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

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ABSTRACT

Two experiments were conducted to determine digestible energy (DE) and metabolizable energy (ME) and the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of crude protein and amino acids in high protein canola meal (CM-HP), conventional canola meal (CM-CV), and soybean meal fed to growing pigs. In Exp. 1, 32 barrows (initial body weight: 47.3 ± 6.2 kg) were housed in metabolism cages and randomly allotted to one of four diets with eight replicate pigs per diet. A corn-based diet (973 g/kg corn) and three diets that contained both corn and each of the two sources of canola meal or soybean meal were formulated. Feces and urine were collected for 5 days after a 5-day adaptation period. The DE and ME values were 14.40 and 13.84 MJ/kg in corn, 12.43 and 10.34 MJ/kg in CM-HP, 11.02 and 9.65 MJ/kg in CM-CV, and 15.63 and 14.13 MJ/kg in soybean meal, respectively. The DE and ME were greater ($P < 0.05$) in corn and soybean meal than in CM-HP and CM-CV, but the DE and ME were not different between CM-HP and CM-CV. In Exp. 2, eight barrows (initial body weight: 46.4 ± 5.6 kg) were equipped with a T-cannula in the distal ileum and randomly allotted to a replicated 4 × 4 Latin square design with 4 diets and 4 periods in each square. A N-free diet and three cornstarch based diets that contained CM-HP, CM-CV, or soybean meal as the sole source of amino acids were formulated. Each period lasted 7 days and ileal digesta were collected on day 6 and 7 of each period. The AID and SID of crude protein and most amino acids in CM-HP and CM-CV were less ($P < 0.05$) than in soybean meal. The AID and SID of crude protein in CM-HP was greater ($P < 0.05$) than in CM-CV. However, no differences were observed in AID and SID of any amino acids between CM-HP and CM-CV. The concentration of standardized ileal digestible crude protein and almost all amino acids was greater ($P < 0.05$) in soybean meal than in CM-HP and CM-CV, and CM-HP contained more ($P < 0.05$) standardized ileal digestible crude protein and amino acids than CM-CV. In conclusion, increased concentration of crude protein in canola meal does not compromise the concentration of DE and ME, and does not compromise AID or SID of amino acids. As a consequence, the novel CM-HP supplies the same amount of DE and more digestible amino acids for growing pigs compared with CM-CV.



*Abbreviations:* ADF, acid detergent fiber; AID, apparent ileal digestibility; ATTD, apparent total tract digestibility; CM-CV, conventional canola meal; CM-HP, high protein canola meal; DE, digestible energy; GE, gross energy; ME, metabolizable energy; NDF, neutral detergent fiber; SEM, standard error of the mean; SID, standardized ileal digestibility.

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## 1. Introduction

Canola meal is often included in diets fed to pigs, but inclusion levels may be restricted by the concentration of glucosinolates in the meal (Schone et al., 2001) and also by the relatively high concentration of fiber in canola meal (Newkirk, 2009; Barthet and Daun, 2011). However, new varieties of canola with reduced concentration of fiber and greater concentration of crude protein and oil have been identified, and the canola meal produced from these varieties contains more protein and less fiber than conventional canola meal (Jia et al., 2012; Trindade Neto et al., 2012; Berrocoso et al., 2015; Parr et al., 2015). The digestibility of energy is greater in high protein canola meal (CM-HP) than in conventional canola meal (CM-CV) when fed to broilers and turkeys (Jia et al., 2012), but there is limited information about the digestibility of energy in CM-HP fed to pigs.

The standardized ileal digestibility (SID) of amino acids in yellow-seeded CM-HP fed to pigs has been reported (Trindade Neto et al., 2012; Liu et al., 2014), but black-seeded high protein varieties of canola are also available. In our recent work we observed that the SID of amino acids in CM-HP from black-seeded canola is not greater than in CM-CV (Berrocoso et al., 2015), but the CM-HP used in that experiment had concentrations of total glucosinolates that was approximately 15 μmol/g, whereas the CM-CV used in the experiment only contained 8.69 μmol/g of total glucosinolates. This difference in concentrations of glucosinolates may have influenced the results. It is, therefore, possible that the SID of amino acids and the digestibility of energy in CM-HP may be greater in CM-HP with a reduced concentration of glucosinolates.

Therefore, the objectives of these experiments were to determine the concentration of digestible energy (DE) and metabolizable energy (ME) and the apparent ileal digestibility (AID) and SID of crude protein and amino acids in CM-HP produced from new high protein canola varieties with reduced concentrations of glucosinolates and to compare these values to values obtained for CM-CV and soybean meal when fed to growing pigs.

## 2. Materials and methods

### 2.1. 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).

The main ingredients that were used in these experiments were yellow dent corn, CM-HP, CM-CV, and soybean meal (Table 1). The CM-HP was sourced from *Brassica napus* selected for low concentrations of glucosinolates and less fiber and more crude protein than in traditional canola (Table 2). The CM-CV used in this experiment was sourced from conventional *B. napus*. The soybean meal that was used was sourced from Dupont, Gibson City, IL, the U.S., and corn was grown locally and obtained from the University of Illinois Feed Mill (Champaign, IL, U.S.).

### 2.2. Energy measurements

In experiment 1, 32 growing barrows (initial body weight: 47.3 ± 6.2 kg) were allotted to a randomized complete block design with four diets and eight replicate pigs per diet to determine the apparent total tract digestibility (ATTD) of gross energy (GE) and the DE and ME in CM-HP, CM-CV, and soybean meal. 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.

Four corn-based diets were formulated (Table 3). The basal diet contained 973 g/kg corn (as-fed basis). As-fed basis, the CM-HP diet contained 718.5 g/kg corn and 260.0 g/kg CM-HP, the CM-CV diet contained 669.5 g/kg corn and 310.0 g/kg CM-CV, and the soybean meal diet contained 726.0 g/kg corn and 250.0 g/kg soybean meal. The diets containing CM-HP, CM-CV, or soybean meal were formulated to contain approximately 180 g/kg of crude protein. Vitamins and minerals were included in all diets to meet or exceed the requirements for growing pigs (NRC, 2012). Corn, canola meal, and soybean meal were the only sources of energy in the diets.

The amount of feed supplied daily to the pigs was calculated as three times the maintenance energy requirement (i.e., 0.82 MJ ME per $kg^{0.60}$; NRC, 2012) of the smallest pig in each replicate and divided into two equal meals that were fed at 08:00 and 17:00 h. Water was available at all times.

Pigs were fed experimental diets for 12 days. The initial 5 days were considered an adaptation period to the diet. Fecal markers were fed on day 6 (5 g chromic oxide per kg) and on day 11 (5 g ferric oxide per kg), 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 collections started on day 6 at 17:00 h and ceased on d 11 at 17:00 h. Urine buckets were placed under the metabolism cages to permit total collection. They were emptied in the morning and afternoon, and a preservative of 50 mL of 6N HCL was added to each bucket when they were emptied. The collected urine was weighed and a 10% subsample was stored at −20 °C.

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 and lyophilized before analysis for GE (Kim et al., 2009). 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

**Table 1**
Analyzed nutrient composition of high protein canola meal (CM-HP), conventional canola meal (CM-CV), and soybean meal, as-fed basis.

| Item | Ingredient | | |
|---|---|---|---|
| | CM-HP | CM-CV | Soybean meal |
| Analyzed value | | | |
| Gross energy (MJ/kg) | 18.03 | 17.87 | 17.77 |
| Dry matter (g/kg) | 894.0 | 889.0 | 890.0 |
| Crude protein (g/kg) | 450.3 | 405.2 | 494.8 |
| Ash (g/kg) | 76.4 | 71.4 | 57.4 |
| Acid-hydrolyzed crude fat (g/kg) | 20.9 | 16.4 | 6.7 |
| Neutral detergent fiber (g/kg) | 151.0 | 188.8 | 67.4 |
| Acid detergent fiber (g/kg) | 92.2 | 143.2 | 38.3 |
| Phosphorus (g/kg) | 12.0 | 10.4 | 6.2 |
| Calcium (g/kg) | 5.8 | 6.1 | 3.3 |
| Carbohydrates (g/kg) | | | |
| Fructose | 0.2 | 0.2 | 1.1 |
| Glucose | 0.3 | 0.4 | 1.2 |
| Sucrose | 53.4 | 60.0 | 74.5 |
| Raffinose | 5.2 | 3.5 | 10.7 |
| Stachyose | 6.5 | 8.0 | 30.7 |
| Starch | 0.0 | 0.0 | 5.6 |
| Indispensable amino acids (g/kg) | | | |
| Arginine | 25.4 | 23.1 | 34.7 |
| Histidine | 11.2 | 10.1 | 12.4 |
| Isoleucine | 15.4 | 14.6 | 21.0 |
| Leucine | 28.4 | 26.7 | 36.5 |
| Lysine | 23.3 | 21.1 | 28.8 |
| Methionine | 8.3 | 7.3 | 6.5 |
| Phenylalanine | 16.6 | 15.2 | 23.9 |
| Threonine | 16.3 | 15.6 | 18.0 |
| Tryptophan | 6.2 | 5.3 | 6.4 |
| Valine | 20.4 | 18.6 | 22.2 |
| Dispensable amino acids (g/kg) | | | |
| Alanine | 18.0 | 16.6 | 20.4 |
| Aspartic acid | 27.4 | 25.5 | 52.0 |
| Cysteine | 10.7 | 9.0 | 5.9 |
| Glutamic acid | 76.5 | 66.6 | 84.9 |
| Glycine | 20.7 | 19.2 | 20.2 |
| Proline | 24.6 | 23.4 | 23.2 |
| Serine | 14.8 | 13.6 | 20.0 |
| Tyrosine | 10.7 | 10.7 | 17.6 |
| Total amino acids (g/kg) | 374.9 | 342.2 | 454.6 |

Scientific, Swedesboro, NJ) before analyses. Diets and ingredient samples (Table 1) were analyzed for dry matter (Method 930.15; AOAC Int., 2007) and GE using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Ingredient samples were analyzed for crude protein by combustion (Method 999.03; AOAC Int., 2007) using a Rapid N cube (Elementar Americas Inc, Mt. Laurel, NJ), ash (Method 975.03; AOAC Int., 2007), acid detergent fiber (ADF; Method 973.18; AOAC Int., 2007), neutral detergent fiber (NDF; Holst, 1973), and acid hydrolyzed ether extract, which was determined by acid hydrolysis using 3N HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (Method 2003.06, AOAC Int., 2007) on a Soxtec

**Table 2**
Analyzed glucosinolates of high protein canola meal (CM-HP) and conventional canola meal (CM-CV), as-fed basis.

| Item (μmol/g) | Ingredient | |
|---|---|---|
| | CM-HP | CM-CV |
| Progoitrin | 3.40 | 5.5 |
| Glucoalyssin | 0.9 | 1.0 |
| Gluconapoleiferin | 0.3 | 0.3 |
| Gluconapin | 1.2 | 0.9 |
| 4-hydroxyglucobrassicin | 1.4 | 7.7 |
| Glucobrassicanapin | 0.6 | 0.7 |
| Glucoerucin | 0.8 | 0.8 |
| Glucobrassicin | 0.5 | 0.8 |
| Gluconasturtin | 0.4 | 0.3 |
| Neoglucobrassicin | 0.7 | 1.1 |
| Total Glucosinolates | 10.2 | 19.1 |

**Table 3**
Composition of experimental diets containing corn, high protein canola meal (CM-HP), conventional canola meal (CM-CV), and soybean meal, as-fed basis, experiment 1.

| Item | Diet | | | |
|---|---|---|---|---|
| | Corn | CM-HP | CM-CV | Soybean meal |
| Ingredient (g/kg) | | | | |
| Ground corn | 972.5 | 718.5 | 669.5 | 726.0 |
| CM-HP | – | 260.0 | – | – |
| CM-CV | – | – | 310.0 | – |
| Soybean meal | – | – | – | 250.0 |
| Ground limestone | 11.0 | 11.0 | 10.5 | 12.0 |
| Dicalcium phosphate | 9.5 | 3.5 | 3.0 | 5.0 |
| Salt | 4.0 | 4.0 | 4.0 | 4.0 |
| Vitamin-mineral premix[1] | 3.0 | 3.0 | 3.0 | 3.0 |
| Analyzed composition | | | | |
| Dry matter (g/kg) | 859.1 | 858.8 | 869.7 | 870.0 |
| Gross energy (MJ/kg) | 15.78 | 16.09 | 16.04 | 16.04 |

[1] Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D3 as cholecalciferol, 2208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

2050 automated analyzer (FOSS North America, Eden Prairie, MN). Ingredients were also analyzed for sucrose, raffinose, stachyose, fructose, and glucose (Janauer and Englmaier, 1978), starch (Method 948.02; AOAC International, 2007), calcium and phosphorus (Method 985.01; AOAC International, 2007), and amino acids [Method 982.30 E (a, b, c); AOAC International, 2007]. Fecal and urine samples were also analyzed for GE. The two canola meals were analyzed for glucosinolates (Table 2; ISO, 1992).

### 2.2.1. Calculations

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 using the direct procedure (Adeola, 2001). The DE and ME in the corn diet were divided by 0.973 to calculate the DE and ME in corn. The contributions of DE and ME from corn to the diets containing CM-HP, CM-CV, or soybean meal were then calculated and subtracted from the total DE and ME of these diets, and the concentrations of DE and ME in CM-HP, CM-CV, and soybean meal were calculated by difference (Adeola, 2001). The DE and ME in all ingredients were calculated on an as-fed basis as well as on a dry matter basis. The ATTD of GE was also calculated for all diets using the direct procedure and for the two sources of canola meal and soybean meal using the difference procedure (Adeola, 2001).

### 2.2.2. Statistical analyses

Normality of data was verified and outliers were tested using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC). Data were analyzed by ANOVA using the Mixed Procedure of SAS (SAS Institute Inc., Cary, NC) in a randomized complete block design with pig as experimental unit. The statistical model included diet as the fixed effect and period as the random effect. The Least Significant Means statement in SAS was used to calculate treatment means and the PDIFF option was used to separate means if differences were detected. Statistical significance was considered at $P < 0.05$.

## 2.3. Amino acid digestibility

In experiment 2, eight growing pigs (46.4 ± 5.6 kg) were equipped with a T-cannula in the distal ileum according to procedures adapted from Stein et al. (1998). Pigs were allotted to a replicated 4 × 4 Latin square design with 4 periods and 4 diets in each square to determine the AID and the SID of crude protein and amino acids in CM-HP, CM-CV, and soybean meal. The three ingredients were sourced from the same batch as the ingredients used in Exp. 1. Pigs were housed individually in pens (1.2 × 1.5 m) in an environmentally controlled room. A feeder and a nipple drinker were installed in each pen.

Four diets were formulated (Table 4). Three diets were based on cornstarch and CM-HP, CM-CV, or soybean meal, and the last diet was a N-free diet that was used to estimate basal endogenous losses of crude protein and amino acids. Vitamins and minerals were included in all diets to meet or exceed current requirements for 25–50 kg growing pigs (NRC, 2012) and chromic oxide (4 g/kg) was included in all diets as an indigestible marker.

Individual pig weights were recorded at the beginning 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 07:00 h each day. Water was available at all times throughout the experiment. The initial 5 days of each period was considered an adaptation period to the diet whereas ileal digesta were collected for 8 h on day 6 and 7. A 225-mL plastic bag was attached to the cannula barrel by a zip tie, and digesta that flowed into the bag were collected.

**Table 4**
Composition of experimental diets containing high protein canola meal (CM-HP), conventional canola meal (CM-CV), soybean meal, and in the N-Free diet, as-fed basis, experiment 2.

| | Diet | | | |
|---|---|---|---|---|
| Item | CM-HP | CM-CV | Soybean meal | N-free |
| Ingredient (g/kg) | | | | |
| CM-HP | 350.0 | – | – | – |
| CM-CV | – | 400.0 | – | – |
| Soybean meal | – | – | 330.0 | – |
| Soybean oil | 30.0 | 30.0 | 30.0 | 40.0 |
| Solka floc[1] | – | – | – | 40.0 |
| Monocalcium phosphate | 5.0 | 5.0 | 12.5 | 20.0 |
| Ground limestone | 9.0 | 9.0 | 6.5 | 5.0 |
| Sucrose | 100.0 | 100.0 | 100.0 | 200.0 |
| Chromic oxide | 4.0 | 4.0 | 4.0 | 4.0 |
| Cornstarch | 495.0 | 445.0 | 510.0 | 679.0 |
| Magnesium oxide | – | – | – | 1.0 |
| Potassium carbonate | – | – | – | 4.0 |
| Sodium chloride | 4.0 | 4.0 | 4.0 | 4.0 |
| Vitamin mineral premix[2] | 3.0 | 3.0 | 3.0 | 3.0 |
| Analyzed composition (g/kg) | | | | |
| Dry matter | 916.2 | 918.0 | 922.7 | 925.6 |
| Crude protein | 161.7 | 162.9 | 161.1 | 3.5 |
| Indispensable amino acids | | | | |
| Arginine | 8.4 | 9.8 | 10.6 | 0.1 |
| Histidine | 3.7 | 4.3 | 4.0 | 0.0 |
| Isoleucine | 5.9 | 6.7 | 7.2 | 0.3 |
| Leucine | 10.2 | 11.7 | 12.1 | 0.0 |
| Lysine | 8.0 | 9.1 | 9.3 | 0.0 |
| Methionine | 3.0 | 3.2 | 2.1 | 0.0 |
| Phenylalanine | 6.1 | 6.9 | 8.0 | 0.4 |
| Threonine | 5.8 | 6.9 | 6.0 | 0.1 |
| Tryptophan | 2.2 | 2.4 | 2.3 | 0.4 |
| Valine | 7.4 | 8.4 | 7.5 | 0.1 |
| Total indispensable amino acids | 60.7 | 69.4 | 69.1 | 1.0 |
| Dispensable amino acids | | | | |
| Alanine | 6.4 | 7.2 | 6.7 | 0.2 |
| Aspartic acid | 10.0 | 11.6 | 17.7 | 0.3 |
| Cysteine | 3.8 | 4.0 | 2.1 | 0.1 |
| Glutamic acid | 27.1 | 29.3 | 27.9 | 0.4 |
| Glycine | 7.1 | 8.2 | 6.5 | 0.1 |
| Proline | 9.6 | 10.4 | 7.9 | 0.6 |
| Serine | 5.6 | 6.4 | 7.1 | 0.0 |
| Tyrosine | 3.5 | 4.3 | 5.1 | 0.0 |
| Total dispensable amino acids | 73.1 | 81.4 | 81.0 | 1.7 |

[1] Fiber Sales and Development Corp., Urbana, OH.
[2] Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D3 as cholecalciferol, 2208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

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 amino acids in the digesta.

At the conclusion of the experiment, ileal samples were thawed, 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 soybean meal 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 dry matter, crude protein, and amino acids as described for experiment 1, and chromium concentration was determine after nitric acid-perchloric acid wet ash sample preparation (Method 990.08, AOAC Int., 2007).

### 2.3.1. *Calculations*

Values for AID, basal endogenous losses, and SID of crude protein and amino acids in the three amino acid containing diets were calculated (Stein et al., 2007). Because CM-HP, CM-CV, or soybean meal were the only amino acid containing ingredients in these diets, the AID and SID values obtained for each diet also represent the AID and SID of crude protein and amino acids in each ingredient. The SID of crude protein and each amino acid was multiplied by the concentration of crude protein or the corresponding amino acid (as-fed basis) in the ingredients to calculate the concentration of standardized ileal digestible crude protein and amino acids for each ingredient.

**Table 5**
Energy digestibility and concentrations of digestible energy (DE) and metabolizable energy (ME) in corn, high protein canola meal (CM-HP), conventional canola meal (CM-CV), and soybean meal, as-fed basis, experiment 1[1,2].

| Item | Corn | CM-HP | CM-CV | Soybean meal | SEM | *P*-value |
|---|---|---|---|---|---|---|
| Diet | | | | | | |
| Total feed intake (kg) | 8.31 | 9.24 | 9.52 | 8.68 | | |
| Gross energy intake (MJ) | 131.11[b] | 148.60[a] | 152.68[a] | 139.19[b] | 3.521 | <0.01 |
| Dry feces output (kg) | 0.77[c] | 1.25[b] | 1.53[a] | 0.75[c] | 0.085 | <0.01 |
| Gross energy in dry feces (MJ/kg) | 19.23[ab] | 18.51[c] | 18.60[bc] | 19.51[a] | 0.268 | <0.01 |
| Fecal Gross energy output (MJ) | 14.73[c] | 23.19[b] | 28.52[a] | 14.66[c] | 1.758 | <0.01 |
| ATTD[3], gross energy | 0.89[a] | 0.84[b] | 0.81[c] | 0.90[a] | 0.011 | <0.01 |
| DE in diet (MJ/kg) | 14.00[ab] | 13.58[b] | 13.05[c] | 14.36[a] | 0.167 | <0.01 |
| Urine output (kg) | 14.57 | 34.56 | 31.27 | 33.58 | 7.288 | 0.123 |
| Gross energy in urine (MJ/kg) | 0.35 | 0.26 | 0.30 | 0.25 | 0.051 | 0.425 |
| Urinary gross energy output (MJ) | 4.35 | 8.51 | 7.76 | 7.26 | 1.411 | 0.051 |
| ME in diet (MJ/kg) | 13.46[a] | 12.63[b] | 12.25[b] | 13.58[a] | 0.243 | <0.01 |
| Ingredient | | | | | | |
| DE (MJ/kg) | 14.40[a] | 12.43[b] | 11.02[b] | 15.63[a] | 0.620 | <0.01 |
| ME (MJ/kg) | 13.84[a] | 10.34[b] | 9.65[b] | 14.13[a] | 0.825 | <0.01 |
| DE (MJ/kg dry matter) | 16.80[a] | 14.31[b] | 13.00[b] | 18.02[a] | 0.716 | <0.01 |
| ME (MJ/kg dry matter) | 16.14[a] | 11.90[b] | 11.39[b] | 16.30[a] | 0.955 | <0.01 |

[a–c] means within a row lacking a common superscript letter differ ($P < 0.05$).
[1] Each least squares mean represents eight observations.
[2] Diet intake, fecal output, and urine output were based on 5 days of collection.
[3] ATTD = apparent total tract digestibility.

### 2.3.2. Statistical analyses

Data were analyzed by ANOVA using the PROC MIXED procedure (SAS Institute Inc., Cary, NC) as described for experiment 1 with the exception that the statistical model included diet as the fixed effect and pig and period as the random effects.

## 3. Results

### 3.1. Energy digestibility

Pigs fed the CM-HP and CM-CV diets had greater ($P < 0.05$) intake of GE than pigs fed the corn or soybean meal diets (Table 5). Compared with the corn or soybean meal diets, pigs fed CM-HP or CM-CV diets had less ($P < 0.05$) energy concentration in dry feces, but greater ($P < 0.05$) feces output. As a consequence, pigs fed the CM-HP and CM-CV diets had less ($P < 0.05$) ATTD of GE compared with pigs fed the corn or soybean meal diets, and pigs fed the CM-HP diet had greater ($P < 0.05$) ATTD of GE compared with pigs fed the CM-CV diet. Diets containing either source of canola meal contained less ($P < 0.05$) DE than the diet containing soybean meal. The corn and CM-HP diets contained more ($P < 0.05$) DE than the diet containing CM-CV. Urine output and energy concentration in urine were not different among diets. Values for ME were greater ($P < 0.05$) in the corn and soybean meal diets than in CM-HP and CM-CV diets. There were no differences in DE and ME between CM-HP and CM-CV, but both sources of canola meal contained less ($P < 0.05$) DE and ME than soybean meal and corn on as-fed basis as well as on a dry matter-basis.

### 3.2. Amino acid digestibility

The AID of crude protein and all amino acids was greater ($P < 0.05$) in soybean meal than in CM-HP and CM-CV, except that the AID of tryptophan, cysteine, glutamic acid, glycine, and proline was not different among the three ingredients (Table 6). The basal endogenous loss of crude protein was 20.01 g per kg dry matter intake and values for lysine, methionine, threonine, and tryptophan were 0.53, 0.08, 0.67, and 0.12 g per kg dry matter intake, respectively. The SID of crude protein and all amino acids was also greater ($P < 0.05$) in soybean meal than in CM-HP and CM-CV, except that the SID of tryptophan, cysteine, and glutamic acid was not different among the three ingredients and the SID of glycine was not different between soybean meal and CM-HP (Table 7). No differences were observed in the AID or SID of crude protein and amino acids between CM-HP and CM-CV.

The concentrations of standardized ileal digestible crude protein and all amino acids, except methionine, cysteine, glycine, and proline were greater ($P < 0.05$) in soybean meal than in CM-HP and CM-CV (Table 8). The concentrations of standardized ileal digestible methionine and cysteine were less ($P < 0.05$) in soybean meal than in CM-HP and CM-CV, and the concentrations of standardized ileal digestible glycine and proline were not different between soybean meal and CM-HP. The concentrations of standardized ileal digestible crude protein and all amino acids were greater ($P < 0.05$) in CM-HP than in CM-CV, except for the concentrations of threonine, aspartic acid, proline, and tyrosine, which were not different between CM-HP and CM-CV.

**Table 6**
Apparent ileal digestibility (AID) of crude protein and amino acids in high protein canola meal (CM-HP), conventional canola meal (CM-CV), and soybean meal by growing pigs, experiment 2[1].

| Item | Ingredient | | | SEM | *P*-value |
|---|---|---|---|---|---|
| | CM-HP | CM-CV | Soybean meal | | |
| Crude protein | $0.71^{b}$ | $0.66^{b}$ | $0.80^{a}$ | 0.017 | <0.01 |
| Indispensable amino acids | | | | | |
| Arginine | $0.79^{b}$ | $0.79^{b}$ | $0.91^{a}$ | 0.015 | <0.01 |
| Histidine | $0.80^{b}$ | $0.80^{b}$ | $0.88^{a}$ | 0.011 | <0.01 |
| Isoleucine | $0.76^{b}$ | $0.75^{b}$ | $0.87^{a}$ | 0.013 | <0.01 |
| Leucine | $0.77^{b}$ | $0.76^{b}$ | $0.86^{a}$ | 0.013 | <0.01 |
| Lysine | $0.74^{b}$ | $0.73^{b}$ | $0.83^{a}$ | 0.012 | <0.01 |
| Methionine | $0.84^{b}$ | $0.83^{b}$ | $0.88^{a}$ | 0.010 | <0.01 |
| Phenylalanine | $0.78^{b}$ | $0.77^{b}$ | $0.87^{a}$ | 0.013 | <0.01 |
| Threonine | $0.68^{b}$ | $0.69^{b}$ | $0.79^{a}$ | 0.016 | <0.01 |
| Tryptophan | 0.84 | 0.83 | 0.88 | 0.015 | 0.10 |
| Valine | $0.73^{b}$ | $0.72^{b}$ | $0.84^{a}$ | 0.014 | <0.01 |
| Mean | $0.76^{b}$ | $0.76^{b}$ | $0.86^{a}$ | 0.013 | <0.01 |
| Dispensable amino acids | | | | | |
| Alanine | $0.73^{b}$ | $0.72^{b}$ | $0.80^{a}$ | 0.016 | <0.01 |
| Aspartic acid | $0.67^{b}$ | $0.67^{b}$ | $0.82^{a}$ | 0.020 | <0.01 |
| Cysteine | 0.76 | 0.75 | 0.75 | 0.017 | 0.98 |
| Glutamic acid | 0.83 | 0.82 | 0.86 | 0.015 | 0.12 |
| Glycine | 0.64 | 0.64 | 0.71 | 0.034 | 0.26 |
| Proline | 0.45 | 0.39 | 0.60 | 0.090 | 0.13 |
| Serine | $0.71^{b}$ | $0.71^{b}$ | $0.84^{a}$ | 0.014 | <0.01 |
| Tyrosine | $0.75^{b}$ | $0.77^{b}$ | $0.86^{a}$ | 0.012 | <0.01 |
| Mean | $0.71^{b}$ | $0.70^{b}$ | $0.80^{a}$ | 0.023 | <0.01 |
| All amino acids | $0.73^{b}$ | $0.73^{b}$ | $0.83^{a}$ | 0.018 | <0.01 |

a–b within a row, means without a common superscript letter are different ($P < 0.05$).
[1] Each least squares mean represents eight observations.

**Table 7**
Standardized ileal digestibility (SID) of crude protein and amino acids in high protein canola meal (CM-HP), conventional canola meal (CM-CV), and soybean meal by growing pigs, experiment 2[1,2].

| Item | Ingredient | | | SEM | *P*-value |
|---|---|---|---|---|---|
| | CM-HP | CM-CV | Soybean meal | | |
| Crude protein | $0.83^{b}$ | $0.78^{b}$ | $0.93^{a}$ | 0.018 | <0.01 |
| Indispensable amino acids | | | | | |
| Arginine | $0.87^{b}$ | $0.86^{b}$ | $0.97^{a}$ | 0.015 | <0.05 |
| Histidine | $0.85^{b}$ | $0.84^{b}$ | $0.92^{a}$ | 0.011 | <0.01 |
| Isoleucine | $0.81^{b}$ | $0.79^{b}$ | $0.91^{a}$ | 0.013 | <0.01 |
| Leucine | $0.82^{b}$ | $0.81^{b}$ | $0.91^{a}$ | 0.013 | <0.01 |
| Lysine | $0.80^{b}$ | $0.78^{b}$ | $0.88^{a}$ | 0.012 | <0.01 |
| Methionine | $0.87^{b}$ | $0.85^{b}$ | $0.92^{a}$ | 0.010 | <0.01 |
| Phenylalanine | $0.84^{b}$ | $0.82^{b}$ | $0.91^{a}$ | 0.013 | <0.01 |
| Threonine | $0.79^{b}$ | $0.78^{b}$ | $0.89^{a}$ | 0.016 | <0.01 |
| Tryptophan | 0.89 | 0.88 | 0.92 | 0.015 | 0.09 |
| Valine | $0.80^{b}$ | $0.78^{b}$ | $0.90^{a}$ | 0.014 | <0.01 |
| Mean | $0.83^{b}$ | $0.81^{b}$ | $0.91^{a}$ | 0.013 | <0.01 |
| Dispensable amino acids | | | | | |
| Alanine | $0.83^{b}$ | $0.81^{b}$ | $0.89^{a}$ | 0.016 | <0.01 |
| Aspartic acid | $0.75^{b}$ | $0.74^{b}$ | $0.87^{a}$ | 0.020 | <0.01 |
| Cysteine | 0.82 | 0.81 | 0.87 | 0.017 | 0.05 |
| Glutamic acid | 0.86 | 0.85 | 0.89 | 0.015 | 0.11 |
| Glycine | $0.92^{ab}$ | $0.89^{b}$ | $1.02^{a}$ | 0.034 | <0.05 |
| Proline | $1.11^{b}$ | $1.00^{b}$ | $1.40^{a}$ | 0.090 | <0.01 |
| Serine | $0.81^{b}$ | $0.79^{b}$ | $0.92^{a}$ | 0.014 | <0.01 |
| Tyrosine | $0.83^{b}$ | $0.83^{b}$ | $0.92^{a}$ | 0.012 | <0.01 |
| Mean | $0.87^{b}$ | $0.84^{b}$ | $0.95^{a}$ | 0.023 | <0.01 |
| All amino acids | $0.85^{b}$ | $0.83^{b}$ | $0.93^{a}$ | 0.018 | <0.01 |

a–b within a row, means without a common superscript letter are different ($P < 0.05$).
[1] Each least squares mean represents eight observations.
[2] Values for SID were calculated by correcting the values for the apparent ileal digestibility for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of dry matter intake) as crude protein, 22.01; Arginine, 0.70; Histidine, 0.20; Isoleucine, 0.33; Leucine, 0.60; Lysine, 0.53; Methionine, 0.08; Phenylalanine, 0.40; Threonine, 0.67; Tryptophan, 0.12; Valine, 0.52; Alanine, 0.66; Aspartic acid, 0.89; Cysteine, 0.27; Glutamic acid, 1.03; Glycine, 2.21; Proline, 6.68; Serine, 0.63; Tyrosine, 0.29.

**Table 8**
Standardized ileal digestible crude protein (g/kg) and amino acids (g/kg) in high protein canola meal (CM-HP), conventional canola meal (CM-CV), and soybean meal by growing pigs[1], experiment 2.

| Item | Ingredient | | | SEM | *P*-value |
|---|---|---|---|---|---|
| | CM-HP | CM-CV | Soybean meal | | |
| Crude protein | 374.57[b] | 317.36[c] | 458.28[a] | 7.600 | <0.01 |
| Indispensable amino acids | | | | | |
| Arginine | 22.08[b] | 19.82[c] | 33.53[a] | 0.374 | <0.01 |
| Histidine | 9.55[b] | 8.51[c] | 11.45[a] | 0.119 | <0.01 |
| Isoleucine | 12.45[b] | 11.60[c] | 19.13[a] | 0.206 | <0.01 |
| Leucine | 23.27[b] | 21.62[c] | 33.13[a] | 0.384 | <0.01 |
| Lysine | 18.70[b] | 16.51[c] | 25.31[a] | 0.294 | <0.01 |
| Methionine | 7.18[a] | 6.20[b] | 5.95[c] | 0.078 | <0.01 |
| Phenylalanine | 13.86[b] | 12.50[c] | 21.85[a] | 0.227 | <0.01 |
| Threonine | 12.89[b] | 12.14[b] | 16.10[a] | 0.268 | <0.01 |
| Tryptophan | 5.54[b] | 4.65[c] | 5.91[a] | 0.091 | <0.01 |
| Valine | 16.23[b] | 14.50[c] | 20.03[a] | 0.274 | <0.01 |
| Mean | 141.65[b] | 128.00[c] | 192.17[a] | 2.209 | <0.01 |
| Dispensable amino acids | | | | | |
| Alanine | 14.90[b] | 13.40[c] | 18.19[a] | 0.288 | <0.01 |
| Aspartic acid | 20.61[b] | 18.88[b] | 45.11[a] | 0.648 | <0.01 |
| Cysteine | 8.77[a] | 7.31[b] | 5.12[c] | 0.141 | <0.01 |
| Glutamic acid | 65.69[b] | 56.53[c] | 75.57[a] | 1.147 | <0.01 |
| Glycine | 19.14[a] | 17.04[b] | 20.60[a] | 0.700 | <0.01 |
| Proline | 27.32[ab] | 23.31[b] | 32.49[a] | 2.124 | <0.01 |
| Serine | 12.04[b] | 10.81[c] | 18.47[a] | 0.215 | <0.01 |
| Tyrosine | 8.84[b] | 8.88[b] | 16.13[a] | 0.146 | <0.01 |
| Mean | 177.50[b] | 155.88[c] | 231.85[a] | 4.774 | <0.01 |
| All amino acids | 319.19[b] | 283.89[c] | 424.06[a] | 6.759 | <0.01 |

[a–c] within a row, means without a common superscript letter are different ($P < 0.05$).
[1] Each least squares mean represents eight observations.

## 4. Discussion

### 4.1. Chemical characteristics of ingredients

Canola meal is the co-product produced when oil is extracted from canola seeds via a combination of mechanical press and solvent extraction and is widely used as a protein source in swine diets (Bell, 1993; Newkirk, 2011; Trindade Neto et al., 2012). Canola meal has relatively high concentration of fiber because canola hulls remain with the meal after processing. Therefore, a greater concentration of fiber in canola meal than in soybean meal is expected and is consistent with published values (González-Vega and Stein, 2012; NRC, 2012). Canola meal also contains glucosinolates, which have antinutritional properties and can reduce feed intake and amino acid digestibility in pigs (Bell, 1993; Tripathi and Mishra, 2007). Because the CM-HP used in our previous research (Berrocoso et al., 2015) contained almost twice as many glucosinolates as the CM-CV used in the experiment, we hypothesized that results for SID of amino acids and the ATTD of energy might have been negatively influenced by these high levels of glucosinolates.

The concentration of GE in CM-CV observed in this experiment is in close agreement with the values reported by NRC (2012). The lower concentration of crude protein in CM-CV than in soybean meal is also consistent with published reports (González-Vega and Stein, 2012; NRC, 2012; Maison and Stein, 2014). However, canola meal contained more phosphorus than soybean meal, which is also in agreement with published values (González-Vega and Stein, 2012; Slominski et al., 2012).

New varieties of *B. napus* result in canola meal with increased crude protein and decreased NDF and ADF (Khajali and Slominski, 2012; Slominski et al., 2012; Trindade Neto et al., 2012; Berrocoso et al., 2015) when compared with conventional canola meals (Thacker, 1990; Landero et al., 2012). The main reason for this observation is the increased size and thinner hull of the seeds from the newer varieties, which reduce the proportion of canola hull in the meal, and therefore also reduce the concentration of fiber and increases the concentration of crude protein and amino acids.

The concentration of amino acids in CM-CV and soybean meal 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), but the concentration of most amino acids in the CM-HP used in this experiment is 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 amino acids, except for methionine, threonine, cysteine, glycine, and proline are greater in soybean meal than in CM-HP, the concentrations of crude protein and amino acids in CM-HP are greater than in CM-CV.

The concentration of glucosinolates in CM-CV used in this experiment is less than the values reported by Xi et al. (2002) and Slominski et al. (2012), and the concentration is much less than the values in traditional “old-type” rapeseed meal, which contains 120–150 μmol/g of total glucosinolates (Canola Council of Canada, 2009). The old-type rapeseed meals are not suitable for feeding to pigs, which is the reason varieties with low concentrations of glucosinolates and erucic acids were selected. However, the concentration of glucosinolates in the CM-CV (19.1 μmol/g) that was used in this experiment is greater than the average for Canadian canola meal, which is approximately 7.2 μmol/g (Newkirk et al., 2003). In contrast, the concentration of glucosinolates in the HP-CV used in this experiment was less than in meals used in previous experiments (Slominski et al., 2012; Liu et al., 2014; Berrocoso et al., 2015). We were, therefore, successful in identifying sources of CM-HP with less glucosinolates and CM-CV with greater concentrations of glucosinolates than those used in the experiment by Berrocoso et al. (2015).

### 4.2. Energy digestibility

The values for GE, DE, and ME in soybean meal correspond with values by Goebel and Stein (2011), and the values for DE and ME for corn that were calculated 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 CM-CV are in close agreement with some reported values (NRC, 1998; de Blas et al., 2010; Liu et al., 2014; Berrocoso et al., 2015), but are less than values reported by Bourdon and Aumaître (1990), Montoya and Leterme (2009), NRC (2012) and Maison et al. (2015). The slightly reduced concentration of DE and ME in CM-CV compared with data reported by NRC (2012) and Maison et al. (2015), is mainly due to the increased ADF and NDF and the reduced acid hydrolyzed ether extract in the CM-CV used in this experiment. The reason for the reduced ATTD of GE in the canola meal diets compared with the soybean meal diet may be that canola meal contains more non-digestible ADF, NDF, and lignin than soybean meal (Landero et al., 2012).

It was expected that the ATTD of GE was greater in CM-HP than in CM-CV because of the reduced hull and fiber content and because of the lower concentration of glucosinolates, but results indicate that CM-HP did not contain more DE and ME than CM-CV, despite the increased protein concentration and decreased fiber and glucosinolate concentrations. The reason for this observation may be that CM-HP contained more ash and less sucrose than CM-CV, and the total concentration of GE was not different between the two canola meals.

### 4.3. Amino acid digestibility

Values for AID and SID of amino acids in soybean meal and CM-CV agree with previously reported values (Stein et al., 2001, 2005; González-Vega et al., 2011; González-Vega and Stein, 2012; NRC, 2012; Trindade Neto et al., 2012; Berrocoso et al., 2015). The observation that AID and SID of almost all amino acids in both CM-HP and CM-CV were less than in soybean meal may be a result of the greater concentration of ADF and NDF in canola meals than in soybean meal because fiber has a negative effect on values for amino acid digestibility (Sauer et al., 1980; Lenis et al., 1996; Nyachoti et al., 1997). The glucosinolates in the canola meals also have a negative effect on amino acid digestibility (Gilani et al., 2005).

The values for the AID and SID of crude protein and most amino acids in the CM-HP observed in this experiment are greater than values reported for different sources of high-protein canola meal (Trindade Neto et al., 2012; Liu et al., 2014). It is possible that the variety of canola meal may affect the digestibility of some amino acids (Xi et al., 2002; Trindade Neto et al., 2012; Maison and Stein, 2014). 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 crude protein and amino acids, but that was not the case. The reason for this observation is not clear, but Trindade Neto et al. (2012) and Berrocoso et al. (2015) also did not observe differences in amino acid digestibility between CM-HP and CM-CV. It also appears that the concentration of total glucosinolates may not be as important for the SID of amino acids as we had hypothesized because contrary to our hypothesis, there was no difference in SID of amino acids between CM-HP and CM-CV, although CM-HP contained much less glucosinolates than CM-CV. This observation indicates that reduction of the concentration of glucosinolates in canola meal to less than 20 μmol/g may not impact the digestibility of amino acids. These observations are supported by recent reports that up to 40% CM-CV or 40% CM-HP may be included in diets fed to weanling pigs without negatively impacting growth performance of the pigs (Parr et al., 2015). Likewise, it was concluded that CM-CV or CM-HP may replace all soybean meal in diets fed to growing-finishing pigs without negatively impacting growth performance or carcass characteristics (Little et al., 2015). In both of these experiments, CM-CV and CM-HP contained less than 20 μmol/g of glucosinolates, which indicates that in terms of amino acid digestibility there may not be a great advantage of reducing glucosinolates to less than 20 μmol/g.

The observation that values for the concentration of all standardized ileal digestible amino acids in CM-HP was greater than in CM-CV indicates that CM-HP provides more digestible amino acids for growing pigs compared with CM-CV, because of the increased concentration of amino acids in CM-HP compared with CM-CV. Likewise, the concentrations of digestible methionine and cysteine in CM-HP are greater than in soybean meal.

## 5. Conclusions

Canola meal produced from high-protein canola seeds or conventional canola seeds have lower digestibility of amino acids than soybean meal and CM-HP has SID of amino acids that is not different from CM-CV. The two sources of canola meals also have concentrations of DE and ME that are not different, but the concentration of DE and ME in both sources of canola meal is less than in soybean meal.

## Conflict of interest

The authors declare that they have no competing interest.

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