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Digestibility of energy and detergent fiber and digestible and metabolizable energy values in canola meal, 00-rapeseed meal, and 00-rapeseed expellers fed to growing pigs[1]

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ABSTRACT: There are limited data on the DE and ME values and the digestibility of fiber in canola meal, rapeseed meal, and rapeseed expellers fed to pigs. This experiment was conducted to measure the apparent total tract digestibility (ATTD) of energy, ADF, and NDF and to calculate DE and ME values in canola meal, 00-rapeseed meal, and 00-rapeseed expellers fed to growing pigs. Twenty-three barrows (initial BW: 27.7 ± 2.92 kg) were allotted to an 8 × 23 Youden square design with 8 periods and 23 animals. Twenty-three diets were prepared: a corn basal diet and 22 diets based on corn and 1 of 22 test ingredients. The test ingredients were 6 canola meals from solvent-extraction crushing plants in North America, eleven 00-rapeseed meals from solvent-extraction crushing plants in Europe, and five 00-rapeseed expellers from mechanical-press crushing plants in Europe. Pigs were placed in metabolism cages that allowed for the total, but separate, collection of feces and urine. The DE and ME values were calculated for each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers using the difference procedure. The ATTD of GE and the DE and ME values in canola meal were not different from the values in 00-rapeseed meal, but 00-rapeseed expellers had greater ($P < 0.01$) ATTD of GE and DE and ME values than 00-rapeseed meal. Average DE and ME values were 3,378 and 3,127 kcal/kg DM in canola meal, 3,461 and 3,168 kcal/kg DM in 00-rapeseed, and 4,005 and 3,691 kcal/kg DM in 00-rapeseed expellers. The ATTD of ADF was 12.3% greater ($P < 0.01$) in 00-rapeseed meal than in canola meal, but no differences were observed in ATTD of NDF between canola meal and 00-rapeseed meal. No differences were observed in ATTD of ADF and NDF between 00-rapeseed meal and 00-rapeseed expellers. The models for predicting the DE and ME values of canola and rapeseed products were DE = –1,583 + 6.64 × ash + 7.01 × ADF – 33.17 × NDF + 98.66 × ADL + 1.07 × GE ($R^2 = 0.94$) and ME = –630.8 + 14.13 × ash + 5.02 × crude fiber + 3.45 × ADF + 1.03 × DE ($R^2 = 0.98$). In conclusion, the digestibility of energy and NDF and the DE and ME values are not different between canola meal and 00-rapeseed meal. However, 00-rapeseed expellers have greater energy digestibility and contain 7.6% more DE and 7.7% more ME than 00-rapeseed meal.

Key words: 00-rapeseed expellers, 00-rapeseed meal, canola meal, energy, fiber, pigs

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INTRODUCTION

Canola and 00-rapeseeds were developed through conventional plant breeding from rapeseed (*Brassica napus*) to obtain low levels of erucic acid in the oil and low levels of glucosinolates in the coproducts produced from the plants (Thomas, 2005; Newkirk, 2009). Canola meal, 00-rapeseed meal, and 00-rapeseed expellers are the coproducts generated after oil extraction processing and can be used as ingredients in animal diets (Newkirk, 2009). However, the concentration of fat, protein, AA, and carbohydrates in canola seed may vary depending on seed variety and climatic, agronomic, harvesting, and processing conditions (Barthet and Daun, 2011; Newkirk, 2011). These differences may affect the digestibility of energy-yielding nutrients

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in meals (Bourdon and Aumaître, 1990; Bell, 1993; Newkirk et al., 2003; Montoya and Leterme, 2010). Results of previous research have indicated that DE and ME values in canola meal and rapeseed meal range from 2,800 to 3,273 and 2,550 to 3,013 kcal/kg (as-fed basis) and in canola expellers and rapeseed expellers from 3,155 to 3,779 and 2,920 to 3,540 kcal/kg, respectively (as-fed basis; de Blas et al., 2010; NRC, 2012). However, to our knowledge, there are no comparative data for the DE and ME in canola meal and 00-rapeseed meal and for the DE and ME in 00-rapeseed meal and 00-rapeseed expellers. There are also limited data on the digestibility of fiber in canola meal, rapeseed meal, and rapeseed expellers fed to pigs.

Therefore, the objective of this experiment was to compare DE and ME values and the apparent total tract digestibility (**ATTD**) of energy, ADF, and NDF between canola meal obtained from North America and 00-rapeseed meal from Europe and between 00-rapeseed meal and 00-rapeseed expellers. The second objective was to develop equations to predict DE and ME values in canola and 00-rapeseed products.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

The experiment was approved by the Institutional Animal Care and Use Committee at the University of Illinois. Twenty-three growing barrows (initial BW: 27.7 ± 2.92 kg; G-Performer boars × F-25 females; Genetiporc, Alexandria, MN) were allotted to a 8 × 23 Youden square design with 8 periods and 23 diets in each square. Each experimental period was 14 d. Pigs were placed in metabolic cages (0.8 by 1.6 m) that were equipped with a feeder and a nipple drinker, a fully slatted floor, a screen floor, and urine trays. Housing pigs in metabolic cages allowed for the total but separate collection of urine and fecal materials from each pig. The average BW of pigs at the conclusion of the experiment was 108.9 ± 9.0 kg.

Ingredients, Diets, and Feeding

Six samples of canola meal were obtained from solvent-extraction crushing plants in North America, 11 samples of 00-rapeseed meal were obtained from solvent-extraction crushing plants in Europe, and 5 samples of 00-rapeseed expellers were obtained from mechanical-press crushing plants in Europe (Table 1). Twenty-three diets were prepared (Tables 2 and 3): a corn basal diet and 22 diets based on corn and 1 of 22 test ingredients. Vitamins and minerals were included in all diets to meet or exceed requirements for growing pigs (NRC, 1998).

Experimental diets were fed to the pigs at a daily level of 3 times the estimated maintenance requirement for energy (i.e., 106 kcal of ME per kg of metabolic BW; NRC, 1998). The daily feed allotments were divided into 2 equal meals and fed at 0700 and 1700 h. Water was supplied at all times throughout the experiment.

Data and Sample Collection

Individual pigs were weighed at the beginning of each period and the amount of feed supplied to each pig each day was recorded. The initial 7 d of each period was considered an adaptation period to the diet. Fecal markers were fed on d 8 and 13 and fecal collections were initiated when the first marker appeared in the feces and ceased when the second marker appeared (Adeola, 2001). Urine was collected from d 8 to 13 in urine buckets over a preservative of 50 mL of 3 *N* HCl. Buckets were covered by gauze to prevent solids from contaminating the urine. Fecal samples and 20% of the collected urine were stored at –20°C immediately after collection. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet and a 200-mL subsample was collected and filtered for analysis. All collected fecal samples were dried at 60°C in a forced-air drying oven for 10 d and finely ground through a 1-mm screen in a Wiley Mill (model 4; Thomas Scientific, Swedesboro, NJ) before analysis.

Chemical Analysis

Samples of canola meal, 00-rapeseed meal, 00-rapeseed expellers, corn, diets, and feces were analyzed for DM (method 930.15; Hortwitz and Latimer, 2007), GE using a bomb calorimeter (model 6300; Parr Instruments, Moline, IL), ADF (method 978.10; Hortwitz and Latimer, 2007), and NDF (Holst, 1973). Urine samples were lyophilized before being analyzed for GE (Kim et al., 2009).

Samples of canola meal, 00-rapeseed meal, 00-rapeseed expellers, corn, and diets were also analyzed for ash (method 942.05; Hortwitz and Latimer, 2007) and CP by combustion (method 990.03; Hortwitz and Latimer, 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Canola meal, 00-rapeseed meal, and 00-rapeseed expellers were analyzed for acid-hydrolyzed ether extract (**AEE**), which was determined using 3 *N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (method 954.02; Hortwitz and Latimer, 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Crude fiber (method 978.10; Hortwitz and Latimer, 2007) and ADL (method 973.18; Hortwitz

Table 1. Analyzed composition of canola meal, 00-rapeseed meal, and 00-rapeseed expellers (as-is basis)

Sample origin	DM, %	CP, %	AEE,[1] %	Ash, %	Crude fiber, %	ADF, %	NDF, %	ADL, %	GE, kcal/kg
Corn	85.1	7.40	–	1.09	–	2.27	12.78	–	3,806
Canola meal									
1	90.5	39.3	4.31	8.40	7.92	16.3	24.6	6.81	4,229
2	89.2	36.8	3.80	6.59	10.9	18.5	30.0	7.75	4,204
3	90.2	39.8	3.01	7.32	10.2	18.2	30.6	7.80	4,207
4	89.8	38.1	4.44	7.36	10.3	19.7	31.5	8.43	4,237
5	90.4	36.7	3.79	7.39	10.9	19.7	34.7	7.56	4,196
6	89.4	37.6	3.58	6.93	7.02	18.4	32.8	8.65	4,235
Average	89.9	38.1	3.82	7.33	9.54	18.5	30.7	7.83	4,218
00-rapeseed meal									
1	89.1	36.4	3.58	6.57	7.69	19.3	31.6	8.18	4,150
2	90.3	38.0	4.19	7.39	6.99	17.0	28.2	6.65	4,254
3	88.1	37.5	3.47	6.61	7.24	16.8	24.9	7.60	4,173
4	89.1	35.6	5.25	6.89	6.88	19.0	29.7	8.13	4,257
5	90.0	32.8	5.91	6.55	7.68	21.9	34.7	7.89	4,331
6	88.0	36.5	3.61	6.63	6.83	18.8	30.1	7.90	4,180
7	88.6	37.1	3.72	6.61	7.09	22.0	27.3	8.24	4,229
8	89.0	37.3	3.68	6.86	7.14	20.5	30.7	7.84	4,234
9	88.6	35.6	2.71	6.93	7.75	19.9	33.7	8.89	4,146
10	88.9	37.1	3.01	7.08	7.04	18.5	28.9	8.22	4,179
11	88.6	34.2	3.39	8.03	7.64	18.8	30.9	7.58	4,181
Average	88.9	36.2	3.87	6.92	7.27	19.3	30.1	7.92	4,210
00-rapeseed expellers									
1	89.9	36.1	10.8	6.33	5.69	15.6	20.8	6.43	4,668
2	89.9	34.5	13.0	5.74	5.54	15.7	19.8	6.54	4,771
3	91.2	36.2	13.8	6.01	5.55	17.0	24.5	7.21	4,768
4	95.2	35.2	11.7	6.54	5.79	17.9	26.7	7.28	4,835
5	93.0	35.8	8.27	6.51	6.63	23.3	32.7	8.38	4,561
Average	91.8	35.6	11.5	6.23	5.84	17.9	24.9	7.17	4,721

[1]AEE = acid-hydrolyzed ether extract.

and Latimer, 2007) were analyzed in canola meal, 00-rapeseed meal, and 00-rapeseed expellers.

Calculations and Statistical Analysis

Following chemical analysis, the ATTD of energy, ADF, and NDF were calculated and the DE and ME values were calculated for each diet (Adeola, 2001). The DE and ME in the corn diet were divided by 97,20% to calculate the DE and ME in corn. The contribution of DE or ME from corn to the DE or ME of all other diets was calculated and the DE and ME values in each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers were calculated using the difference procedure (Adeola, 2001). The ATTD of energy, ADF, and NDF in each diet was calculated for each diet and for each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers.

Outliers were identified using the UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC). Data were analyzed using the PROC MIXED of SAS. The differences among sources of canola meal, 00-rapeseed meal, or 00-rapeseed expellers were analyzed using source as fixed effect and pig and period as random effect. To compare the differences between canola meal and 00-rapeseed meal, the model included continent as fixed effect and pig and period as random effects. To compare the differences between 00-rapeseed meal and 00-rapeseed expellers, the model included processing method as fixed effect and pig and period as random effects. The pig was the experimental unit for all analysis. Significance among means was assessed at an α level of 0.05.

Correlation coefficients among chemical components and DE and ME values in canola meal, 00-rapeseed meal, and 00-rapeseed expellers were determined using PROC CORR (in SAS). Prediction equations were developed by PROC REG as previously described (Sulabo and Stein, 2013). The best regression models were determined using multiple criteria analyses where the conceptual predictive statistic [**C(p)**] criterion, R^2, Akaike information criterion (**AIC**), root mean square error (**RMSE**), and *P*-value of the model were considered. The prediction equation with C(p) criterion close to *p*, in which *p* is the number of variables in the

Table 2. Ingredient composition (%) of experimental diets (as-fed basis)[1]

Item	Corn	Canola meal	00-rapeseed meal	00-rapeseed expellers	Limestone	Monocalcium phosphate	Salt	Vitamin mineral premix[2]
Corn	97.20	–	–	–	1.15	0.95	0.40	0.30
Canola meals								
1	62.97	35.00	–	–	0.75	0.58	0.40	0.30
2	59.75	38.30	–	–	0.71	0.54	0.40	0.30
3	63.37	34.60	–	–	0.75	0.58	0.40	0.30
4	61.52	36.50	–	–	0.72	0.56	0.40	0.30
5	59.66	38.40	–	–	0.70	0.54	0.40	0.30
6	60.84	37.20	–	–	0.71	0.55	0.40	0.30
00-rapeseed meals								
1	59.36	–	38.70	–	0.70	0.54	0.40	0.30
2	61.41	–	36.60	–	0.72	0.57	0.40	0.30
3	60.74	–	37.30	–	0.71	0.55	0.40	0.30
4	58.29	–	39.80	–	0.68	0.53	0.40	0.30
5	53.88	–	44.30	–	0.64	0.48	0.40	0.30
6	59.46	–	38.60	–	0.70	0.54	0.40	0.30
7	60.24	–	37.80	–	0.70	0.56	0.40	0.30
8	60.44	–	37.60	–	0.70	0.56	0.40	0.30
9	58.29	–	39.80	–	0.68	0.53	0.40	0.30
10	60.24	–	37.80	–	0.70	0.56	0.40	0.30
11	56.13	–	42.00	–	0.66	0.51	0.40	0.30
00-rapeseed expellers								
1	58.97	–	–	39.10	0.69	0.54	0.40	0.30
2	56.63	–	–	41.50	0.66	0.51	0.40	0.30
3	59.07	–	–	39.00	0.69	0.54	0.40	0.30
4	57.70	–	–	40.40	0.68	0.52	0.40	0.30
5	58.29	–	–	39.80	0.68	0.53	0.40	0.30

[1]Diets were formulated to a constant CP.

[2]The vitamin–mineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: 11,128 IU vitamin A as retinyl acetate, 2,204 IU vitamin D_3 as cholecalciferol, 66 IU vitamin E as DL-α-tocopheryl acetate, 1.42 mg vitamin K as menadione nicotinamide bisulfite, 0.24 mg thiamin as thiamine mononitrate, 6.58 mg riboflavin, 0.24 mg pyridoxine as pyridoxine hydrochloride, 0.03 mg vitamin B_{12}, 23.5 mg D-pantothenic acid as D-calcium pantothenate, 1.0 mg niacin as nicotinamide, 43.0 mg nicotinic acid, 1.58 mg folic acid, 0.44 mg biotin, 10 mg Cu as copper sulfate, 125 mg Fe as iron sulfate, 1.26 mg I as potassium iodate, 60 mg Mn as manganese sulfate, 0.3 mg Se as sodium selenite, and 100 mg Zn as zinc oxide.

candidate model + 1; the least AIC, which is a measure of fit; and the least RMSE, which is a measure of precision, was considered the optimal model.

RESULTS AND DISCUSSION

The concentrations of DM, CP, and ash in canola meal, 00-rapeseed meal, and 00-rapeseed expellers (Table 1) agreed with values for canola meal and canola expellers reported by Spragg and Mailer (2007), Rostagno et al. (2011), and NRC (2012). The average concentration of AEE in canola meal was in agreement with values reported by Spragg and Mailer (2007), Seneviratne et al. (2010), and Woyengo et al. (2010). However, the GE values in canola meal, 00-rapeseed meal, and 00-rapeseed expellers in this study were less than values reported by NRC (2012). The ADF concentrations for canola meal, 00-rapeseed meal, and 00-rapeseed expellers were in agreement with values in canola meal, rapeseed meal, and rapeseed expellers, respectively, reported by Sauvant et al. (2004) and de Blas et al. (2010). However, the concentration of NDF was greater than values for canola meal and canola expellers reported by Sauvant et al. (2004) and NRC (2012). Differences in the chemical composition among sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers that were observed in this experiment are most likely a result of variations in concentrations of nutrients in the seeds and differences in oil extraction procedures (Barthet and Daun, 2011; Newkirk, 2011). Differences in the quantities of gums and phospholipids added back to the meal may also result in differences among sources. The observation that the concentration of AEE and the GE value were similar in canola meal and 00-rapeseed meal indicates that gross composition of canola seeds probably was similar to that in 00-rapeseed and that the oil extraction procedures used in North America were as efficient as the procedures used in Europe. However, the concentration of AEE and GE in 00-rapeseed meal was less than in 00-rapeseed expellers. This observation indicates that the efficiency of oil removal using

Table 3. Analyzed DM, energy, and nutrient composition of experimental diets (as-fed basis)

Sample origin	DM, %	CP, %	Ash, %	GE, kcal/kg	ADF, %	NDF, %
Corn	85.3	6.95	1.09	3,682	2.27	12.8
Canola meal						
1	86.7	17.6	4.89	3,872	7.95	17.6
2	86.3	17.1	5.38	3,907	8.59	16.1
3	86.6	17.4	5.07	3,867	7.74	16.1
4	86.8	17.7	5.33	3,938	8.59	19.3
5	86.9	18.4	5.15	3,874	8.99	18.6
6	88.1	18.6	4.79	3,957	8.98	19.7
Average	86.9	17.8	5.10	3,902	8.47	17.9
00-rapeseed meal						
1	86.7	17.2	5.33	3,881	8.73	17.8
2	86.9	18.3	4.81	3,887	7.55	16.0
3	86.8	18.8	4.91	3,857	8.05	15.3
4	87.5	18.0	4.68	3,932	9.00	17.9
5	87.1	17.3	5.08	3,971	11.48	21.7
6	86.3	17.5	5.05	3,867	8.74	18.1
7	86.7	17.2	4.79	3,899	8.62	15.2
8	86.7	18.8	4.72	3,905	8.75	18.9
9	86.4	17.3	5.08	3,858	9.37	16.3
10	86.6	18.6	5.18	3,856	8.50	17.9
11	87.3	18.0	3.33	3,865	9.53	19.5
Average	86.8	17.9	4.81	3,889	8.93	17.7
00-rapeseed expellers						
1	87.2	17.4	4.68	4,047	7.04	14.2
2	87.6	18.0	4.27	4,136	7.92	15.2
3	87.4	16.9	4.96	4,107	7.97	14.9
4	88.4	17.2	4.93	4,108	8.30	17.1
5	87.3	17.4	4.79	4,030	8.88	18.9
Average	87.6	17.4	4.73	4,086	8.02	16.1

the solvent extraction procedure is greater than if the mechanical press procedure is used (Barthet and Daun, 2011; Newkirk, 2011).

The GE intake and the excretion of GE in urine were not different among pigs fed diets containing different sources of canola meal or 00-rapeseed meal, but the excretion of GE in feces, DE, ME, ATTD of GE, ATTD of ADF, and ATTD of NDF were different ($P < 0.05$; Table 4). The excretion of GE in urine, ATTD of ADF, and ATTD of NDF were not different among pigs fed different sources of 00-rapeseed expellers, whereas GE intake, the excretion of GE in feces, DE, ME, and ATTD of GE were different ($P < 0.05$).

The GE intake of pigs fed diets containing canola meal was not different from that in pigs fed diets containing 00-rapeseed meal, and GE intake was not different between pigs fed diets containing 00-rapeseed meal and 00-rapeseed expellers (Table 4). The excretion of GE in feces from pigs fed diets containing canola meal was not different from that of pigs fed diets containing 00-rapeseed meal, but more GE was excreted in the feces from pigs fed diets containing 00-rapeseed meal than for pigs fed diets containing 00-rapeseed expellers ($P < 0.05$). The excretion of GE in urine for pigs fed diets containing canola meal was less ($P < 0.05$) than for pigs fed diets containing 00-rapeseed meal, whereas no difference between 00-rapeseed meal and 00-rapeseed expellers were observed. The DE and ME values and ATTD of GE for diets containing canola meal did not differ from diets containing 00-rapeseed meal, but the DE and ME values and ATTD of GE were less ($P < 0.01$) in diets containing 00-rapeseed meal than in diets containing 00-rapeseed expellers. The ATTD of ADF for diets containing canola meal was less ($P < 0.01$) than for diets containing 00-rapeseed meal, whereas the values for 00-rapeseed meal diets were less ($P < 0.05$) than for 00-rapeseed expellers diets. The ATTD of NDF for diets containing canola meal was not different from values for diets containing 00-rapeseed meal, but the ATTD of NDF in diets containing 00-rapeseed meal was less ($P < 0.05$) than for diets containing 00-rapeseed expellers.

The DE and ME values, ATTD of ADF, and ATTD of NDF were different among sources of canola meal ($P < 0.05$), and the DE and ME values, ATTD of ADF, and ATTD of NDF were also different ($P < 0.05$) among the 11 sources of 00-rapeseed meal (Table 5). Differences ($P < 0.05$) among the 5 sources of 00-rapeseed expellers were also observed ($P < 0.05$) for DE and ME values and ATTD of NDF.

The DE and ME values and the ATTD of GE for canola meal and 00-rapeseed meal were not different. However, the DE and ME values and the ATTD of GE in 00-rapeseed meal were less ($P < 0.01$) than in 00-rapeseed expellers. The ATTD of ADF in canola meal was less ($P < 0.01$) than in 00-rapeseed meal, whereas no difference between 00-rapeseed meal and 00-rapeseed expellers was observed. The ATTD of NDF was not different between canola meal and 00-rapeseed meal, and the ATTD of NDF in 00-rapeseed meal was not different from the ATTD of NDF in 00-rapeseed expellers.

The DE and ME values of corn in this experiment were 3,907 and 3,780 kcal/kg (DM basis), which was in agreement with previously published values (Sauvant et al., 2004; NRC, 2012). The average DE and ME values for canola meal, 00-rapeseed meal, and 00-rapeseed expellers that were calculated in this experiment were less than the values for canola meal and canola expellers reported by Woyengo et al. (2010) and NRC (2012). However, the values were greater than the values for 00-rapeseed meal, 00-rapeseed expellers, and canola expellers reported by de Blas et al. (2010), Seneviratne et al. (2010), and Grageola et al. (2013). The reason for these differences among experiments may be that as we observed in this experiment, differences within each

Table 4. Intake and output of GE, DE and ME, and apparent total tract digestibility (ATTD) of energy, ADF, and NDF in diets containing canola meal, 00-rapeseed meal, and 00-rapeseed expellers (DM basis)[1]

Item	GE intake, kcal/d	GE output, fecal, kcal/d	GE output, urine, kcal/d	DE, kcal/kg	ME, kcal/kg	ATTD of GE, %	ATTD of ADF, %	ATTD of NDF, %
Corn	6,727	807.9	201.2	3,231	3,126	87.76	53.78	69.02
Canola meal								
1	7,917	1,392	253	3,183	3,046	82.22	46.76	63.65
2	8,002	1,534	253	3,143	2,999	80.46	37.60	54.27
3	7,727	1,394	321	3,166	3,006	81.86	41.99	58.19
4	8,095	1,525	334	3,189	3,021	81.00	38.77	60.39
5	7,969	1,610	278	3,075	2,896	79.37	39.90	57.82
6	8,430	1,663	359	3,156	2,987	79.77	43.09	60.39
Average	8,023	1,520	300	3,152	2,993	80.78	41.35	59.12
SEM[2]	881	140	43.21	29.30	39.75	0.75	1.66	1.57
P-value[2]	0.08	<0.01	0.12	0.01	<0.01	<0.01	<0.01	<0.01
00-rapeseed meal								
1	7,818	1,418	324	3,163	3,003	81.52	42.82	59.31
2	7,634	1,436	369	3,148	2,963	81.19	40.82	57.34
3	7,657	1,334	335	3,183	3,016	82.53	46.33	58.27
4	7,910	1,399	324	3,233	3,072	82.22	47.68	61.73
5	8,092	1,770	364	3,105	2,932	78.19	49.63	61.61
6	8,015	1,512	335	3,140	2,981	81.20	43.58	60.71
7	7,998	1,376	352	3,215	3,046	82.47	46.76	56.14
8	8,150	1,504	333	3,190	3,024	81.69	44.65	62.09
9	8,288	1,578	337	3,116	2,954	80.78	45.85	55.54
10	7,886	1,416	384	3,160	2,974	81.95	45.82	61.46
11	8,081	1,589	363	3,109	2,932	80.43	41.97	60.27
Average	7,957	1,485	347	3,160	2,991	81.29	45.08	59.50
SEM[3]	887	169	54.42	32.01	36.78	0.82	2.18	1.69
P-value[3]	0.66	0.01	0.95	0.03	0.01	0.01	0.03	<0.01
00-rapeseed expellers								
1	7,936	1,151	343	3,455	3,279	85.37	46.65	59.94
2	7,869	1,329	445	3,422	3,201	82.74	47.49	59.32
3	8,361	1,351	311	3,430	3,280	83.53	48.84	60.66
4	8,186	1,402	339	3,396	3,224	82.66	46.05	62.24
5	8,461	1,518	362	3,299	3,127	81.84	48.28	64.58
Average	8,163	1,350	360	3,400	3,222	83.23	47.46	61.35
SEM[4]	1,051	160	56.42	35.88	38.79	0.88	2.49	1.83
P-value[4]	<0.01	<0.01	0.09	0.01	0.02	0.01	0.86	0.20
Canola meal vs. 00-rapeseed meal								
SEM	860	145	37.56	18.75	24.83	0.49	1.11	0.93
P-value	0.69	0.87	0.02	0.80	0.78	0.48	0.001	0.65
00-rapeseed meal vs. 00-rapeseed expellers								
SEM	846	144	41.36	18.03	20.18	0.46	1.07	0.86
P-value	0.26	<0.001	0.39	<0.001	<0.001	<0.001	0.04	0.05

[1]Data are least square means of 8 observations for all treatments.

[2]Comparison of the 6 diets containing canola meal.

[3]Comparison of the 11 diets containing 00-rapeseed meal.

[4]Comparison of the 5 diets containing 00-rapeseed expellers.

group of ingredients exist. The ATTD of GE for canola meal, 00-rapeseed meal, and 00-rapeseed expellers that were calculated in this study are less than the values for canola meal and canola expellers reported by Woyengo et al. (2010). However, the ATTD of GE for 00-rapeseed expellers was greater than the ATTD of GE for canola expellers reported by Seneviratne et al. (2010) and Grageola et al. (2013). The average ATTD of ADF for canola meal, 00-rapeseed meal, and 00-rapeseed expellers in this study were 38.62, 43.37, and 45.83 and the ATTD of NDF were 51.90, 52.37, and 53.47, respectively. To our knowledge, values for the ATTD of ADF and NDF in canola meal, 00-rapeseed meal, and 00-rapeseed expellers have not been previously reported, but results

Table 5. Digestible energy and ME values and apparent total tract digestibility (ATTD) of energy, ADF, and NDF in canola meal, 00-rapeseed meal, and 00-rapeseed expellers (DM basis)[1]

Item	DE, kcal/kg	ME, kcal/kg	ATTD of GE, %	ATTD of ADF, %	ATTD of NDF, %
Corn	3,907	3,780	87.76	53.78	69.02
Canola meal					
1	3,442	3,225	75.15	44.53	59.89
2	3,388	3,156	68.02	34.13	44.07
3	3,395	3,102	71.52	39.17	48.31
4	3,491	3,182	69.92	35.69	55.03
5	3,143	2,816	68.68	37.19	48.73
6	3,408	3,096	65.64	41.00	55.36
Average	3,378	3,096	69.82	38.62	51.90
SEM[2]	88.89	119.58	4.08	2.29	2.47
P-value[2]	0.01	<0.01	0.20	<0.01	<0.01
00-rapeseed meal					
1	3,452	3,172	65.96	40.54	52.31
2	3,347	2,989	68.78	37.79	47.68
3	3,543	3,236	73.33	44.48	47.11
4	3,652	3,378	75.70	46.88	54.30
5	3,294	3,007	68.11	49.03	58.78
6	3,423	3,146	71.04	41.68	55.79
7	3,622	3,313	76.24	45.07	42.84
8	3,527	3,229	68.65	42.94	58.09
9	3,341	3,059	69.95	44.47	46.64
10	3,444	3,087	68.06	44.09	56.37
11	3,338	3,028	71.10	40.15	56.17
Average	3,453	3,149	70.63	43.37	52.37
SEM[3]	92.65	104.9	4.17	2.56	2.85
P-value[3]	0.04	0.01	0.39	0.02	<0.01
00-rapeseed expellers					
1	4,252	3,933	81.57	44.67	46.95
2	4,129	3,700	77.69	45.98	51.17
3	4,122	3,879	78.74	47.34	51.28
4	3,844	3,560	76.84	44.24	56.64
5	3,676	3,382	76.78	46.93	61.31
Average	4,005	3,691	78.32	45.83	53.47
SEM[4]	98.16	105.78	2.70	2.98	3.59
P-value[4]	<0.01	<0.01	0.28	0.93	<0.01
Canola meal vs. 00-rapeseed meal					
SEM	73.13	97.43	4.49	1.69	1.96
P-value	0.14	0.34	0.45	<0.001	0.81
00-rapeseed meal vs. 00-rapeseed expellers					
SEM	67.53	74.37	3.91	1.60	2.15
P-value	<0.001	<0.001	<0.001	0.08	0.54

[1]Data are least square means of 8 observations for all treatments.

[2]Comparison of the 6 diets containing canola meal.

[3]Comparison of the 11 diets containing 00-rapeseed meal.

[4]Comparison of the 5 diets containing 00-rapeseed expellers.

of this experiment indicate that the fiber in canola and rapeseed products may be poorly fermentable. The most likely reason for this poor fermentability is that most of the fiber in these ingredients is insoluble (Bach Knudsen, 1997), but further studies are needed to investigate fermentation properties of the fiber in canola and rapeseed products. The poor ATTD of ADF and NDF may also be the reason for the reduced ATTD of GE in the canola or 00-rapeseed products compared with the ATTD of GE for the diets containing corn.

The differences in DE and ME among sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers indicate that variations in energy values within canola meal and rapeseed products exist. These differences may be the results of differences in genetic selection and growing conditions for canola and rapeseed, which may affect the chemical composition of seeds and consequently affect the energy value in the meals. Differences among crushing plants in the efficiency of oil extraction or the components that are added back to the meals may influence the concentration of fat in the meals, which, in turn, may also affect the energy values among sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers. The implication of these observations is that it may not always be accurate to use book values for DE and ME for canola or rapeseed products.

The observation that the average DE, ME, and ATTD of GE for canola meal from North American were not different from the values for 00-rapeseed meal is most likely a result of the fact that both canola and rapeseeds are selected from the same variety (*B. napus*) and the same extraction procedure (solvent extraction) was used to remove oil from seeds. As a result, the concentrations of nutrients in the meals were not different, which also resulted in DE and ME values not being different. However, 00-rapeseed expellers had greater DE, ME, and ATTD of GE than 00-rapeseed meal, which is likely a result of the concentration of AEE and GE in 00-rapeseed expellers being greater than in 00-rapeseed meal. The differences are consistent with the expeller procedure being less efficient in oil removal than the extraction procedure. However, due to increased demand for virgin rapeseed oil from the human food industry, the price of rapeseed oil produced using the mechanical press procedure is sometimes greater than the price for oil produced using the solvent extraction procedure. As a consequence, it may be economical for crushing plants to use the mechanical press procedure, although the yield of oil is less than if the solvent extraction procedure is used.

The concentration of AEE, GE, ADF, and NDF in canola meal and rapeseed meal may influence DE, ME, and NE when used in pig diets (Bourdon and Aumaître, 1990; Montoya and Leterme, 2010). In this study, the AEE concentration in canola meal, 00-rapeseed meal, and 00-rapeseed expellers was positively ($P < 0.001$) correlated with the concentrations of GE, DE, ME, and ATTD of GE but the concentrations of ash, crude fiber, and NDF were negatively ($P < 0.01$) correlated with GE, DE, and ME (Table 6). The concentrations of CP

Table 6. Correlation coefficients (r) between chemical components and GE, DE, and ME values in canola meal, 00-rapeseed meal, and 00-rapeseed expellers (DM basis)[1]

	Correlation coefficient[2]										
Item	CP	AEE	Ash	Crude fiber	ADF	NDF	ADL	GE	DE	ME	ATTD of GE
GE	–0.54*	0.97**	–0.74**	–0.68**	–0.45	–0.74**	–0.59*	1.00	0.93**	0.90**	0.76**
DE	–0.31	0.88**	–0.68**	–0.69**	–0.48	–0.82**	–0.52	0.93**	1.00	0.99**	0.83**
ME	–0.29	0.87**	–0.66**	–0.66**	–0.46	–0.80**	–0.50	0.90**	0.99**	1.00	0.85**
ATTD of GE	–0.27	0.75**	–0.41	–0.56*	–0.36	–0.77**	–0.55*	0.76**	0.83**	0.85**	1.00

[1]A total of 6 canola meal, eleven 00-rapeseed meal, and five 00-rapeseed expellers were used.

[2]AEE = acid-hydrolyzed ether extract; ATTD = apparent total tract digestibility.

*$P < 0.01$; **$P < 0.001$.

and ADL were negatively ($P < 0.01$) correlated with the concentration of GE, and the concentration of ash, crude fiber, NDF, and ADL were negatively ($P < 0.01$) correlated with the ATTD of GE. The concentrations of GE, DE, and ME in canola meal, 00-rapeseed meal, and 00-rapeseed expellers were highly correlated ($P < 0.001$, $R^2 > 0.90$). The reduced concentration of AEE and the greater concentration of ash, CF, ADF, NDF, and ADL in 00-rapeseed meal than in 00-rapeseed expellers may be the reasons for the reduced digestibility of energy in 00-rapeseed meal. This observation indicates that oil extraction procedures affect the digestibility of energy in rapeseed products and the concentration of AEE, ash, CF, ADF, NDF, and ADL is related to DE, ME, and ATTD of GE in 00-rapeseed products.

The optimal models to predict GE, DE, and ME were (Table 7)

$$GE = 4{,}927 - 7.95 \times CP + 43.43 \times AEE + 1.36 \times ADF - 12.30 \times NDF + 36.35 \times ADL, \quad [1]$$

$$DE = -1{,}583 + 6.64 \times ash + 7.01 \times ADF - 33.17 \times NDF + 98.66 \times ADL + 1.07 \times GE, \quad \text{and } [2]$$

$$ME = -630.8 + 14.13 \times ash + 5.02 \times crude\ fiber + 3.45 \times ADF + 1.03 \times DE. \quad [3]$$

All of these 3 models had $R^2 > 0.94$, which indicates that the concentration of chemical components of canola meal, 00-rapeseed meal, and 00-rapeseed expellers can be used to predict the concentration of GE, DE, and ME in these ingredients when fed to growing pigs.

Conclusion

The DE, ME, and ATTD of energy in canola meal and 00-rapeseed meal were not different, which indicates that values obtained with canola meal are also representative for 00-rapeseed meal and vice versa. The DE, ME, and ATTD of energy in 00-rapeseed expellers are greater than in extracted 00-rapeseed meal, which is likely a result of the increased concentration of oil in 00-rapeseed expellers than in 00-rapeseed meal. Therefore, the digestibility of energy in 00-rapeseed expellers is greater than in 00-rapeseed meal. The fiber in canola and rapeseed products is poorly fermented, which may negatively affect the digestibility of energy in these products. Differences among sources of canola meal and 00-rapeseed meal products may result from differences in seed varieties and differences in climatic, agronomic, harvesting, and processing conditions. However, prediction equations derived from our data can be used to estimate the DE and ME of canola and rapeseed products fed to growing pigs.

Table 7. Prediction equations for GE, DE and ME in canola meal, 00-rapeseed meal, and 00-rapeseed expellers (DM basis)[1,2]

Equation	C(p)	R^2	AIC	RMSE	P-value
GE = 4,927 – 7.95 × CP + 43.43 × AEE + 1.36 × ADF – 12.30 × NDF + 36.35 × ADL	6.05	0.966	169.11	41.67	<0.001
GE = 4,509 + 47.49 × AEE + 3.46 × ADF – 10.25 × NDF + 31.57 × ADL	5.17	0.963	168.60	41.83	<0.001
DE = –1,583 + 6.64 × ash + 7.01 × ADF – 33.17 × NDF + 98.66 × ADL + 1.07 × GE	6.08	0.942	197.56	79.56	<0.001
DE = 3,307 + 52.63 × AEE – 40.51 × NDF + 143.74 × ADL	4.39	0.934	196.52	80.22	<0.001
ME = –630.8 + 14.13 × ash + 5.02 × crude fiber + 3.45 × ADF + 1.03 × DE	5.01	0.977	174.35	47.66	<0.001
ME = –266.9 – 0.35 × AEE + 1.52 × ADF + 0.98 × DE	3.84	0.976	173.40	47.43	<0.001

[1]Units for GE, DE, and ME are kilocalories/kilogram of DM; units for nutrients are percent of DM.

[2]C(p) = conceptual predictive statistic, the criterion used to determine candidate models that maximize explained variability ($R2$) with as few variables as possible. Candidate models are those where C(p) is close to p, in which p is the number of variables in the candidate model + 1. Prediction equation with the lowest Akaike information criterion (AIC), which is a measure of fit, and root mean square error (RMSE), which is a measure of precision, is the optimal model. AEE = acid-hydrolyzed ether extract.

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