Effects of diet energy concentration and an exogenous carbohydrase on growth performance of weanling pigs fed diets containing canola meal produced from high protein or conventional canola seeds

T. F. Pedersen,*[1] Y. Liu,† and H. H. Stein*‡[2]

*Department of Animal Sciences, University of Illinois, Urbana 61801; †Department of Animal Science, University of California, Davis 95616; and ‡Division of Nutritional Sciences, University of Illinois, Urbana 61801.

ABSTRACT: The objectives were to determine effects of diet NE and an exogenous carbohydrase on growth performance and physiological parameters of weanling pigs fed a corn-soybean meal (SBM) diet or diets containing high protein canola meal (CM-HP) or conventional canola meal (CM-CV). A total of 492 pigs (initial BW: 9.15 ± 0.06 kg) were used in a randomized complete block design with 12 dietary treatments and 9 pens per treatment. A control diet based on corn and SBM and 4 diets containing 20% or 30% CM-HP or 20% or 30% CM-CV were formulated to a similar NE by adjusting inclusion of choice white grease. Four additional diets also contained 20% or 30% CM-HP or 20% or 30% CM-CV, but no additional choice white grease, and NE in these diets, therefore, was less than in the control diet. The control diet and the diets containing 30% CM-HP or CM-CV without increased choice white grease were also formulated with inclusion of an exogenous carbohydrase. Pigs were fed experimental diets for 22 d and 1 pig per pen was sacrificed at the conclusion of the experiment. Results indicated that compared with the control diet, there was no impact of canola meal on final BW, ADG, ADFI, or G:F, but pigs fed CM-CV had greater ($P < 0.05$) final BW, ADG, and ADFI than pigs fed CM-HP, and pigs fed diets with reduced NE had greater ($P < 0.05$) ADG and ADFI than pigs fed diets with constant NE. Only minor effects of CM-HP or CM-CV on intestinal weight, gut fill, digesta pH, cecal VFA concentrations, and serum concentrations of urea N, total N, or albumin were observed, but the weight of the thyroid gland increased ($P < 0.05$) as the concentration of dietary canola meal increased. Serum concentrations of IgG were reduced if canola meal was included in the diets without the carbohydrase, but that was not the case if the carbohydrase was included in the diet (interaction, ($P < 0.05$). In conclusion, up to 30% CM-HP or CM-CV in diets fed to weanling pigs from 2 wk postweaning did not impact growth performance cosmpared with pigs fed a corn-SBM diet, and NE in diets containing canola meal does not have to be similar to that of corn-SBM diets. However, inclusion of CM-CV containing 4.43 μmol/g glucosinolates in the diets resulted in improved growth performance compared with inclusion of CM-HP containing 12.60 μmol/g glucosinolates.

Key words: canola meal, high-protein canola meal, immune response, intestinal morphology, pigs, thyroid gland

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INTRODUCTION

Inclusion of canola meal (**CM**) in diets fed to weanling pigs has resulted in reduced growth performance (Baidoo et al., 1986; 1987; McIntosh et al., 1986; Landero et al., 2013), which has been assumed to be a result of the greater fiber concentration in CM than in soybean meal (**SBM)** or a result of the presence of glucosinolates in CM. It has, however, been suggested that if diets containing CM are formulated based on NE and standardized ileal digestibility (**SID**) of AA, inclusion levels of up to 20% may be used in diets for weanling pigs without negatively impacting pig performance (Landero et al., 2011; Sanjayan et al., 2014). However, new varieties of

[1]Current address: Aarhus University, 8000 Aarhus C, Denmark.
[2]Corresponding author: hstein@illinois.edu
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Table 1. Ingredient composition of experimental diets (as-fed basis)

	Diet											
	Constant NE					Reduced NE				Carbohydrase		
	Control	CM-HP		CM-CV		CM-HP		CM-CV		Control	CM-HP	CM-CV
Ingredient, %	0%	20%	30%	20%	30%	20%	30%	20%	30%	0%	30%	30%
Ground corn	53.68	51.72	51.26	46.02	41.57	52.82	52.87	48.22	44.97	53.68	52.87	44.97
CM-HP[1]	–	20.00	30.00	–	–	20.00	30.00	–	–	–	30.00	–
CM-CV[1]	–	–	–	20.00	30.00	–	–	20.00	30.00	–	–	30.00
Whey powder	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Soybean meal, 47.5% CP	29.00	10.00	–	15.00	8.50	10.00	–	15.00	8.50	29.00	–	8.50
Fish meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Choice white grease	1.00	2.10	2.60	3.20	4.40	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Phytase premix[2]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	–	–	–
Ground limestone	1.30	1.10	1.00	0.70	0.43	1.10	1.00	0.70	0.43	1.30	1.00	0.43
L-lysine HCL, 78% Lys	0.28	0.39	0.45	0.37	0.40	0.39	0.45	0.37	0.40	0.28	0.45	0.40
DL-Met	0.08	0.02	–	0.04	0.03	0.02	–	0.04	0.03	0.08	–	0.03
L-Thr	0.06	0.07	0.09	0.07	0.07	0.07	0.08	0.07	0.07	0.06	0.08	0.07
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Carbohydrase premix[3]	–	–	–	–	–	–	–	–	–	0.50	0.50	0.50
Titanium dioxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[4]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]The phytase premix (Optiphos, Huvepharma, Sofia, Bulgaria) provided 500 units of phytase per kilogram of complete diet.

[3]The carbohydrase premix (Hemicell; Elanco, Indianapolis, IN) provided 2000 units of mannanase per kilogram of complete diet and 500 units of microbial phytase (Optiphos, Huvepharma, Sofia, Bulgaria) per kilogram of complete diet.

[4]The vitamin- mineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

high-protein canola have been developed, resulting in production of high protein CM (**CM-HP**) containing 43% to 47% CP (Liu et al., 2014; 2016; Berrocoso et al., 2015). High protein CM contains less fiber than conventional CM (**CM-CV**), which makes CM-HP a possible alternative to SBM (Berrocoso et al., 2015; Little et al., 2015; Parr et al., 2015). Results of a recent experiment indicated that there were no negative effects on growth performance of inclusion of up to 40% CM-HP or CM-CV in diets for weanling pigs (Parr et al., 2015). However, energy levels in all diets were balanced by adding fat to CM diets to compensate for the reduced NE in CM compared with SBM, but the effect of including CM-HP in diets without adjusting to a constant NE has not been investigated. It is also possible that pigs can utilize the fiber in canola meal better if exogenous carbohydrases are added to the diet.

Therefore, the present experiment was conducted to test the hypothesis that inclusion of 20% or 30% CM-HP or CM-CV will not affect growth performance regardless of whether or not NE in the diets is equalized and that addition of a carbohydrase to the diet may improve the nutritional value of CM.

MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Pigs used in the experiment were the offspring of L-359 boars that were mated to C-46 females (Pig Improvement Company, Hendersonville, TN).

Diets and Animals

A control diet based on corn and soybean meal was formulated to meet requirements for all nutrients for weanling pigs (NRC, 2012; Tables 1 and 2). Two diets containing 20% or 30% CM-HP and 2 diets containing 20% or 30% CM-CV were also formulated. The NE concentrations in these diets were maintained at the same level as that of the control diet by adding increasing quantities of choice white grease as the concentration of CM increased in the diets. The concentration of DE in CM-HP, CM-CV, and SBM were estimated from data published by Berrocoso et al. (2015) and NE of all ingredients was calculated according to NRC (2012). Four additional diets containing 20 or 30%

Table 2. Energy and nutrient concentration in experimental diets (as-fed basis)[1]

	Diet											
	Constant NE					Reduced NE				Carbohydrase		
	Control	CM-HP		CM-CV		CM-HP		CM-CV		Control	CM-HP	CM-CV
Item	0%	20%	30%	20%	30%	20%	30%	20%	30%	0%	30%	30%
GE, kcal/kg	3839	3988	4039	4073	4167	3926	3888	3911	3955	3888	3822	3918
NE, kcal/kg[2]	2452	2452	2452	2452	2452	2402	2380	2352	2299	2452	2380	2299
DM, %	89.06	90.33	90.95	89.78	89.99	89.79	90.36	89.24	89.80	88.94	87.96	88.53
CP, %	21.42	19.35	19.48	20.05	21.69	21.41	18.49	19.83	21.38	19.89	19.22	19.73
Ash, %	5.41	5.96	5.78	6.11	6.00	6.13	5.77	6.35	6.10	6.22	5.82	6.08
AEE[3], %	3.84	5.05	4.98	6.62	8.01	4.48	3.39	3.96	3.10	2.91	3.68	3.08
NDF, %	7.52	12.32	12.88	12.63	13.06	10.64	13.15	11.90	13.29	8.32	13.34	14.45
ADF, %	5.92	8.68	9.63	9.19	10.85	7.94	8.77	8.76	11.15	4.84	9.24	9.22
Lignin, %	0.96	2.18	2.82	2.56	3.77	2.12	2.29	2.54	4.10	0.86	2.43	3.33
Ca, %	0.67	0.68	0.76	0.60	0.61	0.68	0.74	0.58	0.60	0.69	0.67	0.60
P, %	0.45	0.50	0.50	0.51	0.54	0.46	0.46	0.50	0.57	0.42	0.46	0.54
Phytase, FTU[4]	650	1000	810	590	530	600	530	600	890	790	800	700
Indispensable AA, %												
Arg	1.28	1.07	0.98	1.13	1.14	1.11	0.96	1.13	1.07	1.19	0.97	1.18
His	0.49	0.47	0.46	0.47	0.50	0.49	0.46	0.48	0.47	0.46	0.46	0.51
Ile	0.75	0.67	0.67	0.72	0.72	0.69	0.63	0.67	0.73	0.73	0.63	0.74
Leu	1.65	1.51	1.47	1.56	1.58	1.58	1.48	1.56	1.56	1.60	1.46	1.64
Lys	1.36	1.34	1.37	1.34	1.53	1.50	1.25	1.40	1.39	1.29	1.33	1.47
Met	0.36	0.37	0.36	0.36	0.39	0.35	0.35	0.35	0.40	0.34	0.36	0.39
Phe	0.88	0.75	0.75	0.85	0.86	0.83	0.75	0.83	0.84	0.85	0.75	0.89
Thr	0.84	0.85	0.85	0.87	0.89	0.84	0.83	0.86	0.83	0.77	0.80	0.92
Trp	0.26	0.26	0.26	0.26	0.28	0.27	0.25	0.25	0.27	0.25	0.24	0.26
Val	0.80	0.78	0.78	0.80	0.85	0.82	0.77	0.81	0.80	0.75	0.78	0.87
Dispensable AA, %												
Ala	1.01	0.98	0.94	0.98	1.00	1.00	0.95	1.00	0.97	0.94	0.95	1.05
Asp	2.00	1.56	1.35	1.68	1.66	1.62	1.35	1.70	1.55	1.90	1.34	1.70
Cys	0.27	0.37	0.40	0.34	0.39	0.37	0.40	0.33	0.36	0.27	0.40	0.36
Glu	3.43	3.12	3.03	3.21	3.29	3.28	3.04	3.26	3.16	3.25	3.03	3.45
Gly	0.88	0.88	0.88	0.88	0.95	0.91	0.87	0.90	0.88	0.77	0.88	0.99
Pro	1.21	1.27	1.30	1.19	1.31	1.33	1.31	1.25	1.21	1.09	1.25	1.37
Ser	0.91	0.78	0.73	0.82	0.82	0.80	0.73	0.83	0.78	0.82	0.72	0.87
Tyr	0.70	0.59	0.59	0.66	0.66	0.64	0.58	0.63	0.65	0.67	0.58	0.67
Total AA	19.08	17.62	17.17	18.12	18.82	18.43	16.96	18.24	17.92	17.94	16.93	19.33

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]Values for NE were calculated, but all other values were analyzed.

[3]AEE = acid hydrolyzed ether extract.

[4]FTU = phytase units.

CM-HP or 20 or 30% CM-CV were also formulated, but additional choice white grease was not added to these diets, and the NE was, therefore, allowed to be reduced as CM inclusion increased. Three additional diets that were similar to the control diets and the diets containing 30% CM-HP or 30% CM-CV without extra choice white grease were also formulated, but an exogenous carbohydrase (Hemicell; Elanco, Indianapolis, IN) was added to these diets to provide 2,000 units of mannanase per kilogram of complete feed.

A total of 492 pigs with an initial BW of 9.15 ± 0.06 kg were used in a completely randomized block design, with weaning date being the blocking factor. All pigs had been weaned for 14 d at the start of the experiment. There were 3 blocks with 2 replicates and 1 block with 3 replicates and there were 4, 5, or 6 pigs per pen depending on pig availability. The number of female and castrated male pigs in each pen also varied according to availability, but within each replicate, the number of pigs per pen and the distribution between female and male pigs were constant. Pens were 1.2 × 1.4 m and each pen was equipped with a feeder, a nipple drinker, and a fully slatted floor. Feed was provided on an ad libitum basis during the 22-d experiment. Water was available at all times.

Data Recordings and Sample Collections

The BW of pigs was recorded at the start and conclusion of the experiment and daily feed allotments were also recorded. At the conclusion of the experiment, 2 blood samples were drawn from the female pig from each pen that had a BW closest to the pen average by jugular vena puncture into 10 mL lithium heparinized tubes (BD vacutainers, Franklin Lakes, NJ) and placed on ice. Blood samples were centrifuged at 1,500 × *g* at 4°C for 15 min to obtain serum. Serum samples were then stored at -20°C until analysis. The pigs that were chosen for blood sampling were then sacrificed by captive bolt penetration and exsanguination. The intestinal tract from the start of the duodenum to the end of the rectum was removed and the weight of the full digestive tract was recorded. The thyroid gland was also removed and the weight was recorded. Samples of intestinal tissue were collected for histological analysis in segments of 3 cm from the middle of the duodenum, jejunum, and colon and fixed in 10% neutral buffered formalin until histological analysis. After collection, each sample was cut in 2–3 mm thick cross-sections and embedded in paraffin for slide preparation. Slides were scanned using a 2.0-HT NanoZoomer (Hamamatsu, Bridgewater, NJ), and the villus height and crypt depth were measured by NDP.View2. For each sample, 8 to 12 villus and associated crypts were measured. The villus height was measured from the villus tip to the crypt mouth and the crypts were measured from the crypt mouth to the top of the crypt valley.

The pH was determined in contents from the ileum, cecum, and colon using a pH 110 m (Oakton Instruments, Vernon Hills, IL), and cecal contents were collected and preserved in 2 *M* HCl (ratio 1:1) for VFA analysis. Fecal samples were oven dried and analyzed for Ti and GE. After sampling, the intestines were flushed with water and the weight of the empty intestinal tract was recorded.

Chemical Analysis

All diets, ingredients, and ileal and fecal samples were analyzed for GE using bomb calorimetry (Model 6300; Parr Instruments, Moline, IL). Benzoic acid was used as the standard for calibration. Diets and ingredients were analyzed for DM after drying for 2 h at 135°C in a forced-air oven (method 930.15; AOAC, 2007), and for ash (method 942.05; AOAC, 2007). All diets and ingredients were also analyzed for N using the combustion procedure (method 990.03; AOAC, 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Aspartic acid was used as a calibration standard and CP was calculated as N × 6.25. Diets and ingredients were also analyzed for ADF and NDF using Ankom Technology methods 12 and 13, respectively (Ankom 2000; Ankom Technology, Macedon, NY). After ADF analysis, acid detergent lignin was determined using Ankom Technology method 9 (Ankom Daisy^{II} Incubator; Ankom Technology, Macedon, NY). Diet and ingredient samples were also analyzed for Ca and P using inductively coupled plasma spectroscopy (method 985.01 A, B, and C; AOAC, 2007) after wet ash sample preparation (method 975.03 B [b]; AOAC, 2007). All diets and ingredients were analyzed for AA on a Hitachi Amino Acid Analyzer, Model L8800 (Hitachi High Technologies America, Inc., Pleasanton, CA) using ninhydrin for postcolum derivatization and norleucine as the internal standard (method 982.30 E [a, b, and c]; AOAC, 2007). Ingredients were also analyzed for phytic acid (Ellis et al., 1977), and all diets were analyzed for phytase activity (Phytex Method, Version 1; Eurofins, Des Moines, IA). The concentration of Ti in diets and fecal samples were measured following the procedure of Myers et al. (2004). Glucosinolates were analyzed in both sources of CM by high-performance liquid chromatography as described by Lee et al. (2008). Serum samples were analyzed for blood urea nitrogen (**BUN**), total protein, and albumin using a Beckman-Coulter AU680 analyzer (Beckman Coulter, Inc., Danvers, MA). The concentration of IgG in serum was measured using a sandwich ELISA kit according to the manufacturer's instructions (Bethyl Laboratories, Inc., Montgomery, TX).

All cecal digesta samples were analyzed for VFA by gas chromatography according to Erwin et al. (1961), using a gas chromatograph (Hewlett-Packard 5890A Series II, Palo Alto, CA) and a glass column (180 cm × 4 mm i.d.) packed with 10% SP-1200/1% H_3PO_4 on 80/100 + mesh Chomosorb WAW (Supelco Inc., Bellefonte, PA). Nitrogen was the carrier gas with a flow rate of 75 mL/min. Oven, detector, and injector temperatures were 125, 175, and 180°C, respectively.

Analyses for AA, Ca, P, and Ti were conducted at the Experiment Station Chemical Laboratory, University of Missouri, Columbus, MO, and analyses for phytic acid and phytase were conducted by Eurofins Scientific Inc., Nutritional Analysis Center, Des Moines, IA. Glucosinolates in the 2 sources of canola meal were analyzed by Dow AgroSciences LLC, Indianapolis, IN, and all other analyses were conducted in the Stein Monogastric Nutrition Laboratory at the University of IL, Urbana.

Calculations and Statistical Analyses

At the conclusion of the experiment, ADG, ADFI, and G:F were calculated for each pen and summarized within treatment. The full and empty intestinal weight

Table 3. Composition of ingredients (as-fed basis)[1]

Item	CM-HP	CM-CV	SBM	Corn	Whey powder	Fish meal
GE, kcal/kg	4467	4196	4247	3822	3605	4272
DE, kcal/kg[2]	3312	2789	3619	3451	3494	3958
ME, kcal/kg[2]	2893	2492	3294	3395	3415	3528
NE, kcal/kg[2]	1893	1692	2087	2672	2704	2351
DM, %	90.96	87.46	88.65	85.55	91.78	90.64
CP, %	43.24	36.03	47.53	7.02	11.93	60.65
Ash, %	5.90	7.30	7.83	1.58	7.64	20.75
AEE[3], %	2.36	2.96	2.10	4.60	0.50	8.06
NDF, %	26.37	27.64	6.87	12.00	0.18	16.81
ADF, %	18.81	21.65	6.50	4.37	0.14	5.33
Lignin	6.31	8.53	0.40	0.62	0.09	2.71
Ca, %	0.44	0.64	0.28	0.01	0.52	5.88
P, %	0.82	0.89	0.57	0.28	0.60	3.00
Phytic acid, %	2.55	2.74	1.73	0.98	–	–
Indispensable AA, %						
Arg	2.38	1.96	3.44	0.33	0.25	3.50
His	1.05	0.85	1.17	0.17	0.18	1.30
Ile	1.38	1.18	1.87	0.22	0.62	2.08
Leu	2.83	2.39	3.51	0.72	1.09	4.12
Lys	2.35	1.88	2.90	0.27	1.00	4.48
Met	0.82	0.65	0.63	0.12	0.16	1.68
Phe	1.61	1.40	2.20	0.31	0.35	2.33
Thr	1.71	1.44	1.79	0.24	0.68	2.45
Trp	0.56	0.45	0.67	0.06	0.22	0.63
Val	1.77	1.46	1.85	0.27	0.51	2.37
Dispensable AA, %						
Ala	1.81	1.54	1.99	0.48	0.53	3.62
Asp	2.91	2.39	5.30	0.49	1.12	5.40
Cys	1.02	0.78	0.59	0.15	0.23	0.48
Glu	6.84	5.76	8.32	1.11	1.86	7.56
Gly	2.04	1.70	1.97	0.29	0.23	4.17
Pro	2.75	2.27	2.55	0.60	0.67	2.93
Ser	1.63	1.46	2.20	0.31	0.49	2.28
Tyr	1.18	1.05	1.72	0.25	0.32	1.83

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal; SBM = soybean meal.

[2]Values for DE, ME, and NE were calculated; all other values were analyzed.

[3]AEE = acid hydrolyzed ether extract.

and the thyroid gland weight were calculated according to BW by dividing full and empty weight and thyroid gland weight by BW. The concentration of IgG in serum samples was calculated by multiplying the absorbance with the dilution ratio.

Apparent total tract digestibility (**ATTD**) of energy was calculated using the following equation, which was adopted from Stein et al. (2007):

$$\text{ATTD} = \left(1 - \left(\frac{GE_{Fecal}}{GE_{Diet}}\right) \times \left(\frac{Marker_{Diet}}{Marker_{Fecal}}\right)\right) \times 100$$

Table 4. Analyzed concentration of glucosinolates in canola meal (as-fed basis)[1]

Item	CM-HP	CM-CV
Glucosinolates, μmol/g		
Progoitrin	4.29	0.85
Glucoalyssin	0.69	0.39
Gluconapoleiferin	0.00	0.00
Gluconapin	1.81	0.38
4-hydroxyglucobrassicin	2.48	0.62
Glucbrassicanapin	0.15	0.07
Glucoerucin	2.14	1.43
Glucobrassicin	0.19	0.06
Gluconasturtiin	–	0.58
Neoglucobrassicin	0.85	0.06
Total Glucosinolates	12.60	4.43

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

Normality of data was verified and outliers were tested using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC); outliers were identified as values that deviated from the treatment mean by more than 3 times the interquartile range. Data were separately analyzed by ANOVA using the Proc MIXED of SAS. The first statistical model included canola meal type (CM-HP vs. CM-CV), canola meal diet concentration (20% vs. 30%), energy concentration (constant energy vs. reduced energy), and all possible interactions as fixed effects and block and replicate within block as the random effects. The second statistical model included diet (control vs. 30% CM-HP vs. 30% CM-CV), carbohydrase level (without or with carbohydrase), and their interactions as fixed effects and block and replicate within block as the random effects. Pen was the experimental unit for all analyses. In each model, treatment means were calculated using the LSMEANS statement and means were separated using the PDIFF option of PROC MIXED. Significance and tendency were considered at $P < 0.05$ and $0.05 \leq P < 0.10$, respectively.

RESULTS

Composition of Ingredients and Diets

The chemical composition of ingredients (Table 3) was in agreement with expected values. The GE concentration was 4,467 in CM-HP and 4,196 in CM-CV; CP was 43.24% in CM-HP and 36.03% in CM-CV. Concentrations of ADF and NDF were 18.01% and 26.37% in CM-HP and 21.65 and 27.64% in CM-CV. The concentration of total glucosinolates in CM-CV and CM-HP was 4.43% and 12.60 mmol/g, respectively (Table 4). The concentration of energy and nutrients in all diets was in agreement with formulated values.

Table 5. Growth performance of weanling pigs fed diets containing 2 sources of canola meal with constant or reduced energy level[1]

	Constant NE				Reduced NE					*P*-values		
Item[2]	CM-HP, 20%	CM-HP, 30%	CM-CV, 20%	CM-CV, 30%	CM-HP, 20%	CM-HP, 30%	CM-CV, 20%	CM-CV, 30%	Pooled SEM	CM level	CM type	Energy level
Initial BW, kg	8.97	9.02	9.04	9.02	8.92	9.06	8.96	9.07	0.360	0.715	0.887	0.983
Final BW, kg	18.89	18.91	20.06	19.91	19.56	19.41	20.31	20.40	0.693	0.897	0.012	0.209
ADG, kg	0.453	0.446	0.502	0.496	0.495	0.472	0.517	0.514	0.019	0.365	< 0.01	0.021
ADFI, kg	0.722	0.721	0.779	0.738	0.769	0.767	0.800	0.817	0.033	0.700	0.036	< 0.01
Gain:Feed	0.633	0.624	0.648	0.674	0.651	0.620	0.648	0.635	0.035	0.580	0.101	0.580

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]No interactions were observed for CM level × CM type, CM level × energy level, CM type × energy level, or CM level × CM type × energy level.

Growth Performance

A total of 5 pigs were removed from the experiment. Four pigs from the second block died from fibrinous peritonitis on d 2 or 3 of the experiment and one pig in block 3 died because of a rectum prolapse on d 19. The death of these pigs was not considered related to the experimental treatments and no further diseases were recorded.

There were no significant interactions for any of the growth performance parameters (Table 5). Initial and final BW was not influenced by concentration of CM in the diets or by dietary energy concentration, but pigs fed the CM-CV diets had greater ($P < 0.05$) final BW than pigs fed diets containing CM-HP. There was no impact of CM concentration in diets for ADG, ADFI, or G:F, but pigs fed CM-CV had greater ($P < 0.05$) ADG and ADFI than pigs fed diets containing CM-HP. Pigs fed diets with reduced NE also had greater ($P < 0.05$) ADG and ADFI than pigs fed diets with constant NE.

There were no diet × carbohydrase interactions observed and there were no effects of the carbohydrase on initial or final BW of pigs (Table 6). There were also no effects of carbohydrase addition on ADG, ADFI, or G:F. The ADG for pigs fed the CM-CV diet was greater ($P < 0.05$) than ADG for pigs fed the CM-HP diets, but was not different from the ADG of pigs fed the control diets. There were no differences in ADFI and G:F among CM-CV, CM-HP, and control diets.

Intestinal Tract and Thyroid Gland

There were no interactions among CM type, CM level, and dietary energy concentration for full intestine percentage, empty intestine weight, and gut fill weight and percentage (Table 7). However, increasing the concentration of CM in the diets reduced ($P < 0.05$) the weight of the empty intestines of pigs. Reducing diet NE increased ($P < 0.05$) gut fill and tended ($P = 0.099$) to increase gut fill as percentage of BW. The full intestine weight was greater ($P < 0.05$) in pigs fed 30% CM-CV than pigs fed 30% CM-HP with constant NE, but no difference was observed among diets with reduced NE (interaction, $P < 0.05$). Pigs fed diets containing 30% CM-HP or 20% CM-CV had greater ($P < 0.05$) empty intestine as percentage of live BW compared with pigs fed 30% CM-CV if diets with constant NE were provided, but this was not the case with the reduced NE (interaction, $P < 0.05$). Pigs fed 20% CM-CV had heavier ($P < 0.05$) thyroid gland (% of live BW) compared with pigs fed 30% CM-CV or 20% CM-HP if NE was constant, but no differences were observed in thyroid gland weight among diets if NE was not kept constant (interaction, $P < 0.05$).

There were no interactions among diet type and enzyme supplementation for full intestine and empty intestine (Table 8). Gut fill of pigs fed the 30% CM-HP diet was greater ($P < 0.05$) than for pigs fed the control diet if no carbohydrase was used, but that was not the case if the carbohydrase was added to the diet (interaction, $P < 0.05$). Likewise, gut fill calculated as

Table 6. Growth performance of weanling pigs fed diets containing 2 sources of canola meal without or with addition of a carbohydrase[1]

	Without carbohydrase			With carbohydrase			Pooled	*P*-values		
Item	Control	CM-HP, 30%	CM-CV, 30%	Control	CM-HP, 30%	CM-CV, 30%	SEM	Diet	Carbohydrase	Diet × carbohydrase
Initial BW, kg	8.97	9.06	9.07	9.02	9.02	9.01	0.368	0.978	0.940	0.979
Final BW, kg	19.76	19.37	20.36	19.84	18.92	20.56	0.674	0.104	0.917	0.846
ADG, kg	0.491	0.470	0.512	0.493	0.450	0.526	0.019	< 0.01	0.920	0.644
ADFI, kg	0.790	0.765	0.815	0.765	0.768	0.827	0.032	0.145	0.887	0.790
Gain:Feed	0.620	0.619	0.635	0.652	0.585	0.635	0.033	0.097	0.958	0.167

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

Table 7. Intestine and thyroid gland weight of weanling pigs fed diets containing 2 sources of canola meal with constant or reduced energy level[1]

	Constant NE				Reduced NE					*P*-values		
Item[2]	CM-HP, 20%	CM-HP, 30%	CM-CV, 20%	CM-CV, 30%	CM-HP, 20%	CM-HP, 30%	CM-CV, 20%	CM-CV, 30%	Pooled SEM	CM level	CM type	Energy level
Full intestine,[3] kg	2.37^{ab}	2.23^{b}	2.35^{ab}	2.50^{a}	2.45^{ab}	2.49^{ab}	2.57^{a}	2.34^{ab}	0.094	0.480	0.408	0.145
Full intestine,% of live BW	12.17	12.91	13.34	12.35	12.74	13.09	11.83	12.48	0.531	0.606	0.535	0.670
Empty intestine, kg	1.68	1.58	1.66	1.69	1.68	1.58	1.74	1.56	0.060	0.035	0.512	0.773
Empty intestine,[3]% of live BW	8.66^{ab}	9.15^{a}	9.38^{a}	8.30^{bc}	9.13^{ab}	8.31^{bc}	7.81^{c}	8.32^{bc}	0.309	0.281	0.086	0.023
Gut fill, kg	0.68	0.64	0.69	0.82	0.77	0.90	0.80	0.78	0.062	0.250	0.601	0.024
Gut fill,% of live BW	3.50	3.75	3.96	4.04	4.00	4.79	3.91	4.16	0.338	0.160	0.988	0.099
Thyroid gland,[3,4]% of live BW	1.08^{c}	1.45^{abc}	1.81^{a}	1.28^{bc}	1.20^{bc}	1.53^{ab}	1.13^{bc}	1.53^{ab}	0.141	0.167	0.220	0.578

$^{a–c}$Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]No interactions were observed for CM level × CM type, CM level × energy level, CM type × energy level, and CM level × CM type × energy level except where indicated.

[3]An interaction was observed for CM level × CM type × energy level.

[4]Weight of thyroid gland as percent of BW multiplied by 1,000.

percentage of BW was greater ($P < 0.05$) for pigs fed the diets containing CM-HP or CM-CV if no carbohydrase was used compared with pigs fed the control diet, but if the carbohydrase was used, pigs fed the 2 CM diets did not have greater gut fill calculated as percentage of BW than pigs fed the control diet (interaction, $P < 0.05$). There was a tendency ($P = 0.085$) for an interaction between diet and enzyme for thyroid weight calculated as percentage of BW with thyroid glands being heavier ($P < 0.05$) from pigs fed the 2 CM diets than pigs fed the control diet if no enzyme was used, but if the carbohydrase was added to the diets, no differences in thyroid gland weights were observed.

pH and Volatile Fatty Acids

The pH of ileal contents was reduced by level of CM-CV in the diet, but concentration of dietary CM-HP had no impact on ileal pH (interaction, $P < 0.05$; Table 9). Increased concentration of CM-HP in the diets reduced ($P < 0.05$) cecal pH, whereas cecal pH was not affected as the inclusion level of CM-CV increased (interaction, $P < 0.05$). Pigs fed CM-CV had lower ($P < 0.05$) colon pH compared with pigs fed CM-HP diets. Pigs fed the diets with the reduced NE had lower ($P < 0.05$) pH in colon digesta than pigs fed diets with constant NE.

The concentration of butyrate, valerate, and total short-chain fatty acids were decreased ($P < 0.05$) as the CM level increased in the diets. Pigs fed CM-CV had less ($P < 0.05$) valerate and tended ($P = 0.083$) to have less propionate compared with pigs fed CM-HP diets. The concentrations of isovalerate and total branched chain fatty acids in cecal content were not different as the inclusion level of CM was increased with constant NE, but the concentrations of isovalerate and total branched-chain fatty acids were reduced ($P < 0.05$) if the CM level was increased with reduced NE (interaction, $P < 0.05$). The ratio of short-chain fatty acids and branched-chain fatty acids was not different as the inclusion level of CM increased with constant

Table 8. Intestine and thyroid gland weight of weanling pigs fed diets containing 2 sources of canola meal without or with addition of a carbohydrase[1]

	Without carbohydrase			With carbohydrase				*P*-value		
Item	Control	CM-HP, 30%	CM-CV, 30%	Control	CM-HP, 30%	CM-CV, 30%	Pooled SEM	Diet	Carbohydrase	Diet × carbohydrase
Full intestine, kg	2.34	2.49	2.34	2.59	2.46	2.42	0.112	0.659	0.273	0.468
Full intestine, % of live BW	11.39	13.09	12.48	12.60	12.54	14.22	0.622	0.101	0.120	0.168
Empty intestine, kg	1.68	1.58	1.56	1.71	1.69	1.58	0.068	0.178	0.378	0.774
Empty intestine, % of live BW	8.19	8.32	8.32	8.30	8.33	9.25	0.362	0.280	0.245	0.386
Gut fill, kg	0.66^{b}	0.90^{a}	0.78^{ab}	0.89^{a}	0.77^{a}	0.85^{ab}	0.061	0.593	0.305	0.019
Gut fill, % of live BW	3.19^{c}	4.79^{ab}	4.16^{ab}	4.30^{ab}	3.92^{bc}	4.98^{a}	0.330	0.043	0.194	0.009
Thyroid gland,[2]% of live BW	1.13^{b}	1.53^{a}	1.53^{a}	1.19^{b}	1.14^{b}	1.18^{b}	0.201	0.109	0.016	0.085

$^{a–c}$Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]Weight of thyroid gland as percent of BW multiplied by 1,000.

Table 9. Digesta pH, cecal VFA concentration, and blood parameters of weanling pigs fed diets containing 2 sources of canola meal with constant or reduced energy level[1]

	Constant NE				Reduced NE					*P*-value		
Item[2]	CM-HP, 20%	CM-HP, 30%	CM-CV, 20%	CM-CV, 30%	CM-HP, 20%	CM-HP, 30%	CM-CV, 20%	CM-CV, 30%	Pooled SEM	CM level	CM type	Energy level
Digesta pH												
Ileum[3]	6.83	7.04	7.00	6.55	6.77	6.92	7.02	6.76	0.122	0.320	0.506	0.874
Cecum[4]	5.88	5.79	5.65	5.68	5.77	5.48	5.36	5.37	0.061	0.049	< 0.001	< 0.001
Colon	6.45	6.57	6.43	6.47	6.41	6.44	6.30	6.30	0.083	0.338	0.071	0.015
Cecal VFA, μg/g												
Acetate	5.13	4.76	5.25	4.86	5.40	4.72	5.33	5.66	0.319	0.212	0.221	0.206
Propionate	1.68	1.70	1.53	1.46	2.00	1.61	1.65	1.65	0.151	0.270	0.083	0.175
Isobutyrate	0.010	0.015	0.013	0.010	0.023	0.015	0.013	0.010	0.006	0.573	0.351	0.454
Butyrate	0.753	0.678	0.678	0.519	0.910	0.509	0.783	0.571	0.096	0.003	0.277	0.595
Isovalerate[5]	0.012	0.011	0.017	0.011	0.020	0.016	0.011	0.013	0.003	0.293	0.457	0.320
Valerate	0.162	0.162	0.099	0.082	0.281	0.093	0.132	0.072	0.036	0.011	0.003	0.472
Short chain fatty acids	7.73	7.31	7.57	6.93	8.63	6.95	7.90	7.95	0.538	0.078	0.865	0.209
Branched chain fatty acids[5]	0.179	0.178	0.119	0.099	0.316	0.115	0.146	0.085	0.040	0.013	0.003	0.436
SC:BC[6]	55.70	49.96	82.82	83.11	39.59	75.17	64.05	125.79	15.27	0.014	< 0.001	0.366
Blood parameters												
Blood urea nitrogen,[5] mg/dL	7.29	5.85	9.18	5.74	6.07	6.29	7.51	7.18	0.868	0.032	0.076	0.662
Total N, g/dL	4.83	5.06	5.00	5.27	5.03	5.10	5.06	4.92	0.101	0.149	0.439	0.882
Albumin, g/dL	2.97	3.06	3.08	3.24	3.02	3.07	3.21	3.04	0.090	0.620	0.075	0.978
IgG, μM/mL	39.50	33.51	30.15	28.20	29.36	25.26	20.22	21.25	3.434	0.228	0.003	< 0.001

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]No interactions were observed for CM level × CM type, CM level × energy level, CM type × energy level, or CM level × CM type × energy level except where indicated.

[3]An interaction was observed for CM level × CM type. Ileal pH was decreased as the inclusion level of CM-CV increased, whereas no difference was detected as the inclusion level of CM-HP increased.

[4]An interaction was observed for CM level × CM type. Cecal pH was decreased as the inclusion level of CM-HP increased, whereas no difference was detected as the inclusion level of CM-CV increased.

[5]An interaction was observed for CM level × energy level. Isovalerate, branched chain fatty acids, and blood urea nitrogen were not different as the inclusion level of canola meal increased with constant energy level, whereas isovalerate, branched chain fatty acids, and blood urea nitrogen were reduced as the inclusion level of canola meal increased with reduced energy level.

[6]SC:BC = short-chain fatty acid to branched-chain fatty acid ratio. Interaction was observed for CM level × energy level. SC:BC was not different as the inclusion level of canola meal increased with constant energy level, whereas SC:BC was increased as the inclusion level of canola meal increased with reduced energy level.

NE, whereas the ratio was increased ($P < 0.05$) as the inclusion level of CM increased with reduced NE (interaction, $P < 0.05$).

Blood urea nitrogen was not different as the inclusion level of CM increased with constant NE, but blood urea nitrogen was decreased as the CM level increased with reduced NE (interaction, $P < 0.05$; Table 9). Adding CM-CV to the diets tended ($P = 0.075$) to increase serum albumin, but decreased ($P < 0.05$) serum IgG compared with CM-HP. The serum IgG concentration was reduced ($P < 0.05$) as the NE level was reduced.

Pigs fed CM-HP or CM-CV had lower ($P < 0.05$) cecal pH compared with pigs fed the control diet if the carbohydrase was not added to the diets, but no difference was observed among diets if the carbohydrase was added (interaction, $P < 0.05$; Table 10). Pigs fed CM-HP diets had greater ($P < 0.05$) colon pH compared with pigs fed control or CM-CV diets, and supplementation of carbohydrase increased ($P < 0.05$) colon pH.

No differences were observed in the concentration of acetate, propionate, isobutyrate, and isovalerate among dietary treatments. Pigs fed CM-HP and CV had less ($P < 0.05$) butyrate, valerate, and total branched-chain fatty acids compared with pigs fed the control diets, whereas pigs fed CM-HP had less ($P < 0.05$) total short-chain fatty acids, but pigs fed CM-CV had greater ($P < 0.05$) ratio of short chain fatty acids to branched chain fatty acids compared with pigs fed the control diets. Supplementation of enzyme tended ($P = 0.070$) increased butyrate, but did not impact other volatile fatty acids in cecal content.

Adding CM-HP reduced ($P < 0.05$) serum albumin concentration, and adding CM-CV reduced ($P < 0.05$) both serum total nitrogen and albumin compared with the control diets. Supplementation of carbohydrase reduced ($P < 0.05$) serum albumin compared with the diets without carbohydrase. The concentration of serum IgG was greater ($P < 0.05$) in pigs fed the control diet than in pigs fed CM-HP or CM-CV diets if

Table 10. Digesta pH, cecal VFA concentration, and blood parameters of weanling pigs fed diets containing 2 sources of canola meal without or with addition of a carbohydrase[1]

	Without carbohydrase			With carbohydrase				*P*-value		
Item	Control	CM-HP, 30%	CM-CV, 30%	Control	CM-HP, 30%	CM-CV, 30%	Pooled SEM	Diet	Carbohydrase	Diet × carbohydrase
Digesta pH										
Ileum	6.59	6.92	6.76	6.84	6.59	6.63	0.141	0.893	0.535	0.124
Cecum	5.90[a]	5.48[b]	5.37[b]	5.40[b]	5.54[b]	5.34[b]	0.093	0.012	0.043	0.010
Colon	6.29	6.45	6.31	6.46	6.98	6.50	0.110	0.006	0.002	0.185
Cecal VFA, μg/g										
Acetate	5.25	4.76	5.70	5.95	5.34	5.27	0.377	0.150	0.239	0.116
Propionate	1.77	1.63	1.66	2.00	1.85	1.65	0.173	0.204	0.164	0.551
Isobutyrate	0.008	0.013	0.018	0.037	0.012	0.018	0.010	0.418	0.138	0.214
Butyrate	0.853	0.509	0.571	1.059	0.680	0.573	0.083	< 0.001	0.070	0.432
Isovalerate	0.011	0.016	0.014	0.021	0.015	0.014	0.004	0.835	0.322	0.293
Valerate	0.166	0.093	0.072	0.198	0.161	0.064	0.027	< 0.001	0.169	0.382
Short chain fatty acids	8.05	7.01	8.01	9.24	8.05	7.57	0.585	0.055	0.127	0.169
Branched chain fatty acids	0.183	0.115	0.085	0.235	0.182	0.075	0.031	< 0.001	0.129	0.374
SC:BC[2]	56.66	75.20	125.82	49.42	53.15	137.11	20.35	< 0.001	0.652	0.591
Blood urea nitrogen, mg/dL	7.63	6.19	7.08	6.63	7.08	6.52	0.963	0.861	0.771	0.573
Total N, g/dL	5.23	5.10	4.92	5.31	5.07	5.06	0.115	0.050	0.531	0.766
Albumin, g/dL	3.21	3.07	3.04	3.12	2.81	2.83	0.091	0.022	0.017	0.646
IgG, μM/mL	37.29[a]	25.39[bc]	21.17[c]	26.93[bc]	28.74[b]	22.94[bc]	2.521	0.001	0.401	0.018

[a–c]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]SC:BC = short-chain fatty acid to branched-chain fatty acid ratio.

no enzyme was added to the diets, but no difference was observed in serum IgG level if carbohydrase was added to the diets (interaction, $P < 0.05$).

Intestinal Morphology

Reduced NE in the diets decreased ($P < 0.05$) duodenal crypt depth but tended ($P < 0.05$) to increase villi height to crypt depth ratio (Table 11). Jejunal villi height was decreased ($P < 0.05$) as the inclusion level of CM-HP increased, but no difference was observed in jejunal villi height as the inclusion level of CM-CV increased (interaction, $P < 0.05$). No differences were observed in colon crypt depth among dietary treatments.

Pigs fed the CM-HP diets had greater ($P < 0.05$) duodenal villi height compared with pigs fed the control diet, but jejunal villi height was not different for pigs fed the CM-HP diet compared with that of pigs fed the CM-CV diets (Table 12). Supplementation of the carbohydrase reduced ($P < 0.05$) duodenal villi height, but had no effect on jejunal villi height and crypt depth. Pigs fed the CM-HP diet had lower ($P < 0.05$) duodenal crypt depth than pigs fed the control diet if no carbohydrase was added to the diets, but no differences were observed among the 3 diets if the carbohydrase was added (interaction, $P = 0.059$). The duodenal villi height to crypt depth ratio was lower ($P < 0.05$) in pigs fed the CM-CV diet compared with pigs fed the control diet if no carbohydrase was added, but this was not the case if the carbohydrase was added to the diets (interaction, $P < 0.05$). No differences were observed in colon crypt depth among the 3 diets if the carbohydrase was not used, but adding CM-HP or CM-CV reduced colon crypt depth compared with the control diet if the carbohydrase was added (interaction, $P < 0.05$).

Energy Digestibility

The GE in feces was greater ($P < 0.05$) if CM-HP was included in the diets compared with CM-CV, and reducing NE in the diets also reduced ($P < 0.05$) GE concentration in feces (Table 13). The ATTD of GE was decreased as the inclusion level of CM-CV increased, but no difference was observed in ATTD of GE as the inclusion level of CM-HP increased in the diets (interaction, $P < 0.05$).

Pigs fed CM-HP diet had greater ($P < 0.05$) GE in feces compared with the control diet if the carbohydrase was not used, but no differences were observed in fecal GE concentration among the 3 diets if the carbohydrase was added to the diets (interaction, $P < 0.05$; Table 14). The ATTD of GE was greater ($P < 0.05$) in the control diet compared with CM-HP or CM-CV diets regardless of carbohydrase concentration, and the

Table 11. Gut morphology of weanling pigs fed diets containing 2 sources of canola meal with constant or reduced energy level[1]

	Constant NE				Reduced NE					*P*-value		
Item[2]	CM-HP, 20%	CM-HP, 30%	CM-CV, 20%	CM-CV, 30%	CM-HP, 20%	CM-HP, 30%	CM-CV, 20%	CM-CV, 30%	Pooled SEM	CM level	CM type	Energy level
Duodenum												
Villus height, μm	567	511	552	547	537	569	511	545	25.03	0.942	0.656	0.802
Crypt depth, μm	444	438	464	451	432	417	399	418	21.44	0.768	0.985	0.009
VH:CD[3]	1.32	1.24	1.24	1.26	1.29	1.43	1.35	1.34	0.062	0.715	0.637	0.053
Jejunum												
Villus height,[4] μm	537	449	504	486	537	476	486	541	26.70	0.142	0.823	0.395
Crypt depth, μm	331	336	347	328	330	313	311	327	19.70	0.749	0.920	0.168
VH:CD	1.70	1.39	1.55	1.58	1.69	1.60	1.65	1.75	0.130	0.371	0.627	0.138
Colon												
Crypt depth, μm	529	535	549	529	568	524	577	550	26.34	0.260	0.523	0.306

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]No interactions were observed for CM level × CM type, CM level × energy level, CM type × energy level, or CM level × CM type × energy level except where indicated.

[3]VH:CD = villus height:crypt depth.

[4]An interaction was observed for CM level × CM type. Jejunal villus height was decreased as the inclusion level of CM-HP increased, whereas no difference was detected as the inclusion level of CM-CV increased.

ATTD of GE was greater for the CM-HP diet than for the CM-CV diet if the carbohydrase was not used, but this was not the case if the carbohydrase was added to the diets (interaction, $P < 0.05$).

DISCUSSION

The chemical composition of CM-CV and CM-HP was in agreement with expected values and demonstrated the greater concentrations of CP and AA in CM-HP compared with CM-CV. However, the very low concentration of glucosinolates in CM-CV was unexpected and resulted in diets that were different in concentrations of glucosinolates, which may have influenced the results.

Inclusion of up to 25% CM-CV in diets fed to weanling pigs did not affect ADG, ADFI, or G:F in previous research (King et al., 2001; Landero et al., 2011; 2013; Seneviratne et al., 2011; Sanjayan et al., 2014). Recently, it was reported that up to 40% CM-HP or CM-CV may be used in diets fed to weanling pigs from 2 wk postweaning without negatively affecting growth performance although the weight of the thyroid gland is increased and concentrations of serum thyroxins are reduced as CM concentration in the diet increases (Parr et al., 2015). Both CM-HP and CM-CV contain less ME and NE than soybean meal (Liu et al., 2014; 2016; Berrocoso et al., 2015), and to compensate for the reduced ME and NE in diets containing canola meal, dietary fat was increased in all of the above experiments as CM was included to maintain a constant NE among experimental diets. However, to our knowledge, it has never been demonstrated that NE needs to be constant if CM is included in diets fed to weanling pigs and results of this experiment confirmed that it is not necessary to

Table 12. Gut morphology of weanling pigs fed diets containing 2 sources of canola meal without or with addition of a carbohydrase[1]

	Without carbohydrase			With carbohydrase			Pooled SEM	*P*-value		
Item	Control	CM-HP, 30%	CM-CV, 30%	Control	CM-HP, 30%	CM-CV, 30%		Diet	Carbohydrase	Diet × carbohydrase
Duodenum										
Villus height, μm	600	571	546	490	537	528	25.32	0.780	0.007	0.119
Crypt depth, μm	379^{a}	418^{bc}	418^{ab}	463^{c}	402^{abc}	439^{abc}	23.53	0.668	0.082	0.059
VH:CD[2]	1.59^{a}	1.44^{ab}	1.34^{bc}	1.16^{c}	1.39^{abc}	1.30^{bc}	0.088	0.534	0.018	0.032
Jejunum										
Villus height, μm	497	476	541	530	464	477	23.52	0.137	0.464	0.132
Crypt depth, μm	360	312	327	351	331	339	17.03	0.034	0.515	0.507
VH:CD[2]	1.51	1.60	1.76	1.56	1.49	1.49	0.122	0.633	0.194	0.297
Colon	510^{b}	524^{b}	550^{ab}	606^{a}	519^{b}	490^{b}	26.30	0.282	0.638	0.017

[a–c]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]VH:CD = villus height:crypt depth.

Table 13. Apparent total tract digestibility (ATTD, %) of energy in pigs fed diets containing 2 sources of canola meal with constant or reduced energy level[1]

	Constant NE				Reduced NE					*P*-value		
Item	CM-HP, 20%	CM-HP, 30%	CM-CV, 20%	CM-CV, 30%	CM-HP, 20%	CM-HP, 30%	CM-CV, 20%	CM-CV, 30%	Pooled SEM	CM level	CM type	Energy level
GE, kcal/kg	4435	4416	4359	4361	4334	4361	4248	4306	40.85	0.497	0.012	0.005
ATTD of GE,[2]%	79.16	78.30	81.85	76.48	80.81	79.29	81.85	72.92	1.264	< 0.001	0.159	0.769

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]GE values are analyzed GE in dried fecal samples.

maintain constant NE among diets containing CM. It was not surprising that ADFI was greater for pigs fed diets where NE was allowed to be reduced compared with pigs fed diets in which NE was constant, but it was surprising that ADG also was greater for pigs fed diets with the lower NE. It thus appears that inclusion of choice white grease in diets containing canola meal may not always result in improved growth performance. It is possible that this response is a result of an overestimation of the NE of choice white grease because widely different values for NE in choice white grease and other fat sources have been published (Sauvant et al., 2004; NRC, 2012; Kil et al., 2011). Nevertheless, the observations on responses to dietary NE indicate that under the conditions of this experiment, no negative effects of reducing diet NE were observed because pigs were able to compensate for the reduced NE by consuming more feed. The observation that G:F was not reduced as NE in diets was reduced and that G:F increased for pigs fed CM-CV at constant NE indicates that the NE for the CM used in this experiment may have been underestimated. The NE in both sources of CM was calculated from a published prediction equation that is based on DE and concentrations of ether extract, starch, crude protein, and ADF (Noblet et al., 1994). The DE values used in this equation for CM-HP and CM-CV (3,312 and 2,798 kcal per kg, respectively) were obtained in a previous experiment in our laboratory (Berrocoso et al., 2015). The value for CM-CV is in very good agreement with the DE (2,772 kcal/kg) reported by Sauvant et al. (2004). However, values for DE in CM-CV that are between 3,100 and 3,300 kcal/kg DM have also been reported (Montoya and Leterme, 2010; NRC, 2012), so it is possible that the DE values used in the calculation of NE may have been underestimated, especially for CM-CV, which would explain the increased G:F for the pigs fed the CM-CVP diets.

The lack of overall negative effects on growth performance of including CM in the diets at 20% or 30% is in agreement with previous experiments (King et al., 2001; Landero et al., 2011; 2013; Seneviratne et al., 2011; Sanjayan et al., 2014; Parr et al., 2015) and confirms that weanling pigs can utilize up to 30% CM without negative effects on growth performance. However, the observation that ADFI and ADG was greater for pigs fed CM-CV than for pigs fed CM-HP was in contrast to our previous experiment in which no difference between CM-HP and CM-CV was observed (Parr et al., 2015). It is possible that the greater concentration of glucosinolates in CM-HP (12.60 μmol/g) compared with CM-CV (4.43 μmol/g) is responsible for this difference because glucosinolates reduce palatability of diets and growth of animals (Tripathi and Mishra, 2007). At 30% inclusion rate, the glucosinolate concentration in diets containing CM-HP can be calculated at 3.72 μmol/g, whereas 30% CM-CV in the diet resulted in only 1.32 μmol/g of glucosinolates. This difference may have caused the difference in feed intake between the 2 sources of CM. However, in the experiment by Parr et al. (2015), concentrations of glucosinolates were approximately 9 and 15 μmol/g in CM-CV and CM-HP, respectively, and those differences did not result in differences in ADFI between pigs fed CM-CV and CM-HP.

The small and inconsistent changes in intestinal digesta pH and in concentrations of VFA in cecal contents indicate that hindgut fermentation was not increased to any large extend in pigs fed diets containing

Table 14. Apparent total tract digestibility (ATTD, %) of energy in pigs fed diets containing 2 sources of canola meal without or with addition of a carbohydrase[1,2]

	Without carbohydrase			With carbohydrase			Pooled	*P*-value		
Item	Control	CM-HP, 30%	CM-CV, 30%	Control	CM-HP, 30%	CM-CV, 30%	SEM	Diet	Carbohydrase	Diet × carbohydrase
Fecal GE, kcal/kg	4195^{c}	4367^{a}	4307^{ab}	4309^{ab}	4325^{ab}	4252^{bc}	45.26	0.055	0.856	0.048
ATTD of GE, %	88.83^{a}	79.27^{c}	72.73^{d}	84.22^{b}	78.55^{c}	77.40^{c}	1.167	< 0.001	0.833	0.001

$^{a–c}$Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]CM-HP = high protein canola meal; CM-CV = conventional canola meal.

[2]GE values are analyzed GE in dried fecal samples.

CM compared with pigs fed the control diet. This observation is somewhat surprising because a total tract fermentability of nonstarch polysaccharides in CM of close to 70% has been reported (Pustjens et al., 2014). It is, however, possible that because pigs had a BW of less than 10 kg at the start of this experiment, they were not able to ferment non-starch polysaccharides to the same extent as the pigs used in previous studies.

Glucosinolates in CM may result in thyroid gland hypertrophy (Tripathi and Mishra, 2007), which is likely the reason for the increased weights of the thyroid glands that were observed as CM was increased in the diets. This observation is in agreement with previous data that also indicated that serum concentrations of triiodothyronine and thyroxine were reduced as CM was increased in the diets (Parr et al., 2015). The effect of CM on thyroid gland function is a consequence of a reduction in iodine uptake by the thyroid gland that is caused by some of the metabolites from glucosinolates (Bell, 1984).

The lack of consistent responses to CM-HP and CM-CV on BUN, total N, or serum albumin is likely a result of the fact that diets were formulated to be balanced for digestible indispensable AA and as CM increased in the diets, inclusions of crystalline Lys and Thr increased. The biological value of all diets, therefore, was expected to be similar and the data for blood N components confirm this hypothesis.

The reduced ATTD of GE that was observed as both CM-HP and CM-CV were included in the diets was expected because the ATTD of GE in CM-HP and CM-CV is much less than in soybean meal (Liu et al., 2014; 2016; Berrocoso et al., 2015). Reduced ATTD of GE in CM-containing diets has also been observed in previous experiments with weanling pigs (Landero et al., 2011; 2013). The reason for this observation is most likely that the increased concentration of fiber in CM compared with SBM results in reduced ATTD of GE.

The lack of responses to the carbohydrase on growth performance and ATTD of GE may be a result of the substrates that were available in the diets. The fiber in CM mostly consists of cellulose, homogalacturonan, arabinan, and minor amounts of xyloglucans and arabinogalactans (Pustjens et al., 2012). However, the carbohydrase used in this experiment mainly has activity toward mannans and the fact that there are virtually no mannans in CM may have prevented the enzyme from exerting its expected effect. In a previous experiment, it also was observed that addition of carbohydrases to diets containing CM did not result in improved growth performance (Sanjayan et al., 2014). However, a positive response to addition of a mixture of β-glucanase and xylanase to a wheat based diet containing 25% canola meal has been reported (Zijlstra et al., 2004), but this response may have been obtained because the wheat in these diets contains arabinoxylans and betaglucans, which may have served as substrates for the added enzymes.

In conclusion, in agreement with results of previous experiments and under the conditions of this experiment, it appears that weanling pigs tolerate at least 30% CM-HP or CM-CV from 2 wk postweaning without negative effects on growth performance if diets are balanced for digestible indispensable AA. At these inclusion levels, growth performance of pigs fed diets containing either CM-HP or CM-CV was not different from that of pigs fed a corn-soybean meal based control diet. However, pigs fed diets containing CM-CV with 4.43 μmol/g glucosinolates had improved growth performance compared with pigs fed diets containing CM-HP that contained 12.60 μmol/g glucosinolates. Results also indicate that it is not necessary to balance diets for NE by increasing inclusions of fat in the diets as the concentration of CM-HP or CM-CV increases because pigs will compensate for the reduced NE in CM by increasing feed intake.

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