Published November 20, 2014

# Effects of protein concentration and heat treatment on concentration of digestible and metabolizable energy and on amino acid digestibility in four sources of canola meal fed to growing pigs

Y. Liu,* M. Song,*[1] T. Maison,* and H. H. Stein*[2]

*Department of Animal Sciences, University of Illinois at Urbana-Champaign, Urbana 61801

**ABSTRACT:** Two experiments were conducted to determine DE and ME and the apparent ileal digestibility (AID) and the standardized ileal digestibility (SID) of CP and AA in 4 sources of canola meal (high-protein [CM-HP], high-temperature-processed [CM-HT], low-temperature-processed [CM-LT], and conventional [CM-CV] canola meal) and in conventional soybean meal (SBM) fed to growing pigs. In Exp. 1, 48 growing barrows (initial BW: 39.7 ± 1.58 kg) were individually housed in metabolism cages and randomly assigned to 6 treatments in a randomized complete block design with 2 blocks of 24 pigs and 8 replicate pigs per treatment. The 6 diets included a corn-based basal diet and 5 diets that were formulated by mixing corn and 1 of the sources of canola meal (39.0% inclusion) or SBM (28.5% inclusion). Feces and urine were collected for 5 d following a 5-d adaptation period. The DE and ME in each source of canola meal and in SBM were calculated using the difference procedure. The DE and ME in the 4 sources of canola meal were less ($P < 0.05$) than in corn and SBM (DE: 2,854, 2,680, 2,892, and 2,883 vs. 3,324 and 3,784 kcal/kg, respectively; ME: 2,540, 2,251, 2,681, and 2,637 vs. 3,213 and 3,523 kcal/kg, respectively). No differences in the concentrations of DE and ME were observed among the 4 sources of canola meal. In Exp. 2, 12 growing barrows (initial BW: 34.0 ± 1.41 kg) that had a T-cannula installed in the distal ileum were randomly allotted to a repeated 6 × 6 Latin square design with 6 diets and 6 periods in each square. Five diets that contained 35% SBM or 45% of 1 of the 4 sources of canola meal as the sole source of CP and AA were formulated, and a N-free diet was also used. Each period lasted 7 d and ileal digesta were collected on d 6 and 7 of each period. The AID and SID of CP and all AA in SBM were greater ($P < 0.05$) than in the 4 sources of canola meal. Compared with CM-CV, CM-HP had greater ($P < 0.05$) AID of Ile, Lys, Asp, Cys, and Pro and greater ($P < 0.05$) SID of Lys and Cys. However, no differences between CM-HT and CM-LT were observed. In conclusion, regardless of the concentration of CP and the processing used, canola meal provides less DE and ME to pigs than corn and SBM, and the SID of AA in canola meal is less than in SBM. The processing temperature used in this experiment did not affect DE and ME or SID of AA in canola meal. The SID of Lys and Cys was greater in CM-HP than in CM-CV.

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


J. Anim. Sci. 2014.92:4466–4477
doi:10.2527/jas2013-7433

## INTRODUCTION

Canola meal is an important protein source that can be used in diets for pigs because of a favorable balance of AA (Bell, 1993; King et al., 2001). Compared with soybean meal (**SBM**), canola meal contains less CP and has a reduced AA digestibility, but the concentration of dietary fiber is approximately 3 times greater than that of SBM, which may contribute to reduced DE in canola meal and reduced digestibility of nutrients (Bell and Keith, 1989; Fan et al., 1995; González-Vega and Stein, 2012). Seeds of yellow-colored canola are often bigger than conventional black seeds of canola, and canola meal produced from these yellow seeds contain more CP and less fiber than conventional canola meal (Slominski et al., 2012; Trindade Neto et al., 2012). However, limited

[1]Present address: Department of Animal Science and Biotechnology, College of Agriculture and Life Sciences, Chungnam National University, 99 Daehangro, Yuseong-gu, Daejeon 305-764, South Korea.
[2]Corresponding author: hstein@illinois.edu
Received November 25, 2013.
Accepted July 26, 2014.

data have been reported for the digestibility of AA and the concentration of DE and ME in canola meal produced from yellow-seeded canola when fed to growing pigs.

Overheating of oilseed meals during processing may result in destruction of AA and reduced digestibility of AA (Fontaine et al., 2007; González-Vega et al., 2011). The apparent ileal digestibility (**AID**) of Lys in canola meal may decrease by at least 5% during the desolventizing process (Anderson-Hafermann et al., 1993). The reason for this reduction is that heating may lead to the formation of Maillard reaction products (Hurrell, 1990), and it is possible that if a lower-temperature process is used instead of the traditional process (temperature of 95°C to 115°C), AA will not be destroyed. This hypothesis has, however, not been tested. Therefore, 2 experiments were conducted to test the hypothesis that concentration of CP in canola meal and the temperature used during processing will affect the DE and ME and the AID and standardized ileal digestibility (**SID**) of AA in canola meal fed to growing pigs. A second objective was to compare these values with the values obtained in SBM.

## MATERIALS AND METHODS

### *General*

The protocol for each experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois at Urbana-Champaign. Two experiments were conducted. Pigs used in the experiments were the offspring of G-Performer boars and F-25 sows (Genetiporc Inc., Alexandria, MN).

Four canola meals were used in the experiments: 1) high-protein canola meal (**CM-HP**), 2) high-temperature-processed canola meal (**CM-HT**), 3) low-temperature-processed canola meal (**CM-LT**), and 4) conventional canola meal (**CM-CV**). All canola meals were produced from canola seeds that were grown within a narrow geographical area in western Canada in 2010. All canola meals were produced using the conventional prepress solvent extraction process. The desolventizer-toaster temperature for production of CM-HP, CM-LT, and CM-CV was between 91°C and 95°C, but the desolventizer-toaster temperatures used for production of CM-HT was between 99°C and 105°C. The desolventizer-toaster temperatures were automatically monitored during the processing. The SBM that was used was sourced from Dupont (Gibson City, IL), and the corn was a commercial hybrid of yellow dent corn that was grown in eastern Illinois in 2010. All feed ingredients were analyzed in duplicate for DM (method 927.05; AOAC International, 2007), ash (method 942.05, AOAC International, 2007), CP (method 990.03; AOAC International, 2007), and acid hydrolyzed ether extraction (**AEE**) determined by acid hydrolysis using 3 *N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (method 2003.06, AOAC International, 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN), and N-free extract was calculated by difference. Ingredients were also analyzed in duplicate for GE using an adiabatic bomb calorimeter (model 6300; Parr Instruments, Moline, IL), crude fiber (method 978.10; AOAC International, 2007), ADF (method 973.18; AOAC International, 2007), NDF (Holst, 1973), lignin (method 973.18 (A-D), AOAC International, 2007), sucrose, raffinose, stachyose, fructose, and glucose (Janauer and Englmaier, 1978), Ca and P (method 985.01; AOAC International, 2007), phytate (Ellis et al., 1977), microminerals (method 999.11; AOAC International, 2007), and AA (method 982.30 E (a, b, c); AOAC International, 2007), respectively (Tables 1 and 2). The concentration of phytate P in each ingredient was calculated as 28.2% of phytate (Sauvant et al., 2004), and nonphytate P was calculated as the difference between the concentration of total P and phytate P. Particle size was determined according to ANSI/ASAE (2008), and glucosinolates were analyzed by high-performance liquid chromatography as described by Lee et al. (2008).

### *Experiment 1: Energy Measurements*

Experiment 1 was conducted to determine DE and ME in corn, the 4 sources of canola meal, and SBM. A total of 48 barrows (39.7 ± 1.58 kg initial BW) were allotted to 6 dietary treatments in 2 blocks of 24 pigs providing 8 replicate pigs per diet in a randomized complete block design. 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 that allowed for the total, but separate, collection of urine and fecal materials from each pig. Fecal materials were collected from the screen floor and urine was collected from the urine trays.

A corn diet was formulated by mixing 97.30% corn and vitamins and minerals (Table 3). Four additional diets were formulated by mixing 59.20% corn with 39.00% of each source of canola meal. The last diet was formulated by mixing 69.25% corn with 28.50% SBM. The quantity of feed provided per pig daily was calculated as 3 times the estimated requirement for maintenance energy (i.e., 106 kcal ME/kg$^{0.75}$; NRC, 1998) for the smallest pig in each replicate and was divided into 2 equal meals. Water was available at all times. The experimental diets were provided for 12 d.

The initial 5 d were considered an adaptation period to the diet. Fecal markers were fed on d 6 and on d 11, and fecal collections were initiated when the first marker appeared in the feces and ceased when the second marker appeared (Baker and Stein, 2009; Kim et al., 2009). Urine was collected in urine buckets over a preservative of 50 mL of 6 *N* HCl. Fecal samples and 20% of the collected urine

**Table 1.** Analyzed composition of high-protein canola meal (CM-HP), high-temperature-processed canola meal (CM-HT), low-temperature-processed canola meal (CM-LT), conventional canola meal (CM-CV), and soybean meal (SBM), as-fed basis

| | Ingredient | | | | |
|---|---|---|---|---|---|
| Item | CM-HP | CM-HT | CM-LT | CM-CV | SBM |
| GE, kcal/kg | 4,326 | 4,285 | 4,336 | 4,181 | 4,206 |
| DM, % | 90.22 | 88.44 | 90.35 | 88.63 | 87.55 |
| Ash, % | 7.85 | 6.51 | 6.74 | 8.03 | 6.48 |
| AEE,[1] % | 3.32 | 3.65 | 3.25 | 3.39 | 1.87 |
| Crude fiber, % | 8.77 | 7.90 | 7.23 | 7.64 | 3.15 |
| NFE,[2] % | 25.56 | 34.36 | 36.14 | 35.37 | 28.94 |
| NDF, % | 20.81 | 28.06 | 26.98 | 30.91 | 8.34 |
| ADF, % | 13.84 | 18.96 | 19.20 | 18.76 | 4.72 |
| Lignin, % | 4.22 | 8.23 | 8.19 | 7.58 | 0.37 |
| Sucrose, % | 6.84 | 6.70 | 7.08 | 8.23 | 7.28 |
| Raffinose, % | 0.13 | 0.50 | 0.54 | 0.30 | 1.02 |
| Stachyose, % | 0.32 | 1.05 | 1.03 | 1.44 | 5.14 |
| Fructose, % | ND[3] | ND | ND | 0.17 | 0.71 |
| Glucose, % | 0.10 | ND | ND | ND | 0.94 |
| Ca, % | 0.80 | 0.65 | 0.65 | 0.79 | 0.50 |
| Total P, % | 1.43 | 1.06 | 1.11 | 1.20 | 0.68 |
| Phytate,[4] % | 4.06 | 2.90 | 2.98 | 3.13 | 1.58 |
| Phytate P,[5] % | 1.14 | 0.82 | 0.84 | 0.88 | 0.44 |
| Nonphytate P, % | 0.29 | 0.24 | 0.27 | 0.32 | 0.24 |
| Cr, mg/kg | 2.10 | 2.40 | 3.30 | 0.50 | <0.10 |
| Co, mg/kg | 1.58 | <0.20 | <0.20 | <0.20 | <0.20 |
| Cu, mg/kg | 7.0 | 5.7 | 5.8 | 5.6 | 13.9 |
| Fe, mg/kg | 100 | 149 | 162 | 236 | 113 |
| Mg, % | 0.64 | 0.59 | 0.60 | 0.56 | 0.30 |
| Mn, mg/kg | 54 | 61 | 62 | 60 | 36 |
| Mo, mg/kg | 1.3 | 0.9 | 0.9 | 0.7 | 3.0 |
| K, % | 1.53 | 1.17 | 1.20 | 1.34 | 2.30 |
| Se, mg/kg | 0.06 | 0.40 | 0.30 | 0.06 | 0.04 |
| S, % | 0.82 | 0.67 | 0.69 | 0.76 | 0.39 |
| Na, mg/kg | 29 | 38 | 35 | 1180 | 35 |
| Zn, mg/kg | 53.2 | 51.7 | 52.0 | 67.9 | 43.3 |
| Particle size, μm | 554 | 459 | 480 | 464 | 730 |

[1]AEE = acid hydrolyzed ether extract.

[2]NFE = N-free extract = 100 – (CP + crude fat + crude fiber +ash).

[3]ND = nondetectable.

[4]Calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[5]Calculated as the difference between phytate P and total P.

**Table 2.** Analyzed CP and amino acid composition of high-protein canola meal (CM-HP), high-temperature-processed canola meal (CM-HT), low-temperature-processed canola meal (CM-LT), conventional canola meal (CM-CV), and soybean meal (SBM), as-fed basis

| | Ingredient | | | | |
|---|---|---|---|---|---|
| Item | CM-HP | CM-HT | CM-LT | CM-CV | SBM |
| CP, % | 44.72 | 36.02 | 36.99 | 34.20 | 47.11 |
| Indispensable AA, % | | | | | |
| Arg | 2.50 | 2.05 | 2.13 | 1.87 | 3.25 |
| His | 1.14 | 0.94 | 0.98 | 0.86 | 1.16 |
| Ile | 1.71 | 1.48 | 1.53 | 1.34 | 2.16 |
| Leu | 2.93 | 2.46 | 2.54 | 2.29 | 3.49 |
| Lys | 2.41 | 2.01 | 2.10 | 1.80 | 2.85 |
| Met | 0.83 | 0.69 | 0.72 | 0.67 | 0.64 |
| Phe | 1.65 | 1.38 | 1.44 | 1.30 | 2.27 |
| Thr | 1.69 | 1.42 | 1.47 | 1.43 | 1.71 |
| Trp | 0.61 | 0.45 | 0.47 | 0.40 | 0.69 |
| Val | 2.19 | 1.85 | 1.92 | 1.72 | 2.24 |
| Total | 17.66 | 14.73 | 15.30 | 13.68 | 20.46 |
| Dispensable AA, % | | | | | |
| Ala | 1.82 | 1.53 | 1.58 | 1.44 | 1.95 |
| Asp | 3.09 | 2.41 | 2.49 | 2.42 | 5.07 |
| Cys | 1.05 | 0.79 | 0.84 | 0.74 | 0.59 |
| Glu | 7.07 | 5.70 | 5.86 | 5.25 | 7.98 |
| Gly | 2.03 | 1.74 | 1.81 | 1.67 | 1.90 |
| Pro | 2.62 | 2.18 | 2.21 | 2.02 | 2.29 |
| Ser | 1.45 | 1.16 | 1.20 | 1.19 | 1.90 |
| Tyr | 1.12 | 0.99 | 1.02 | 0.97 | 1.63 |
| Total | 20.25 | 16.50 | 17.01 | 15.70 | 23.31 |
| Calculated value | | | | | |
| Lys:CP | 5.39 | 5.58 | 5.68 | 5.26 | 6.05 |

were stored at -20°C immediately after collection. At the conclusion of the experiment, urine samples were thawed, and a subsample was collected for energy analysis. Fecal samples were dried in a forced-air drying oven and finely ground, and urine samples were lyophilized before analysis, as described by Kim et al. (2009). Fecal and diet samples were analyzed in duplicate for DM, and fecal, diet, and urine samples were analyzed in duplicate for GE, as explained for the ingredients. Diet samples were also analyzed for AEE, ADF, and NDF.

Following chemical analysis, the apparent total tract digestibility (**ATTD**) of energy was calculated for each diet. The amounts of energy lost in the feces and in the urine were determined, and the quantities of DE and ME in each of the 6 diets were calculated (Baker and Stein, 2009; Kim et al., 2009). The DE and ME in corn were then calculated by dividing the DE and ME values for the corn diet by the inclusion rate of corn in the diet being analyzed. These values were then used to calculate the contribution from corn to the DE and ME in the diets containing canola meal or SBM. The DE and ME in each source of canola meal and in SBM were then calculated by difference as previously described (Baker and Stein, 2009; Kim et al., 2009).

Outliers were identified using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC), but no outliers were removed from the data. Data were analyzed by ANOVA using the PROC MIXED procedure of SAS in a randomized complete block design with the pig as the experimental unit. The statistical model included diet or ingredient as the fixed effect and block as the random effect. Treatment means were separated using the LSMEANS statement and the PDIFF option of PROC

**Table 3.** Composition of diets (as-fed basis), Exp. 1

| | Diet[1] | | | | | |
|---|---|---|---|---|---|---|
| Item | Corn | CM-HP | CM-HT | CM-LT | CM-CV | SBM |
| Ingredient, % | | | | | | |
| Ground corn | 97.30 | 59.20 | 59.20 | 59.20 | 59.2 | 69.25 |
| CM-HP | — | 39.00 | — | — | — | — |
| CM-HT | — | — | 39.00 | — | — | — |
| CM-LT | — | — | — | 39.00 | — | — |
| CM-CV | — | — | — | — | 39.00 | — |
| SBM | — | — | — | — | — | 28.50 |
| Ground limestone | 1.20 | 0.75 | 0.75 | 0.75 | 0.75 | 1.10 |
| Monocalcium phosphate | 0.80 | 0.35 | 0.35 | 0.35 | 0.35 | 0.45 |
| Salt | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Vitamin-mineral premix[2] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Analyzed composition | | | | | | |
| DM, % | 87.26 | 88.55 | 88.08 | 88.84 | 88.32 | 87.90 |
| GE, kcal/kg | 3,771 | 3,961 | 3,963 | 3,985 | 3,935 | 3,894 |
| CP, % | 7.24 | 21.54 | 18.24 | 18.50 | 18.38 | 18.31 |
| Acid hydrolyzed ether extract, % | 3.13 | 3.53 | 3.19 | 3.33 | 3.04 | 3.47 |
| ADF, % | 3.48 | 7.77 | 10.86 | 10.83 | 10.53 | 4.82 |
| NDF, % | 9.47 | 13.85 | 17.00 | 16.21 | 16.97 | 9.47 |

[1]CM-HP = high-protein canola meal; CM-HT = high-temperature-processed canola meal; CM-LT = low-temperature-processed canola meal; CM-CV = conventional canola meal; SBM = soybean meal.

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

MIXED. Statistical significance and tendency were considered at $P < 0.05$ and $0.05 \leq P < 0.10$, respectively.

### *Experiment 2: AA Digestibility*

Experiment 2 was conducted to determine the AID and the SID of CP and AA in the 4 sources of canola meal and SBM. Twelve growing barrows (34.0 ± 1.41 kg initial BW) were randomly allotted to a repeated 6 × 6 Latin square design with 6 diets and six 7-d periods in each square. Thus, there were 12 replicate pigs per diet. Pigs were surgically equipped with a T-cannula in the distal ileum using procedures adapted from Stein et al. (1998). Pigs were housed in individual pens (1.2 × 1.5 m) with tri-bar floors in an environmentally controlled room. A feeder and a nipple drinker were installed in each pen.

Six diets were prepared (Table 4). Five diets each contained 1 of the 4 sources of canola meal (45% inclusion) or SBM (35% inclusion) as the only AA-containing ingredient, and the last diet was a N-free diet that was used to calculate endogenous losses of AA and CP. Soybean oil and sucrose were included in all diets (4% and 20% in the N-free diet and 3% and 10% in all other diets). Solka floc (Fiber Sales and Development Corp., Urbana, OH) was included in the N-free diet (4%) to increase the concentration of crude fiber, and potassium carbonate and magnesium oxide were added to the N-free diet to meet the requirement for K and Mg in the diet. Vitamins and minerals were included in all diets to meet or exceed requirement estimates (NRC, 1998). All diets also contained 0.4% chromic oxide as an indigestible marker. Pigs were fed at a daily level of 3 times the maintenance energy requirement for energy, and water was available at all times. Pig weights were recorded at the beginning of the experiment and at the end of each period, and the amount of feed supplied each day was also recorded.

Each experimental period lasted 7 d. The initial 5 d of each period were an adaptation period to the diet, and ileal digesta were collected for 8 h on d 6 and 7 as described by Stein et al. (1999). In short, cannulas were opened, a plastic bag was attached to the cannula barrel, and digesta flowing into the bag were collected. Bags were removed whenever they were filled with digesta or at least once every 30 min and immediately frozen at –20°C to prevent bacterial degradation of the AA in the digesta. At the conclusion of the experiment, ileal samples were thawed and mixed within animal and diet, and a subsample was collected for chemical analysis. Samples from each diet were collected as well. Digesta samples were lyophilized and finely ground before chemical analysis. Digesta and diet samples were analyzed in duplicate for Cr (method 990.08; AOAC International, 2007) and for DM, CP, and AA as explained for the ingredients. Diet samples were also analyzed for AEE, ADF, and NDF.

**Table 4.** Composition of diets (as-fed basis), Exp. 2

| | Diet[1] | | | | | |
|---|---|---|---|---|---|---|
| Item | CM-HP | CM-HT | CM-LT | CM-CV | SBM | N free |
| Ingredient, % | | | | | | |
| CM-HP | 45.00 | — | — | — | — | — |
| CM-HT | — | 45.00 | — | — | — | — |
| CM-LT | — | — | 45.00 | — | — | — |
| CM-CV | — | — | — | 45.00 | — | — |
| SBM | — | — | — | — | 35.00 | — |
| Soybean oil | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 4.00 |
| Ground limestone | 0.55 | 0.55 | 0.55 | 0.55 | 0.95 | 1.00 |
| Monocalcium phosphate | 0.55 | 0.55 | 0.55 | 0.55 | 0.70 | 1.30 |
| Sucrose | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 20.00 |
| Cornstarch | 39.80 | 39.80 | 39.80 | 39.80 | 49.25 | 68.10 |
| Solka floc[2] | — | — | — | — | — | 4.00 |
| Magnesium oxide | — | — | — | — | — | 0.10 |
| Potassium carbonate | — | — | — | — | — | 0.40 |
| Salt | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Vitamin-mineral premix[3] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Chromic oxide | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Analyzed composition, % | | | | | | |
| CP | 19.76 | 15.17 | 15.52 | 15.46 | 16.79 | 0.41 |
| Acid-hydrolyzed ether extract | 4.74 | 4.79 | 4.18 | 4.45 | 3.90 | 1.15 |
| ADF | 6.62 | 9.28 | 9.18 | 9.39 | 2.39 | 1.27 |
| NDF | 9.02 | 11.29 | 11.38 | 13.41 | 2.70 | 1.83 |
| Indispensable AA | | | | | | |
| Arg | 1.07 | 0.85 | 0.87 | 0.80 | 1.18 | 0.01 |
| His | 0.48 | 0.37 | 0.39 | 0.36 | 0.42 | 0.00 |
| Ile | 0.72 | 0.58 | 0.60 | 0.54 | 0.77 | 0.01 |
| Leu | 1.26 | 1.02 | 1.03 | 0.98 | 1.28 | 0.02 |
| Lys | 1.03 | 0.83 | 0.85 | 0.75 | 1.04 | 0.01 |
| Met | 0.35 | 0.27 | 0.28 | 0.26 | 0.22 | 0.00 |
| Phe | 0.72 | 0.58 | 0.59 | 0.55 | 0.85 | 0.01 |
| Thr | 0.72 | 0.61 | 0.60 | 0.63 | 0.63 | 0.01 |
| Trp | 0.25 | 0.17 | 0.17 | 0.19 | 0.24 | 0.03 |
| Val | 0.93 | 0.74 | 0.77 | 0.69 | 0.80 | 0.01 |
| Dispensable AA | | | | | | |
| Ala | 0.78 | 0.63 | 0.64 | 0.63 | 0.72 | 0.01 |
| Asp | 1.32 | 1.02 | 1.03 | 1.03 | 1.87 | 0.02 |
| Cys | 0.50 | 0.36 | 0.34 | 0.31 | 0.27 | 0.00 |
| Glu | 3.06 | 2.37 | 2.40 | 2.27 | 2.92 | 0.02 |
| Gly | 0.87 | 0.72 | 0.73 | 0.72 | 0.70 | 0.01 |
| Pro | 1.12 | 0.88 | 0.92 | 0.85 | 0.86 | 0.02 |
| Ser | 0.64 | 0.55 | 0.52 | 0.56 | 0.72 | 0.01 |
| Tyr | 0.48 | 0.42 | 0.42 | 0.40 | 0.57 | 0.01 |

[1]CM-HP = high-protein canola meal; CM-HT = high-temperature-processed canola meal; CM-LT = low-temperature-processed canola meal; CM-CV = conventional canola meal; SBM = soybean meal.

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

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

The AID for CP and AA in diets containing canola meal or SBM were calculated (Stein et al., 2007). Because canola meal or SBM was the only ingredient contributing CP and AA to each diet, these values also represent the digestibility for each of the ingredients. The basal endogenous losses of CP and each AA were determined on the basis of the flow to the distal ileum obtained after feeding the N-free diet, and SID values were calculated by correcting the AID of CP and

**Table 5.** Analyzed glucosinolates of high-protein canola meal (CM-HP), high-temperature-processed canola meal (CM-HT), low-temperature-processed canola meal (CM-LT), and conventional canola meal (CM-CV), as-fed basis

| | Ingredient | | | |
|---|---|---|---|---|
| Item, μmol/g | CM-HP | CM-HT | CM-LT | CM-CV |
| Glucobrassicanapin | 0.63 | 0.58 | 0.56 | 0.43 |
| Glucoalyssin | 0.83 | 0.65 | 0.68 | 0.50 |
| Glucobrassicin | 0.67 | 0.45 | 0.48 | 0.11 |
| Glucoerucin | 1.18 | 1.02 | 0.98 | 0.6 |
| Gluconapin | 1.67 | 1.71 | 1.94 | 0.83 |
| Gluconapoleiferin | 0.48 | — | — | 0.47 |
| Gluconasturtiin | 1.86 | 2.04 | 2.13 | 0.25 |
| Hydroxyglucobrassicin | 4.01 | 2.32 | 3.19 | 0.12 |
| Neoglucobrassicin | 0.95 | 1.29 | 1.04 | 0.37 |
| Progoitrin | 4.36 | 3.08 | 3.61 | 1.34 |
| Total | 16.64 | 13.14 | 14.61 | 5.02 |

each AA for the basal endogenous losses (Stein et al., 2007). Data were analyzed as outlined for Exp. 1.

## RESULTS

### Composition of Ingredients

The concentrations of NDF and lignin were 20.81% and 4.22% in CM-HP, 28.06% and 8.23% in CM-HT, 26.98% and 8.19% in CM-LT, and 30.91% and 7.58% in CM-CV, but SBM contained 8.34% NDF and 0.37% lignin (Table 1). Likewise, the concentration of raffinose and stachyose were 0.13% and 0.32% in CM-HP, 0.50% and 1.05% in CM-HT, 0.54% and 1.03% in CM-LT, and 0.30% and 1.44% in CM-CV, but SBM contained 1.02% raffinose and 5.14% stachyose. The concentrations of total P and phytate P were 1.43% and 1.14% in CM-HP, 1.06% and 0.82% in CM-HT, 1.11% and 0.84% in CM-LT, and 1.20% and 0.88% in CM-CV. However, SBM contained 0.68% total P and 0.44% phytate P. Conventional canola meal contained 1,180 mg/kg sodium, whereas CM-HP, CM-HT, CM-LT, and SBM contained 29, 38, 35, and 35 mg/kg of sodium, respectively. The particle size was 554 μm for CM-HP, 459 μm for CM-HT, 480 μm for CM-LT, 464 μm for CM-CV, and 730 μm for SBM.

The concentration of CP in CM-HP was 44.72%, whereas CM-HT, CM-LT, and CM-CV contained 36.02%, 36.99%, and 34.20% CP, respectively, but SBM contained 47.11% CP (Table 2). The concentrations of Lys and total indispensable AA were 2.41% and 17.66% in CM-HP, 2.01% and 14.73% in CM-HT, 2.10% and 15.30% in CM-LT, and 1.80% and 13.68% in CM-CV but 2.85% and 20.46% in SBM. Likewise, the concentrations of Cys and total dispensable AA were 1.05% and 20.25% in CM-HP, and 0.79% and 16.50% in CM-HT, 0.84% and 17.01% in CM-LT, and 0.74% and 15.70% in CM-CV. However, SBM contained 0.59% Cys and 23.31% total dispensable AA.

The concentrations of glucobrassicin, glucoerucin, gluconapin, and gluconasturtiin were 0.67, 1.18, 1.67, and 1.86 μmol/g in CM-HP, 0.45, 1.02, 1.71, and 2.04 μmol/g in CM-HT, and 0.48, 0.98, 1.94, and 2.13 μmol/g in CM-LT. However, CM-CV contained 0.11 μmol/g of glucobrassicin, 0.60 μmol/g of glucoerucin, 0.83 μmol/g of gluconapin, and 0.25 μmol/g of gluconasturtiin (Table 5). The concentrations of hydroxyglucobrassicin, neoglucobrassicin, and progoitrin were 4.01, 0.95, and 4.36 μmol/g in CM-HP, 2.32, 1.29, and 3.08 μmol/g in CM-HT, and 3.14, 1.04, and 3.61 μmol/g in CM-LT; however, CM-CV contained 0.12 μmol/g of hydroxyglucobrassicin, 0.37 μmol/g of neoglucobrassicin, and 1.34 μmol/g of progoitrin. As a consequence, the total concentrations of glucosinolates in CM-HP, CM-HT, CM-LT, and CM-CV were 16.64, 13.14, 14.61, and 5.02 μmol/g, respectively.

### Energy Measurements

There were no differences in the total feed intake among pigs fed the experimental diets (Table 6). Pigs fed the 4 canola meal diets had greater ($P < 0.05$) GE intake than pigs fed the corn or the SBM diet. Compared with pigs fed the corn or the SBM diet, pigs fed the canola meal diets had less ($P < 0.05$) GE concentration in dry feces but greater ($P < 0.05$) feces output. As a consequence, pigs fed the canola meal diets had reduced ($P < 0.05$) ATTD of GE compared with pigs fed the corn or SBM diet. Diets containing either source of canola meal contained less ($P < 0.05$) DE than the diet containing SBM. The corn diets also contained more ($P < 0.05$) DE than the diet containing CM-HT. There was no difference in DE among the diets containing the 4 sources of canola meal. Urine output and energy concentration in urine were not different among diets, but pigs fed the CM-HP, CM-HT, or CM-LT diets excreted more ($P < 0.05$) GE in the urine than pigs fed the corn diet. Pigs fed the CM-HT diet also excreted more ($P < 0.05$) GE in urine than pigs fed the SBM diet. Values for ME were greater ($P < 0.05$) in the corn and SBM diets than in the 4 sources of canola meals.

There were no differences in DE and ME among the 4 sources of canola meal (Table 7), but all sources of canola meal contained less ($P < 0.05$) DE and ME than SBM and corn. This was true on an as-fed basis as well as on a DM basis. The DE in SBM was greater ($P < 0.05$) than in corn, but ME in corn was not different from SBM.

### AA Digestibility

There were no differences in the AID of CP among the 4 sources of canola meal (Table 8). However, CM-HP had greater ($P < 0.05$) AID for Lys than the other 3

**Table 6.** Energy digestibility of pigs fed diets containing corn, high-protein canola meal (CM-HP), high-temperature-processed canola meal (CM-HT), low-temperature-processed canola meal (CM-LT), conventional canola meal (CM-CV), and soybean meal (SBM), as-fed basis, Exp. 1[1,2]

| | Diet | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | Corn | CM-HP | CM-HT | CM-LT | CM-CV | SBM | SEM | *P*-value |
| Total feed intake, kg | 6.43 | 6.90 | 6.84 | 6.80 | 6.88 | 6.30 | 0.20 | 0.164 |
| GE intake, kcal | 23,794[a] | 27,127[b] | 26,763[b] | 26,712[b] | 26,759[b] | 24,299[a] | 828 | <0.05 |
| Dry feces output, kg | 0.72[a] | 1.41[b] | 1.44[b] | 1.23[b] | 1.31[b] | 0.71[a] | 0.09 | <0.05 |
| GE in dry feces, kcal/kg | 4,752[a] | 4,298[d] | 4,495[b] | 4499[b] | 4,389[c] | 4,580[b] | 30 | <0.05 |
| Fecal GE output, kcal | 3,426[a] | 6,063[b] | 6,489[b] | 5546[b] | 5738[b] | 3,230[a] | 420 | <0.05 |
| ATTD,[3] GE % | 85.56[a] | 77.51[b] | 75.78[b] | 79.23[b] | 78.49[b] | 86.70[a] | 1.49 | <0.05 |
| DE in diet, kcal/kg | 3,226[a,b] | 3,071[b,c] | 3,003[c] | 3,157[b,c] | 3,089[bc] | 3378[a] | 59 | <0.05 |
| Urine output, kg | 12.68 | 36.51 | 31.02 | 25.41 | 23.07 | 23.20 | 6.68 | 0.222 |
| GE in urine, kcal/kg | 71.81 | 45.53 | 65.76 | 89.43 | 62.50 | 56.38 | 16.44 | 0.545 |
| Urinary GE output, kcal | 634[a] | 1,209[b,c] | 1,512[c] | 1,368[b,c] | 1074[a,b,c] | 927[a,b] | 201 | <0.05 |
| ME in diet, kcal/kg | 3,127[a] | 2,893[b] | 2,780[b] | 2,948[b] | 2,931[b] | 3,229[a] | 65 | <0.05 |

[a–d]Within a row, means followed by the same or no superscript letter are not different (*P* > 0.05).

[1]Each least squares mean represents 8 observations.

[2]Diet intake, fecal output, and urine output were based on 5 d of collection.

[3]ATTD = apparent total tract digestibility.

source of canola meal, greater (*P* < 0.05) AID for Trp than CM-LT, and greater (*P* < 0.05) AID for Ile and Cys than CM-CV. High-temperature-processed canola meal had greater (*P* < 0.05) AID for Ile, Lys, and Cys than CM-CV, and CM-LT had greater (*P* < 0.05) AID for Lys and Cys but less (*P* < 0.05) AID for Trp than CM-CV. No differences between CM-HT and CM-LT were observed. However, the AID for CP and all AA was greater (*P* < 0.05) in SBM than in all sources of canola meal.

There were no differences in the SID of CP among the 4 sources of canola meal (Table 9). However, CM-HP had greater (*P* < 0.05) SID for Lys than the other 3 source of canola meal, greater (*P* < 0.05) SID for Trp than CM-LT, and greater (*P* < 0.05) SID for Cys than CM-CV. High-temperature-processed canola meal had greater (*P* < 0.05) SID for Lys and Cys than CM-CV, and CM-LT had greater (*P* < 0.05) SID for Lys and Cys but less (*P* < 0.05) SID for Trp than CM-CV. There were no differences in SID of any AA between CM-HT and CM-LT. However, the SID for CP and all AA were greater (*P* < 0.05) in SBM than in all the sources of canola meal.

## DISCUSSION

### *Composition of Ingredients*

Canola is the registered name for rapeseed containing less erucic acid and glucosinolates than conventional rapeseed (Bell, 1993). Both erucic acid and glucosinolates have antinutritional properties in diets fed to pigs (Bell, 1993). Canola meal is the coproduct that is produced when canola oil has been extracted from the seeds using solvent extraction and is widely used as a protein source in swine diets (Thacker, 1990; Bell, 1993; Trindade Neto et al., 2012). Unlike SBM, canola hulls stay with the meal, and because of the small seed size, the hull is a relatively high proportion of the canola seed, which results in greater concentration of fiber in canola meal than in SBM. Therefore, the reduced

**Table 7.** Energy concentration in corn, high-protein canola meal (CM-HP), high-temperature-processed canola meal (CM-HT), low-temperature-processed canola meal (CM-LT), conventional canola meal (CM-CV), and soybean meal (SBM), Exp. 1[1]

| | Ingredient | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | Corn | CM-HP | CM-HT | CM-LT | CM-CV | SBM | SEM | *P*-value |
| As-fed basis | | | | | | | | |
| DE, kcal/kg | 3,324[b] | 2,854[c] | 2,680[c] | 2,892[c] | 2,883[c] | 3,784[a] | 89 | <0.05 |
| ME, kcal/kg | 3,213[a] | 2,540[b] | 2,251[b] | 2,681[b] | 2,637[b] | 3,523[a] | 165 | <0.05 |
| DM basis | | | | | | | | |
| DE, kcal/kg | 3,828[b] | 3,163[c] | 3,029[c] | 3,202[c] | 3,030[c] | 4,322[a] | 100 | <0.05 |
| ME, kcal/kg | 3,702[a] | 2,815[b] | 2,545[b] | 2,967[b] | 2,771[b] | 4,024[a] | 183 | <0.05 |

[a–c]Within a row, means followed by the same or no superscript letter are not different (*P* > 0.05).

[1]Each least squares mean represents 8 observations.

**Table 8.** Apparent ileal digestibility (AID) of CP and AA in high-protein canola meal (CM-HP), high-temperature-processed canola meal (CM-HT), low-temperature-processed canola meal (CM-LT), conventional canola meal (CM-CV), and soybean meal (SBM) by growing pigs, Exp. 2[1]

| Item | CM-HP | CM-HT | CM-LT | CM-CV | SBM | SEM | *P*-value |
|---|---|---|---|---|---|---|---|
| CP, % | 66.5[b] | 63.9[b] | 61.9[b] | 61.6[b] | 78.5[a] | 2.08 | <0.05 |
| Indispensable AA, % | | | | | | | |
| Arg | 77.3[b] | 78.7[b] | 78.7[b] | 77.9[b] | 91.2[a] | 1.49 | <0.05 |
| His | 78.2[b] | 77.3[b] | 77.3[b] | 74.6[b] | 86.0[a] | 1.25 | <0.05 |
| Ile | 71.0[b] | 71.0[b] | 70.5[b,c] | 67.7[c] | 86.3[a] | 1.15 | <0.05 |
| Leu | 73.1[b] | 73.6[b] | 72.2[b] | 72.4[b] | 85.1[a] | 1.36 | <0.05 |
| Lys | 73.0[b] | 67.9[c] | 67.8[c] | 60.6[d] | 83.2[a] | 1.42 | <0.05 |
| Met | 81.2[b] | 80.0[b] | 79.4[b] | 80.2[b] | 86.6[a] | 0.96 | <0.05 |
| Phe | 72.6[b] | 73.9[b] | 72.3[b] | 72.6[b] | 86.7[a] | 1.32 | <0.05 |
| Thr | 63.1[b] | 63.6[b] | 61.0[b] | 62.3[b] | 78.0[a] | 1.43 | <0.05 |
| Trp | 81.1[b] | 78.4[bc] | 75.1[c] | 80.7[b] | 86.2[a] | 1.40 | <0.05 |
| Val | 67.4[b] | 67.1[b] | 66.1[b] | 63.0[b] | 80.9[a] | 1.47 | <0.05 |
| Mean | 72.7[b] | 72.0[b] | 73.3[b] | 69.8[b] | 85.2[a] | 1.65 | <0.05 |
| Dispensable AA, % | | | | | | | |
| Ala | 69.0[b] | 69.0[b] | 67.2[b] | 65.3[b] | 76.4[a] | 1.93 | <0.05 |
| Asp | 66.5[b] | 64.7[b,c] | 63.1[b,c] | 61.5[c] | 83.1[a] | 1.61 | <0.05 |
| Cys | 72.2[b] | 74.1[b] | 71.1[b] | 63.8[c] | 80.1[a] | 1.31 | <0.05 |
| Glu | 80.3[b] | 80.8[b] | 80.1[b] | 78.9[b] | 87.1[a] | 0.92 | <0.05 |
| Gly | 62.2[b] | 62.1[b] | 63.9[b] | 59.0[b] | 70.6[a] | 1.79 | <0.05 |
| Pro | 61.8[b] | 56.0[b,c] | 61.28[b] | 50.3[c] | 72.7[a] | 3.57 | <0.05 |
| Ser | 65.4[b] | 65.7[b] | 62.3[b] | 65.9[b] | 84.1[a] | 1.56 | <0.05 |
| Tyr | 71.2[b] | 72.8[b] | 71.4[b] | 70.9[b] | 86.4[a] | 1.18 | <0.05 |
| Mean | 69.9[b] | 69.1[b] | 68.3[b] | 64.8[b] | 80.9[a] | 2.16 | <0.05 |
| All AA | 70.7[b] | 70.7[b] | 69.8[b] | 66.8[b] | 82.7[a] | 1.68 | <0.05 |

[a–d]Within a row, means followed by the same or no superscript letter are not different ($P > 0.05$).

[1]Each least squares mean represents 12 observations.

protein level and the increased fiber concentration observed for canola meals were expected and are consistent with published values (González-Vega and Stein, 2012; NRC, 2012). Conventional canola meal contained 30 to 40 times more sodium than the other 3 sources of canola meal and SBM. This is likely due to the manufacturing process to commercially refine canola oil, where an acid extraction is used to remove phospholipids, free fatty acids, and other suspended materials, followed by an alkaline neutralization step in which sodium hydroxide is used (Unǵer, 2011). The recovered solids from these refining steps are added back to the meal, which likely resulted in the elevated level of sodium in CM-CV compared with the other sources of canola meal. However, CM-CV has a GE similar to and a P concentration greater than SBM, which is also in agreement with published values (González-Vega and Stein, 2012; Slominski et al., 2012). During the refining process of canola oil, phospholipids are often removed and added back to the meal, therefore increasing the oil content by 1.5% to 2.5% and also increasing the phosphorus content (Unǵer, 2011).

Canola meal may become more competitive in the feed market if DE and CP can be increased and concentration of fiber and glucosinolates can be reduced. By selecting yellow-seeded canola, which has larger seeds, CP in the meal is increased and NDF, ADF, and lignin concentrations are reduced, as shown for CM-HP used in these experiments. This observation also agrees with published values from Slominski et al. (2012) and Trindade Neto et al. (2012), who also compared CM-HP and CM-CV and reported that compared with the black CM-CV, yellow CM-HP contains more protein and less fiber because the increased size and thinner hull of yellow canola directly reduce the proportion of canola hull in the meal. Slominski et al. (1994, 2012) reported that the difference in fiber concentrations between yellow- and black-seeded canola is mainly due to the concentration of lignin with associated polyphenols. The concentration of glucosinolates in CM-HP is in close agreement with the values reported by Slominski et al. (2012) and is much less than the values in traditional rapeseed meal containing 120 to 150 μmol/g of total glucosinolates (Canola Council of Canada, 2009). However, CM-HP used in this experiment contained more glucosinolates than average for Canadian canola meal (Newkirk et al., 2003), which is approximately 7.2 μmol/g, and also more than CM-CV. The reason for the increased glucosinolates level in CM-HP compared with CM-CV is likely related to the different variety of canola used to produce the meal.

**Table 9.** Standardized ileal digestibility (SID) of CP and AA in high-protein canola meal (CM-HP), high-temperature-processed canola meal (CM-HT), low-temperature-processed canola meal (CM-LT), conventional canola meal (CM-CV), and soybean meal (SBM) fed to growing pigs, Exp. 2[1,2]

| Item | CM-HP | CM-HT | CM-LT | CM-CV | SBM | SEM | *P*-value |
|---|---|---|---|---|---|---|---|
| CP, % | 73.9[b] | 73.5[b] | 71.4[b] | 71.1[b] | 87.1[a] | 2.08 | <0.05 |
| Indispensable AA, % | | | | | | | |
| Arg | 82.0[b] | 84.8[b] | 84.5[b] | 84.1[b] | 95.5[a] | 1.49 | <0.05 |
| His | 80.8[b] | 80.7[b] | 80.6[b] | 78.2[b] | 89.0[a] | 1.25 | <0.05 |
| Ile | 74.4[b] | 75.3[b] | 74.6[b] | 72.4[b] | 89.5[a] | 1.15 | <0.05 |
| Leu | 76.2[b] | 77.3[b] | 75.9[b] | 76.2[b] | 88.0[a] | 1.36 | <0.05 |
| Lys | 76.1[b] | 71.8[c] | 71.6[c] | 64.3[d] | 86.2[a] | 1.42 | <0.05 |
| Met | 83.0[b] | 82.3[b] | 81.6[b] | 82.6[b] | 89.4[a] | 0.96 | <0.05 |
| Phe | 75.8[b] | 77.8[b] | 76.2[b] | 76.7[b] | 89.4[a] | 1.32 | <0.05 |
| Thr | 69.4[b] | 71.0[b] | 68.6[b] | 69.5[b] | 85.1[a] | 1.43 | <0.05 |
| Trp | 84.9[b] | 84.0[b,c] | 80.7[c] | 85.7[b] | 90.1[a] | 1.40 | <0.05 |
| Val | 72.0[b] | 72.8[b] | 72.0[b] | 69.2[b] | 86.2[a] | 1.47 | <0.05 |
| Mean | 76.5[b] | 76.6[b] | 77.9[b] | 74.8[b] | 89.0[a] | 1.65 | <0.05 |
| Dispensable AA, % | | | | | | | |
| Ala | 75.5[b] | 76.9[b] | 75.2[b] | 73.4[b] | 83.5[a] | 1.93 | <0.05 |
| Asp | 71.1[b] | 70.6[b] | 68.9[b] | 67.3[b] | 86.2[a] | 1.61 | <0.05 |
| Cys | 74.9[b] | 77.8[b] | 75.1[b] | 68.1[c] | 84.9[a] | 1.31 | <0.05 |
| Glu | 82.6[b] | 83.8[b] | 83.1[b] | 82.0[b] | 89.5[a] | 0.92 | <0.05 |
| Gly | 74.9[b] | 78.0[b] | 77.3[b] | 74.7[b] | 85.9[a] | 3.27 | <0.05 |
| Pro | 102.7[b] | 104.6[b] | 110.4[b] | 103.0[b] | 125.21[a] | 4.08 | <0.05 |
| Ser | 71.5[b] | 72.9[b] | 69.9[b] | 72.9[b] | 89.5[a] | 1.56 | <0.05 |
| Tyr | 75.6[b] | 77.8[b] | 76.4[b] | 76.0[b] | 90.0[a] | 1.18 | <0.05 |
| Mean | 79.8[b] | 81.6[b] | 80.8[b] | 77.7[b] | 90.8[a] | 2.16 | <0.05 |
| All AA | 77.7[b] | 79.3[b] | 78.4[b] | 75.8[b] | 89.6[a] | 1.68 | <0.05 |

[a–c]Within a row, means followed by the same or no superscript letter are not different ($P > 0.05$).

[1]Each least squares mean represents 12 observations.

[2]Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg DMI) as CP, 15.97; Arg, 0.54; His, 0.14; Ile, 0.17; Leu, 0.41; Lys, 0.35; Met, 0.07; Phe, 0.25; Thr, 0.49; Trp, 0.10; Val, 0.47; Ala, 0.56.

Heating is an effective way to improve the nutritional value of canola meal by denaturing the native protein structure in the meal (Canola Council of Canada, 2009). However, excessive heating may cause protein and AA damage, which may change the energy concentration of ingredients (Ford, 1973; Fontaine et al., 2007; González-Vega et al., 2011). The lack of a difference in the concentrations of GE between CM-HT and CM-LT indicates that the heat treatment used to produce CM-HT did not result in Maillard reactions. This observation is in agreement with data reported by Montoya and Leterme (2009), who did not observe differences in GE between toasted and nontoasted meals. Likewise, the concentration of Lys was not reduced in CM-HT compared with CM-LT, and the Lys:CP ratio was not changed. Maillard reactions in proteins result in reduced concentrations of Lys and reduced SID of Lys, whereas the concentration of CP is not changed (Almeida et al., 2014). Therefore, calculation of the Lys:CP ratio indicates if a protein has been heat damaged, and the observation that the Lys:CP ratios were similar for CM-HT and CM-LT indicates that there was no difference in heat damage between these 2 ingredients.

The CM-HT contained slightly less total glucosinolates than CM-LT, which concurs with the observation reported by Jensen et al. (1995), who also observed that heat treatment reduced the concentration of glucosinolates in rapeseed meal. However, the difference in processing temperatures between CM-HT and CM-LT that was used in this experiment was relatively modest, and it is possible that greater differences in processing temperatures may result in a different outcome.

The AA composition of SBM that was determined in this experiment concurs with published values (NRC, 2012). The AA compositions of the CM-HT, CM-LT, and CM-CV are also in close agreement with published values for conventional canola meal (González-Vega and Stein, 2012; NRC, 2012). Canola meal has a greater concentration of sulfur-containing AA than SBM, which was also observed in this experiment. High-protein canola meal also has greater concentrations of all AA than CM-CV, which is consistent with Slominski et al. (2012) and Trindade Neto et al. (2012).

### *Energy Measurements*

The GE, DE, and ME values in SBM correspond with values of Goebel and Stein (2011) but are greater than other reported values (Baker and Stein, 2009; NRC, 2012), which is likely because SBM used in the present experiment contains more fat (1.87% vs. 0.83%) than SBM used by Baker and Stein (2009). The values for DE and ME for corn that were determined in this experiment are in close agreement with previously published values (Baker and Stein, 2009; Goebel and Stein, 2011; NRC, 2012).

Values for DE and ME in the 4 canola meals are in close agreement with DE and ME values reported by Bourdon and Aumaître (1990) and NRC (2012) but lower than the DE and ME values reported by Montoya and Leterme (2009). The DE in CM-CV is greater than values previously reported for rapeseed meal or canola meal by Noblet et al. (1993), NRC (1998), and Sauvant et al. (2004). The reason for the reduced ATTD of GE in the canola meal diets compared with the SBM diet may be that canola meal contains more nondigestible ADF, NDF, and lignin than SBM (Landero et al., 2011). It was expected that the ATTD of GE was greater in CM-HP than in CM-CV because of the reduced hull and fiber contents because canola meal containing less fiber contains more DE than conventional canola meal (Bell et al., 1998; de Lange et al., 1998; Montoya and Leterme, 2009). In broilers, the apparent and true metabolizable energy concentration in canola meal with reduced fiber was also greater than that of canola meal with more fiber (Newkirk et al., 1997; Slominski et al., 1999; Jia et al., 2012). The reason why CM-HP did not contain more DE and ME than CM-HT, CM-LT, and CM-CV, despite the increased protein concentration and decreased fiber concentration, is not clear.

The lack of a difference in DE and ME between CM-HT and CM-LT is in agreement with the data reported by Montoya and Leterme (2009), who did not observe a difference in the DE between toasted and nontoasted canola meal. We are not aware of other published data on the impact of processing temperature on the DE and ME of canola meal, but results from the present experiment and the experiment by Montoya and Leterme (2009) indicate that use of high temperatures during processing of canola meal does not reduce the DE and ME in the meal.

### *AA Digestibility*

Values for AID and SID of AA in SBM and CM-CV agree with previously reported values (González-Vega and Stein, 2012; NRC, 2012). However, The SID of AA obtained from CM-CV is less than the values reported by Stein et al. (2001) and by Trindade Neto et al. (2012). The differences between the present results and previously reported values may be explained by differences in varieties, soil conditions, fertilizer levels, and weather conditions, which influence digestibility values for AA in canola meal (Fan et al., 1996; Canola Council of Canada, 2009). The SID of Lys and the Lys:CP ratio in SBM and CM-CV are less than the values reported by Stein et al. (2001, 2005) and Trindade Neto et al. (2012). The most likely reason for these differences is that overheating of the SBM and canola meal during the desolventizer-toasting phase may result in Maillard reactions, which negatively affects Lys concentration and digestibility (Newkirk et al., 2003; Pahm et al., 2008; González-Vega et al., 2011). The observation that AID and SID of AA in all 4 canola meals were less than in SBM may be a result of the greater concentration of ADF and NDF in canola meals than in SBM because increased fiber concentration has a depressive effect on values for AA digestibility (Lenis et al., 1996; Nyachoti et al., 1997; González-Vega and Stein, 2012). The glucosinolates in the canola meals may also have a negative effect on AA digestibility (Gilani et al., 2005; González-Vega and Stein, 2012).

The AID and SID of AA in CM-HP observed in this experiment are slightly less than previously reported values (Trindade Neto et al., 2012), but this may be a result of the different variety used in this experiment. The increased SID of Lys and Cys in CM-HP compared with CM-CV is in agreement with the results of Trindade Neto et al. (2012). The increased concentration of AA in combination with the equal or greater AID and SID for AA results in CM-HP providing more digestible AA for growing pigs compared with CM-CV.

Canola meal produced by the cold-pressing process with a temperature not exceeding 60°C has greater AID and SID of several AA compared with the AID and SID in canola meal produced with the conventional prepress solvent extraction process (Trindade-Neto et al., 2012). Likewise, the AID of AA in nontoasted canola meal fed to broiler chickens is greater than in toasted canola meal (Newkirk et al., 2003). The observation that the AID and SID of AA were not different between CM-HT and CM-LT indicates that the desolventizer temperature used to produce CM-HT was not high enough to reduce the AA digestibility in this canola meal compared with CM-LT, which is also in agreement with the data for DE and ME and with the calculated values for the Lys:CP ratio.

In conclusion, the 4 canola meals used in the present experiments have reduced digestibility of energy and AA compared with SBM and lower digestibility of energy than corn, but neither protein concentration nor processing temperature influenced DE and ME in canola meal. Canola meal produced from a high-protein variety of canola has AID and SID of AA that are similar to or greater than the AID and SID in conventional canola meal, which results in greater concentrations of digestible AA in high-protein canola meal than in conventional canola meal. However, the processing temperature used in this experiment did not influence AID and SID of AA in canola meal.

## LITERATURE CITED

Almeida, F. N., J. K. Htoo, J. Thomson, and H. H. Stein. 2014. Effects of heat treatment on apparent and standardized ileal digestibility of amino acids in canola meal fed to growing pigs. Anim. Feed Sci. Technol. 187:44–52.

Anderson-Hafermann, J. C., Y. Zhang, and C. M. Parsons. 1993. Effects of processing on the nutritional quality of canola meal. Poult. Sci. 72:326–333.

American National Standards Institute/American Society of Agricultural Engineers (ANSI/ASAE). 2008. Method of determining and expressing fineness of feed materials by sieving. ANSI/ASAE Standard S319.4. American Society of Agricultural and Biological Engineers, St. Joseph, MI.

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

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.

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

Bell, J. M., and M. O. Keith. 1989. Factors affecting the digestibility by pigs of energy and protein in wheat, barley and sorghum diets supplemented with canola meal. Anim. Feed Sci. Technol. 24:253–265.

Bell, J. M., R. T. Tyler, and G. Rakow. 1998. Nutritional composition and digestibility by 80-kg to 100-kg pigs of prepress solvent-extracted meals from low glucosinolate *Brassica juncea, B. napus* and *B. rapa* seed and of solvent-extract soybean meal. Can. J. Anim. Sci. 78:199–203.

Bourdon, D., and A. Aumaître. 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 meal feed industry guide. www.canolacouncil.org/media/516716/canola_meal_feed_guide_english.pdf. (Accessed 3 November 2012).

de Lange, C. F. M., V. M. Gabert, D. Gillis, and J. F. Patience. 1998. Digestible energy contents and apparent ileal amino acid digestibilites in regular or partial mechanically dehulled canola meal samples fed to growing pigs. Can. J. Anim. Sci. 78:641–648.

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

Fan, M. Z., W. C. Sauer, and C. F. M. de Lange. 1995. Amino acid digestibility in soybean meal, extruded soybean and full-fat canola for early-weaned pigs. Anim. Feed Sci. Technol. 52:189–203.

Fan, M. Z., W. C. Sauer, and V. M. Gabert. 1996. Variability of apparent ileal amino acid digestibility in canola meal for growing-finishing pigs. Can. J. Anim. Sci. 76:563–569.

Fontaine, J., U. Zimmer, P. J. Moughan, and S. M. Rutherfurd. 2007. Effect of heat damage in an autoclave on the reactive lysine contents of soy products and corn distillers dried grains with solubles. Use of the results to check on lysine damage in common qualities of these ingredients. J. Agric. Food Chem. 55:10737–10743.

Ford, J. E. 1973. Some effects of processing on nutritive value. In: J. W. Porter and B. A. Rolls, editors, Proteins in human nutrition. Academic Press, London. p. 515–529.

Gilani, G. S., K. A. Cockell, and E. Sepehr. 2005. Effect of antinutritional factors on protein digestibility and amino acid availability in foods. J. AOAC Int. 88:967–987.

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

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.

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.

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

Hurrell, R. F. 1990. Influence of the Maillard reaction on the nutritional value of foods. In: P. A. Finot, H. U. Aeschbacher, R. F. Hurrell, and R. Liardon, editors, The Maillard reaction in food processing, human nutrition and physiology. Birkhäuser, Basel, Switzerland. p. 245–258.

Janauer, G. A., and P. Englmaier. 1978. Multi-step time program for the rapid gas-liquid chromatography of carbohydrates. J. Chromatogr. A 153:539–542.

Jensen, S. K., Y. Liu, and B. O. Eggum. 1995. The effect of heat treatment on glucosinolates and nutritional value of rapeseed meal in rats. Anim. Feed Sci. Technol. 53:17–28.

Jia, W., D. Mikulski, A. Rogiewicz, Z. Zduńczyk, J. Jankowski, and B. A. Slominski. 2012. Low-fiber canola. Part 2. Nutritive value of the meal. J. Agric. Food Chem. 60:12231–12237.

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.

King, R. H., P. E. Eason, D. K. Kerton, and F. R. Dunshea. 2001. Evaluation of solvent-extracted canola meal for growing pigs and lactating sows. Aust. J. Agric. Res. 52:1033–1041.

Landero, J. L., E. Beltranena, M. Cervantes, A. Morales, and R. T. Zijlstra. 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.

Lee, K.-C., W. Chan, Z. Liang, N. Liu, Z. Zhao, A. W.-M. Lee, and Z. Cai. 2008. Rapid screening method for intact glucosinolates in Chinese medicinal herbs by using liquid chromatography coupled with electrospray ionization ion trap mass spectrometry in negative ion mode. Rapid Commun. Mass Spectrom. 22:2825–2834.

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.

Montoya, C. A., and P. Leterme. 2009. Determination of the digestible energy and prediction of the net energy content of toasted and non-toasted canola meals from *Brassica juncea* and *Brassica napus* in growing pigs by the total faecal collection and the indigestible marker methods. Can. J. Anim. Sci. 89:481–487.

Newkirk, R. W., H. L. Classen, T. A. Scott, and M. J. Edney. 2003. The digestibility and content of amino acids in toasted and non-toasted canola meals. Can. J. Anim. Sci. 83:131–139.

Newkirk, R. W., H. L. Classen, and R. T. Tyler. 1997. Nutritional evaluation of low glucosinolate mustard meals (*Brassica juncea*) in broiler diets. Poult. Sci. 76:1272–1277.

Noblet, J., H. Fortune, C. Dupire, and S. Dubois. 1993. Digestible, metabolizable and net energy values of 13 feedstuffs for growing pigs: Effect of energy system. Anim. Feed Sci. Technol. 42:131–149.

NRC. 1998. Nutrient requirements of swine. 10th ed. Natl. Acad. Press, Washington, DC.

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

Nyachoti, C. M., C. F. M. de Lange, and H. Schulze. 1997. Estimating endogenous amino acid flows at the terminal ileum and true ileal amino acid digestibilities in feedstuffs for growing pigs using the homoarginine method. J. Anim. Sci. 75:3206–3213.

Pahm, A. A., C. Pedersen, D. Hoehler, and H. H. Stein. 2008. Factors affecting the variability in ileal amino acid digestibility in corn distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 86:2180–2189.

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, p. 77-81.

Sauvant, D., J. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials. 2nd ed. Wageningen Acad. Publ., Wageningen, The Netherlands.

Slominski, B. A., L. D. Campbell, and W. Guenter. 1994. Carbohydrate and dietary fiber components of yellow- and brown-seeded canola. J. Agric. Food Chem. 42:704–707.

Slominski, B. A., W. Jia, A. Rogiewicz, C. M. Nyachoti, and D. Hickling. 2012. Low-fiber canola. Part 1. Chemical and nutritive composition of the meal. J. Agric. Food Chem. 60:12225–12230.

Slominski, B. A., J. Simbaya, L. D. Campbell, G. Rakow, and W. Guenter. 1999. Nutritive value for broilers of meals derived from newly developed varieties of yellow-seeded canola. Anim. Feed Sci. Technol. 78:249–262.

Stein, H. H., S. Aref, and R. A. Easter. 1999. Comparative protein and amino acid digestibilities in growing pigs and sows. J. Anim. Sci. 77:1169–1179.

Stein, H. H., S. W. Kim, T. T. Nielsen, and R. A. Easter. 2001. Standardized ileal protein and amino acid digestibility by growing pigs and sows. J. Anim. Sci. 79:2113–2122.

Stein, H. H., C. Pedersen, A. R. Wirt, and R. A. Bohlke. 2005. Additivity of values for apparent and standardized ileal digestibility of amino acids in mixed diets fed to growing pigs. J. Anim. Sci. 83:2387–2395.

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.

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. Butterworths, Stoneham, MA. p. 69–78.

Tran, G., and D. Sauvant. 2004. Chemical data and nutritional value In: Tables of composition and nutritional value of feed materials. 2nd ed. Wageningen Acad. Publ., Wageningen, The Netherlands. p. 17–24.

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.

Unǵer, E. H. 2011. Processing. In: J. K. Daun, N. A. M. Eskin, and D. Hickling, editors, Canola: Chemistry, production, processing, and utilization. AOCS Press., Urbana, IL. p. 163–188.