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The nutritional value of expeller-pressed canola meal for grower-finisher pigs[1]

R. W. Seneviratne,* M. G. Young,† E. Beltranena,*‡ L. A. Goonewardene,*‡ R. W. Newkirk,§ and R. T. Zijlstra*[2]

*Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada T6G 2P5; †Gowans Feed Consulting, Wainwright, Alberta, Canada T9W 1N3; ‡Alberta Agriculture and Rural Development, Edmonton, Alberta, Canada T6H 5T6; and §Canadian International Grains Institute, Winnipeg, Manitoba, Canada R3C 3G7

ABSTRACT: Expeller-pressed (EP) canola meal contains more residual oil than solvent-extracted canola meal and might be an attractive feedstuff for swine, but it has been poorly characterized. In Exp. 1, six ileal-cannulated barrows (36 kg of BW) were fed at 3× maintenance either a 44% EP canola meal diet or a N-free diet in a crossover design to measure energy and AA digestibility and calculate standardized ileal digestible (SID) AA and NE content, with 6 observations per diet. Each period consisted of a 5-d diet adaptation and a 2-d feces and 3-d digesta collection. The EP canola meal contained (% of DM) 38.5% CP, 13.3% ether extract, 2.42% Lys, 1.54% Thr, 0.62% Met, and 23.2 μmol/g of glucosinolates. Apparent total tract energy digestibility was 75.0% and the DE and predicted NE content were 3.77 and 2.55 Mcal/kg (in DM), respectively. The SID AA content (% of DM) was 1.77% Lys, 1.04% Thr, and 0.52% Met. In Exp. 2, a total of 1,100 pigs (25 kg of BW) housed in 50 pens were fed 5 dietary regimens with 0, 7.5, 15, and 22.5% or decreasing amounts (22.5, 15, 7.5, and 0%, respectively) of EP canola meal over 4 phases to validate performance and carcass characteristics. Diets were formulated to contain equal NE:SID Lys for each growth phase (g/Mcal; 4.04, d 0 to 25; 3.63, d 26 to 50; 3.23, d 51 to 77; 2.83, d 78 to 90). At slaughter, carcass characteristics were measured for all pigs, and jowl fat was sampled for 2 pigs per pen. For d 51 to 90, the 22.5% EP canola meal regimen was reduced to 18% (22.5/18%) because of decreased ADFI in phases 1 and 2. Overall (d 0 to 90), increasing dietary EP canola meal linearly decreased ($P < 0.001$) ADG and ADFI and linearly increased ($P < 0.01$) G:F. For 0 and 22.5/18% EP canola meal, respectively, ADG was 978 and 931 g/d, ADFI was 2.77 and 2.58 kg/d, and G:F was 0.366 and 0.378. Increasing dietary EP canola meal did not alter the carcass backfat thickness, loin depth, or jowl fat fatty acid profile. Pigs fed 22.5/18% EP canola meal reached slaughter weight 3 d after ($P < 0.05$) pigs fed 0% EP canola meal. In summary, EP canola meal provided adequate energy and AA; however, ADG was reduced by 3 g/d per 1% of EP canola meal inclusion, likely because of increased dietary glucosinolates. Thus, the amount of EP canola meal included in swine diets should be targeted to an expected growth performance and carcass quality. Finally, diets formulated to contain an equal NE and SID AA content did not entirely eliminate the risks for reduced growth performance associated with inclusion of an alternative feedstuff.

Key words: amino acid, canola meal, digestibility, energy, expeller-pressed, pig

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INTRODUCTION

With the increasing cost of feed energy, alternative feedstuffs for pigs should be explored. As such, canola meal has been fed, although mostly as an AA source. Extraction of oil from canola seed in solvent-extraction plants is 95% efficient, resulting in low DE in canola meal (Spragg and Mailer, 2007). Canola oil can also be extracted using an expeller press without solvents but with a less efficient oil removal (75%). Hence, expeller-pressed (**EP**) canola meal contains 10 to 15% oil (Lem-

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[2]Corresponding author: ruurd.zijlstra@ualberta.ca

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Table 1. Ingredient composition and nutrient content of diets used in Exp. 1

Item	Expeller-pressed canola meal	N free
Ingredient, % as-fed		
Corn starch[1]	48.63	85.32
Expeller-pressed canola meal	44.00	—
Sugar	2.85	5.00
Solka-Floc[2]	—	3.00
Canola oil	1.14	2.00
Limestone	1.50	1.00
Mono-dicalcium phosphate	—	1.20
Salt	0.50	0.50
Mineral premix[3]	0.50	0.50
Vitamin premix[4]	0.50	0.50
Chromic oxide	0.38	0.38
K_2CO_3	—	0.50
MgO (58% Mg)	—	0.10
Analyzed nutrient content, % of DM		
Moisture	6.04	10.35
CP	17.21	0.57
Ether extract	7.10	0.66
Crude fiber	6.40	2.14
Ca	0.91	0.64
P	0.48	0.25
AA		
Ala	0.75	0.03
Arg	1.03	0.01
Asp	1.23	0.03
Cys	0.38	0.02
Glu	3.00	0.09
Gly	0.85	0.02
His	0.45	0.01
Leu	1.22	0.05
Lys	1.01	0.02
Met	0.32	—
Phe	0.68	0.01
Pro	0.98	0.06
Ser	0.66	0.02
Thr	0.71	0.01
Trp	0.22	0.02
Tyr	0.46	0.01
Val	0.87	0.01

[1]Melojel (National Starch and Chemical Co., New York, NY).

[2]International Fiber Corp. (New York, NY).

[3]Provided the following per kilogram of diet: Zn, 100 mg (as $ZnSO_4$); Fe, 80 mg (as $FeSO_4$); Cu, 50 mg (as $CuSO_4$); Mn, 25 mg (as $MnSO_4$); I, 0.5 mg [as $Ca(IO_3)_2$]; and Se, 0.1 mg (as Na_2SeO_3).

[4]Provided the following per kilogram of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 0.2 mg; vitamin B_{12}, 0.025 mg.

ing and Lember, 2005) and might still be a valuable AA source in swine diets.

The nutritional value of EP canola meal is not well known. The ME content of EP canola meal seems greater than that of solvent-extracted canola meal (Smulikowska et al., 1997, 2006), but the digestible AA profile is unknown. Individually housed grower-finisher pigs may tolerate 10 to 18% EP canola meal in diets without detrimental effects on growth performance and minor effects on carcass characteristics (Brand et al., 2001); however, these results require validation in group-housed pigs. Finally, an increased dietary inclusion of EP canola meal can reduce pork quality (Whitney et al., 2006) because the remaining canola oil, which is rich in unsaturated fatty acids, may soften carcass fat (Rowghani et al., 2007).

The hypotheses were that EP canola meal contains valuable energy and AA and that feeding EP canola meal would result in equal growth performance if diets were formulated using NE and standardized ileal digestible (**SID**) AA. Potential changes in carcass characteristics and fatty acid profile by feeding EP canola meal could be mitigated by feeding decreasing amounts of EP canola meal. The objectives were to determine the DE and NE and digestible AA profile of EP canola meal using ileally cannulated pigs (Exp. 1), and to evaluate growth performance and carcass characteristics of grower-finisher pigs fed 0, 7.5, 15, and 22.5% and decreasing amounts of EP canola meal (Exp. 2).

MATERIALS AND METHODS

The animal protocols were approved by the University of Alberta Animal Care and Use Committee for Livestock, and followed guidelines established by the Canadian Council on Animal Care (1993).

Experimental Design and Diets

In Exp. 1, two diets were formulated (Table 1). The N-free diet was used to estimate basal ileal endogenous losses of AA (Stein et al., 2006). The EP canola meal diet contained EP canola meal (Associated Proteins, Ste. Agathe, Manitoba, Canada) as the sole source of CP and AA to measure AA digestibility. In addition, the ratio of corn starch to sugar and canola oil was identical to that of the N-free diet to allow measurement of energy digestibility of EP canola meal (Stein et al., 2006). Diets were formulated to meet or exceed vitamin and mineral requirements (NRC, 1998) and included chromic oxide as an indigestible marker.

In Exp. 2, the effect of including increasing amounts of EP canola meal at 7.5, 15, or 22.5% was tested together with a control dietary regimen based on soybean meal (0% EP canola meal; Table 2 and 3) in 4 growth phases. In phases 3 and 4, the greatest dietary EP canola meal was reduced from 22.5 to 18% to ameliorate observed reductions in ADFI. A fifth dietary regimen gradually decreased EP canola meal from 22.5 to 15 and 7.5%, and then to 0% for phases 1 to 4, respectively. Within each phase, diets were formulated to be isocaloric and isolysinic, with constant ratios of Thr, Met, Cys, and Trp to Lys. Diets were fortified with premixes to meet the mineral and vitamin requirements (NRC, 1998).

Experimental Procedures

The digestibility experiment was conducted at the Swine Research and Technology Centre at the Uni-

Table 2. Ingredient composition and nutrient content of the phase 1 and 2 diets,[1] Exp. 2

	Expeller-pressed canola meal, %							
	Phase 1				Phase 2			
Item	0	7.5	15	22.5	0	7.5	15	22.5
Ingredient, % as-fed								
Wheat	34.60	30.82	26.92	23.03	34.72	30.94	27.04	22.48
Corn	30.00	30.00	30.00	30.00	35.00	35.00	35.00	35.00
Expeller-pressed canola meal	—	7.50	15.00	22.50	—	7.50	15.00	22.50
DDGS blend[2]	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Soybean meal	15.76	11.70	7.66	3.61	11.54	7.48	3.44	—
Limestone	1.30	1.32	1.40	1.48	1.26	1.27	1.35	1.43
Canola meal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tallow	1.03	1.40	1.81	2.21	0.30	0.67	1.07	1.55
Salt	0.44	0.43	0.43	0.43	0.48	0.48	0.48	0.48
L-Lys-HCl	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.33
Mono-dicalcium phosphate	0.34	0.31	0.28	0.25	0.18	0.15	0.12	0.09
Premix[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Thr	0.04	0.03	0.01	—	0.03	0.02	0.01	—
$CuSO_4$	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Calculated content, as-fed basis								
SID[4] Lys, %	0.97	0.97	0.97	0.97	0.87	0.87	0.87	0.87
NE, Mcal/kg	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
CP, %	20.27	20.62	20.96	21.31	18.75	19.10	19.44	19.96
Ether extract, %	3.84	4.99	6.17	6.64	3.26	4.41	5.59	6.83
Ca, %	0.70	0.74	0.80	0.86	0.55	0.61	0.67	0.69
P, %	0.56	0.61	0.66	0.71	0.48	0.53	0.58	0.60
Glucosinolates,[5] μmol/g	—	1.74	3.48	5.22	—	1.74	3.48	5.22
Available P, %	0.30	0.30	0.30	0.30	0.21	0.21	0.21	0.21
SID Lys:NE, g/Mcal	4.04	4.04	4.04	4.04	3.63	3.63	3.63	3.63

[1]The phase 1 diet was fed from 23 to 53 kg of BW, and the phase 2 diet was fed from 54 to 80 kg of BW.

[2]The distillers dried grain with solubles (DDGS) was cofermented from wheat and corn (Husky Energy, Lloydminster, Saskatchewan, Canada).

[3]Provided the following per kilogram of diet: Zn, 125 mg (as ZnO); Fe, 100 mg (as $FeSO_4$); Cu, 14 mg (as $CuSO_4$); Mn, 25 mg (as MnO); I, 0.3 mg [as $Ca(IO_3)_2$]; Se, 0.3 mg (as Na_2SeO_3); vitamin A, 6,000 IU; vitamin D, 1,000 IU; vitamin E, 25 IU; niacin, 20 mg; D-pantothenic acid, 12 mg; riboflavin, 4 mg; menadione, 2 mg; folic acid, 0.5 mg; thiamine, 1 mg; D-biotin, 0.1 mg; vitamin B_{12}, 0.02 mg.

[4]SID = standardized ileal digestible.

[5]Calculated from measured total glucosinolates in expeller-pressed canola meal.

versity of Alberta (Edmonton, Alberta, Canada). The growth performance study was conducted at Drumloche Research Farm (Lougheed, Alberta, Canada).

Exp. 1 (Digestibility Study). Two diets were tested over 6 experimental periods using cannulated grower-finisher pigs. Six crossbred barrows (initial BW, 36.2 ± 1.9 kg; initial age, 91 ± 7 d; Duroc × Large White/Landrace F_1; Genex Hybrid, Hypor, Regina, Saskatchewan, Canada) were surgically fitted with a T-cannula at the distal ileum. The pigs were fed the 2 diets in a crossover design to provide 6 observations per diet. Pigs were housed in individual metabolism pens (1.2 × 1.2 m) that allowed freedom of movement. Pens had a plastic-coated, expanded metal floor, polyvinyl chloride walls (0.9 m high) fitted with Plexiglas windows (0.3 × 0.3 m), a single-space dry feeder, and a nipple drinker. To avoid orts, daily feed allowance was set at 3 times the estimated maintenance requirement for energy (3 × 110 kcal of DE/kg of $BW^{0.75}$; NRC, 1998), which was divided into 2 equal meals at 0800 and 1600 h. Diets were fed as a dry mash, and pigs had free access to water throughout the experiment. The 10-d experimental periods consisted of a 5-d acclimation to the experimental diets, followed by a 2-d collection of feces and a 3-d collection of ileal digesta.

Feces were collected continuously with bags that were replaced a minimum of 2 times per day, at 0800 and 1600 h. The plastic bags were attached to a ring system glued to the skin around the anus (van Kleef et al., 1994). Digesta was collected for 10 h each of 3 consecutive days using bags containing 5% formic acid attached to the open cannula barrel for 10 h. Bags were removed whenever full or at least every 30 min. Collected feces and digesta were pooled by pig observation and frozen at −20°C. Before analyses, feces and digesta were thawed, homogenized, subsampled, and freeze-dried.

Exp. 2 (Performance Study). Growth performance was evaluated for 90 d. In total, 1,100 crossbred pigs [550 barrows and 550 gilts; Duroc (Designed Genetics Inc., Lockport, Manitoba, Canada) × Large White/Landrace (Line 277; Fast Genetics, Saskatoon, Saskatchewan, Canada)] were used, with an initial age of 64 d. Average BW at d 0 was 22.6 ± 1.27 kg. Pigs

Table 3. Ingredient composition and nutrient content of the phase 3 and 4 diets,[1] Exp. 2

	Expeller-pressed canola meal, %							
	Phase 3				Phase 4			
Item	0	7.5	15	18	0	7.5	15	18
Ingredient, % as-fed								
Wheat	31.35	37.91	33.03	24.32	—	6.09	12.07	5.00
Corn	20.00	20.00	28.13	31.47	20.00	20.00	24.12	26.64
Expeller-pressed canola meal	—	7.50	15.00	18.00	—	7.50	15.00	18.00
Barley	24.59	14.65	5.65	8.01	60.76	48.38	30.88	32.44
DDGS blend[2]	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Soybean meal	5.83	1.71	—	—	1.08	—	—	—
Limestone	1.20	1.26	1.33	1.37	1.11	1.18	1.26	1.29
Canola meal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Salt	0.46	0.46	0.47	0.47	0.43	0.44	0.45	0.45
L-Lys-HCl	0.35	0.35	0.29	0.26	0.35	0.26	0.15	0.11
Mono-dicalcium phosphate	0.09	0.05	—	—	0.17	0.08	—	—
Premix[3]	0.10	0.10	0.10	0.10	0.07	0.07	0.07	0.07
L-Thr	0.03	0.01	—	—	0.03	—	—	—
Calculated content, as-fed basis								
SID[4] Lys, %	0.76	0.76	0.76	0.76	0.65	0.65	0.65	0.65
NE, Mcal/kg	2.35	2.35	2.35	2.35	2.30	2.30	2.30	2.30
CP, %	17.12	17.75	18.66	18.95	14.64	16.25	18.12	18.47
Ether extract, %	2.77	3.53	4.44	4.93	2.89	3.63	4.43	4.90
Ca, %	0.60	0.65	0.71	0.74	0.55	0.61	0.67	0.69
P, %	0.49	0.54	0.59	0.62	0.48	0.53	0.58	0.60
Glucosinolates,[5] μmol/g	—	1.74	3.48	4.18	—	1.74	3.48	4.18
Available P, %	0.24	0.25	0.24	0.24	0.21	0.21	0.21	0.21
SID Lys:NE, g/Mcal	3.23	3.23	3.23	3.23	2.83	2.83	2.83	2.83

[1]Phase 3 diet was fed from 81 to 95 kg of BW and phase 4 diet was fed from 96 to 118 kg of BW.

[2]The distillers dried grains with solubles (DDGS) was cofermented from wheat and corn (Husky Energy, Lloydminster, Saskatchewan, Canada).

[3]Provided the following per kilogram of phase 3 diet: Zn, 125 mg (as ZnO); Fe, 100 mg (as $FeSO_4$); Cu, 14 mg (as $CuSO_4$); Mn, 25 mg (as MnO); I, 0.3 mg [as $Ca(IO_3)_2$]; Se, 0.3 mg (as Na_2SeO_3); vitamin A, 6,000 IU; vitamin D, 1,000 IU; vitamin E, 25 IU; niacin, 20 mg; D-pantothenic acid, 12 mg; riboflavin, 4 mg; menadione, 2 mg; folic acid, 0.5 mg; thiamine, 1 mg; D-biotin, 0.1 mg; vitamin B_{12}, 0.02 mg; or 70% thereof in the phase 4 diet.

[4]SID = standardized ileal digestible.

[5]Calculated from measured total glucosinolates in expeller-pressed canola meal.

were randomly placed within sex to 25 pens/sex with 22 pigs/pen, and pens were blocked by BW. Pens were then randomly allocated to 5 dietary regimens within sex and block, with 10 pens per dietary regimen. On arrival, pigs were fed a pregrower diet for 5 d and then switched to the phase 1 diets.

The flooring of each pen (6.15 × 2.39 m) was fully slatted concrete, and the siding was concrete panels with open slotting. Each pen was equipped with 1 wet-dry feeder (model F1-115, Crystal Spring Hog Equipment, St. Agathe, Manitoba, Canada) and was located halfway along the dividing wall between pens. One bowl drinker was located at the back of the pen. The room was ventilated using negative pressure and was maintained within the thermoneutral zone for the pigs, with a 12-h light (0700 to 1900 h), 12-h dark cycle. Pigs had free access to diets as a dry mash and water. Pigs were injected intramuscularly with porcine circovirus vaccine (Circumvent, Intervet Canada Ltd., Whitby, Ontario, Canada) 1 wk before and 1 wk after weaning.

Five test dietary regimens (Tables 2 and 3) were fed in 4 phases with changeover from 1 phase to the next after consuming a fixed amount of the previous diet. Pigs were weighed at the initiation of feeding the experimental diets (d 0) and on d 34, 64, 76, and 90. With a robotic feed delivery system (Feed Logic, Feed Logic Co., Willmar, MN), feed was delivered to each pen and each feed delivery was recorded. Feed remaining in the feeder was determined on weigh days for each pen by multiplying the measured feed bulk left in the feeder with bulk weight of the feed, which resulted in a maximum weight error of 0.1%. Collected data were used to calculate pen ADG, ADFI, and G:F.

Pigs were slaughtered at a commercial slaughter facility (Britco Pork Inc., Langley, British Columbia, Canada). Pigs were fed phase 4 diets until reaching the predetermined market weight (118 kg); the first pigs reached market weight on d 90. The warm pig carcasses were graded for backfat and loin depth by using a light-reflectance probe (Destron PG-100, Destron Technologies, Markham, Ontario, Canada) between the third and fourth last ribs at 7 cm off the midline. Without harming the economic value of the carcass, jowl fat was sampled from 2 randomly selected pigs per pen, returned frozen to Edmonton, and dissected free of skin and meat before grinding and homogenization.

Chemical Analyses

For Exp. 1, the diets, EP canola meal, and freeze-dried digesta and feces were ground in a Retch mill (model ZMI, Brinkman Instruments, Rexdale, Ontario, Canada) using a 1-mm screen. The EP canola meal was analyzed for CP (method 984.13A-D), ether extract (method 920.39A), ADF (method 973.18), total dietary fiber (method 985.29), ash (method 942.05), Ca (method 968.08), P (method 946.06), phytate (method 986.11), and available Lys (method 975.44) using AOAC (2006) methods, and NDF (Holst, 1973) was analyzed at the University of Missouri, Columbia. The glucosinolate profile of EP canola meal was determined by gas chromatography analysis (POS Pilot Plant Corp, Saskatoon, Saskatchewan, Canada) using the method of the Canadian Grain Commission developed by Heaney and Fenwick (1980) and modified by Daun and McGregor (1981). Diets, EP canola meal, and digesta were analyzed for AA (method 982.30E; AOAC, 2006), and diets, EP canola meal, digesta, and feces were analyzed for DM (method 930.15; AOAC, 1990) at the University of Missouri. Chromic oxide in diets, digesta, and feces was determined by spectrophotometry (model 80-2097-62, KBUltraspec III, Pharmacia, Cambridge, UK) at 440 nm after ashing at 450°C overnight (Fenton and Fenton, 1979). The GE content of diets, EP canola meal, digesta, and feces were determined using an adiabatic bomb calorimeter (model 5003, IKA-Werke GmbH & Co. KG, Staufen, Germany); benzoic acid was used as a standard. For Exp. 2, jowl fat was analyzed for fatty acid profile by gas chromatography (method 996.06; AOAC, 2006).

Calculations

For Exp. 1, the apparent ileal digestibility (**AID**) and apparent total tract digestibility values of the EP canola meal diet were calculated using the indicator method (Eq. [2]; Stein et al., 2007). For AA, the direct method was used because EP canola meal was the sole ingredient contributing AA in the diet. Each pig fed the N-free diet was used to calculate its own basal endogenous AA loss (Eq. [3]; Stein et al., 2007). The SID for the AA in EP canola meal was calculated using AID and the basal endogenous AA loss (Eq. [7]; Stein et al., 2007). The SID AA content was calculated by multiplying the AA content in the ingredient by the corresponding SID. For energy, the difference method was used (Adeola, 2001) to calculate digestibility of EP canola meal using the ratio of corn starch, sugar, and canola oil in the N-free diet (Stein et al., 2006). The DE content was calculated using GE multiplied by its digestibility value. The NE content of EP canola meal was predicted by an equation (Eq. [4]; Noblet et al., 1994) using the analyzed macronutrient and determined DE content.

The lean yield of the carcass was calculated using the equation developed by the Canadian Pork Council (1994):

$$\text{Lean, \%} = 68.1863 - 0.7833 \times \text{Fat, mm} + 0.0689 \times \text{Lean, mm} + 0.0008 \times \text{Fat} \times \text{Fat} - 0.0002 \times \text{Lean} \times \text{Lean} + 0.0006 \times \text{Fat} \times \text{Lean}.$$

The iodine value of jowl fat was calculated using the following equation (AOCS, 1998):

$$\text{C16:1 (0.95)} + \text{C18:1 (0.86)} + \text{C18:2 (1.732)} + \text{C18:3 (2.616)} + \text{C20:1 (0.785)} + \text{C22:1 (0.723)}.$$

Statistical Analyses

In Exp. 1, means and SEM were calculated using the MEANS procedure (SAS Inst. Inc., Cary, NC). In Exp. 2, data were analyzed using the MIXED procedure of SAS. Pen was considered the experimental unit. Block was the random effect in the model, and period was the repeated term solely for analyses of growth performance variables. Analysis of variance determined the differences among diets, sex, and the interaction between diet and sex, and provided least squares means for each main effect for all dependent variables. Linear and quadratic effects were tested by 2 contrast statements for diets with 0, 7.5, 15, and 22.5% reduced to 18% EP canola meal, excluding the dietary regimen with decreasing amounts of EP. The IML procedure of SAS was used to generate coefficients because phases 3 and 4 had unequally spaced inclusion of EP canola meal. Decreasing amounts of EP canola meal inclusion over the 4 growth periods were compared with the 0% EP canola meal (control) diet using a preplanned contrast. Warm carcass weight was used as a covariate for analysis of carcass characteristics. To test the hypotheses, $P < 0.05$ was considered significant. If pertinent, trends ($0.05 \leq P < 0.10$) were reported.

RESULTS

Chemical Characteristics and Nutrient Digestibility

The EP canola meal sample used for the present animal studies contained 38.5% CP, 13.3% ether extract, and 28.0% NDF (DM basis; Table 4). This sample contained 2.42% Lys, with a laboratory-defined availability of 89%. The total glucosinolate content was 23.2 μmol/g of DM.

The energy digestibility of the EP canola meal diet was 72.9% at the ileum and 85.1% for the total tract (Table 5). The AID of this diet was 72.1% for Lys. The AID of energy of the EP canola meal sample was 61.0%, and the apparent total tract digestibility was 75.0%. After the correction for basal endogenous losses, the SID was 73.2% for Lys. The DE content of the EP canola meal was 3.77 Mcal/kg of DM. The calculated NE content was 2.55 Mcal/kg of DM. The SID content was 1.77% for Lys, 1.04% for Thr, 0.52% for Met, and 0.39% for Trp (DM basis).

Growth Performance and Carcass Characteristics

During the experiment, 113 pigs were removed and excluded from analyses. Reasons were death (27%), lameness (11%), twisted gut (7%), scours (6%), poor growth (6%), and tail biting (4%); removal appeared not to be related to dietary regimen.

Only the main effect of dietary regimen was described, because dietary regimen × sex interactions were not detected for growth performance and carcass variables. Sex differences are not reported. Increasing the inclusion of EP canola meal linearly ($P < 0.001$) reduced pig BW at d 34, 64, 76, and 90 (Table 6). Pigs fed the greatest inclusion of EP canola meal were 3.7 kg lighter at d 90. Pigs fed decreasing amounts of EP canola meal also had less ($P < 0.001$) BW at d 34, 64, and 76 than pigs fed 0% EP canola meal; however, BW of pigs was not different between these 2 dietary regimens at d 90.

For the entire trial (d 0 to 90), d 0 to 34, and d 35 to 64, increasing the inclusion of EP canola meal quadratically ($P = 0.01$) reduced ADG (Table 6). Inclusion of EP canola meal did not affect ADG for d 65 to 76 and d 77 to 90. Pigs fed decreasing amounts of EP canola meal had less ($P < 0.01$) ADG for d 0 to 34 and d 35 to 64 than pigs fed 0% EP canola meal, but ADG did not differ for d 65 to 76, d 77 to 90, and overall (d 0 to 90).

For the entire trial (d 0 to 90), increasing the inclusion of EP canola meal linearly reduced ($P < 0.001$) ADFI (Table 6). Inclusion of EP canola meal linearly ($P < 0.001$) reduced ADFI for d 0 to 34, d 35 to 64, and d 65 to 76, but did not affect ADFI for d 77 to 90. Pigs fed decreasing amounts of EP canola meal had less ($P < 0.01$) ADFI for d 0 to 34 and d 35 to 64 than pigs fed 0% EP canola meal, but ADFI did not differ for d 65 to 76, d 77 to 90, and overall (d 0 to 90).

For the entire trial (d 0 to 90), increasing the inclusion of EP canola meal linearly increased ($P < 0.001$) G:F (Table 6). Inclusion of EP canola meal linearly increased ($P < 0.05$) G:F for d 0 to 34 and quadratically increased ($P < 0.05$) G:F for d 65 to 76, but did not affect G:F for d 35 to 64 and d 77 to 90. Pigs fed decreasing amounts of EP canola meal had a greater ($P < 0.01$) G:F for 0 to 34, but not for any other period or overall (d 0 to 90).

Increasing the inclusion of EP canola meal linearly ($P < 0.001$) reduced carcass weight and backfat, and linearly increased ($P < 0.05$) lean yield and days to slaughter (Table 7). Pigs fed decreasing amounts of EP canola meal did not have different carcass characteristics from pigs fed 0% EP canola meal, but tended to reach ($P < 0.10$) shipping weight 1.5 d later.

Increasing the inclusion of EP canola meal did not affect the jowl fat fatty acid profile and calculated iodine value (Table 8). Pigs fed decreasing amounts of EP canola meal did not have a different jowl fat fatty acid profile and calculated iodine value compared with pigs fed 0% EP canola meal.

Table 4. Chemical content of expeller-pressed canola meal, Exp. 1

Characteristic, % of DM	Expeller-pressed canola meal
Moisture	4.4
GE, Mcal/kg	5.03
CP	38.5
Ether extract	13.3
Crude fiber	7.7
ADF	17.5
NDF	28.0
Total dietary fiber	27.0
Phytic acid	2.27
Ash	6.9
Ca	0.56
P	1.06
AA	
Ala	1.62
Arg	2.31
Asp	2.63
Cys	0.88
Glu	6.19
Gly	1.86
His	1.03
Ile	1.40
Leu	2.65
Lys	2.42
Met	0.62
Phe	1.51
Pro	2.20
Ser	1.41
Thr	1.54
Trp	0.47
Tyr	1.06
Val	1.90
Available Lys	2.16
Total glucosinolates,[1] μmol/g	23.2

[1]Contained the following glucosinolates (μmol/g of expeller-pressed canola meal): 3-butenyl, 3.42; 4-pentenyl, 0.25; 2-OH-3-butenyl, 5.23; 2-OH-4-pentenyl, 0.08; CH_3-thiobutenyl, 0.16; phenylethyl, 0.21; CH_3-thiopentenyl, 0.08; 3-CH_3-indolyl, 0.39; 4-OH-3-CH_3-indolyl, 4.37; total aliphatics, 8.99.

DISCUSSION

Canola is a major oilseed crop (Raymer, 2002). Canola oil constitutes 40% of the seed and is its most valuable component. Solvent extraction, expeller pressing, and cold pressing can extract oil to produce raw canola oil and solvent-extracted canola meal, EP canola meal, and cold-pressed canola cake, respectively, as alternative feedstuffs (Leming and Lember, 2005). Practical inclusion of solvent-extracted canola meal is limited to 15% in diets for grower-finisher pigs, despite a suggested maximum inclusion of 25% (Canola Council of Canada, 2009). The main reason is its smaller content of available energy and AA, mainly because it has less digestible fiber and CP compared with soybean meal (Bell, 1993). The lack of knowledge about the nutritional quality of EP canola meal and its effects on growth performance and carcass quality limits its application in swine feed formulation. In Exp. 1, the NE and SID Lys content of EP canola meal were established at 2.55 Mcal NE/kg of DM and 1.77% in the DM, respectively,

Table 5. Apparent ileal digestibility (AID) of AA of the expeller-pressed canola meal diet, standardized ileal digestibility (SID) and SID AA content of expeller-pressed canola meal, AID and apparent total tract digestibility of energy of the expeller-pressed canola meal and diet, and DE and NE content of expeller-pressed canola meal,[1] Exp. 1

	Expeller-pressed canola meal diet		Expeller-pressed canola meal		
Item	AID, %	SEM	SID, %	SEM	SID content, % of DM
AA					
Ala	70.4	1.0	72.1	1.1	1.17
Arg	81.8	1.0	83.1	1.0	1.92
Asp	70.7	1.4	72.0	1.4	1.89
Cys	71.8	1.8	72.7	1.8	0.64
Glu	83.7	0.7	84.3	0.7	5.22
Gly	60.3	1.8	63.6	1.9	1.18
His	80.9	0.7	81.7	0.7	0.84
Ile	73.4	1.1	74.3	1.1	1.04
Leu	78.0	0.9	78.8	0.9	2.09
Lys	72.1	0.8	73.2	0.8	1.77
Met	83.4	0.7	83.9	0.7	0.52
Phe	77.1	1.0	78.0	1.0	1.18
Pro	47.4	8.3	57.2	9.6	0.77
Ser	69.3	1.1	70.6	1.0	1.00
Thr	66.2	1.3	67.6	1.2	1.04
Trp	83.0	1.1	83.9	1.1	0.39
Tyr	74.1	1.2	75.1	1.2	0.80
Val	69.4	1.0	70.5	1.0	1.34
Energy					
AID	72.9	0.7	61.0	3.5	—
Apparent total tract	85.1	0.2	75.0	1.9	—
DE, Mcal/kg of DM	—	—	—	—	3.77
NE,[2] Mcal/kg of DM	—	—	—	—	2.55

[1]Treatment means are based on 6 observations.
[2]Predicted using Eq. [4] (Noblet et al., 1994) using the analyzed nutrient and determined DE content.

indicating that EP canola meal contains valuable energy and AA. In Exp. 2, however, feeding EP canola meal reduced ADG and ADFI compared with feeding a diet based on soybean meal.

The nutritional value of EP canola meal may vary among samples globally. The EP canola meal used in the present study had a slightly greater CP (38.5 vs. 38.1%), a greater ether extract (13.3 vs. 10.3%), and a decreased crude fiber content (7.7 vs. 12.1%) on a DM basis compared with the EP canola meal in the Dutch database (Centraal Veevoederbureau, 2003). The amounts of CP, GE, and ether extract in EP canola meal used in the present study were similar to those of EP canola meal produced in Western Australia (Spragg and Mailer, 2007), whereas an Estonian study (Leming and Lember, 2005) reported less CP (36.1%) and ether extract (12.2%) and greater GE (5.14 Mcal/kg) on a DM basis. A Chinese EP canola meal contained 38.9% CP and 4.66 Mcal/kg of GE on a DM basis (Li et al., 2002). Combined, the greatest differences were observed in the content of energy-yielding substrates, residual oil, and CP, and therefore GE. Differences are most likely caused by the efficiency of oil extraction among expeller-pressing plants using various equipment and conditions, thereby altering the content of the remaining macronutrients (Leming and Lember, 2005).

The measured DE content of 3.77 Mcal/kg (DM basis) in the present study was 0.57 Mcal/kg greater than the DE content of 3.20 Mcal/kg (DM basis) included in the North American feedstuff tables (NRC, 1998) for solvent-extracted canola meal, but the DE content remained 0.15 Mcal/kg less than the DE content of 3.92 Mcal/kg (DM basis) for soybean meal. Previously, a DE content of 3.70 and 4.11 Mcal/kg (DM basis) was reported for EP canola meal (Mullan et al., 2000; Woyengo et al., 2009). The NE content of EP canola meal used in present study was predicted using the measured DE content and macronutrient composition (Noblet et al., 1994). The NE content of 2.55 Mcal/kg (DM basis) in EP canola meal was 0.81 and 0.34 Mcal/kg greater than the NE content of 1.74 and 2.21 Mcal/kg (DM basis) for solvent-extracted canola meal and soybean meal, respectively (Sauvant et al., 2004). These values indicate that EP canola meal, which contains more residual oil, has a greater energy value than solvent-extracted canola meal and soybean meal, mainly because energy digestibility of EP canola meal is identical to the value reported for soybean meal (Sauvant et al., 2004).

Table 6. Effect of feeding expeller-pressed canola meal on growth performance,[1] Exp. 2

	Expeller-pressed canola meal, %						*P*-value		
Item	0	7.5	15	22.5/18[2]	Decreasing[3]	SEM	Linear	Quadratic	Decreasing vs. 0%
BW, kg									
d 34	54.5	53.8	53.6	53.0	53.6	0.3	<0.001	0.833	<0.001
d 64	83.8	82.3	80.6	79.4	80.7	0.7	<0.001	0.812	<0.001
d 76	97.2	95.5	93.7	93.2	94.3	0.6	<0.001	0.902	0.001
d 90	109.8	108.3	106.7	106.1	108.0	0.7	<0.001	0.980	0.901
ADG, kg/d									
d 0 to 34	0.931	0.906	0.909	0.866	0.898	0.009	<0.001	0.199	0.008
d 35 to 64	1.042	1.017	0.945	0.915	0.944	0.026	<0.001	0.867	0.002
d 65 to 76	0.952	0.932	0.907	0.958	0.961	0.017	0.475	0.099	0.715
d 77 to 90	0.988	0.998	0.972	0.983	0.975	0.024	0.327	0.684	0.281
d 0 to 90	0.978	0.963	0.934	0.931	0.945	0.009	<0.001	0.010	0.201
ADFI, kg/d									
d 0 to 34	1.949	1.856	1.833	1.769	1.795	0.025	<0.001	0.421	0.001
d 35 to 64	2.829	2.725	2.552	2.432	2.558	0.047	<0.001	0.796	0.001
d 65 to 76	3.130	3.188	2.873	3.021	3.085	0.045	0.001	0.298	0.447
d 77 to 90	3.163	3.149	3.159	3.092	3.260	0.047	0.430	0.584	0.162
d 0 to 90	2.768	2.724	2.598	2.579	2.671	0.021	0.001	0.282	0.481
G:F									
d 0 to 34	0.478	0.487	0.494	0.491	0.499	0.006	0.045	0.173	0.001
d 35 to 64	0.369	0.375	0.370	0.378	0.369	0.005	0.163	0.816	1.000
d 65 to 76	0.306	0.295	0.317	0.320	0.311	0.006	0.038	0.036	0.530
d 77 to 90	0.312	0.318	0.309	0.321	0.301	0.007	0.767	0.890	0.684
d 0 to 90	0.366	0.369	0.373	0.378	0.370	0.003	0.007	0.482	0.153

[1]Treatment means are based on 10 pens.
[2]For d 0 to 34 and d 35 to 64, 22.5% expeller-pressed canola meal; for d 65 to 76 and d 77 to 90, 18% expeller-pressed canola meal.
[3]For d 0 to 34, d 35 to 64, d 65 to 76, and d 77 to 90, diets contained 22.5, 15, 7.5, and 0% expeller-pressed canola meal, respectively.

The EP canola meal is a supplemental protein feedstuff, and in the present study, its CP digestibility was 75.0%, identical to the 75.0% shown in the Dutch feedstuff tables (Centraal Veevoederbureau, 2003). The SID Lys content of 1.77% (DM basis) in EP canola meal was 0.03 and 1.06% less than the SID Lys content of solvent-extracted canola meal and soybean meal, respectively (NRC, 1998). In canola meal, the CP content is negatively correlated with residual oil content (Spragg and Mailer, 2007). Thus, the SID Lys content is less in EP canola meal because of its greater residual oil content. The SID Lys content of EP canola meal used in the present study was 0.32% (DM basis) greater than reported previously (Woyengo et al., 2009). Interestingly, 96% of Lys in EP canola meal was analyzed as available, and thus assumed to be chemically intact, indicating that steam conditioning followed by expelling did not heat damage Lys (Van Barneveld, 1994).

Formulating swine diets by using the NE and SID AA systems reduces the risks associated with including coproducts as alternative feedstuffs in swine diets (Zijlstra and Payne, 2007). In the present study, increasing the inclusion of EP canola meal reduced ADFI, which reduced ADG and slightly increased G:F. The reduced

Table 7. Effect of feeding expeller-pressed canola meal on carcass characteristics and days after d 90 required for pigs to reach slaughter weight,[1] Exp. 2

	Expeller-pressed canola meal, %						*P*-value		
Item	0	7.5	15	22.5/18[2]	Decreasing[3]	SEM	Linear	Quadratic	Decreasing vs. 0%
Carcass wt, kg	95.7	94.8	93.8	93.1	94.8	0.5	0.001	0.546	0.144
Backfat,[4] mm	20.6	20.4	19.5	19.8	20.2	0.3	0.007	0.983	0.293
Loin depth,[4] mm	63.5	63.2	63.1	62.3	63.0	0.5	0.109	0.535	0.431
Estimated lean,[4] %	59.9	60.0	60.4	60.2	60.1	0.2	0.025	0.832	0.325
d 90 to slaughter,[5] d	26.5	28.1	29.3	29.6	28.1	0.8	<0.001	0.630	0.056

[1]Treatment means are based on 10 pens.
[2]For d 0 to 34 and d 35 to 64, 22.5% expeller-pressed canola meal; for d 65 to 76 and d 77 to 90, 18% expeller-pressed canola meal.
[3]For d 0 to 34, d 35 to 64, d 65 to 76, and d 77 to 90, diets contained 22.5, 15, 7.5, and 0% expeller-pressed canola meal, respectively.
[4]Warm carcass weight was used as a covariate for statistical analyses.
[5]Pen average number of days from d 90 until slaughter.

Table 8. Effect of feeding expeller-pressed canola meal on jowl fat fatty acid profile and iodine value,[1] Exp. 2

	Expeller-pressed canola meal, %						*P*-value		
Variable	0	7.5	15	22/18[2]	Decreasing[3]	SEM	Linear	Quadratic	Decreasing vs. 0%
Fatty acid, %									
10:0 (capric)	0.10	0.09	0.08	0.08	0.08	0.01	0.410	0.750	0.660
12:0 (lauric)	0.09	0.09	0.08	0.08	0.08	0.04	0.703	0.865	0.421
14:0 (myristic)	1.45	1.40	1.34	1.30	1.35	0.02	0.600	0.280	0.160
16:0 (palmitic)	23.22	22.41	21.04	20.37	21.42	0.17	0.220	0.943	0.427
16:1 (palmitoleic)	2.73	2.57	2.45	2.29	2.52	0.07	0.300	0.970	0.700
18:0 (stearic)	9.78	9.36	8.38	8.27	8.85	0.20	0.625	0.801	0.817
18:1 (oleic)	3.39	3.43	3.58	3.55	3.53	0.05	0.333	0.461	0.349
18:2 (linoleic)	11.34	12.02	13.10	13.47	12.17	0.20	0.498	0.544	0.843
18:3 (α-linolenic)	0.72	1.02	1.41	1.60	1.23	0.02	0.176	0.861	0.495
20:0 (arachidic)	0.18	0.18	0.17	0.18	0.18	0.01	0.060	0.910	0.430
20:1 (gadoleic)	0.98	0.98	1.05	1.07	1.01	0.02	0.120	0.480	0.290
20:2 (dihomo-γ-linolenic)	0.55	0.55	0.59	0.59	0.54	0.01	0.670	0.690	0.700
20:3 (podocarpic)[4]	0.08	0.08	0.08	0.08	0.08	0.01	0.530	0.020	0.500
20:4 (arachidonic)	0.19	0.18	0.19	0.18	0.18	0.01	0.964	0.267	0.882
Iodine value	68.9	69.9	69.9	70.4	69.7	1.0	0.320	0.869	0.600

[1]Treatment means are based on 10 observations.
[2]For d 0 to 34 and d 35 to 64, 22.5% expeller-pressed canola meal; for d 65 to 76 and d 77 to 90, 18% expeller-pressed canola meal.
[3]For d 0 to 34, d 35 to 64, d 65 to 76, and d 77 to 90, diets contained 22.5, 15, 7.5, and 0% expeller-pressed canola meal, respectively.
[4]For 0, 7.5, 15, 22/18 expeller-pressed canola meal and the decreasing treatment, the mean podocarpic acid content was 0.079, 0.081, 0.083, 0.080, and 0.081%, respectively, with a pooled SEM of 0.002%.

ADFI could be due to differences in energy content, dietary macronutrient profile, or residual antinutritional factors (Nyachoti et al., 2004), such as glucosinolates, in EP canola meal. Calculated dietary energy content was maintained across diets; therefore, the dietary macronutrient profile and glucosinolates may explain the reduced ADFI. The content of ether extract was 2.8% (as-fed) greater for the diets containing 22.5 than 0% EP canola meal for d 0 to 34. Increased dietary fat may reduce ADFI of pigs (Azain, 2001), in part because pigs eat to meet their energy requirement (NRC, 1998); however, diets were formulated to an equal NE content in the present study. Extra dietary fat may also reduce feed intake directly (Rayner and Miller, 1993), although 6% added rapeseed oil did not reduce ADFI (Lauridsen et al., 1999). Therefore, dietary fat was likely not the cause for the reduced ADFI for pigs fed increased amounts of EP canola meal.

Glucosinolates are another factor in canola coproducts that may reduce performance (Lee et al., 1984). Feeding greater amounts of glucosinolates may reduce ADFI, enlarge the thyroid, reduce plasma thyroid hormones, and cause liver and kidney abnormalities and mortality (Bunting, 1981; Van Etten and Tookey, 1983; Schöne et al., 1997b). Depending on the nature of glucosinolates and the reaction conditions, isothiocyanates, oxazolidine-2-thiones, thiocyanates, or nitriles may be formed (Pusztai, 1989) that can impair growth performance. Although canola contains less glucosinolates than older rapeseed varieties, sufficient quantities of glucosinolates may remain after processing to cause reduced ADFI and ADG if fed to pigs for long periods, at increased amounts (Mullan et al., 2000), or both. Although pigs fed diets containing canola meal may reduce their growth performance (Bell et al., 1991), the exact cause is uncertain. For example, improper feed formulation (i.e., not based on NE and SID AA), the presence of glucosinolates, taste, or other factors in the diet, such as fiber, may reduce ADG (Bell, 1993). Considering the ether extract and glucosinolate data relative to the existing body of knowledge, the increased presence of glucosinolates was likely the main cause for reduced ADFI. Specifically, the content of total glucosinolates was 5.2 μmol/g greater in the diet containing 22.5% EP canola meal than in the control diet, and pigs may be able to tolerate only 2.5 μmol/g of dietary glucosinolates (Bell, 1993; Schöne et al., 1997a,b).

Pigs in the present study had an excellent growth performance. The ADG for d 0 to 90 was 0.931 kg/d with diets containing 22.5, reduced to 18%, EP canola meal, whereas ADG was 0.757 kg/d in an Australian study with 20% EP canola meal (Mullan et al., 2000). In the latter study, inclusion of 20% EP canola meal reduced ADG by 4.5% via both a reduced ADFI and G:F (Mullan et al., 2000), whereas reduced ADFI was the main cause for reduced ADG in the present study. In the present study, carcass weight was reduced with a similar BW at shipment for slaughter (data not shown), providing further evidence that diets containing coproducts had increased fiber, which reduced dressing percentage. Thus, market BW should be increased by up to 3 kg to account for the reduced dressing percentage in pigs fed EP canola meal.

Feeding high-fat diets to finisher pigs may reduce carcass lean and increase carcass fat (Overland et al., 1999). The dietary regimen that gradually decreased the inclusion of EP canola meal from 22.5 to 0% over the 4 growth periods provided more dietary fat during

the energy-dependent stage of growth and less fat during the energy-independent stage. None of the carcass characteristics was different between the decreasing amount of EP canola meal feeding and the soybean meal control regimen, indicating that initially feeding EP canola meal at increased amounts but then gradually decreasing the amount did counteract the potential negative effects of feeding high-fat diets on carcass and pork quality. The continued inclusion of EP canola meal throughout the study, however, reduced carcass weight, indicating that increased EP canola meal inclusion reduced carcass value. The iodine value of fat estimates the concentration of unsaturated fatty acids, and therefore indicates carcass fat quality (i.e., firmness; Eggert et al., 2001). We obtained a fat sample from the jowl because it has limited economic value and responds to changes in dietary fat similar to backfat (Benz et al., 2007). Feeding diets containing an unsaturated fat source can reduce the degree of saturation in pork fat (Whitney et al., 2006). Furthermore, diets high in fat (e.g., the EP canola meal diets) can inhibit de novo synthesis of fatty acids (Bee et al., 1999, 2002), thereby further altering the fatty acid profile. Adequately firm pork fat should have an iodine number below 70 (Lea et al., 1970), although more recently a threshold iodine value of 74 for North American pork has been suggested (Boyd, 1997). The iodine value of jowl fat from all feeding regimens was below 70 in the present study, indicating that feeding EP canola meal did not reduce fat quality.

Feeding pigs accounts for as much as 70% of variable costs of pork production (Payne and Zijlstra, 2007). Energy is the most expensive component in swine diets; therefore, accurate determination of energy content of feedstuffs is important (Zijlstra and Beltranena, 2007). In the present study, inclusion of up to 22.5%, reduced to 18%, EP canola meal linearly reduced feed cost per unit of BW gain (data not shown), indicating the importance of using alternative feedstuffs. Practically, however, an increase in net income can be achieved in swine operations only with sufficient space to overcome the reduced facility use attributable to reduced ADG.

In summary, EP canola meal is a source of DE and AA. The EP canola meal can be included in swine diets to reduce feed costs per unit of BW gain without affecting carcass and fat quality. However, 1% inclusion of EP canola meal may reduce ADG by 3 g/d. Therefore, inclusion of EP canola meal should be targeted to ensure an expected growth rate and to meet marketing strategy targets. Diets formulated to equal NE may still result in unequal ADG because of differences in ADFI most likely caused by excessive intake of glucosinolates. In conclusion, EP canola meal is a valuable feedstuff to consider in swine feed formulation. Finally, the amount of EP canola meal included in swine diets should be determined not only by targeting expected growth performance, but also by considering the animal flow and facility turnover rate of a particular farm.

LITERATURE CITED

Adeola, O. 2001. Digestion and balance techniques in pigs. Pages 903–916 in Swine Nutrition. A. J. Lewis and L. L. Southern, ed. CRC Press, New York, NY.

AOAC. 1990. Official Methods of Analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.

AOAC. 2006. Official Methods of Analysis. 18th ed. Assoc. Off. Anal. Chem., Arlington, VA.

AOCS. 1998. Recommended practice Cd 1c-85: Calculated iodine value. In Official Methods and Recommended Practices of the AOCS. 5th ed. Am. Oil. Chem. Soc., Champaign, IL.

Azain, M. 2001. Fat in swine nutrition. Pages 95–105 in Swine Nutrition. A. J. Lewis and L. L. Southern, ed. CRC Press, Boca Raton, FL.

Bee, G., S. Gebert, and R. Messikomer. 2002. Effect of dietary energy supply and fat source on the fatty acid pattern of adipose and lean tissues and lipogenesis in the pig. J. Anim. Sci. 80:1564–1574.

Bee, G., R. Messikommer, and S. Gebert. 1999. Dietary fats and energy levels differently affect lipogenic enzyme activity in finishing pigs. Fett/Lipid 101:336–342.

Bell, J. M. 1993. Factors affecting the nutritional value of canola meal: A review. Can. J. Anim. Sci. 73:679–697.

Bell, J. M., M. O. Keith, and D. S. Hutcheson. 1991. Nutritional value of very low glucosinolate canola meal. Can. J. Anim. Sci. 71:497–506.

Benz, J. M., M. D. Tokach, S. S. Dritz, J. L. Nelssen, J. M. DeRouchey, and R. D. Goodband. 2007. Effects of increasing added choice white grease in corn- and sorghum-based diets on growth performance and fat quality characteristics of finishing pigs. Pages 150–158 in Swine Day 2007. Kansas State Univ., Manhattan.

Boyd, R. D. 1997. Relationship between dietary fatty acid profile and body fat composition in growing pigs. PIC USA T&D Tech. Memo 153. Pig Improve. Co., Franklin, KY.

Brand, T. S., D. A. Brandt, and C. W. Cruywagen. 2001. Utilization of growing-finishing pig diets containing high levels of solvent or expeller oil extracted canola meal. N. Z. J. Agric. Res. 44:31–35.

Bunting, E. S. 1981. Production and Utilization of Protein in Oilseed Crops. Martinus Nijhoff, The Hague, the Netherlands.

Canadian Council on Animal Care. 1993. Guide to the Care and Use of Experimental Animals. 2nd ed. Vol. 1. Can. Counc. Anim. Care, Ottawa, Ontario, Canada.

Canadian Pork Council. 1994. National Pork Carcass Cutout Project (1992). Can. Pork Counc., Ottawa, Ontario, Canada.

Canola Council of Canada. 2009. Canola Meal Feed Industry Guide. 4th ed. Canola Counc. Canada, Winnipeg, Manitoba, Canada.

Centraal Veevoederbureau. 2003. The Livestock Feed Table. Centraal Veevoederbureau, Lelystad, the Netherlands.

Daun, J. K., and D. I. McGregor. 1981. Glucosinolate analysis of rapeseed (canola). Method of the Grain Research Laboratory. Can. Grain Comm., Winnipeg, Manitoba, Canada.

Eggert, J. M., M. A. Belury, A. Kempa-Steczko, S. E. Mills, and A. P. Schinckel. 2001. Effects of conjugated linoleic acid on the belly firmness and fatty acid composition of genetically lean pigs. J. Anim. Sci. 79:2866–2872.

Fenton, T. W., and M. Fenton. 1979. An improved procedure for the determination of chromic oxide in feed and feces. Can. J. Anim. Sci. 59:631–634.

Heaney, R. K., and G. R. Fenwick. 1980. The analysis of glucosinolates in *Brassica* species using gas chromatography. Direct determination of the thiocyanate ion precursors, glucosbrassicin and neoglucobrassicin. J. Sci. Food Agric. 31:593–599.

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

Lauridsen, C., S. Højsgaard, and M. T. Sørensen. 1999. Influence of dietary rapeseed oil, vitamin E, and copper on the performance

and the antioxidative and oxidative status of pigs. J. Anim. Sci. 77:906–916.

Lea, C. H., P. A. T. Swoboda, and D. P. Gatherum. 1970. A chemical study of soft fat in crossbred pigs. J. Agric. Sci. Camb. 74:1–11.

Lee, P. A., S. Pittam, and R. Hill. 1984. The voluntary food intake by growing pigs of diets containing 'treated' rapeseed meals or extracts of rapeseed meal. Br. J. Nutr. 52:159–164.

Leming, R., and A. Lember. 2005. Chemical composition of expeller-extracted and cold-pressed canola meal. Agraarteadus 16:103–109.

Li, D., X. Pengbin, G. Liming, F. Shijun, and H. Canghai. 2002. Determination of apparent ileal amino acid digestibility in rapeseed meal and cake processed at different temperatures using the direct and difference method with growing pigs. Arch. Anim. Nutr. 56:339–349.

Mullan, B. P., J. R. Pluske, J. Allen, and D. J. Harris. 2000. Evaluation of Western Australian canola meal for growing pigs. Aust. J. Agric. Res. 51:547–553.

Noblet, J., H. Fortune, X. S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72:344–354.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Nyachoti, C. M., R. T. Zijlstra, C. F. M. de Lange, and J. F. Patience. 2004. Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions. Can. J. Anim. Sci. 84:549–566.

Overland, M., K. A. Rorvik, and A. Skrede. 1999. Effect of trimethylamine oxide and betaine in swine diets on growth performance, carcass characteristics, nutrient digestibility, and sensory quality of pork. J. Anim. Sci. 77:2143–2153.

Payne, L. R., and R. T. Zijlstra. 2007. A guide to application of net energy in swine feed formulation. Pages 159–165 in Advances in Pork Production, Proc. Banff Pork Semin. Vol. 18. R. O. Ball and R. T. Zijlstra, ed. Univ. Alberta, Edmonton, Alberta, Canada.

Pusztai, A. 1989. Biological effects of dietary lectins. Pages 17–29 in Recent Advances of Research in Antinutritional Factors in Legume Seeds. J. Huisman, T. F. B. van der Poel, and I. E. Liener, ed. Pudoc, Wageningen, the Netherlands.

Raymer, L. P. 2002. Canola: An emerging oilseed crop. Pages 122–126 in Trends in New Crops and New Uses. J. Janick, and A. Whikey, ed. ASHS Press, Alexandria, VA.

Rayner, D. V., and S. Miller. 1993. Voluntary intake and gastric emptying in pigs: Effects of fat and a CCK inhibitor. Physiol. Behav. 54:917–922.

Rowghani, E., M. Arab, S. Nazifi, and Z. Bakhtiari. 2007. Effect of canola oil on cholesterol and fatty acid composition of egg-yolk of laying hens. Int. J. Poult. Sci. 6:111–114.

Sauvant, D., J.-M. Perez, and G. Tran. 2004. Tables of Composition and Nutritional Value of Feed Materials: Pigs, Poultry, Cattle, Sheep, Goats, Rabbits, Horses, Fish. 2nd ed. Wageningen Academic Publishers, Wageningen, the Netherlands, and INRA, Paris, France.

Schöne, F., B. Groppel, A. Hennig, G. Jahreis, and R. Lange. 1997a. Rapeseed meal, methimazole, thiocyanate and iodine affect growth and thyroid. Investigations into glucosinolate tolerance in the pig. J. Sci. Food Agric. 74:69–80.

Schöne, F., B. Rudolph, U. Kirchheim, and G. Knapp. 1997b. Counteracting the negative effects of rapeseed and rapeseed press cake in pig diets. Br. J. Nutr. 78:947–962.

Smulikowska, S., A. Mieczkowska, J. Czerwiński, D. Weremko, and C. V. Nguyen. 2006. Effects of exogenous phytase in chickens fed diets with differently processed rapeseed expeller cakes. J. Anim. Feed Sci. 15:237–252.

Smulikowska, S., B. Pastuszewska, A. Mieczkowska, and A. Ochtabińska. 1997. Chemical composition, energy value for chickens, and protein utilization in rats of rapeseed expeller cakes produced by different pressing technologies. J. Anim. Feed Sci. 6:109–121.

Spragg, J., and R. Mailer. 2007. Canola meal value chain quality improvement. A final report prepared for AOF and Pork CRC. JCS Solutions Pty Ltd., Victoria, Australia.

Stein, H. H., M. L. Gibson, C. Pedersen, and M. G. Boersma. 2006. Amino acid and energy digestibility in ten samples of distillers dried grain with solubles fed to growing pigs. J. Anim. Sci. 84:853–860.

Stein, H. H., B. Sève, M. F. Fuller, P. J. Moughan, and C. F. M. de Lange. 2007. Invited review: Amino acid bioavailability and digestibility in pig feed ingredients: Terminology and application. J. Anim. Sci. 85:172–180.

Van Barneveld, R. J., E. S. Batterham, and B. W. Norton. 1994. The effect of heat on amino acids for growing pigs. 1. A comparison of ileal and faecal digestibilities of amino acids in raw and heat-treated field peas (*Pisum sativum* cultivar Dundale). Br. J. Nutr. 72:221–241.

Van Etten, C. H., and H. L. Tookey. 1983. Glucosinolates. Pages 15–30 in Handbook of Naturally Occurring Food Toxicants. M. Rechcigl Jr., ed. CRC Press, Boca Raton, FL.

van Kleef, D. J., K. Deuring, and P. van Leeuwen. 1994. A new method of faeces collection in the pig. Lab. Anim. 28:78–79.

Whitney, M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356–3363.

Woyengo, T. A., E. Kiarie, and C. M. Nyachoti. 2009. Energy and amino acid utilization in expeller-extracted canola fed to growing pigs. J. Anim. Sci. 87 (E-Suppl. 2):183. (Abstr.)

Zijlstra, R. T., and E. Beltranena. 2007. Latest developments in alternative feedstuffs for pigs. Pages 167–172 in Proc. Manitoba Swine Semin. Vol. 21. I. Seddon, ed. Manitoba Swine Semin. Comm., Winnpeg, Manitoba, Canada.

Zijlstra, R. T., and R. L. Payne. 2007. Net energy system for pigs. Pages 80–90 in Manipulating Pig Production XI. J. E. Patterson and J. A. Barker, ed. Australas. Pig Sci. Assoc., Werribee, Victoria, Australia.