Energy concentration and amino acid digestibility in high-protein canola meal, conventional canola meal, and soybean meal fed to growing pigs

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ABSTRACT: Two experiments were conducted to determine DE and ME and the standardized ileal digestibility (SID) of CP and AA in 2 sources of high-protein canola meal (CM-HP1 and CM-HP2), conventional canola meal (CM-CV), and soybean meal (SBM) fed to growing pigs. In Exp. 1, 40 barrows (51.5 ± 4.0 kg initial BW) were housed in metabolism cages and randomly allotted to 1 of 5 diets with 8 replicate pigs per diet. A corn-based diet (97.4% corn) and 4 diets that contained both corn and each of the 3 sources of canola meal or SBM were formulated. Feces and urine were collected for 5 d after a 5-d adaptation period. The DE and ME were 3,347 and 3,268 kcal/kg in corn, 3,312 and 2,893 kcal/kg in CM-HP1, 3,627 and 3,346 kcal/kg in CM-HP2, 2,798 and 2,492 kcal/kg in CM-CV, and 4,000 and 3,796 kcal/kg in SBM, respectively. Values for DE and ME were greater ($P < 0.05$) in SBM than in all other ingredients, but DE and ME were greater ($P < 0.05$) in corn and the 2 high-protein canola meals than in CM-CV. The DE and ME were also greater ($P < 0.05$) in CM-HP2 than in CM-HP1. In Exp. 2, 10 barrows (65.3 ± 10.4 kg initial BW) were equipped with a T-cannula in the distal ileum and randomly allotted to a replicated 5 × 5 Latin square design with 5 diets and 5 periods in each square. A N-free diet and 4 corn starch-based diets that contained CM-HP1, CM-HP2, CM-CV, or SBM as the sole source of AA were formulated. Each period lasted 7 d and ileal digesta were collected on d 6 and 7 of each period. The SID of CP and all AA except Pro were greater ($P < 0.05$) in SBM than in the 3 sources of canola meal. With the exception of His and Lys, no differences in SID of indispensable AA were observed among the 3 sources of canola meal. The SID of His and Lys were greater ($P < 0.05$) in CM-HP1 and CM-HP2 than in CM-CV and the SID of CP was greater ($P < 0.05$) in CM-HP2 than in CM-CV, but no differences in the SID of indispensable AA were observed between CM-HP1 and CM-HP2. In conclusion, the 2 high-protein canola meals used in this experiment have ME values that are not different from corn but greater than in CM-CV. The SID of most AA is greater in SBM than in canola meals, but SID of His and Lys are greater in high-protein canola meals than in CM-CV. As a consequence, high-protein canola meals supply more ME and SID of AA for growing pigs than CM-CV.

Key words: amino acid digestibility, canola meal, energy, high-protein canola meal, pigs, soybean meal

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INTRODUCTION

Canola meal inclusion is usually restricted in diets for pigs in the United States because of concerns about glucosinolates and fiber, which have antinutritional properties and may reduce feed intake as well as digestibility of nutrients (Bell, 1993; Schone et al., 2001; Newkirk, 2009; Barthet and Daun, 2011). However, canola meal is often used as the primary source of AA in diets fed to pigs in Canada, China, Australia, and many European countries because canola meal has a relatively high concentration of AA and most AA are relatively well digested by pigs (González-Vega and Stein, 2012; NRC, 2012; Trindade Neto et al., 2012).

Canola breeding programs have identified yellow-seeded varieties of canola that are nutritionally superior to conventional black-seeded varieties. Canola meal produced from these yellow-seeded varieties contains more protein and less fiber than conventional canola meal (**CM-CV**) because yellow seeds are larger

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and have a thinner hull than black seeds (Downey and Bell, 1990; Thacker, 1990; Khajali and Slominski, 2012; Slominski et al., 2012). Canola meal from yellow-seeded varieties contains more ME than CM-CV when fed to broilers and turkeys (Jia et al., 2012) and the energy components of hulls are more digestible in yellow-seeded rapeseed than in brown-seeded rapeseed when fed to pigs (Bell and Shires, 1982). Standardized ileal digestibility (**SID**) by pigs of AA in yellow-seeded high-protein canola meal (**CM-HP**) has been reported (Trindade Neto et al., 2012). However, recently, black-seeded varieties of high-protein canola has become available and there are limited data for the DE and ME and the SID of AA in CM-HP produced from these varieties. Therefore, the objectives of this work was to determine the DE and ME and the SID of CP and AA in 2 sources of CM-HP produced from black-seeded high-protein canola and to compare these values with values obtained for CM-CV and soybean meal (**SBM**) when fed to growing pigs.

MATERIALS AND METHODS

General

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. Both experiments were conducted at the Swine Research Center at the University of Illinois at Urbana-Champaign. Pigs used in both experiments were the offspring of G-performer boars mated to F-25 gilts (Genetiporc, Alexandria, MN).

Ingredients used included yellow dent corn, 2 sources of reduced-fiber and high-protein canola meal (**CM-HP1** and **CM-HP2**), CM-CV, and SBM (Tables 1, 2, and 3). Both CM-HP were sourced from *Brassica napus* varieties selected for higher protein and lower fiber than conventional *B. napus*, whereas the CM-CV that was used was produced from conventional *B. napus*. The SBM was sourced from Dupont, Gibson City, IL, and corn was grown locally and obtained from the University of Illinois Feed Mill (Champaign, IL).

Experiment 1: Energy Measurements

Diets, Animals, and Experimental Design. In Exp. 1, the apparent total tract digestibility (**ATTD**) of GE and the DE and ME in corn, CM-HP1, CM-HP2, CM-CV, and SBM were determined. A total of 40 growing barrows (51.5 ± 4.0 kg initial BW) were allotted to a randomized complete block design. There were 2 periods with 20 pigs being used in each period, but all pigs had the same approximate age when they were assigned to their diets regardless of period. Within each period, the 20 pigs were blocked by BW and allotted to 5 diets with 4 pigs per diet for a total of 8 replicate pigs per diet. Pigs were placed in metabolism cages that were equipped with a feeder and a nipple drinker, fully slatted floors, a screen floor, and urine trays.

Table 1. Analyzed concentrations of GE, DM, ash, acid-hydrolyzed ether extract (AEE), CP, and AA in 2 sources of high-protein canola meal (CM-HP1 and CM-HP2), conventional canola meal (CM-CV), soybean meal (SBM), and corn (as-fed basis)

	Ingredient				
Item	CM-HP1	CM-HP2	CM-CV	SBM	Corn[1]
GE, kcal/kg	4,370	4,442	4,145	4,257	3,926
DM, %	92.72	92.60	91.22	87.49	88.95
CP, %	44.87	47.54	36.79	48.27	8.63
Ash, %	7.05	6.52	8.14	5.57	1.06
AEE, %	3.48	3.28	3.77	2.48	3.16
Indispensable, AA %					
Arg	2.79	2.87	2.09	3.43	0.38
His	1.23	1.23	0.91	1.24	0.22
Ile	1.77	1.89	1.35	2.32	0.27
Leu	3.18	3.31	2.53	3.73	0.94
Lys	2.61	2.67	2.02	3.07	0.27
Met	0.91	0.91	0.68	0.69	0.16
Phe	1.80	1.90	1.38	2.45	0.38
Thr	1.85	1.84	1.49	1.82	0.27
Trp	0.67	0.71	0.46	0.68	0.06
Val	2.23	2.48	1.72	2.50	0.40
Dispensable, AA %					
Ala	1.88	1.92	1.50	2.02	0.57
Asp	3.00	3.35	2.44	5.34	0.51
Cys	1.21	1.19	0.82	0.68	0.16
Glu	7.36	7.45	5.41	7.86	1.36
Gly	2.18	2.20	1.69	1.98	0.32
Pro	2.81	2.84	2.08	2.29	0.69
Ser	1.74	1.67	1.32	2.03	0.33
Tyr	1.20	1.24	0.96	1.75	0.23
Total AA	40.42	41.67	30.85	45.88	7.52

[1] Corn was also analyzed to contain 55.64% starch, 2.26% ADF, 9.36% NDF, 0.25% P, and 0.01% Ca.

Five corn-based diets were formulated (Table 4). The basal diet contained 97.4% corn (as-fed basis). The CM-HP1 diet contained 71.05% corn and 27.00% CM-HP1 (as-fed basis), and the CM-HP2 diet contained 72.00% corn and 26.00% CM-HP2 (as-fed basis). The CM-CV diet contained 60.80% corn and 37.50% CM-CV (as-fed basis), and the SBM diet contained 71.50% corn and 26.30% SBM (as-fed basis). Vitamins and minerals were included in all diets to meet or exceed the requirements for growing pigs (NRC, 2012). Corn, canola meal, and SBM were the only sources of energy in the diets.

Feeding and Sample Collection. The amount of feed supplied daily to the pigs was calculated as 3 times

Table 2. Analyzed concentrations of carbohydrates and minerals in 2 sources of high-protein canola meal (CM-HP1 and CM-HP2), conventional canola meal (CM-CV), and soybean meal (SBM; as-fed basis)

	Ingredient			
Item	CM-HP1	CM-HP2	CM-CV	SBM
Carbohydrates, %				
Glucose	0.79	0.83	0.47	1.65
Fructose	ND[1]	0.10	0.47	0.63
Sucrose	4.33	5.26	6.47	5.54
Maltose	ND	ND	0.04	0.30
Starch	0.40	0.29	1.54	0.28
Crude fiber	8.24	6.97	9.91	3.38
NDF, %	18.32	17.90	25.04	8.23
ADF, %	12.66	10.95	17.53	4.81
Macrominerals, %				
Ca	0.64	0.51	1.25	0.29
K	1.34	1.31	1.24	2.07
Mg	0.56	0.51	0.62	0.25
Na	0.02	0.03	0.24	0.08
P	1.26	1.16	1.16	0.57
S	0.92	0.87	1.16	0.40
Microminerals, mg/kg				
Co	ND	ND	ND	ND
Cr	3.2	2.8	1.5	0.6
Cu	5.0	4.8	8.0	12.5
Fe	97	100	159	83
Mn	74	78	76	29
Mo	1.1	1.2	2.4	2.5
Se	3.2	2.0	0.4	2.3
Zn	51	49	61	41

[1] ND = nondetectable.

the maintenance energy requirement (i.e., 197 kcal of ME/kg of BW$^{0.60}$; NRC, 2012) of the smallest pig in each replicate and divided into 2 equal meals that were fed at 0800 and 1700 h. Water was available at all times.

Pigs were fed experimental diets for 12 d. The initial 5 d were considered an adaptation period to the diet. Fecal markers were fed on d 6 (0.5% chromic oxide) and 11 (0.5% ferric oxide), and fecal collections were initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared (Adeola, 2001). Feces were collected twice daily and stored at –20°C immediately after collection. Urine was also collected and urine collections started on d 6 at 1700 h and ceased on d 11 at 1700 h. Urine buckets were placed under the metabolism cages to permit total collection. Buckets were emptied in the morning and afternoon and a preservative of 50 mL of 6 *N* HCL was added to each bucket when they were emptied. The collected urine was weighed and a 10% subsample was stored at –20°C.

Table 3. Analyzed glucosinolates of 2 sources of high-protein canola meal (CM-HP1 and CM-HP2) and conventional canola meal (CM-CV; as-fed basis)

	Ingredient		
Item, µmol/g	CM-HP1	CM-HP2	CM-CV
Progoitrin	4.24	3.62	2.11
Glucoalyssin	0.91	0.58	0.42
Gluconapoleiferin	0.70	0.66	0.42
Gluconapin	1.95	2.28	1.39
4-hydroxyglucobrassicin	4.78	4.12	1.85
Glucobrassicanapin	0.79	0.75	0.59
Glucoerucin	0.94	0.93	0.96
Glucobrassicin	0.37	0.52	0.26
Gluconasturtin	0.34	0.30	0.44
Neoglucobrassicin	0.47	0.46	0.27
Total glucosinolates	15.49	14.22	8.69

Sample Analyses. All samples were analyzed in duplicate. After completing sample collections, urine samples were thawed and mixed within animal and diet 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 lyophilized before energy analysis (Kim et al., 2009). Diets and ingredient samples (Table 1) were analyzed for DM (method 930.15; Hortwitz and Latimer, 2007), CP by combustion (method 999.03; Hortwitz and Latimer, 2007) using a Rapid N cube (Elementar Americas Inc., Mt. Laurel, NJ), ash (method 975.03; Hortwitz and Latimer, 2007), ADF (method 973.18; Hortwitz and Latimer, 2007), NDF (Holst, 1973), and acid-hydrolyzed ether extract (**AEE**), which was determined by acid hydrolysis using 3 *N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (method 2003.06; Hortwitz and Latimer, 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Diets, ingredients, feces, and urine samples were also analyzed for GE using bomb calorimetry (model 6300; Parr Instruments, Moline, IL). Ingredients were also analyzed for starch (method 948.02; Hortwitz and Latimer, 2007), Ca and P (method 985.01; Hortwitz and Latimer, 2007), and AA [method 982.30 E (a, b, c); Hortwitz and Latimer, 2007].

The 3 sources of canola meal and the SBM were also analyzed for sugar profile (glucose, fructose, sucrose, and maltose; Churms, 1982; Kakehi and Honda, 1989), oligosaccharides (raffinose, stachyose, and verbascose; Churms, 1982), and crude fiber (method 978.10; Hortwitz and Latimer, 2007). In addition to Ca and P, these samples were also analyzed for Cr, Co, Cu, Fe, Mg, Mn, Mo, K, Se, Na, S, and Zn by inductive coupled plasma–optical emission spectroscopy [method 985.01 (A, B, and C)]. The 3 sources of canola meals were also analyzed for glucosinolates (ISO, 1992).

Table 4. Composition of experimental diets containing corn, 2 sources of high-protein canola meal (CM-HP1 and CM-HP2), conventional canola meal (CM-CV), or soybean meal (SBM; as-fed basis) in Exp. 1

	Diet				
Item	Corn	CM-HP1	CM-HP2	CM-CV	SBM
Ingredient, %					
Ground corn	97.40	71.05	72.00	60.80	71.50
Test ingredient	–	27.00	26.00	37.50	26.30
Ground limestone	1.10	0.80	0.80	0.65	1.00
Monocalcium phosphate	0.80	0.45	0.50	0.35	0.50
Sodium chloride	0.40	0.40	0.40	0.40	0.40
Vitamin–mineral premix[1]	0.30	0.30	0.30	0.30	0.30
Analyzed composition					
GE, kcal/kg	3,767	3,912	3,948	3,889	3,903
DM, %	88.13	89.42	89.49	89.61	89.45
CP, %	8.86	20.13	18.85	17.81	19.55
Ash, %	3.67	4.57	4.28	5.57	4.61
AEE,[2] %	3.56	3.33	3.24	3.80	4.27
NDF, %	11.46	15.53	14.28	17.91	11.75
ADF, %	2.19	5.85	4.60	8.10	3.18

[1] Provided the following quantities of vitamins and microminerals per kilogram of complete diet: 11,136 IU vitamin A as retinyl acetate, 2,208 IU vitamin D_3 as cholecalciferol, 66 IU vitamin E as DL-α tocopheryl acetate, 1.42 mg vitamin K as menadione dimethylprimidinol bisulfite, 0.24 mg thiamin as thiamine mononitrate, 6.59 mg riboflavin, 0.24 mg pyridoxine as pyridoxine hydrochloride, 0.03 mg vitamin B_{12}, 23.5 mg D-pantothenic acid as D-calcium pantothenate, 44.1 mg niacin, 1.59 mg folic acid, 0.44 mg biotin, 20 mg Cu as copper sulfate and copper chloride, 126 mg Fe as ferrous sulfate, 1.26 mg I as ethylenediamine dihydriodide, 60.2 mg Mn as manganese sulfate, 0.3 mg Se as sodium selenite and selenium yeast, and 125.1 mg Zn as zinc sulfate.

[2] AEE = acid-hydrolyzed ether extract.

Calculations and Statistical Analysis. Energy values that were determined from the excretion of GE in the feces and urine were subtracted from the intake of GE to calculate DE and ME for each diet (Adeola, 2001). The DE and ME in the corn diet were divided by 0.974 to calculate the DE and ME in corn. The contributions of DE and ME from corn to the diets containing CM-HP1, CM-HP2, CM-CV, or SBM were then calculated and subtracted from the total DE and ME of these diets and the concentrations of DE and ME in CM-HP1, CM-HP2, CM-CV, and SBM 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 was also calculated for all diets using the direct procedure and for the 3 sources of canola meal and SBM using the difference procedure (Adeola, 2001).

Normality of data was verified and outliers were tested using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC), but no outliers were identified. Data were analyzed by ANOVA using the Mixed Procedure of SAS (SAS Inst. Inc.) in a randomized complete block design with pig as experimental unit. The statistical model included diet as the fixed effect and block as the random effect. The Least Significant Means statement was used to calculate treatment means and the PDIFF option was used to separate means if differences were detected. Statistical significance was considered at $P < 0.05$.

Experiment 2: AA Digestibility

Diets, Animals, and Experimental Design. In Exp. 2, 10 growing pigs (65.3 ± 10.4 kg) were equipped with a T-cannula in the distal ileum according to a procedure adapted from Stein et al. (1998). Pigs were allotted to a replicated 5 × 5 Latin square design with 5 periods and 5 diets in each square to determine the apparent ileal digestibility (**AID**) and the SID of CP and AA in CM-HP1, CM-HP2, CM-CV, and SBM. The 4 ingredients were sourced from the same batch as the ingredients used in Exp. 1. Pigs were housed individually in pens (1.2 by 1.5 m) in an environmentally controlled room. A feeder and a nipple drinker were installed in each pen.

Five diets were formulated (Tables 5 and 6). Four diets were based on cornstarch and CM-HP1, CM-HP2, CM-CV, or SBM, and the last diet was a N-free diet that was used to estimate basal endogenous losses of CP and AA. Vitamins and minerals were included in all diets to meet or exceed current requirements for growing pigs (NRC, 2012) and chromic oxide (0.4%) was included in all diets as an indigestible marker.

Feeding and Sample Collection. Individual pig weights were recorded at the beginning and at the conclusion of each period and the amount of feed supplied each day was also recorded. Pigs were fed at a daily level of 3.4 times the estimated maintenance requirement for energy, and the daily allotment of feed was provided at 0700 h each day. Water was available at

Table 5. Ingredient composition of experimental diets containing 2 sources of high-protein canola meal (CM-HP1 and CM-HP2), conventional canola meal (CM-CV), or soybean meal (SBM), and in the N-free diet (as-fed basis) in Exp. 2

	Diet				
Ingredient, %	CM-HP1	CM-HP2	CM-CV	SBM	N free
CM-HP1	35.00	–	–	–	–
CM-HP2	–	34.00	–	–	–
CM-CV	–	–	45.50	–	–
SBM	–	–	–	34.25	–
Soybean oil	3.00	3.00	3.00	3.00	4.00
Solka-Floc[1]	–	–	–	–	4.00
Monocalcium phosphate	0.75	0.75	0.55	0.75	1.30
Ground limestone	0.55	0.55	0.50	0.85	1.00
Sucrose	10.00	10.00	10.00	10.00	20.00
Chromic oxide	0.40	0.40	0.40	0.40	0.40
Cornstarch	49.60	50.60	39.35	50.05	68.10
Magnesium oxide	–	–	–	–	0.10
Potassium carbonate	–	–	–	–	0.40
Sodium chloride	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00

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

[2] Provided the following quantities of vitamins and microminerals per kilogram of complete diet: 11,136 IU vitamin A as retinyl acetate, 2,208 IU vitamin D_3 as cholecalciferol, 66 IU vitamin E as DL-α tocopheryl acetate, 1.42 mg vitamin K as menadione dimethylprimidinol bisulfite, 0.24 mg thiamin as thiamine mononitrate, 6.59 mg riboflavin, 0.24 mg pyridoxine as pyridoxine hydrochloride, 0.03 mg vitamin B_{12}, 23.5 mg D-pantothenic acid as D-calcium pantothenate, 44.1 mg niacin, 1.59 mg folic acid, 0.44 mg biotin, 20 mg Cu as copper sulfate and copper chloride, 126 mg Fe as ferrous sulfate, 1.26 mg I as ethylenediamine dihydriodide, 60.2 mg Mn as manganese sulfate, 0.3 mg Se as sodium selenite and selenium yeast, and 125.1 mg Zn as zinc sulfate.

Table 6. Nutrient composition of experimental diets containing 2 sources of high-protein canola meal (CM-HP1 and CM-HP2), conventional canola meal (CM-CV), or soybean meal (SBM), and in the N-Free diet (as-fed basis) in Exp. 2

	Diet				
Item	CM-HP1	CM-HP2	CM-CV	SBM	N free
GE, kcal/kg	4,450	4,403	4,378	4,222	3,817
DM, %	93.75	93.86	93.83	93.36	94.21
CP, %	16.19	16.55	16.20	16.06	0.42
Ash, %	6.87	6.09	5.77	5.57	0.16
AEE,[1] %	3.48	3.28	3.22	2.48	1.39
Indispensable AA, %					
Arg	1.00	0.95	1.00	1.11	0.01
His	0.44	0.41	0.43	0.39	0.00
Ile	0.67	0.67	0.70	0.75	0.02
Leu	1.17	1.14	1.20	1.23	0.04
Lys	1.00	0.97	1.01	1.04	0.02
Met	0.32	0.30	0.33	0.22	0.01
Phe	0.64	0.63	0.66	0.77	0.02
Thr	0.67	0.63	0.69	0.60	0.01
Trp	0.24	0.24	0.24	0.29	0.04
Val	0.83	0.83	0.87	0.76	0.01
All indispensable AA	6.98	6.77	7.13	7.16	0.18
Dispensable AA, %					
Ala	0.72	0.69	0.73	0.69	0.02
Asp	1.12	1.18	1.18	1.77	0.02
Cys	0.42	0.39	0.39	0.21	0.01
Glu	2.87	2.69	2.67	2.69	0.07
Gly	0.82	0.78	0.82	0.67	0.01
Pro	1.06	0.98	1.01	0.77	0.03
Ser	0.64	0.55	0.61	0.67	0.01
Tyr	0.41	0.4	0.45	0.51	0.01
All dispensable AA	8.06	7.66	7.86	7.98	0.18

[1] AEE = acid-hydrolyzed ether extract.

all times throughout the experiment. The initial 5 d of each period was considered an adaptation period to the diet and ileal digesta were collected for 8 h on d 6 and 7. A 225-mL plastic bag was attached to the cannula barrel by a zip tie, and digesta that flowed into the bag were collected. Bags were removed whenever they were filled with digesta, or at least once every 30 min, and digesta were immediately stored at –20°C to prevent bacterial degradation of AA in the digesta.

Sample Analysis. At the conclusion of the experiment, ileal samples were thawed and mixed within animal and diet and a subsample was collected for chemical analyses. A sample of each diet, of each source of canola meal, and of the SBM was collected as well. 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 chromium concentration was determined after nitric acid–perchloric acid wet ash sample preparation (method 990.08; Hortwitz and Latimer, 2007). All diet samples were also analyzed for GE, ash, and AEE as described for Exp. 1.

Calculations and Statistical Analysis. Values for AID, basal endogenous losses, and SID of CP and AA in the 4 AA containing diets were calculated (Stein et al., 2007). Because CM-HP1, CM-HP2, CM-CV, or SBM were the only AA-containing ingredients in these diets, the AID and SID values obtained for each diet also represent the AID and SID of CP and AA in each ingredient. The SID of CP and each AA was multiplied by the concentration of CP or the corresponding AA (as-fed basis) in the ingredients to calculate the concentration of standardized ileal digestible CP or AA for each ingredient. Data were analyzed by ANOVA using the PROC MIXED procedure (SAS Inst. Inc.) as described for Exp. 1 with the exception that the statistical model included diet as the fixed effect and pig and period as the random effects.

Table 7. Energy digestibility and concentrations of DE and ME in corn, 2 sources of high-protein canola meal (CM-HP1 and CM-HP2), conventional canola meal (CM-CV), and soybean meal (SBM; as-fed basis) in Exp. 1[1]

Item	Corn	CM-HP1	CM-HP2	CM-CV	SBM	SEM	*P*-value
Diets							
GE intake, kcal	6,624^{c}	7,283^{b}	7,216^{b}	7,575^{a}	7,043^{b}	164.4	<0.01
GE in feces, kcal	891^{c}	1,188^{b}	1,088^{b}	1,561^{a}	827^{c}	43.4	<0.01
GE in urine, kcal	134^{c}	283^{a}	237^{ab}	269^{a}	197^{b}	24.1	<0.01
ATTD[2] of GE, %	86.54^{b}	83.64^{c}	84.93^{c}	79.30^{d}	88.27^{a}	0.6	<0.01
DE, kcal/kg	3,260^{c}	3,272^{c}	3,353^{b}	3,084^{d}	3,445^{a}	23.7	<0.01
ME, kcal/kg	3,183^{b}	3,103^{c}	3,223^{b}	2,922^{d}	3,335^{a}	25.8	<0.01
Ingredients							
ATTD of GE, %	86.54^{b}	78.27^{c}	81.44^{c}	69.96^{d}	92.22^{a}	1.8	<0.01
DE, kcal/kg	3,347^{c}	3,312^{c}	3,627^{b}	2,798^{d}	4,000^{a}	74.7	<0.01
DE, kcal/kg DM	3,763^{bc}	3,572^{c}	3,917^{b}	3,067^{d}	4,572^{a}	81.8	<0.01
ME, kcal/kg	3,268^{b}	2,893^{c}	3,346^{b}	2,492^{d}	3,796^{a}	80.5	<0.01
ME, kcal/kg DM	3,674^{b}	3,120^{c}	3,613^{b}	2,732^{d}	4,339^{a}	32.7	<0.01

$^{a–d}$Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1] Each least squares mean represents 8 observations.

[2] ATTD = apparent total tract digestibility.

RESULTS

Composition of Ingredients

On an as-fed basis, the CP concentration was 44.87, 47.54, 36.79, 48.27, and 8.63% in CM-HP1, CM-HP2, CM-CV, SBM, and corn, respectively. The GE concentration was 4,370, 4,442, 4,145, 4,257, and 3,926 kcal/kg in CM-HP1, CM-HP2, CM-CV, SBM, and corn, respectively. The concentrations of NDF and ADF were 18.32 and 12.66% in CM-HP1, 17.90 and 10.95% in CM-HP2, 25.04 and 17.53% in CM-CV, 8.23 and 4.81% in SBM, and 9.36 and 2.26% in corn. The concentration of AEE was 3.48, 3.28, 3.77, 2.48, and 3.16% in CM-HP1, CM-HP2, CM-CV, SBM, and corn, respectively. The concentration of total glucosinolates was 15.49 µmol/g in CM-HP1, 14.22 µmol/g in CM-HP2, and 8.69 µmol/g in CM-CV.

Experiment 1: Energy Digestibility

Gross energy intake and fecal excretion of GE were greater ($P < 0.05$) by pigs fed the CM-CV diet than by pigs fed the corn, CM-HP1, CM-HP2, or SBM diets (Table 7). Pigs fed the CM-HP1 or CM-HP2 diets had a greater ($P < 0.05$) fecal excretion of GE than pigs fed the corn or SBM diets. Urine excretion of GE was greater ($P < 0.05$) in pigs fed the CM-CV or CM-HP1 diets than in pigs fed the corn or SBM diets, but the urine excretion of GE was not different among pigs fed the 3 canola meal diets. The ATTD of GE was less ($P < 0.05$) in pigs fed the CM-CV diet than in pigs fed the other experimental diets. The ATTD of GE was greater ($P < 0.05$) in pigs fed the SBM diet than in pigs fed all other diets, and the ATTD of GE was greater ($P < 0.05$) in pigs fed the CM-HP1 and CM-HP2 diets than in pigs fed the corn diet. The DE and ME were greater ($P < 0.05$) in the SBM diet and less ($P < 0.05$) in the CM-CV diet than in the other diets. The DE was greater ($P < 0.05$) in the CM-HP2 diet than in the corn or CM-HP1 diets, whereas the ME was greater ($P < 0.05$) in the corn and CM-HP2 diets than in the CM-HP1 diet.

The ATTD of GE was greater ($P < 0.05$) in SBM than in corn, CM-HP1, CM-HP2, and CM-CV and the ATTD of GE in CM-HP1 and CM-HP2 was greater ($P < 0.05$) than in CM-CV, but less ($P < 0.05$) than in corn. The DE and ME (as-is and DM basis) were greatest ($P < 0.05$) in SBM and least ($P < 0.05$) in CM-CV among all ingredients. The DE (DM basis) in CM-HP2 was greater ($P < 0.05$) than in CM-HP1, but not different from corn. The ME (as-is and DM basis) was greater ($P < 0.05$) in corn and CM-HP2 than in CM-HP1.

Experiment 2: AA Digestibility

The AID of CP and all AA was greater ($P < 0.05$) in SBM than in CM-HP1, CM-HP2, and CM-CV, with the exception that the AID of Cys was not different between CM-HP1 and SBM; the AID of Gly was not different among CM-HP1, CM-HP2, and SBM; and no difference in AID of Pro was observed among ingredients (Table 8). The AID of His, Lys, Ala, Glu, and Ser was greater ($P < 0.05$) in CM-HP1 than in CM-CV, but no differences in the AID of CP and other AA were observed between CM-HP1 and CM-CV. The AID of CP, Asp, Cys, and Gly was greater ($P < 0.05$) in CM-HP2 than in CM-CV, but no other differences were observed between these 2 ingredients. No differences

Table 8. Apparent ileal digestibility of CP and AA in 2 sources of high-protein canola meal (CM-HP1 and CM-HP2), conventional canola meal (CM-CV), and soybean meal (SBM) by growing pigs in Exp. 2[1]

	Ingredient					
Item	CM-HP1	CM-HP2	CM-CV	SBM	SEM	*P*-value
CP, %	73.7^{bc}	74.6^{b}	70.7^{c}	82.3^{a}	1.70	<0.01
Indispensable AA, %						
Arg	84.1^{b}	84.7^{b}	83.4^{b}	92.4^{a}	1.05	<0.01
His	83.9^{b}	83.8^{bc}	81.9^{c}	89.2^{a}	0.92	<0.01
Ile	79.5^{b}	77.4^{b}	77.0^{b}	88.8^{a}	1.66	<0.01
Leu	81.2^{b}	80.0^{b}	79.5^{b}	88.3^{a}	1.12	<0.01
Lys	80.5^{b}	78.1^{bc}	75.4^{c}	89.0^{a}	1.75	<0.01
Met	86.1^{b}	85.1^{b}	85.8^{b}	90.0^{a}	0.76	<0.01
Phe	79.4^{b}	79.0^{b}	78.9^{b}	88.2^{a}	1.09	<0.01
Thr	72.6^{b}	72.0^{b}	70.9^{b}	82.4^{a}	1.09	<0.01
Trp	87.6^{b}	87.6^{b}	86.6^{b}	92.4^{a}	0.74	<0.01
Val	76.0^{b}	75.6^{b}	75.3^{b}	86.4^{a}	1.11	<0.01
Mean	80.4^{b}	79.5^{b}	78.5^{b}	88.7^{a}	1.06	<0.01
Dispensable AA, %						
Ala	76.9^{b}	76.1^{bc}	73.4^{c}	81.3^{a}	1.30	<0.01
Asp	73.6^{bc}	75.2^{b}	71.9^{c}	85.7^{a}	1.34	<0.01
Cys	77.1^{bc}	79.0^{ab}	76.5^{c}	80.8^{a}	1.07	<0.01
Glu	86.0^{b}	85.6^{bc}	84.1^{c}	89.3^{a}	0.90	<0.01
Gly	66.6^{ab}	69.3^{a}	63.1^{b}	71.7^{a}	2.40	<0.05
Pro	52.2	59.8	35.5	39.5	9.55	0.08
Ser	77.4^{b}	74.0^{c}	73.8^{c}	86.8^{a}	1.30	<0.01
Tyr	72.2^{b}	75.8^{b}	77.5^{b}	88.1^{a}	2.77	<0.01
Mean	75.2^{b}	76.5^{b}	71.3^{c}	81.2^{a}	1.61	<0.01
All AA	77.6^{bc}	77.9^{b}	74.7^{b}	84.8^{a}	1.20	<0.01

$^{a–c}$Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1] Each least squares mean represents 10 observations.

Table 9. Standardized ileal digestibility (SID) of CP and AA in 2 sources of high-protein canola meal (CM-HP1 and CM-HP2), conventional canola meal (CM-CV), and soybean meal (SBM) by growing pigs in Exp. 2[1,2]

	Ingredient					
Item	CM-HP1	CM-HP2	CM-CV	SBM	SEM	*P*-value
CP, %	81.3^{bc}	82.5^{b}	78.9^{c}	90.0^{a}	1.70	<0.01
Indispensable AA, %						
Arg	87.5^{b}	88.3^{b}	86.8^{b}	95.5^{a}	1.05	<0.01
His	86.5^{b}	86.6^{b}	84.6^{c}	92.2^{a}	0.92	<0.01
Ile	80.4^{b}	80.7^{b}	80.2^{b}	91.3^{a}	1.05	<0.01
Leu	84.1^{b}	83.1^{b}	82.4^{b}	91.1^{a}	1.12	<0.01
Lys	80.8^{b}	80.8^{b}	78.0^{c}	90.9^{a}	1.29	<0.01
Met	87.6^{b}	86.7^{b}	87.2^{b}	92.2^{a}	0.76	<0.01
Phe	82.8^{b}	82.4^{b}	82.2^{b}	91.0^{a}	1.09	<0.01
Thr	78.8^{b}	78.6^{b}	76.9^{b}	89.3^{a}	1.09	<0.01
Trp	90.5^{b}	90.5^{b}	89.5^{b}	94.8^{a}	0.74	<0.01
Val	79.2^{b}	78.9^{b}	78.4^{b}	90.0^{a}	1.11	<0.01
Mean	83.8^{b}	83.0^{b}	81.9^{b}	92.1^{a}	1.06	<0.01
Dispensable AA, %						
Ala	83.2^{b}	82.6^{b}	79.5^{c}	87.8^{a}	1.30	<0.01
Asp	78.4^{bc}	79.7^{b}	76.4^{c}	88.7^{a}	1.34	<0.01
Cys	80.6^{c}	82.8^{b}	80.2^{c}	87.8^{a}	1.06	<0.01
Glu	88.3^{b}	88.0^{b}	86.6^{b}	91.8^{a}	0.90	<0.01
Gly	83.8^{bc}	87.5^{ab}	80.2^{c}	92.7^{a}	2.40	<0.01
Pro	91.9	102.8	76.9	93.8	9.55	0.10
Ser	83.2^{b}	80.7^{c}	79.9^{c}	92.3^{a}	1.30	<0.01
Tyr	80.7^{b}	80.3^{b}	81.5^{b}	92.0^{a}	0.95	<0.01
Mean	85.1^{bc}	86.9^{b}	81.4^{c}	91.1^{a}	1.61	<0.01
All AA	84.5^{bc}	85.1^{b}	81.6^{c}	91.6^{a}	1.20	<0.01

$^{a–c}$Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1] Each least squares mean represents 10 observations.

[2] Values for SID were calculated by correcting the values for apparent ileal digestibility for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of DMI) as CP, 13.93; Arg, 0.37; His, 0.12; Ile, 0.24; Leu, 0.37; Lys, 0.29; Met, 0.05; Phe, 0.23; Thr, 0.44; Trp, 0.07; Val, 0.29; Ala, 0.48; Asp, 0.57; Cys, 0.16; Glu, 0.70; Gly, 1.51; Pro, 4.48; Ser, 0.39; and Tyr, 0.20.

were observed in the AID and CP and all AA between CM-HP1 and CM-HP2, except that the AID of Ser was greater ($P < 0.05$) in CM-HP1 than in CM-HP2.

The SID of CP and all AA was greater ($P < 0.05$) in SBM than in CM-HP1, CM-HP2, and CM-CV, except that the SID of Gly was not different between CM-HP2 and SBM and the SID of Pro was not different among ingredients (Table 9). The SID of His, Lys, Ala, and Ser was greater ($P < 0.05$) in CM-HP1 than in CM-CV and the SID of His, Leu, Ala, Asp, Cys, Gly, and total AA was greater ($P < 0.05$) in CM-HP2 than in CM-CV. No differences were observed in the SID of CP and AA between CM-HP1 and CM-HP2, except that the SID of Cys was greater ($P < 0.05$) in CM-HP2 than in CM-HP1 and the SID of Ser was greater ($P < 0.05$) in CM-HP1 than in CM-HP2.

The concentrations of standardized ileal digestible CP and all AA except Met, Cys, and Pro were greater ($P < 0.05$) in SBM than in CM-HP1, CM-HP2, and CM-CV (Table 10). The concentration of standardized ileal digestible Met in SBM was greater ($P < 0.05$) than in CM-CV but less ($P < 0.05$) than in CM-HP1 and CM-HP2. The concentration of standardized ileal digestible Cys was also less ($P < 0.05$) in SBM than in the 3 canola meals, and the concentration of standardized ileal digestible Pro was greater ($P < 0.05$) in SBM than in CM-CV but less ($P < 0.05$) than in CM-HP2. The concentrations of standardized ileal digestible CP and all AA were greater ($P < 0.05$) in CM-HP1 and CM-HP2 than in CM-CV. The concentrations of standardized ileal digestible Arg, Ile, Leu, Phe, Trp, Val, Asp, and Tyr were greater ($P < 0.05$) in CM-HP2 than in CM-HP1, but the concentration of standardized ileal digestible Ser was less ($P < 0.05$) in CM-HP2 than in CM-HP1.

Table 10. Standardized ileal digestible CP (g/kg) and AA (g/kg) in 2 sources of high-protein canola meal (CM-HP1 and CM-HP2), conventional canola meal (CM-CV), and soybean meal (SBM) by growing pigs in Exp. 2[1]

	Ingredient					
Item	CM-HP1	CM-HP2	CM-CV	SBM	SEM	P-value
CP	364.8^{c}	392.4^{b}	290.3^{d}	435.0^{a}	7.43	<0.01
Indispensable AA						
Arg	24.4^{c}	25.4^{b}	18.2^{d}	32.8^{a}	0.27	<0.01
His	10.6^{b}	10.7^{b}	7.7^{c}	11.4^{a}	0.10	<0.01
Ile	14.2^{c}	15.3^{b}	10.8^{d}	21.2^{a}	0.18	<0.01
Leu	26.8^{c}	27.5^{b}	20.9^{d}	34.0^{a}	0.35	<0.01
Lys	21.1^{b}	21.6^{b}	15.8^{c}	28.0^{a}	0.30	<0.01
Met	8.0^{a}	7.9^{a}	5.9^{c}	6.4^{b}	0.06	<0.01
Phe	14.9^{c}	15.7^{b}	11.3^{d}	22.3^{a}	0.19	<0.01
Thr	14.6^{b}	14.5^{b}	11.5^{c}	16.3^{a}	0.19	<0.01
Trp	6.1^{b}	6.4^{a}	4.1^{c}	6.4^{a}	0.04	<0.01
Val	17.7^{c}	19.6^{b}	13.5^{d}	22.5^{a}	0.23	<0.01
Mean	159.6^{c}	164.5^{b}	119.8^{d}	201.9^{a}	1.92	<0.01
Dispensable AA						
Ala	15.6^{b}	15.9^{b}	11.9^{c}	17.8^{a}	0.23	<0.01
Asp	23.5^{c}	26.7^{b}	18.6^{d}	47.5^{a}	0.46	<0.01
Cys	9.8^{a}	9.9^{a}	6.6^{b}	6.0^{c}	0.10	<0.01
Glu	65.0^{b}	65.6^{b}	46.8^{c}	72.2^{a}	0.64	<0.01
Gly	18.3^{a}	19.2^{a}	13.6^{b}	18.3^{a}	0.47	<0.01
Pro	25.8^{ab}	29.2^{a}	16.0^{c}	21.5^{b}	2.22	<0.01
Ser	14.5^{b}	13.5^{c}	10.5^{d}	18.8^{a}	0.21	<0.01
Tyr	9.7^{c}	10.0^{b}	7.8^{d}	16.1^{a}	0.12	<0.01
Mean	181.9^{c}	190.0^{b}	132.0^{d}	218.4^{a}	3.35	<0.01
All AA	341.5^{c}	354.7^{b}	251.8^{d}	420.4^{a}	4.60	<0.01

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

[1] Each least squares mean represents 10 observations.

DISCUSSION

Chemical Characteristics of Ingredients

Canola meal and SBM are the final products after the oil is extracted via solvent extraction from canola seeds and soybeans, respectively. Canola meal is an excellent source of AA and CP that may be used as an ingredient in diets fed to pigs (Newkirk, 2011). However, canola meal contains glucosinolates that are considered antinutritional factors that can reduce feed intake (Tripathi and Mishra, 2007) and canola meal also has a high concentration of fiber that may limit the inclusion level in diets fed to pigs (Schone et al., 2001).

The process of obtaining CM-HP with less fiber than CM-CV started with new varieties of *B. napus* that were selected for high protein and lower fiber. This is the reason for the reduced concentration of NDF and ADF in CM-HP1 and CM-HP2 compared with CM-CV. The greater concentration of glucosinolates in the CM-HP compared with CM-CV was also observed by Landero et al. (2012).

The concentration of GE in CM-CV is slightly less than the values reported by the NRC (2012) but in agreement with values published by de Blas et al. (2010). The reason for the reduction of GE in CM-CV compared with data published by the NRC (2012) is most likely that the source of CM-CV used in this experiment contained more NDF and ADF than CM-CV from the NRC (2012). The high concentration of CP in CM-HP1 and CM-HP2 is mainly due to a reduction of the concentration of AEE, NDF, and ADF compared with CM-CV. These observations are in agreement with data reported by Baker and Stein (2009), who reported that high-protein soybeans contained more AA and CP than conventional soybeans due to a reduction in concentrations of carbohydrates, AEE, and fiber.

Experiment 1: Energy Digestibility

The ATTD of GE and the concentration of DE and ME in corn and SBM concur with reported values (Baker and Stein, 2009; NRC, 2012). The slightly reduced concentration of DE and ME in CM-CV compared with data reported by the NRC (2012) is likely due to the increased ADF and NDF, but the DE and ME obtained in this experiment are in agreement with values published by de Blas et al. (2010).

The greater concentration of DE and ME in CM-HP1 and CM-HP2 compared with CM-CV is most likely due to the reduced fiber concentration and the increased CP in these new sources of canola meal compared with conventional sources. This is in agreement with data reported by Le et al. (2012), and similar results in broiler chickens and young turkeys have also been reported (Jia et al., 2012). The DE and ME in high-protein SBM are also greater than the DE and ME in conventional SBM (Baker and Stein, 2009). This indicates that high-protein plant ingredients contain more DE and ME compared with conventional ingredients.

The fact that CM-CV contains less DE and ME than SBM indicates that if CM-CV is used instead of SBM, the inclusion of added fat may have to be increased if diets are formulated to a constant DE or ME. However, if CM-HP is used instead of CM-CV, less fat is needed in the formulation because of the greater concentration of DE and ME in the CM-HP, and this will reduce the cost of the diet.

Experiment 2: AA Digestibility

The concentration of CP and AA in the CM-CV and SBM used in this experiment are within the range of reported values (de Blas et al., 2010; González-Vega et al., 2011; González-Vega and Stein, 2012; NRC, 2012; Trindade Neto et al., 2012). Concentrations of CP and

AA in the CM-CV used in this experiment are also very close to the average concentrations of 7 sources of canola meal reported by Maison and Stein (2014). The concentrations of CP and most AA, except Lys, Met, and Thr in CM-HP1 and CM-HP2, used in this experiment are slightly greater than the values reported for other sources of CM-HP (Slominski et al., 2012; Trindade Neto et al., 2012). Although the concentration of CP in the 2 sources of CM-HP is close to that of SBM, concentrations of AA in CM-HP are less than in SBM because of a lower concentration of AA in the protein in canola meal compared with SBM.

The AID and SID for CP and AA in SBM observed in this experiment are within the range of previous reports (González-Vega et al., 2011; González-Vega and Stein, 2012; NRC, 2012). Soybean meal is characterized not only by the high concentration of CP and AA, but also by greater AID and SID for CP and AA compared with other plant protein sources (Stein et al., 2008). The low concentration of fiber in SBM may be one of the reasons for the high AA digestibility in SBM because fiber is one of the components that may negatively affect AA digestibility (Sauer et al., 1980; Lenis et al., 1996). The 3 sources of canola meal used in this experiment contained 3 to 4 times more NDF and ADF than SBM, which may have contributed to the reduced AID and SID of CP and AA in the canola meals compared with SBM.

The concentration of glucosinolates in the 3 sources of canola meal used in this experiment is less than reported values for other sources of canola meal (Xi et al., 2002; Slominski et al., 2012), although the CM-HP contained more glucosinolates than CM-CV. Although it has been reported that glucosinolates do not affect AA digestibility (Sauer et al., 1982), feed intake may be decreased if high levels of glucosinolates are present in the diet (Tripathi and Mishra, 2007). However, because pigs were not allowed ad libitum access to feed in this experiment, no differences in feed intake were observed.

The values for AID and SID of CP and AA in CM-CV that were calculated in this experiment are within the range of previously reported values (González-Vega and Stein, 2012; NRC, 2012; Trindade Neto et al., 2012). For most AA, the values are also within the range reported for 7 sources of canola meal (Maison and Stein, 2014), although the values obtained in this experiment are greater than the average AID and SID for the 7 sources of canola meal used by Maison and Stein (2014). Values for the AID and SID of CP and most AA in the CM-HP used in this experiment are greater than values reported for a different source of CM-HP (Trindade Neto et al., 2012). It was expected that the reduced concentrations of NDF and ADF in the CM-HP compared with CM-CV would result in greater AID and SID of CP and AA, but with the exception of His and Lys, the differences between CM-CV and the CM-HP were not significant for any indispensable AA. This result concurs with the data reported by Trindade Neto et al. (2012). However, because of the high CP and AA concentration in the CM-HP, more digestible CP and AA are provided by these meals than by CM-CV.

Conclusions

Results of these experiments indicate that the AID and SID of CP and most AA were greater in SBM than in the 3 sources of canola meal. Although the AID and SID of CP and most AA were not different among the 3 sources of canola meal, the greater concentration of AA in the CM-HP than in CM-CV results in a greater concentration of digestible AA in CM-HP, which will result in a reduced concentration of these meals being needed in the diets. The 2 sources of CM-HP also contain more DE and ME than CM-CV, which may reduce the need for addition of fat to diets containing these ingredients.

LITERATURE CITED

Adeola, O. 2001. Digestion and balance techniques in pigs. In: A. J. Lewis and L. L. Southern, editors, Swine nutrition. 2nd ed. CRC Press, Washington, DC. p. 903–916.

Baker, K. M., and H. H. Stein. 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. doi:10.2527/jas.2008-1414.

Barthet, V. J., and J. K. Daun. 2011. Seed morphology, composition, and quality. In: J. K. Daun, N. A. M. Eskin, and D. Hickling, editors, Canola: Chemistry, production, processing, and utilization. AOCS Press, Urbana, IL. p. 135–145.

Bell, J. M. 1993. Factors affecting the nutritional values of canola meal: A review. Can. J. Anim. Sci. 73:689–697. doi:10.4141/cjas93-075.

Bell, J. M., and A. Shires. 1982. Composition and digestibility by pigs of hull fractions from rapeseed cultivars with yellow or brown seed coats. Can. J. Anim. Sci. 62:557–565. doi:10.4141/cjas82-065.

Churms, S. C. 1982. Carbohydrates. In: G. Zweig and J. Sherma, editors, Handbook of chromatography. CRC Press, Boca Raton, FL. p. 209–254.

de Blas, C., G. G. Mateos, and P. Garcia-Rebollar. 2010. Tablas FEDNA de composicion y valor nutritive de alimentos para la fabricacion de piensos compuestos. 3rd rev. ed. (In Spanish.) Fundacion Española para el Desarrollo de la Nutricion Animal, Madrid, Spain.

Downey, R. K., and J. M. Bell. 1990. New developments in canola research. In: F. Shahidi, editor, Canola and rapeseed: Production, chemistry, nutrition and processing technology. Springer US, New York, NY. p. 37–46.

González-Vega, J. C., B. G. Kim, J. K. Htoo, A. Lemme, and H. H. Stein. 2011. Amino acid digestibility in heated soybean meal fed to growing pigs. J. Anim. Sci. 89:3617–3625. doi:10.2527/jas.2010-3465.

González-Vega, J. C., and H. H. Stein. 2012. Amino acid digestibility in canola, cottonseed, and sunflower products fed to finishing pigs. J. Anim. Sci. 90:4391–4400. doi:10.2527/jas.2011-4631.

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

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

International Organization for Standardization (ISO). 1992. Method using high performance liquid chromatography p. 1-9 in Determination of glucosinolates content. ISO 9167-1:7992(E). ISO, Geneva, Switzerland.

Jia, W., D. Mikulski, A. Rogiewicz, Z. Zdunczyk, J. Jankowski, and B. A. Slominski. 2012. Low-fiber canola. Part II: Nutritive value of the meal. J. Agric. Food Chem. 60:12231–12237. doi:10.1021/jf302118c.

Kakehi, K., and S. Honda. 1989. Silyl ethers of carbohydrates. In: C. J. Biermann and G. D. McGinnis, editors, Analysis of carbohydrates by GLC and MS. CRC Press, Boca Raton, FL. p. 43–85.

Khajali, F., and B. A. Slominski. 2012. Review: Factors that affect the nutritive value of canola meal for poultry. Poult. Sci. 91:2564–2575. doi:10.3382/ps.2012-02332.

Kim, B. G., G. I. Petersen, R. B. Hinson, G. L. Allee, and H. H. Stein. 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. doi:10.2527/jas.2009-2060.

Landero, J. L., E. Beltranena, and R. T. Zijlstra. 2012. Growth performance and preference studies to evaluate solvent-extracted *Brassica napus* or *Brassica juncea* canola meal fed to weaned pig. J. Anim. Sci. 90:406–408. doi:10.2527/jas.53955.

Le, M. H. A., A. D. G. Buchet, E. Beltranena, W. J. J. Gerrits, and R. T. Zijlstra. 2012. Digestible energy and amino acids of canola meal from two species (*Brassica juncea* and *Brassica napus*) fed to distal ileum cannulated grower pigs. J. Anim. Sci. 90:218–220. doi:10.2527/jas.53952.

Lenis, N. P., P. Bikker, J. van der Meulen, J. Th. M. van Diepen, J. G. M. Bakker, and A. W. Jongbloed. 1996. Effect of dietary neutral detergent fiber on ileal digestibility and portal flux of nitrogen and amino acids and on nitrogen utilization in growing pigs. J. Anim. Sci. 74:2687–2699.

Maison, T., and H. H. Stein. 2014. Digestibility by growing pigs of amino acids in canola meal from North America and 00-rapeseed meal and 00-rapeseed expellers from Europe. J. Anim. Sci. 92:3502–3514.

Newkirk, R. 2009. Canola meal. Feed industries guide, 4th ed. Canadian International Grains Institute, Winnipeg, MB, Canada.

Newkirk, R. 2011. Meal nutrients composition. In: J. K. Daun, N. A. M. Eskin, and D. Hickling, editors, Canola: Chemistry, production, processing, and utilization. AOCS Press, Urbana, IL. p. 229–244.

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

Sanderson, P. 1986. A new method of analysis of feedingstuffs for the determination of crude oils and fats. In: W. Haresign and D. J. A. Cole, editors, Recent advances in animal nutrition. Butterworths, London, UK. p. 77–81.

Sauer, W. C., R. Cichon, and R. Misir. 1982. Amino acid availability and protein quality of canola and rapeseed meal for pigs and rats. J. Anim. Sci. 54:292–301.

Sauer, W. C., A. Just, H. Jørgensen, M. Fekadu, and B. O. Eggum. 1980. The influence of diet composition on the apparent digestibility of crude protein and amino acids at the terminal ileum and overall in pigs. Acta Agric. Scand. 30:449–459. doi:10.1080/00015128009435293.

Schone, F., M. Leiterer, H. Hartung, G. Jahreis, and F. Tischendorf. 2001. Rapeseed glucosinolate and iodine in sows affect the milk iodine concentration and the iodine status of piglets. Br. J. Nutr. 85:659–670. doi:10.1079/BJN2001326.

Slominski, B. A., W. Jia, A. Rogiewicz, C. M. Nyachoti, and D. Hickling. 2012. Low-fiber canola. Part II. Chemical and nutritive composition of the meal. J. Agric. Food Chem. 60:12225–12230. doi:10.1021/jf302117x.

Stein, H. H., L. L. Berger, J. K. Drackley, G. C. Fahey Jr., D. C. Hernot, and C. M. Parsons. 2008. Nutritional properties and feeding values of soybeans and their coproducts. In: L. A. Johnson, P. J. White, and R. Galloway, editors, Soybeans chemistry, production, processing, and utilization. AOCS Press, Urbana, IL. p. 613–660.

Stein, H. H., B. Seve, M. F. Fuller, P. J. Moughan, and C. F. M. de Lange. 2007. Invited review: Amino acid bioavailability and digestibility in pig feed ingredients: Terminology and application. J. Anim. Sci. 85:172–180. doi:10.2527/jas.2005-742.

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical note: A technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433–1436.

Thacker, P. A. 1990. Canola meal. In: P. A. Thacker and R. N. Kirkwood, editors, Nontraditional feed sources for use in swine production. Butterworth Publishers, Stoneham, MA. p. 69–78.

Trindade Neto, M. A., F. O. Opepaju, B. A. Slominski, and C. M. Nyachoti. 2012. Ileal amino acid digestibility in canola meals from yellow- and black-seeded *Brassica napus* and *Brassica juncea* fed to growing pigs. J. Anim. Sci. 90:3477–3484. doi:10.2527/jas.2011-4773.

Tripathi, M. K., and A. S. Mishra. 2007. Glucosinolates in animal nutrition: A review. Anim. Feed Sci. Technol. 132:1–27. doi:10.1016/j.anifeedsci.2006.03.003.

Xi, P., D. Li, and L. Gong. 2002. Ileal amino acid digestibility in different cultivars of Chinese rapeseed meals for growing-finishing pigs. Asian-Australas. J. Anim. Sci. 15:1326–1333.