Net energy content of canola meal fed to growing pigs and effect of experimental methodology on energy values¹

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ABSTRACT: An experiment was conducted to determine the digestible energy (DE), metabolizable energy (ME), and net energy (NE) contents of canola meal (CM) and to investigate the effects of basal diet [corn diet vs. corn-soybean meal (SBM) diet] and methodology (difference method vs. regression method) on energy values of CM. Thirty-six growing barrows (20.8 ± 1.0 kg initial body weight [BW]) were individually housed in metabolism crates and randomly allotted to one of six dietary treatments to give six replicates per treatment. The six experimental diets included a corn diet, a corn-SBM diet, a corn diet with 15 or 30% of CM, and a corn-SBM diet with 15 or 30% of CM. The DE, ME, and NE of CM were determined using the corn diet or the corn-SBM diet as a basal diet. In each basal diet, two additional diets containing 15 or 30% of CM were formulated to compare the determined energy values by the difference method and estimated energy values from the regression method. Feeding level was set at 550 kcal ME/kg BW^{0.6} per day. Pigs were fed experimental diets for 16 d including 10 d for adaptation and 6 d for total collection of feces and urine. Pigs were then moved into indirect calorimetry chambers to determine 24 h heat production (HP) and 12 h fasting HP. The DE, ME, and NE

of CM determined by the difference method were within the 95% confidence intervals estimated for the DE, ME, and NE of CM by the regression method regardless of the basal diets used, which indicates that the difference and regression methods give equivalent DE, ME, and NE of CM. However, when the goodness of fit for the linear model was compared, the r^2 of the regression analysis from the corn-SBM diet (0.78) was relatively greater than that from corn diet (0.40). The estimated NE of CM by the prediction equations generated by either the corn diet or corn-SBM diets were 2,096 kcal/kg and 1,960 kcal/kg (as-fed basis), respectively, whereas those values determined by the difference method were 2,233 kcal/kg and 2,106 kcal/kg (as-fed basis), respectively. In conclusion, the NE of CM determined in the current study was, on average, 2,099 kcal/kg (as-fed basis). The difference and regression methods do not give different NE value of CM fed to growing pigs. Although the NE values of CM determined using either the corn diet or the corn-SBM diet were not different, the greater r^2 of the regression analysis from the corn-SBM diet than that from the corn diet suggests that the corn-SBM diet is a more appropriate basal diet for NE determination of ingredients.

Key words: canola meal, heat production, indirect calorimetry, net energy, pig

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Energy values of fibrous or high protein ingredients are often overestimated by digestible energy (DE) and metabolizable energy (ME)

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systems (Noblet et al., 1994). Canola meal (CM), a coproduct of the canola seed crushing industry, is widely used as a protein source but also contains relatively high levels of fiber (Woyengo et al., 2014). Therefore, the energy value of CM needs to be evaluated using net energy (NE) system to provide a more accurate estimate of the energy available for pigs (Noblet, 2007). However, there is limited information on NE value of CM fed to growing pigs.

The regression method and prediction equations are most often used to determine NE of ingredients (Noblet et al., 1993). Recently, however, several studies reported that the difference and regression methods, and the prediction equations give equivalent NE of ingredients (Heo et al., 2014; Jaworski et al., 2016; Kim and Nyachoti, 2017). In addition, balanced diets that meet nutrient requirements of pigs for supporting optimal growth and lean tissue gain have been suggested for determination of NE of diets (Noblet et al., 1993). For this reason, a corn diet, the commonly used basal diet for DE and ME determination, may be inappropriate for NE determination due to insufficient nutrients for pigs (Noblet and van Milgen, 2013), whereas, a corn-soybean meal (SBM) diet that meets the nutrient requirements appears to be more suitable as a basal diet. However, no difference in NE of SBM determined using the corn basal and corn-SBM basal diets has been reported (Liu et al., 2014) and the effect of basal diet needs to be investigated further. To our knowledge, NE values of CM determined by the difference method and the regression method using different basal diets have not been compared yet.

Therefore, the first objective of this experiment was to determine DE, ME, and NE of CM. The second objective was to investigate the effects of basal diet (corn diet vs. corn-SBM diet) and methodology (difference method vs. regression method) on energy values of CM.

MATERIALS AND METHODS

The experimental protocol used in the current study was reviewed and approved by the University of Manitoba Animal Care Committee, and pigs were handled in accordance with the guidelines described by the Canadian Council on Animal Care (2009).

Animals, Housing, and Experimental Diets

Thirty-six growing barrows [(Yorkshire × Landrace) × Duroc] with an average initial BW of 20.8 ± 1.0 kg (mean ± SD) were obtained from

the Glenlea Swine Research Unit, University of Manitoba. All pigs were individually housed in adjustable metabolism crates (1.8×0.6 m) in a temperature-controlled room ($22 \pm 1^\circ\text{C}$) throughout the experiment. The metabolism crates had smooth transparent plastic sides and plastic-covered expanded metal sheet flooring with a screen underneath for fecal collection and a stainless steel urine tray underneath the fecal screen, which allowed for the total, but separate, collection of feces and urine from each pig.

Corn, SBM, and CM used in this experiment were acquired from the Glenlea Research Station, University of Manitoba (Table 1). Six experimental diets, including a corn diet, a corn-SBM diet, a corn diet with 15 or 30% of CM, and a corn-SBM diet with 15 or 30% of CM were formulated (Table 2). The DE, ME, and NE of CM were determined using the corn diet or the corn-SBM diet as a basal diet. In each basal diet (i.e., corn diet, corn-SBM diet), two additional diets containing 15 or 30% of CM were formulated to compare the determined energy values using the difference method and estimated energy values from the regression method. To formulate the diets containing 15 or 30% of CM in a corn diet, 15 or 30% of corn was replaced with the same amount of CM, whereas two additional diets were formulated by mixing 15 or 30% CM with 85 or 70% of the corn-SBM diet, respectively. All experimental diets were supplemented with vitamins and minerals to meet or exceed the requirements of growing pigs (NRC, 2012). The corn-SBM diet was over-formulated compared to the expected nutrient requirements for 25–50 kg pigs to ensure that the corn-SBM diets containing 15 or 30% of CM met current requirement estimates for standardized ileal digestible indispensable AA, standardized total tract digestible P, vitamins, and minerals (NRC, 2012).

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

Item	Ingredients		
	Corn	Soybean meal	Canola meal
DM, %	85.9	88.3	90.9
GE, kcal/kg	3,870	4,129	4,346
CP, %	8.1	44.9	37.8
Ether extract, %	3.2	1.4	2.6
Starch, %	65.5	1.0	0.9
NDF, %	8.6	6.9	24.3
ADF, %	3.1	6.6	19.1
Ca, %	0.01	0.48	0.66
P, %	0.30	0.70	1.13

Table 2. Ingredient composition and calculated and analyzed nutrient composition of experimental diets (as-fed basis)

Item	Corn-basal diet ¹			Corn-SBM-basal diet ¹		
	Basal	15% CM	30% CM	Basal	15% CM	30% CM
Ingredients, %						
Corn	97.160	82.160	67.160	68.460	58.191	47.922
Soybean meal	-	-	-	28.200	23.970	19.740
Canola meal	-	15.000	30.000	-	15.000	30.000
Vegetable oil	-	-	-	1.000	0.850	0.700
Lys-HCl	-	-	-	0.100	0.085	0.070
Limestone	1.000	1.000	1.000	1.000	0.850	0.700
Monocalcium phosphate	1.300	1.300	1.300	0.700	0.595	0.490
Salt	0.400	0.400	0.400	0.400	0.340	0.280
Vitamin-mineral premix ²	0.140	0.140	0.140	0.140	0.119	0.098
Calculated composition ³						
ME, kcal/kg	3,327	3,265	3,203	3,386	3,330	3,274
SID ⁴ Lys, %	0.195	0.396	0.596	0.925	1.017	1.109
SID ⁴ Met, %	0.146	0.214	0.281	0.259	0.310	0.361
Analyzed composition						
DM, %	86.4	86.8	87.1	87.0	87.2	87.4
GE, kcal/kg	3,760	3,821	3,883	3,905	3,942	3,996
CP, %	7.8	12.1	16.3	18.7	20.9	23.7
Ether extract, %	3.0	3.0	2.8	3.3	3.1	3.0
Starch, %	60.7	51.6	40.3	43.0	37.7	31.5
NDF, %	8.2	10.6	12.4	8.5	10.0	12.4
ADF, %	3.1	5.3	7.5	3.9	5.5	8.2
Ca, %	0.63	0.54	0.70	0.53	0.60	0.57
P, %	0.54	0.64	0.77	0.50	0.63	0.71

¹SBM = soybean meal; CM = canola meal.

²Supplied the following per kilogram of finished feed: vitamin A, 2,000 IU; vitamin D, 200 IU; vitamin E, 40 IU; vitamin K, 2 mg; choline, 350 mg; pantothenic acid, 14 mg; riboflavin, 7 mg; folic acid, 1 mg; niacin, 21 mg; thiamin, 1.5 mg; vitamin B₆, 2.5 mg; biotin, 70 µg; vitamin B₁₂, 20 mg; Cu, 10 mg; Zn, 110 mg; Fe, 120 mg; Mn, 10 mg; I, 0.4 mg; Se, 0.3 mg.

³Calculated from [NRC \(2012\)](#) values.

⁴SID = standardized ileal digestible.

Experimental Design and Procedure

This experiment was conducted in two consecutive periods (18 pigs per period) using the same facility and similar experimental conditions and procedures because only 3 indirect calorimetry chambers were available for measuring heat production (HP) of pigs at the same time. Pigs were assigned to one of six experimental diets in a completely randomized design with three replicates per diet (per period).

Feed intake was set at 550 kcal ME/kg BW^{0.60} per day based on BW of pigs on days 1, 5, and 10, which has been reported to be close to ad libitum intake ([Noblet et al., 1994](#)). During the experiment, pigs were fed at 0800 h once daily and trained to consume their daily feed allowance within 1 h after feeding. Pigs were given ad libitum access to water via a low-pressure nipple drinker throughout the experimental period. Each experimental period lasted 16 d with the initial 10 d being the adaptation

period to the experimental conditions and diets. During the last 6 d of each experimental period, total, but separate, fecal and urine collections were conducted for the determination of DE and ME as previously described by [Kim and Nyachoti \(2017\)](#). From day 11 to 16, feces were collected once daily in the morning, weighed, and stored at -20°C. Urine collection commenced on day 11 at 0800 h and terminated on day 16 at 0800 h. Urine was also collected once daily in the morning (in jugs containing 20 mL of 3 N HCl to minimize nitrogen losses). The collected urine was weighed and a 5% subsample was filtered through glass wool, and stored at -20°C.

Before and after each period, the accuracy of indirect calorimetry chambers was validated by burning ethanol in a chamber system, based on the stoichiometric equation of ethanol burning. The ratio of CO₂ production to O₂ consumption in the burning ethanol yields a respiratory quotient (RQ) of 0.667 ([Benedict and Tompkins, 1916](#)).

Acceptable range of RQ was set from 0.640 up to 0.690 and no accuracy problem was observed during the two experimental periods. On day 16, three pigs each were transferred to the indirect calorimetry chambers ($1.22 \times 0.61 \times 0.91$ m; Columbus Instruments, Columbus, OH) from the metabolic crates to measure HP and fasting HP (FHP) based on O_2 consumption, CO_2 production, and urinary nitrogen (N) excretion. Pigs were moved into the calorimetric chambers within 1 h after daily feed allowance was provided and all consumed, and HP was measured continuously for 24 h (fed-state) followed by 12 h (fasting-state) of FHP measurement. The next sets of three pigs were moved to the indirect calorimetric chambers every 2 d (days 18, 20, 22, 24, and 26). Pigs were allotted to one of three indirect calorimetry chambers in a randomized complete block design using the chamber as a blocking factor to avoid possible confounding effects. Pigs had free access to fresh water via a nipple drinker in the chambers, and urine voided during the HP and FHP measurement was collected separately, weighed, subsampled, and stored at -20°C . The experimental temperature inside the chamber was maintained at $22^\circ\text{C} \pm 1^\circ\text{C}$. Personnel movement in the chamber room was limited, except for the regular check and urine collection, to measure HP and FHP under calm conditions. After the day 16 (at the end of collection day), pigs were fed their assigned experimental diets until they were transferred into the indirect calorimetry chambers.

Sample Preparation and Chemical Analyses

Diet and ingredients samples were ground through a 1-mm screen in a Thomas Wiley mill model 4 (Labwrench, Midland, ON, Canada) and thoroughly mixed before chemical analysis. Fecal samples were dried in a forced-air drying oven at 60°C for 5 d and finely ground before chemical analysis. Urine samples from metabolism crates and indirect calorimetry chambers were thawed and pooled separately for each pig, filtered through glass wool, and transferred into a plastic bottle. Diet and ingredient samples were analyzed in duplicate for dry matter (DM), gross energy (GE), crude protein (CP; $N \times 6.25$), ether extract (EE), starch, ash, neutral detergent fiber (NDF), acid detergent fiber (ADF), calcium (Ca), and phosphorus (P), whereas fecal and urine samples were analyzed in duplicate for DM, GE, and CP. The DM content was determined according to AOAC (method 934.01; 2006) and the GE was estimated using an adiabatic bomb calorimeter (model 6400; Parr Instrument, Moline, IL),

which had been calibrated using benzoic acid as a standard. Nitrogen concentration was measured by the combustion method (method 990.03; AOAC, 2006) using the LECO N analyzer (model CNS-2000; LECO Corp., St. Joseph, MI), and CP was calculated as $N \times 6.25$. Ether extract was determined after hexane extraction (method 920.39A; AOAC, 2006) in an extraction apparatus. The ADF and NDF contents were determined according to the method of Goering and Van Soest (1970). Ash content was determined according to AOAC (method 942.05; 2006). To analyze Ca and P, ashed sample was digested according to AOAC (method 985.01; 2006) and read on a Varian inductively coupled plasma mass spectrometer (Varian Inc., Palo Alto, CA). Starch content was determined using an assay kit (Megazyme Total Starch assay kit; Megazyme International Ltd, Wicklow, Ireland).

To determine the GE of urine, 0.5 g of cellulose was dried at 103°C for 24 h and 2 mL of urine sample were mixed with it, and the final weight of the resulting mixture was recorded. The urine-cellulose mixture along with a sample of pure cellulose were dried in an oven at 50°C for 24 h and then weighed to estimate DM content of urine. The GE of the dried urine-cellulose mixture and cellulose itself were determined using an adiabatic bomb calorimeter as described above, from which the GE of urine samples were calculated by the difference method (Fleischer et al., 1981).

Calculations

The apparent total tract digestibility (ATTD) of DM, GE, and CP was calculated as described by Woyengo et al. (2010) and N balance of pigs was calculated according to Kim and Nyachoti (2017).

The HP and FHP (Brouwer, 1965), retained energy (RE; Noblet et al., 1994), and NE values (Noblet et al., 1994) were calculated using the following equations:

$$\text{HP} = 3.866 \times O_2 + 1.200 \times CO_2 - 1.431 \times \text{urinary N excretion},$$

where HP is in kilocalories, O_2 is oxygen consumption in liters, CO_2 is carbon dioxide production in liters, and urinary N excretion is total urinary N excretion in grams. The FHP was also calculated using the same equation for HP.

$$\text{RE} = \text{ME} - \text{HP},$$

where RE, ME, and HP are in kilocalories per day.

Retained energy as protein (RE_p) was calculated as N retention (g) $\times$ 6.25 $\times$ 5.68 (kcal/g) according to Ewan (2001). Retained energy as lipid (RE_l) was calculated as the difference between RE and RE_p (Labussière et al., 2009).

$$NE = (RE + FHP) / DMI,$$

where NE is in kilocalories per kilogram DM, RE and FHP are in kilocalories per day, and DMI is in kilograms.

The RQ was calculated with the ratio of CO_2 production to O_2 consumption (Noblet et al., 2001).

After the energy values of each experimental diet were determined, the DE, ME, and NE of CM were calculated using the difference method (Adeola, 2001). The DE, ME, and NE in the corn diet were divided by 0.9716 to determine the DE, ME, and NE of corn. The contributions of DE, ME, and NE from corn to the diet containing 15 or 30% of CM were then calculated and subtracted from the total DE, ME, and NE of these diets, and the DE, ME, and NE of CM were calculated by difference (Adeola, 2001). However, DE, ME, and NE of CM determined by the corn-SBM diet was calculated by subtracting the energy contribution of the corn-SBM diet from the energy content of the diets containing 15 or 30% of CM (Adeola, 2001).

Statistical Analysis

Homogeneity of variances was verified using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC). No outlier was observed for all measurements. All data were analyzed using the MIXED procedure of SAS. The individual pig was considered the experimental unit. The initial model included diet and period as fixed effect, and pig as random effect for statistical analysis. However, the effect of period was not significant in this study; therefore, it was excluded in the final model. The LSMEANS procedure was used to calculate mean values and the PDIF option was used to separate means. Orthogonal polynomial contrasts were used to determine linear and quadratic effects of inclusion level of CM. Regression equations to estimate the DE, ME, and NE of CM were generated using the REG procedure in SAS (Noblet et al., 1993). The dependent variables in the three prediction equations (in each basal diet) were dietary DE, ME, or NE, kcal/kg (as-fed basis), respectively, and the independent variable was CM inclusion in the diet, % (as-fed basis). The DE, ME, and NE of CM were then predicted by solving the regression equations with 100% of CM inclusion. The energy values of

CM determined by either the difference or regression method was compared according to Jaworski et al. (2016). The CLB and AIC statement in SAS were used to determine the 95% confidence levels and Akaike's information criterion for the regression coefficients used to estimate the DE, ME, and NE of CM, respectively. The DE, ME, and NE of CM determined by the difference method was considered not different from the respective values of CM estimated by the regression method if the values were within the 95% confidence interval for the DE, ME, and NE of CM estimated by the regression method. Probability of $P < 0.05$ was considered significant, whereas $0.05 < P \leq 0.10$ was considered a tendency.

RESULTS

All pigs adapted well to their experimental diets and conditions, remained healthy and readily consumed their daily feed allowance throughout the experimental period.

Energy and Nutrient Digestibility and Nitrogen Balance

The ATTD of DM and GE decreased (linear, $P < 0.01$) with increasing inclusion level of CM in the corn and corn-SBM diets (Table 3). Also, decreased (linear, $P < 0.01$) ATTD of CP was observed for the corn-SBM diets as inclusion level of CM increased. However, inclusion of CM did not affect the ATTD of CP in the corn diet.

The N intake (g), fecal N excretion (g), retained N (g) by pigs linearly increased ($P < 0.01$) as CM inclusion increased in the corn and corn-SBM diets (Table 3). Urinary N excretion (g) linearly increased ($P < 0.05$) for pigs fed corn diets containing increasing inclusion level of CM, but no difference was observed in pigs fed corn-SBM diets with increasing inclusion level of CM. Retained N (%) by pigs fed the corn diets linearly increased ($P < 0.01$) as CM inclusion increased in the diets. There was a tendency for a quadratic decrease ($P \leq 0.10$) in the retained N (%) as CM inclusion increased in the corn and corn-SBM diets.

Energy Balance and Energy Values of Experimental Diets

The energy balance and DE, ME, and NE of experimental diets are presented in Table 4. The DE and ME of the corn and corn-SBM diets decreased (linear, $P < 0.01$) as dietary inclusion level of CM increased. The HP (kcal/kg $BW^{0.6}$) of pigs fed the

Table 3. Apparent total tract digestibility (ATTD) of DM, GE, and CP and N balance of experimental diets fed to growing pigs¹

Item	Corn-basal diet ²				P-value		Corn-SBM-basal diet ²				P-value	
	Basal	15% CM	30% CM	SEM	Linear	Quadratic	Basal	15% CM	30% CM	SEM	Linear	Quadratic
ATTD, %												
DM	89.4	85.7	81.6	0.29	<0.001	0.699	89.7	86.4	81.9	0.47	<0.001	0.289
GE	88.0	84.4	80.6	0.33	<0.001	0.883	88.8	85.6	81.1	0.51	<0.001	0.285
CP	77.6	76.7	75.8	0.84	0.147	0.991	87.9	85.2	80.8	0.87	<0.001	0.416
N balance, g/d												
N intake	13.0	20.8	29.0	0.32	<0.001	0.577	31.1	37.1	42.8	0.57	<0.001	0.860
Fecal excretion	2.9	4.8	7.0	0.18	<0.001	0.582	3.8	5.5	8.2	0.38	<0.001	0.282
Urinary excretion	6.1	6.5	8.2	0.64	0.042	0.395	10.4	9.5	12.1	0.97	0.246	0.168
N retained	4.0	9.5	13.8	0.56	<0.001	0.402	17.0	22.1	22.6	1.06	0.002	0.088
N retained, %	30.2	45.7	47.8	3.02	<0.001	0.090	54.4	59.7	52.7	2.69	0.661	0.083

¹Each value represents the mean of 6 observations.²SBM = soybean meal; CM = canola meal.

corn diets increased (linear, $P < 0.01$), whereas that of pigs fed the corn-SBM diets was not affected by increasing dietary inclusion level of CM. Fasting HP of pigs fed the corn and corn-SBM diets was not affected by increasing CM content in the diets. Total RE tended to decrease (linear, $P \leq 0.10$) from 2,154 to 2,176 and 1,922 kcal/kg DM with increasing CM content in the corn diets, likewise, that

of pigs decreased (linear, $P < 0.01$) from 2,320 to 2,147 and 1,946 kcal/kg DM with increasing CM in the corn-SBM diets. The RE_p increased (linear, $P < 0.01$), whereas RE_L decreased (linear, $P < 0.01$) as increasing CM was included in the corn and corn-SBM diets. The NE of diets decreased (linear, $P < 0.01$) from 3,131 to 3,034 and 2,894 kcal/kg with increasing inclusion level of CM in the

Table 4. Energy balance in growing pigs and energy values of experimental diets¹

Item	Corn-basal diet ²				P-value		Corn-SBM-basal diet ²				P-value	
	Basal	15% CM	30% CM	SEM	Linear	Quadratic	Basal	15% CM	30% CM	SEM	Linear	Quadratic
Energy value, kcal/kg DM												
DE	3,831	3,716	3,593	14.4	<0.001	0.831	3,984	3,872	3,707	23.1	<0.001	0.356
ME	3,683	3,566	3,422	15.9	<0.001	0.479	3,799	3,693	3,517	22.7	<0.001	0.224
HP ³	1,529	1,391	1,500	72.4	0.780	0.185	1,479	1,546	1,571	60.6	0.297	0.782
HP ⁴ , kcal/kg BW ^{0.6}	138	158	165	5.5	0.003	0.356	166	168	169	4.6	0.646	0.943
Total RE ⁵	2,154	2,176	1,922	78.2	0.053	0.172	2,320	2,147	1,946	67.2	0.001	0.864
As protein	140	337	491	19.8	<0.001	0.402	602	786	801	37.7	0.002	0.088
As lipid	2,014	1,839	1,431	76.3	<0.001	0.231	1,718	1,361	1,144	71.8	<0.001	0.439
FHP ⁶	977	858	971	49.9	0.943	0.077	973	1,038	1,016	56.8	0.595	0.543
NE ⁷	3,131	3,034	2,894	47.2	0.003	0.717	3,293	3,185	2,962	28.0	<0.001	0.114
Respiratory quotient												
Fed state	0.98	1.08	1.05	0.024	0.052	0.068	1.02	1.00	0.99	0.008	0.004	0.814
Fasting state	0.75	0.78	0.75	0.015	0.885	0.219	0.74	0.74	0.73	0.005	0.772	0.164
Energy utilization												
ME/DE	0.961	0.960	0.952	0.0021	0.009	0.268	0.953	0.954	0.949	0.0016	0.056	0.213
NE/DE	0.817	0.816	0.805	0.0114	0.474	0.725	0.826	0.823	0.799	0.0067	0.011	0.254
NE/ME	0.850	0.851	0.846	0.0116	0.788	0.853	0.867	0.863	0.842	0.0069	0.025	0.366

¹Each value represents the mean of six observations.²SBM = soybean meal; CM = canola meal.³Heat production = $(3.87 \times O_2 + 1.20 \times CO_2 - 1.43 \times \text{urinary N})/\text{DMI}$.⁴Heat production = Daily HP, kcal/kg BW^{0.6}.⁵Retained energy = (ME intake – HP)/DMI; Retained energy as protein was calculated according to Ewan (2001) as N retention (g) $\times 6.25 \times 5.68$ (kcal/g). Whereas, retained energy as lipid was calculated as the difference between total retained energy and retained energy as protein.⁶Fasting heat production = $(3.87 \times O_2 + 1.20 \times CO_2 - 1.43 \times \text{urinary N})/\text{DMI}$.⁷Net energy = (RE + FHP)/DMI.

Table 5. Energy content of corn fed to growing pigs determined using a corn-basal diet¹

Item	Corn	
	Mean	Standard deviation
As-fed basis		
DE, kcal/kg	3,406	29.0
ME, kcal/kg	3,275	19.8
NE, kcal/kg	2,845	66.9
DM basis		
DE, kcal/kg	3,965	33.8
ME, kcal/kg	3,812	23.0
NE, kcal/kg	3,241	77.9

¹Each value represents the mean of six observations.

corn diets, whereas NE of diets decreased (linear, $P < 0.01$) as CM inclusion increased in the corn-SBM diets (3,293, 3,185, and 2,962 kcal/kg DM for diets containing 0, 15, and 30% CM, respectively). The fed-state RQ of pigs fed the corn diets tended to increase (linear, $P \leq 0.10$), but a linear decrease ($P < 0.01$) was observed for pigs fed the corn-SBM diets with increasing inclusion level of CM. The NE:DE and NE:ME were not affected by CM inclusion, but the ME:DE decreased (linear, $P < 0.01$) as CM inclusion increased in the corn diets. However, the NE:DE and NE:ME decreased (linear, $P < 0.05$) but the ME:DE tended to decrease (linear, $P \leq 0.10$) as CM inclusion increased in the corn-SBM diets.

Energy Values of Corn and CM

The DE, ME, and NE of corn fed to growing pigs were 3,406, 3,275, 2,845 kcal/kg, as-fed basis, respectively (Table 5). Linear regression analyses were used to estimate the relationship between energy contents and dietary CM. The prediction equations estimated

using the corn diet are presented in Table 6. The intercept, slope, and r^2 of the prediction equation for dietary DE were 3,311 ($P < 0.01$), -6.0 ($P < 0.01$), and 0.87, whereas respective values for dietary ME were 3,186 ($P < 0.01$), -6.7 ($P < 0.01$), and 0.87 respectively. The prediction equation for dietary NE had an intercept equal to 2,711 ($P < 0.01$) and a slope estimate of -6.2 ($P < 0.01$) with r^2 of 0.40. The equations derived using the corn-SBM diet are also presented in Table 6. The intercept, slope, and r^2 of the prediction equation for dietary DE were 3,475 ($P < 0.01$), -7.6 ($P < 0.01$), and 0.80, whereas respective values for dietary ME were 3,316 ($P < 0.01$), -7.7 ($P < 0.01$), and 0.81 respectively. The prediction equation for dietary NE had an intercept equal to 2,882 ($P < 0.01$) and a slope estimate of -9.2 ($P < 0.01$) with r^2 of 0.78.

The estimated DE, ME, and NE of CM by the prediction equations generated by either the corn diet or corn-SBM diets were 2,709, 2,515, and 2,096 kcal/kg or 2,717, 2,543, and 1,960 kcal/kg (as-fed basis), respectively (Table 7), whereas those values determined by the difference method were 2,818, 2,646, and 2,233 kcal/kg or 2,782, 2,629, and 2,106 kcal/kg (as-fed basis), respectively. There were, however, no differences in the energy contents of CM fed to growing pigs when determined using either the corn diet or corn-SBM diet (Table 8).

DISCUSSION

Chemical Composition of Ingredients and Diets

Canola meal, a coproduct of canola seed crushing industry for oil extraction via a combination of mechanical press and solvent extraction (Woyengo

Table 6. Regression coefficient used for estimating DE, ME, and NE of canola meal from two different basal diets (as-fed basis)¹

		SE		P-value		r^2	RMSE	AIC ²
Dependent variable	Prediction equation	Intercept	Slope	Intercept	Slope			
Corn-basal diet								
Dietary DE, kcal/kg	$3310.9-6.022 \times (\text{canola meal inclusion, \%})$	11.03	0.57	<0.001	<0.001	0.87	29.6	123
Dietary ME, kcal/kg	$3186.0-6.711 \times (\text{canola meal inclusion, \%})$	12.46	0.64	<0.001	<0.001	0.87	33.4	128
Dietary NE, kcal/kg	$2711.1-6.150 \times (\text{canola meal inclusion, \%})$	36.40	1.88	<0.001	0.005	0.40	97.7	167
Corn-SBM-basal diet ³								
Dietary DE, kcal/kg	$3475.0-7.583 \times (\text{canola meal inclusion, \%})$	18.34	0.95	<0.001	<0.001	0.80	49.2	142
Dietary ME, kcal/kg	$3315.9-7.733 \times (\text{canola meal inclusion, \%})$	18.29	0.94	<0.001	<0.001	0.81	49.1	142
Dietary NE, kcal/kg	$2882.3-9.228 \times (\text{canola meal inclusion, \%})$	23.45	1.21	<0.001	<0.001	0.78	62.9	151

¹Data were subjected to linear regression analysis with the percent inclusion of canola meal as the independent variable and the DE, ME, or NE of the diet (kcal/kg) as the dependent variable. The regression coefficients indicate the change in the DE, ME, or NE of the diets for each percentage point change of canola meal included in the diet; therefore, the coefficient multiplied by 100 is equal to the DE, ME, or NE of canola meal.

²AIC = Akaike's information criterion.

³SBM = soybean meal.

Table 7. Energy content of canola meal determined by the difference and regression methods

Item	Corn-basal diet			Corn-SBM basal diet ¹		
	Difference method ²	Regression method	95 % Confidence interval	Difference method ²	Regression method	95 % Confidence interval
As-fed basis						
DE, kcal/kg	2,818	2,709	2,594–2,824	2,782	2,717	2,525–2,908
ME, kcal/kg	2,646	2,515	2,384–2,647	2,629	2,543	2,353–2,732
NE, kcal/kg	2,233	2,096	1,717–2,475	2,106	1,960	1,716–2,203
DM basis						
DE, kcal/kg	3,100	2,980	2,854–3,107	3,061	2,989	2,778–3,199
ME, kcal/kg	2,910	2,767	2,623–2,911	2,892	2,798	2,589–3,006
NE, kcal/kg	2,457	2,306	1,889–2,723	2,317	2,156	1,888–2,424

¹SBM = soybean meal.

²The values are the mean DE, ME, and NE of canola meal determined using the difference method for the two diets containing 15 or 30% canola meal.

et al., 2010), is widely used as a protein source in swine diets (Canola Council of Canada, 2015; Velayudhan et al., 2017). The GE, CP, and EE of the CM used in the current study were 4,346 kcal/kg, 37.8%, and 2.6%, respectively, similar to average values of 4,332 kcal/kg, 37.5%, 3.2% reported by NRC (2012), respectively. The NDF (24.3%) and ADF (19.1%) contents were slightly less than the values reported by Woyengo et al. (2010) but greater than those reported by Liu et al. (2016), which could be explained by differences in varieties, growing conditions in which the canola seeds were grown, and processing conditions during the oil extraction among the experiments (Mejicanos et al., 2016). The nutrient composition of the corn and SBM used in this experiment is in accordance with values previously reported (NRC, 2012; Kim et al., 2017). Generally, CM contains greater concentration of fiber compared to SBM because, unlike SBM, canola hulls remain with the meal after processing. Also, as a protein source, it contains high levels of protein. Energy value of high fiber and protein diets is often overestimated when determined with either the DE or ME system (Noblet et al., 1994), which necessitates the determination of the NE value in CM to facilitate its effective utilization.

The analyzed nutrient and energy composition of experimental diets were similar to the values calculated from the summation of the ingredient contributions. The GE, CP, NDF, and ADF contents increased whereas starch content decreased as CM inclusion increased in each basal diet.

Energy and Nutrient Digestibility and Nitrogen Balance

Linear reduction in ATTD of DM and GE was observed as CM inclusion increased in each basal

diet, which is most likely caused by the addition of CM resulting in increased dietary fiber content as observed in other studies (Velayudhan and Nyachoti, 2017). In addition, the hull fraction of canola seed is difficult to be digested by digestive system of pigs because half of ADF in CM is lignified (Slominski et al., 2012). Also, the linear reduction in ATTD of CP in corn-SBM diets with increasing CM inclusion is possibly explained by the CP digestibility of CM, similar to corn but less than SBM (NRC, 2012).

The corn diet used in the current study contained insufficient N and AA for protein deposition, and therefore a linear increase in daily N retention (g) and N retention rate (%) by pigs fed the corn diets with increasing CM was expected. Indeed, there was a linear effect of CM inclusion on those of pigs fed the corn diets with increasing inclusion of CM. On the other hand, the corn-SBM diet was formulated to meet or exceed the nutrient requirements of growing pigs (25–50 kg) to support their optimal growth. However, linear increase in N retention (g) of pigs fed these diets with increasing CM inclusion was also observed, which may be attributed to insufficient AA and N intake caused by limited feed intake. Although the feeding level at 550 kcal ME/kg BW^{0.60} has been considered ad libitum feed intake (Noblet et al., 1994), other factors such as experimental conditions and genetic background may affect the feed intake of pigs. Indeed, a greater feeding level was proposed by Zhang et al. (2014) who reported that 573 kcal ME/kg BW^{0.6} was close to the voluntary feed intake for growing pigs.

Energy Balance of Pigs and Energy Values of Experimental Diets

The observation that DE, ME, and NE of the corn and corn-SBM diets linearly decreased as CM

Table 8. Energy content of canola meal determined by corn-basal and corn-soybean meal basal diets

	Energy content of canola meal ¹			
Item	Corn	Corn-soybean meal	SEM	<i>P</i> -value
As-fed basis				
DE, kcal/kg	2,818	2,782	64.2	0.695
ME, kcal/kg	2,646	2,629	69.4	0.864
NE, kcal/kg	2,233	2,106	136.6	0.520
DM basis				
DE, kcal/kg	3,100	3,061	70.6	0.695
ME, kcal/kg	2,910	2,892	76.3	0.864
NE, kcal/kg	2,457	2,317	150.3	0.520

¹The values are the mean DE, ME, and NE of canola meal determined using the difference method for the two diets containing 15 or 30% canola meal.

inclusion increased is closely related to the increased dietary fiber content as a result of CM inclusion. This observation is further supported by the linear decrease in ATTD of DM and GE. In the current study, HP by pigs linearly increased from 138.0 to 157.9 and 165.1 kcal/kg BW^{0.6} as pigs were fed diets containing increasing amounts of CM, which is possibly related to the increased dietary CP due to the addition of CM. The addition of CM to the corn diet resulted in decreased dietary starch content but increased dietary CP content, which has greater heat increment per unit of energy associated with metabolic utilization of energy than that of starch (Noblet et al., 1994; Le Bellego et al., 2001; Noblet et al., 2001). Moreover, the increased dietary fiber is also the possible reason for increased HP by pigs fed the corn diets containing increasing amounts of CM. Due to the low efficiency of utilization of ME from dietary fiber, an increase in dietary fiber often leads to an increase in HP by pigs (Noblet et al., 1989; Jørgensen et al., 1996; Rijnen et al., 2003). However, the effect of dietary fiber on HP needs to be investigated further. In some studies, similar (Ayoade et al., 2012; Heo et al., 2014) or even decreased HP values (Le Goff et al., 2002; Jaworski et al., 2016) have been reported due to the increase in dietary fiber content. This inconsistent response to dietary fiber may partly contribute to no effect on HP by pigs fed the corn-SBM diets containing increasing CM inclusion. Also, the addition of CM increased dietary CP to less extent when added to the corn-SBM diet (increase in 2% of dietary CP per 15% CM inclusion) than when added to the corn diet (increase in 4% of dietary CP per 15% CM inclusion), which may have contributed to the failure to detect a linear effect on HP by pigs fed the corn-SBM diets with increasing CM inclusion.

Increase in size and weight of the visceral organs due to the consumption of increased dietary fiber has been reported (Nyachoti et al., 2000; Agyekum et al., 2012), which possibly results in increased FHP or NE required for maintenance of pigs because the gastrointestinal tract of pigs may account for about 30% of FHP (van Milgen et al., 1998). However, in the current study, no differences in FHP were observed among dietary treatments, which may be a consequence of a relatively short duration of feeding experimental diets. This feeding duration (i.e., 21 d) may be insufficient to induce the enlargement of gastrointestinal tract (Kim and Nyachoti, 2017).

The RQ is typically slightly greater than 1.0 during the fed-state and less than 1.0 during the fasting-state (Agyekum et al., 2016). As expected, the RQ of pigs measured in the fed-state was around 1.0, whereas that of pigs in fasting-state was 0.75. The observation that fed-state RQ of pigs fed the corn-SBM diets linearly decreased from 1.02 to 1.00 and 0.99 with increasing CM inclusion indicates that metabolism of noncarbohydrate is linearly increasing in pigs (Liu et al., 2014). However, the fed-state RQ of pigs fed the corn diets with increasing CM inclusion was not affected in the current experiment. The reason for this observation is unclear because carbohydrate metabolism in the body would also decrease by replacing corn with CM as observed in pigs fed the corn-SBM diets with increasing CM inclusion.

Energy Values of Corn and CM

The DE and ME of feed ingredients fed to pigs are most often determined by either the difference method or the regression method (Adeola, 2001) and the energy values determined by these two methods have been reported to be similar (Bolarinwa and Adeola, 2016; Jaworski et al., 2016). Whereas, for the NE determination, the regression method and the prediction equations are most widely used (Noblet et al., 1993; Noblet et al., 1994; NRC, 2012). However, the difference method has also been recently used to determine NE value of feed ingredients and no difference between determined NE using indirect calorimetry and predicted NE from prediction equations was also reported (Ayoade et al., 2012; Heo et al., 2014; Velayudhan et al., 2015b; Kim and Nyachoti, 2017). Also, according to the study of Jaworski et al. (2016), the NE of wheat bran determined by the difference method was not different from that estimated from the regression method. Likewise,

in the current experiment, the DE, ME, and NE of CM determined by the difference method were within the 95% confidence intervals estimated for the DE, ME, and NE of CM by the linear regression method regardless of the basal diets used, which indicates that the two different methods (i.e., difference method, regression method) give equivalent values for DE, ME, and NE of CM fed to growing pigs.

The efficiency of ME utilization of a diet is dependent on final utilization of dietary energy in pigs (i.e., deposition as protein vs. deposition as lipid). If the energy is deposited as protein, the efficiency of ME utilization of the diet will be less than when it is deposited as lipid because the efficiency of ME utilization for protein deposition is about 60% whereas that for lipid deposition is approximately 80% (Noblet and van Milgen 2013), which may have significant effect on NE of the diet. Therefore, it has been suggested that the NE of diet should be determined based on balanced diets that meet nutrient requirements of pigs for supporting optimal growth and lean tissue gain (Noblet et al., 1993, Noblet and van Milgen, 2013). For this reason, a corn diet, the most commonly used basal diet for DE and ME determination, may be inappropriate for NE determination due to the fact that this diet normally contains insufficient dietary AA and N, consequently reducing growth performance and affecting the NE of the diet. Contrary to our hypothesis, however, the NE of CM determined using either the corn diet (2,233 kcal/kg) or the corn-SBM diet (2,106 kcal/kg) was not different. Similar to our observation, Liu et al. (2014) reported that there were no differences in NE values of SBM determined using either the corn diet or the corn-SBM diet. When the goodness of fit for the linear model was compared, however, the coefficient of determination (i.e., r^2) of the regression analysis from the corn-SBM diet ($r^2 = 0.78$) was relatively greater than that from corn diet ($r^2 = 0.40$), which may indicate a better fit to the linear model. This result is likely caused by less variation in NE of CM determined using the corn-SBM diet than in the corn diet as affected by increasing inclusion level of CM in the diets. In other words, the HP and RE by pigs fed the balanced diets (i.e., corn-SBM diet with increasing inclusion level of CM) that meet the nutrient requirements was less variable compared to those of pigs fed unbalanced diets (i.e., corn diet with increasing inclusion level of CM), thereby reducing the variation in the NE value of diets and feed ingredient.

The values for DE and ME of CM fed to growing pigs obtained in the current study are within the range of previously published values (Woyengo et al., 2010; NRC, 2012; Heo et al., 2013). However, to our knowledge, the NE of CM from *Brassica napus* black, the most widely used variety for swine diet formulation, has not been reported yet. The NE of CM from *Brassica napus* yellow and *Brassica juncea* yellow were recently reported at 2,103 and 2,342 kcal/kg, respectively, by Heo et al. (2013), which is comparable to the NE value obtained in the current study (2,099 kcal/kg; an average of 2,233, 2,096, 2,106, and 1,960 determined by two methods using two different basal diets). This value is also similar to the published value from NRC (2012) calculated from the prediction equations based on chemical composition of CM. The similar NE values between *Brassica napus* black and yellow (2,099 kcal/kg vs. 2,103 kcal/kg) could be attributed to the similar chemical composition between two varieties, whereas greater NDF and less CP content of the *Brassica napus* black used in this experiment than in *Brassica juncea* yellow used in the study of Heo et al. (2013) may have led to a slightly less NE value (2,099 kcal/kg vs. 2,342 kcal/kg).

The values for DE and ME of corn fed to growing pigs determined in the current experiment are in close agreement with previously published values (NRC, 2012; Kim et al., 2017). Also, determined NE of corn (2,845 kcal/kg) is in accordance with the value (2,785 kcal/kg) reported by Liu et al. (2014), but is greater than the value (1,780 kcal/kg) reported by Kil et al. (2013). The reason for this discrepancy is mainly due to the difference in methodology among the experiments. The indirect calorimetry method was used to determine HP, FHP, and RE of pigs in the study of Liu et al. (2014) and the current study, whereas the comparative slaughter method was used to measure the RE of pigs in the study of Kil et al. (2013). In addition to this, experimental conditions such as feeding level (restricted vs. ad libitum), housing condition (group vs. individual), and genetic background may also affect the NE of diets and ingredients among experiments (Kiarie et al., 2015; Velayudhan et al., 2015a).

In conclusion, the NE of CM determined in the current study was, on average, 2,099 kcal/kg, as-fed basis. The difference and regression methods do not give different NE value of CM fed to growing pigs. Furthermore, the NE values of CM determined using a basal diet based on either corn or corn-SBM were not different. However, when the goodness of fit for the linear model was compared, the r^2

of the regression analysis from the corn-SBM diet (balanced diet) was relatively greater than that from the corn diet (unbalanced diet), which suggests that the basal diet that meets the nutrient requirements of pigs is more suitable for NE determination of feed ingredients than basal diet that is nutritionally unbalanced.

Conflict of interest statement. None declared.

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