

The difference method was used to determine the concentration of DE and ME in the feed ingredients included in this experiment. A consequence of using the difference method is that accurate results for the test ingredients are obtained only if the values obtained for corn are accurate. However, values for the DE and ME in corn that were obtained in the present experiment are in close agreement with previous data (Sauvant et al. 2004; Goebel and Stein 2011; NRC 2012). The DE and ME obtained for SBM are also in close agreement with recently reported values (Baker and Stein 2009; Goebel and Stein 2011; Sulabo et al. 2013). Likewise, the ATTD and STTD of P in SBM were within the range of values previously determined in our laboratory (Almeida and Stein 2010; Kim and Stein 2010; Goebel and Stein 2011; Rojas and Stein 2012). However, the ATTD of P in SBM obtained in this experiment is greater than some other reported values (Jongbloed and Kemme 1990; Sauvant et al. 2004; NRC 2012).

Canola Seeds and Canola Meal

Canola accounts for 13% of global oilseed production and it is the second most produced oilseed in the world after soybeans (USDA 2010). Canola meal, which is the co-product after oil is solvent-extracted from CS, is also widely included as a protein source in swine diets (Canola Council of Canada 2009). Values for DE and ME in CS obtained in the present experiment are within the wide range of reported values for CS (Salo 1980; Shaw et al. 1990; Bourdon and Aumaître 1990; Sauvant et al. 2004; NRC 2012). The DE and ME calculated for CM are in agreement with reported values (Bourdon and Aumaître 1990; NRC 2012). The reduced DE and ME in CM compared with SBM may be a consequence of the greater concentration of ADF and NDF in CM, which also explains the reduced ATTD of GE in CM compared with SBM (Landero et al. 2011).

Differences in DE and ME in CM among experiments may also be a consequence of differences in the concentration of fat in the meal (Rundgren 1983). The variability in fat concentration among different sources of CM might be due to differences in processing equipment and efficiencies of oil extraction among crushing plants. However, differences in fat and GE concentrations among sources of CM may also be due to differences in the amount of gums added back to the meal after oil extraction (Woyengo et al. 2010). Most crushing plants add gums from oil refining to the meal, but the concentrations vary among plants (Spragg and Mailer 2007; Canola Council of Canada 2009). The concentration of acid hydrolyzed ether extract in the CM fed in the present experiment is slightly greater than reported values for ether extract (Sauvant et al. 2004; NRC 2012), which may explain the greater ME that was observed for the CM fed in this experiment.

The ATTD of P in CS that was calculated in this experiment is in agreement with some published values (Rodehutscord et al. 1997; DLG 1999), but greater than others (Larsen and Sandström 1993; Sauvant et al. 2004). In contrast, the ATTD of P in CM was greater than most published values (Fan and Sauer 2002; Sauvant et al. 2004; Wu et al. 2008; Akinmusire and

Adeola 2009). The reason for the differences in the ATTD of P in CS and CM may be that there is great variability among sources of canola meal in the percentage of P that is bound to phytate (Weremko et al. 1997; Selle and Ravindran 2008). It is, however, also possible that due to processing, there is less phytate bound P in CM compared with CS (Sauvant et al. 2004). The fact that the ATTD of P was increased as microbial phytase was added to the diet is in agreement with data reported by Akinmusire and Adeola (2009). To our knowledge, the STTD of P has not been previously reported for CS or CM fed to growing pigs. However, data from this experiment indicate that pigs utilize the P in both ingredients relatively well if microbial phytase is added to the diet. It was also observed that the digestibility of P in CS and CM, as well as the other oilseeds and oilseed meals fed in the present experiments, exceeded the percentage concentration of non-phytate P in the ingredients. This observation may be a consequence of release of small amounts of phytate-bound P in the stomach and small intestine of pigs.

The sources of Ca in the diets were ground limestone and the Ca supplied by CS or CM. The greater digestibility of Ca in CM diets than in diets containing CSM or sunflower products indicates that less inorganic Ca is needed when CM is included in the diets. Adding microbial phytase to the diets also improved Ca digestibility, which is in agreement with other experiments (Selle et al. 2009; Goebel and Stein 2011; Rojas and Stein 2012). This observation indicates that microbial phytase liberates organic Ca bound to phytate in oilseeds and oilseed meals.

Cottonseed Meal

Cottonseed is the third most widely produced oilseed in the world, and cottonseed production accounts for approximately 10% of global oilseed production (USDA 2010). In swine and poultry diets, CSM is included primarily as an alternative protein source due to its high protein content. Cottonseed meal must contain not less than 36% CP (Association of American Feed Control Officials 2011). Values for DE and ME of CSM obtained in the present experiment are within the range of previously reported values (Husby and Kroening 1971; Knabe et al. 1979; NRC 2012). The DE and ME in CSM was less than in canola meal and SBM, which is a result of the reduced ATTD of energy in CSM compared with canola meal and SBM. This observation is in agreement with data from Knabe et al. (1979).

The ATTD and STTD of P in CSM that were determined in the present experiment (41.8 and 45.6%, respectively) are in agreement with values reported by NRC (2012), but the ATTD of P is greater than other reported values (DLG 1999; Sauvant et al. 2004; Wu et al. 2008), and the STTD of P is greater than the 30% true total tract digestibility of P in CSM determined by Wu et al. (2008). Phytate bound P in CSM is between 63 and 80% of total P (Godoy et al. 2005; Selle and Ravindran 2008), and the percentage of phytate bound P in the CSM used in the present experiment (69%) is within this range. The improvement in the ATTD of P that was observed as phytase was added to the diet is in agreement with previous data (Han and Wilfred 1988) and the current results confirmed the efficacy of microbial phytase in CSM.

In the CSM diets, most of the Ca was supplied by ground limestone due to the low concentration of Ca in CSM. The ATTD of Ca in limestone is 60 to 70% (Stein et al. 2011), but to our knowledge, there are no other reported data for Ca digestibility in CSM. Because most of the Ca was from ground limestone, the digestibility of Ca in the CSM diets was expected to be relatively high. However, results of this experiment indicate that the ATTD and STTD in the CSM diet were less than in diets containing other oilseeds and oilseed meals, indicating that some Ca from ground limestone may be bound to phytate in CSM. The relatively small increase in the ATTD of Ca that was observed as microbial phytase was added to the diet also indicates that phytase cannot hydrolyze all the Ca-phytate complexes (Selle et al. 2009).

Sunflower Products

Sunflower is the fifth largest oilseed crop in the world, and global sunflower production accounts for approximately 7% of the world oilseed production (USDA 2010). Sunflower seeds contain between 25 and 40% hulls and the seeds may either be decorticated (de-hulled) or un-decorticated before oil extraction (Feedipedia 2012). However, even if the seeds are decorticated before processing, about 30% of the removed shells are usually added back to the decorticated kernels to increase the efficiency of oil extraction (Feedipedia 2012).

The values for DE and ME of SFS obtained in the present experiment (5842 and 5492 kcal kg^{-1}, respectively) are greater than published values (Adams and Jensen 1985; Sauvant et al. 2004; NRC 2012), and values for DE and ME in SFM (2944 and 2725 kcal kg^{-1}, respectively) are also greater than published values (Sauvant et al. 2004; NRC 2012). These differences may be a result of differences in fat concentration and energy digestibility among sources of SFS. In the values reported by Sauvant et al. (2004), the average concentration of crude fat was 48% (DM basis) and the energy digestibility was 71% (Sauvant et al. 2004). However, the concentration of fat in the SFS used in the present experiment was 57% (DM basis) and the ATTD of GE was 82%, which likely is the reason for the greater DE and ME obtained in the present experiment compared with the values reported by Sauvant et al. (2004). The ATTD of energy in SFM reported by Sauvant et al. (2004) is also less than the value obtained for SFM in the present experiment (52 vs. 79%). However, values for DE and ME in SFM-DH obtained in the present experiment (2848 and 2631 kcal kg^{-1}, respectively) are

within the range of published values (Sauvant et al. 2004; NRC 2012). It was surprising that the removal of hulls prior to oil extraction did not affect energy digestibility or the concentration of DE and ME in SFM. The concentrations of NDF and ADF in the SFM-DH used in the present experiment were, however, only 8 to 10 percentage units less than in the SFM that was used, which indicates that the SFM-DH that was used was only partially decorticated. In addition, the concentration of ash was 1.3 percentage units greater in SFM-DH than in SFM, which may be the reason that no differences in DE and ME were observed between the two ingredients.

The ATTD and STTD of P in SFS and SFM-DH are greater than reported values (NRC 2012), and the ATTD of P in SFM obtained in this experiment is also greater than published values (Gomes et al. 1990; Jongbloed and Kemme 1990; DLG 1999; Sauvant et al. 2004; NRC 2012), which may be a result of the reduced phytate concentration in the SFM and SFM-DH used in this experiment. The reduced STTD of P in SFM compared with SFS may also be a result of the greater concentration of phytate bound P in SFM than in SFS. As with the other oilseeds and oilseed meals, microbial phytase released phytate-bound P and improved the STTD of P in sunflower-products.

Although SFS, SFM, and SFM-DH diets had different Ca concentrations, digestibility of Ca was not affected. This observation is consistent with data indicating that the ATTD of Ca is not affected by Ca concentration, if Ca concentration is between 0.33 and 1.04% (Stein et al. 2011).

CONCLUSIONS

The concentration of DE and ME was greater in SFS and CS than in the oilseed meals, but CM, CSM, SFM, and SFM-DH had less DE and ME compared with SBM. It is, therefore, apparent that SFS and CS are good sources of DE and ME when fed to pigs. The STTD of P in CM was not different from SBM and SFS, but both CM and SBM had greater STTD of P than CSM. Inclusion of microbial phytase to the diets increased ATTD and STTD of P and ATTD of Ca in all ingredients.

Based on the data obtained in this and previous experiments, it is possible to include a number of different oilseed products in diets fed to pigs to meet the requirements for STTD P and DE or ME. However, local availability and cost will determine, which ingredients are most economical to include in diets fed to pigs. Sunflower seeds contained at least 689 kcal kg^{-1} more ME than all other feed ingredients used in this experiment. The STTD of P in SBM was at least 4 percentage units greater than the STTD of P in the other ingredients used in this experiment.

ACKNOWLEDGMENTS

The authors acknowledge Archer Daniels Midland Company, Decatur, IL, for donating sunflower meal and dehulled sunflower meal for this research.

Adams, K. L. and Jensen, A. H. 1985. Effect of dietary protein and fat levels on the utilization of the fat in sunflower seeds by the young pig. Anim. Feed Sci. Technol. **13**: 159–170.

Adeola, O. 2001. Digestion and balance techniques in pigs. Pages 903–916 *in* A. J. Lewis and L. L. Southern, eds. Swine nutrition. 2nd ed. CRC Press, Boca Raton, FL.

Akinmusire, A. S. and Adeola, O. 2009. True digestibility of phosphorus in canola and soybean meals for growing pigs: Influence of microbial phytase. J. Anim. Sci. **87**: 977–983.

Almeida, F. N. and Stein, H. H. 2010. Performance and phosphorus balance of pigs fed diets formulated on the basis of values for standardized total tract digestibility of phosphorus. J. Anim. Sci. **88**: 2968–2977.

AOAC International. 2007. W. Horwitz and G. W. Latimer, Jr., eds. Official methods of analysis of AOAC Int. 18th ed. Rev. 2. AOAC Int., Gaithersburg, MD.

Association of American Feed Control Officials. 2011. Official publication of the Association of American Feed Control Officials. AAFCO, Washington, DC.

Baker, K. M. and Stein, H. H. 2009. Amino acid digestibility and concentration of digestible and metabolizable energy in soybean meal produced from conventional, high-protein, or low-oligosaccharide varieties of soybeans and fed to growing pigs. J. Anim. Sci. **87**: 2282–2290.

Bourdon, D. and Aumaître, A. 1990. Low-glucosinolate rapeseeds and rapeseed meals: effect of technological treatments on chemical composition, digestible energy content and feeding value for growing pigs. Anim. Feed. Sci. Technol. **30**: 175–191.

Canola Council of Canada. 2009. Canola Council of Canada home page. [Online] Available: http://www.canola-council.org/meal.html. [2012 Feb. 03].

Chiba, L. I. 2001. Protein supplements. Pages 803–837 *in* A. J. Lewis, and L. L. Southern, eds. Swine nutrition. 2nd ed. CRC Press, Boca Raton, FL.

DLG. 1999. Schweinefütterung auf der basis des verdaulichen phosphors. DLG-Information 1/1999. DLG, Frankfurt, Germany.

Eeckhout, W. and De Paepe, M. 1994. Total phosphorus, phytate-phosphorus and phytase activity in plant feedstuffs. Anim. Feed Sci. Technol. **47**: 19–29.

Ellis, R., Morris, E. R. and Philpot, C. 1977. Quantitative determination of phytate in the presence of high inorganic phosphate. Anal. Biochem **77**: 536–539.

Fan, M. Z. and Sauer, W. C. 2002. Additivity of apparent ileal and fecal phosphorus digestibility values measured in single feed ingredients for growing-finishing pigs. Can. J. Anim. Sci. **82**: 183–191.

Feedipedia. 2012. Animal feed resources information system. [Online] Available: http://www.trc.zootechnie.fr/node [2012 Feb. 03].

Godoy, S., Chicco, C., Meschy, F. and Requena, F. 2005. Phytic phosphorus and phytase activity of animal feed ingredients. Interciencia **30**: 24–28.

Goebel, K. P. and Stein, H. H. 2011. Phosphorus digestibility and energy concentration of enzyme-treated and conventional soybean meal fed to weanling pigs. J. Anim. Sci. **89**: 764–772.

Goldsmith, P. D. 2008. Economics of soybean production, marketing, and utilization. Pages 117–150 *in* L. A. Johnson, P. J. White, and R. Galloway, eds. Soybeans: Chemistry, production, processing and utilization. AOCS Press, Urbana, IL.

Gomes, C. P., De Lima, G. J. M. M., Gomes, M. M. F. and Filho, T. E. 1990. Availability of phosphorus in soyabean meal, defatted rice bran, and sunflower meal for pigs. Rev. Soc. Bras. Zootec. **19**: 498–502.

González-Vega, J. C. and Stein, H. H. 2012. Digestibility of amino acids in canola-, cotton-, and sunflower-products fed to finishing pigs. J. Anim. Sci. **90**: 4391–4400.

Han, Y. W. and Wilfred, A. G. 1988. Phytate hydrolysis in soybean and cottonseed meals by *Aspergillus ficuum* Phytase. J. Agric. Food Chem. **36**: 259–262.

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. J. Assoc. Off. Anal. Chem. **56**: 1352–1356.

Husby, F. M. and Kroening, G. H. 1971. Energy value of cottonseed meal for swine. J. Anim. Sci. **33**: 592–594.

Jongbloed, A. W. and Kemme, P. A. 1990. Apparent digestible phosphorus in the feeding of pigs in relation to availability, requirement, and environment. 1. Digestible phosphorus in feedstuffs from plant and animal origin. Neth. J. Agric. Sci. **38**: 567–575.

Knabe, D. A., Tanksley, Jr., T. D. and Hesby, J. H. 1979. Effect of lysine, crude fiber and free gossypol in cottonseed meal on the performance of growing pigs. J. Anim. Sci. **49**: 134–142.

Kim, B. G. and Stein, H. H. 2010. Energy concentration and phosphorus digestibility in yeast products, fish meal, and soybean meal fed to growing pigs. J. Anim. Sci. **88** (E-Suppl. 3): 86. (Abstr.)

Kim, B. G., Petersen, G. I., Hinson, R. B., Allee, G. L. and Stein, H. H. 2009. Amino acid digestibility and energy concentration in a novel source of high-protein distillers dried grains and their effects on growth performance of pigs. J. Anim. Sci. **87**: 4013–4021.

Landero, J. L., Beltranena, E., Cervantes, M., Morales, A. and Zijlstra, R. T. 2011. The effect of feeding solvent-extracted canola meal on growth performance and diet nutrient digestibility in weaned pigs. Anim. Feed Sci. Technol. **170**: 136–140.

Larsen, T. and Sandström, B. 1993. Effect of dietary calcium level on mineral and trace element utilization from a rapeseed (*Brassica napus* L.) diet fed to ileum-fistulated pigs. Br. J. Nutr. **69**: 211–224.

National Research Council. 1998. Nutrient requirements of swine. 10th ed. National Academy Press, Washington, DC.

National Research Council. 2012. Nutrient requirements of swine. 11th Ed. National Academy Press, Washington, DC.

Rodehutscord, M., Faust, M. and Hof, C. 1997. Digestibility of phosphorus in protein-rich ingredients for pig diets. Arch. Anim. Nutr. **50**: 201–211.

Rojas, O. J. and Stein, H. H. 2012. Digestibility of phosphorus by growing pigs of fermented and conventional soybean meal without and with microbial phytase. J. Anim. Sci. **90**: 1506–1512.

Rundgren, M. 1983. Low-glucosinolate rapeseed products for pigs – a review. Anim. Feed. Sci. Technol. **9**: 239–262.

Salo. 1980. Nutritive value of full fat rapeseeds for growing pigs. J. Sci. Agric. Soc. Finland **52**: 1–6.

Sauvant, D., Perez, J. and Tran, G. 2004. Tables of composition and nutritional value of feed materials: Pigs, poultry, cattle, sheep, goats, rabbits, horses, fish. 2nd ed. Wageningen Academic Publishers, Wageningen, the Netherlands and INRA Editions, Versailles, France.

Selle, P. H. and Ravindran, V. 2008. Phytate-degrading enzymes in pig nutrition. Livest. Sci. **113**: 99–122.

Selle, P. H., Cowieson, A. J. and Ravindran, V. 2009. Consequences of calcium interactions with phytate and phytase for poultry and pigs. Livest. Sci. **124**: 126–141.

Shaw, J., Baidoo, S. K. and Aherne, F. X. 1990. Ileal and faecal energy digestibility coefficients of full-fat canola seed for swine. Anim. Feed Sci. Technol. **28**: 71–77.

Spragg, J. and Mailer, R. 2007. Canola meal value chain quality improvement. A final report prepared for AOF and Pork CRC. JCS Solutions Pty Ltd., Berwick, Victoria, Australia.

Stein, H. H. 2011. Standardized total tract digestibility (STTD) of phosphorus. Pages 47–52 *in* Proc. Midwest Swine Nutr. Conf., Indianapolis, IN.

Stein, H. H., Adeola, O., Cromwell, G. L., Kim, S. W., Mahan, D. C. and Miller, P. S. 2011. Concentration of dietary calcium supplied by calcium carbonate does not affect the apparent total tract digestibility of calcium, but reduces digestibility of phosphorus by growing pigs. J. Anim. Sci. **89**: 2139–2144.

Sulabo, R. C., Ju, W. S. and Stein, H. H. 2013. Amino acid digestibility and energy content of copra expellers, palm kernel expellers, palm kernel meal, and soybean meal fed to growing pigs. J. Anim. Sci. **91**: 1391–1399.

Thacker, P. A. 1990. Canola meal. Pages 69–78 *in* P. A. Thacker and R. N. Kirkwood, eds. Non traditional feed sources in swine production. Butterworths Publishers, Stoneham, MA.

Tran, G. and Sauvant, D. 2004. Chemical data and nutritional value. Pages 17–24 *in* D. Sauvant, J. M. Perez, and G. Tran, eds. Tables of composition and nutritional value of feed materials: Pigs, poultry, cattle, sheep, goats, rabbits, horses, fish. 2nd ed. Wageningen Academic Publishers, Wageningen, the Netherlands and INRA Editions, Versailles, France.

US Department of Agriculture. 2010. World oilseed production 2010. [Online] Available: http://www.soystats.com/2011/page_29.htm [2012 Feb. 03].

Wahlstrom, R. C. 1990. Sunflower seeds. Pages 473–480 *in* P. A. Thacker and R. N. Kirkwood, eds. Non traditional feed sources in swine production. Butterworths Publishers, Stoneham, MA.

Weremko, D., Fandrejewski, H., Zebrowska, T., Han, I. K., Kim, J. H. and Cho, W. T. 1997. Bioavailability of phosphorus in feeds of plant origin for pigs. Asian Austral. J. Anim. **10**: 551–566.

Widmer, M. R., McGinnis, L. M. and Stein, H. H. 2007. Energy, phosphorus, and amino acid digestibility of high-protein distillers dried grains and corn germ fed to growing pigs. J. Anim. Sci. **85**: 2994–3003.

Woyengo, T. A., Kiarie, E. and Nyachoti, C. M. 2010. Energy and amino acid utilization in expeller-extracted canola meal fed to growing pigs. J. Anim. Sci. **88**: 1433–1441.

Wu, X., Ruan, Z., Zhang, Y. G., Hou, Y. Q., Yin, Y. L., Li, T. J., Huang, R. L., Chu, W. Y., Kong, X. F., Gao, B. and Chen, L. X. 2008. True digestibility of phosphorus in different resources of feed ingredients in growing pigs. Asian Austral. J. Anim. **21**: 107–119.