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Effects of feeding canola meal from high-protein or conventional varieties of canola seeds on growth performance, carcass characteristics, and cutability of pigs

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ABSTRACT: The objectives of this experiment were to determine growth performance, visceral mass differences, carcass characteristics, fresh meat quality, and carcass cutability of growing-finishing pigs fed diets containing high-protein canola meal (CM-HP) or conventional canola meal (CM-CV). Seven dietary treatments were fed to investigate effects of increasing inclusion rates of CM-HP or CM-CV in a corn–soybean meal diet containing no canola meal (control). Inclusion rates were 33, 66, or 100% replacement of soybean meal with either CM-HP or CM-CV. Pigs (140 barrows and 140 gilts; 2 barrows and 2 gilts per pen) were fed experimental diets in 3 phases with each phase lasting 35, 28, and 28 d, respectively. Within each phase, diets were formulated to be similar in concentrations of standardized ileal digestible indispensable AA and in standardized total tract digestible P, but NE concentrations were not equalized among diets. At the conclusion of the experiment, 1 pig per pen was harvested. Over the 91-d growing-finishing period, no effects of CM-HP on ADG, ADFI, or G:F were observed, but final BW tended ($P = 0.06$) to be reduced as increasing levels of CM-HP were included in the diets. There was a linear increase ($P < 0.05$) in ADFI and a linear reduction ($P < 0.05$) in G:F as CM-CV inclusion level increased. Pigs fed CM-CV also had greater ($P < 0.05$) ADG and ADFI than pigs fed diets containing CM-HP. There was a linear increase ($P < 0.01$) in liver weights, as a percentage of live weight, as CM-CV inclusion increased, but that was not the case if CM-HP was included in the diets. There was a linear increase ($P < 0.05$) in kidney weights, as a percentage of live weight, as CM-HP or CM-CV inclusion increased. There were no differences among treatments for ending live weight, HCW, carcass yield, loin eye area, 10th rib backfat thickness, or estimated carcass lean. Shear force, cook loss, LM moisture, LM extractible lipid, and drip loss were also not different among treatment groups. There were no differences among treatments for any subjective LM quality evaluations (color, marbling, firmness). Pigs fed CM-HP had increased ($P < 0.05$) boneless lean cutting yields and boneless carcass cutting yields compared with pigs fed CM-CV. In conclusion, CM-HP and CM-CV may fully replace soybean meal as protein supplements in growing-finishing pig diets without substantially impairing pig performance or carcass quality.

Key words: carcass characteristics, conventional canola meal, growth performance, high-protein canola meal, pig, soybean meal

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INTRODUCTION

Soybean meal (**SBM**) is the most used protein ingredient in finishing swine diets in the United States (Cromwell, 1998; Stein et al., 2008). The demand for SBM has increased over the past 30 yr (USDA, 2013). As the demand for SBM increases with increased livestock, poultry, and aquaculture production, protein alternatives for SBM have been researched (Goldsmith, 2008). Canola meal is an alternative to SBM as a protein supplement for pigs (Bell, 1975; Baidoo et al., 1987; Maison, 2013). Conventional canola meal (**CM-CV**) contains less CP but more fiber than SBM. This limits the availability of indispensable AA and DE in pig diets (Thacker, 1992). Increased fiber can decrease carcass yield by increasing intestinal mass, and additional DE is required to make up for lost nutrient availability (Hochstetler et al., 1959; Pond et al., 1988; Pluske et al., 1998). The presence of glucosinolates in meal from some varieties of canola causes

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hypothyroidism and enlarges thyroid glands in pigs, which may lead to muscle growth inhibition (Spencer, 1985; Busato et al., 1991; Mullan et al., 2000). A new hybridized high-protein variety of canola (*Brassic napus)* may result in meal with more DE and ME than CM-CV (Liu et al., 2014). Meal produced from the crushing of this variety of canola contains approximately 45% CP and may be a more desirable option as a SBM alternative than CM-CV. Effects of CM-CV and high-protein canola meal (**CM-HP**) included in diets for weanling pigs has been reported (Parr et al., 2014), but to our knowledge, no research has been reported on feeding CM-HP to growing-finishing pigs. Therefore, the objectives of this experiment were to determine growth performance, visceral mass differences, carcass characteristics, fresh meat quality, and carcass cutability of growing-finishing pigs fed diets containing CM-HP or CM-CV as a replacement of SBM.

MATERIALS AND METHODS

The experiment was conducted at the Swine Research Center at the University of Illinois and the experimental protocol was approved by the Institutional Animal Care and Use Committee at the University of Illinois.

Feed Ingredients, Experimental Design, and Dietary Treatments

The CM-HP that was used in this experiment was sourced from black-seeded *Brassica napus* selected for thinner seed coats, which results in canola meal with less fiber and more CP than traditional canola meal (Liu et al., 2014). The CM-CV was sourced from traditional black-seeded *Brassica napus*. Both sources of canola meal were processed in a traditional 2-stage oil extraction facility with the first step consisting of mechanical expelling of the oil and the second step consisting of solvent extraction of the residual oil. The SBM that was used was sourced from Dupont (Gibson City, IL) and corn was grown locally and obtained from the University of Illinois Feed Mill (Champaign, IL).

A 3-phase 91-d feeding program was used with grower diets fed from d 0 to 35 (Table 1), early finisher diets fed from d 36 to 63 (Table 2), and late finisher diets fed from d 64 to 91 (Table 3). Seven dietary treatments were used for each phase; a corn–SBM diet containing no canola meal, 3 diets containing increasing inclusion rates (low, medium, or high) of CM-HP, and 3 diets containing increasing inclusion rates (low, medium, or high) of CM-CV. Canola meal replaced 33, 66, or 100% of SBM in the diets, and all diets were formulated to meet current estimates for nutrient requirements for growing and finishing pigs (NRC, 2012). All diets were formulated based on values for the standardized total tract digestibility of P, standardized ileal digestibility of AA, and NE that were calculated for the same meals in previous experiments.

A total of 280 barrows and gilts were used in the live portion of this experiment. Pigs were the offspring of G-Performer boars and Fertilis 25 sows (Genetiporc Inc., Alexandria, MN) and they were divided into 2 blocks based on farrowing groups (initial BW: 28.0 ± 3.53 kg and 26.8 ± 3.30 kg for block 1 and 2, respectively). All pigs were between 9 and 10 wk old at the start of the experiment. There were 4 pigs per pen and 5 pens replicates per block for a total of 10 replicates per treatment and 70 pens for the experiment. There were 2 gilts and 2 barrows in each pen. There were 4 pigs per pen and 5 pens replicates per block for a total of 10 replicates per treatment and 70 pens for the experiment. There were 2 gilts and 2 barrows in each pen. Pigs were housed in a mechanically ventilated building with part solid and part slotted concrete floors throughout the study period. Pen divisions and gates consisted of vertical steel rods, and pen dimensions were 2.59 × 1.83 m, which provided a floor space of 1.18 m^2/pig. Each pen had 1 single-space dry box feeder mounted on the front gate and a nipple-type water drinker. The thermostat was set at 18.5°C throughout the study period and ambient temperature was maintained using thermostatically controlled heaters and fan ventilation. Pigs were weighed at the beginning of the experiment and again at the end of each of the 3 feeding phases (d 35, 63, and 91). Daily feed allotments were recorded, and data were summarized to calculate ADG, ADFI, and G:F for each pen during each phase of the feeding period. One pig from each pen was randomly selected at the conclusion of the feeding period to determine dressing percentage, visceral mass, carcass characteristics, meat quality, and carcass fabrication characteristics. A controlled randomization was used to select these pigs to ensure that an equal number of gilts and barrows were harvested for all treatments.

Slaughter Procedures and Evisceration

Selected pigs (1 pig per pen; 35 pigs per block) were transported to the University of Illinois Meat Science Laboratory (Urbana, IL) and held overnight in lairage. Pigs were provided ad libitum access to water during this time but had no access to feed. Pigs were weighed immediately before slaughter to determine ending live weight. Pigs were slaughtered under the supervision of the Food Safety and Inspection Service branch of the United States Department of Agriculture using head-to-heart electrical immobilization and exsanguination. Heart, liver, kidney, and thyroid gland weights were recorded immediately after evisceration.

Table 1. Ingredient composition of experimental diets, phase 1 (d 0 to 35), as-fed basis

	Diet						
		CM-HP[1]			CM-CV[1]		
Item	Control[1]	33%	66%	100%	33%	66%	100%
Ingredient, %							
Corn	68.33	67.93	67.48	66.96	66.08	63.72	61.33
Canola meal, high protein	–	9.57	19.15	28.72	–	–	–
Canola meal, conventional	–	–	–	–	11.68	23.35	35.00
Soybean meal, 48% CP	27.00	18.00	9.00	–	18.00	9.00	–
Phytase premix[2]	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.21	1.30	1.38	1.30	1.13	0.92	0.60
Dicalcium phosphate	0.52	0.25	–	–	0.15	–	–
L-Lysine HCl	0.18	0.21	0.25	0.28	0.23	0.28	0.34
DL-Methionine	0.02	–	–	–	–	–	–
L-Threonine	0.02	0.02	0.02	0.02	0.01	0.01	0.01
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[3]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed composition, %							
DM	88.98	88.78	89.33	88.52	87.66	89.64	89.34
CP	19.10	20.57	18.59	18.68	19.74	20.16	19.75
ADF	4.44	4.70	6.38	7.24	5.25	7.01	8.27
NDF	8.72	9.14	10.50	12.53	10.45	12.27	13.12
Ca	0.76	0.70	0.74	0.95	0.60	0.40	0.68
P	0.43	0.44	0.44	0.45	0.41	0.43	0.52
Indispensable AA. %							
Arg	1.17	1.13	1.00	0.95	1.15	1.12	1.03
His	0.49	0.49	0.45	0.45	0.49	0.51	0.49
Ile	0.80	0.77	0.70	0.66	0.78	0.78	0.71
Leu	1.74	1.64	1.53	1.50	1.63	1.67	1.55
Lys	1.06	1.08	0.95	0.98	1.12	1.05	1.08
Met	0.30	0.32	0.31	0.33	0.32	0.33	0.35
Phe	0.93	0.87	0.77	0.73	0.87	0.86	0.76
Thr	0.72	0.73	0.67	0.68	0.71	0.75	0.73
Trp	0.22	0.23	0.22	0.21	0.21	0.23	0.23
Val	0.89	0.90	0.85	0.86	0.91	0.95	0.92
Total	8.32	8.16	7.45	7.35	8.19	8.25	7.85
Dispensable AA. %							
Ala	1.00	0.96	0.91	0.91	0.96	1.00	0.95
Asp	1.81	1.63	1.34	1.15	1.64	1.49	1.24
Cys	0.29	0.33	0.36	0.39	0.32	0.38	0.43
Glu	3.42	3.38	3.08	3.05	3.33	3.41	3.26
Gly	0.77	0.80	0.76	0.79	0.80	0.86	0.86
Pro	1.16	1.18	1.15	1.22	1.15	1.25	1.27
Ser	0.83	0.78	0.70	0.66	0.78	0.77	0.71
Tyr	0.59	0.53	0.49	0.47	0.57	0.53	0.50
Total	9.87	9.59	8.79	8.64	9.55	9.69	9.22
All AA	18.19	17.75	16.24	15.99	17.74	17.94	17.07
Calculated composition							
NE, kcal/kg	2496	2471	2444	2414	2425	2350	2274
Glucosinolates, mmol/g	–	0.98	1.95	2.93	2.23	4.46	6.69

[1]Percentage of high-protein canola meal (CM-HP) and conventional canola meal (CM-CV) as a replacement for soybean meal.

[2]Optiphos 2000; Enzyvia, Sheridan, IN.

[3]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, 2208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin 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.

Table 2. Ingredient composition of experimental diets, phase 2 (d 35 to 63), as-fed basis

	Diet						
		CM-HP[1]			CM-CV[1]		
Item	Control[1]	33%	66%	100%	33%	66%	100%
Ingredient, %							
Corn	74.50	74.16	73.83	73.43	72.73	70.91	69.05
Canola meal, high protein	–	7.45	14.89	22.34	–	–	–
Canola meal, conventional	–	–	–	–	9.08	18.16	27.24
Soybean meal, 48% CP	21.00	14.00	7.00	–	14.00	7.00	–
Phytase premix[2]	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.15	1.23	1.28	1.20	1.10	0.90	0.65
Dicalcium phosphate	0.40	0.18	–	–	0.10	–	–
L-Lysine HCl	0.20	0.23	0.25	0.28	0.24	0.28	0.32
L-Threonine	0.03	0.03	0.03	0.03	0.03	0.03	0.02
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[3]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed composition, %							
DM	88.16	88.42	88.61	88.36	88.65	88.52	88.29
CP	15.55	15.78	15.26	17.36	16.57	16.80	15.98
ADF	3.59	4.38	4.69	5.41	5.06	6.17	7.28
NDF	9.03	10.21	9.84	10.47	11.23	12.23	12.60
Ca	0.62	0.76	0.70	0.86	0.70	0.55	0.39
P	0.39	0.43	0.42	0.43	0.38	0.39	0.42
Indispensable AA, %							
Arg	0.93	0.93	0.89	0.88	0.90	0.88	0.88
His	0.39	0.41	0.41	0.42	0.39	0.40	0.41
Ile	0.63	0.65	0.62	0.59	0.57	0.62	0.61
Leu	1.40	1.49	1.42	1.40	1.30	1.40	1.37
Lys	0.83	0.97	0.92	0.88	0.96	0.89	0.97
Met	0.25	0.26	0.30	0.31	0.25	0.31	0.32
Phe	0.73	0.74	0.70	0.66	0.66	0.69	0.66
Thr	0.57	0.62	0.60	0.63	0.58	0.61	0.64
Trp	0.20	0.18	0.20	0.19	0.18	0.19	0.19
Val	0.72	0.76	0.76	0.77	0.70	0.76	0.78
Total	6.65	7.01	6.82	6.73	6.49	6.75	6.83
Dispensable AA, %							
Ala	0.83	0.88	0.84	0.86	0.81	0.84	0.85
Asp	1.42	1.32	1.18	1.04	1.20	1.16	1.06
Cys	0.24	0.28	0.34	0.38	0.26	0.34	0.36
Glu	2.70	2.91	2.85	2.88	2.54	2.73	2.80
Gly	0.63	0.68	0.68	0.71	0.65	0.68	0.73
Pro	0.97	1.07	1.09	1.13	0.97	1.05	1.10
Ser	0.67	0.68	0.63	0.62	0.63	0.62	0.62
Tyr	0.50	0.49	0.46	0.44	0.44	0.46	0.44
Total	7.96	8.31	8.07	8.06	7.50	7.88	7.96
All AA	14.61	15.32	14.89	14.79	13.99	14.63	14.79
Calculated composition nutrcomposition							
NE, kcal/kg	2,536	2,515	2,495	2,472	2,480	2,422	2,363
Glucosinolates, mmol/g	–	0.76	1.52	2.28	1.73	3.47	5.20

[1]Percentage of high-protein canola meal (CM-HP) and conventional canola meal (CM-CV) as a replacement for soybean meal.

[2]Optiphos 2000; Enzyvia, Sheridan, IN.

[3]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.

Table 3. Ingredient composition of experimental diets, phase 3 (d 63 to 91), as-fed basis

	Diet						
		CM-HP[1]			CM-CV[1]		
Item	Control[1]	33%	66%	100%	33%	66%	100%
Ingredient, %							
Corn	77.82	77.51	77.19	76.84	76.27	74.67	73.07
Canola meal, high protein	–	6.38	12.77	19.15	–	–	–
Canola meal, conventional	–	–	–	–	7.78	15.57	23.35
Soybean meal, 48% CP	18.00	12.00	6.00	–	12.00	6.00	–
Phytase premix[2]	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.07	1.15	1.12	1.07	1.04	0.82	0.60
Dicalcium phosphate	0.24	0.06	–	–	–	–	–
L-Lysine HCl	0.14	0.17	0.19	0.21	0.18	0.21	0.25
L-Threonine	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[3]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed composition, %							
DM	90.25	90.11	90.35	90.12	90.07	90.09	90.07
CP	17.11	15.15	15.72	16.13	15.74	15.65	15.74
ADF	3.47	3.94	4.82	5.13	5.03	5.59	6.47
NDF	9.09	9.25	9.33	10.91	10.33	11.22	12.82
Ca	0.53	0.55	0.57	0.68	0.45	0.44	0.42
P	0.35	0.35	0.37	0.40	0.33	0.35	0.41
Indispensable AA, %							
Arg	0.89	0.86	0.92	0.78	0.96	0.82	0.87
His	0.39	0.39	0.43	0.38	0.42	0.39	0.42
Ile	0.63	0.59	0.63	0.54	0.67	0.58	0.60
Leu	1.47	1.38	1.46	1.34	1.52	1.38	1.41
Lys	0.83	0.82	0.92	0.74	0.87	0.77	0.97
Met	0.26	0.24	0.28	0.27	0.29	0.29	0.30
Phe	0.74	0.69	0.72	0.62	0.77	0.66	0.67
Thr	0.55	0.55	0.61	0.54	0.62	0.56	0.64
Trp	0.17	0.19	0.20	0.18	0.19	0.19	0.19
Val	0.71	0.71	0.78	0.70	0.78	0.71	0.78
Total	6.64	6.42	6.95	6.09	7.09	6.35	6.85
Dispensable AA, %							
Ala	0.83	0.82	0.88	0.80	0.89	0.82	0.87
Asp	1.35	1.21	1.33	0.93	1.39	1.09	1.05
Cys	0.26	0.26	0.33	0.33	0.30	0.33	0.36
Glu	2.72	2.65	2.92	2.56	2.91	2.62	2.79
Gly	0.58	0.62	0.70	0.61	0.68	0.63	0.72
Pro	1.00	1.01	1.12	1.06	1.08	1.05	1.14
Ser	0.65	0.63	0.67	0.56	0.70	0.61	0.63
Tyr	0.50	0.46	0.46	0.42	0.51	0.44	0.45
Total	7.89	7.66	8.31	7.27	8.46	7.59	8.01
All AA	14.53	14.08	15.26	13.36	15.55	13.94	14.86
Calculated composition							
NE, kcal/kg	2,562	2,544	2,525	2,506	2,513	2,463	2,412
Glucosinolates, mmol/g	–	0.65	1.30	1.95	1.49	2.97	4.46

[1]Percentage of high-protein canola meal (CM-HP) and conventional canola meal (CM-CV) as a replacement for soybean meal.

[2]Optiphos 2000; Enzyvia, Sheridan, IN.

[3]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.

Intestinal weights were collected as described by Boler et al. (2014). Initially, the full intact intestinal tract was weighed. The large intestine was separated from the small intestine at the ileocecal junction. The small intestine was separated from the stomach between the pylorus of the stomach and the duodenum of the small intestine. The stomach was removed from the esophagus where the esophagus empties into the cardia of the stomach. Each section of the intestinal tract was rinsed with water to remove all digestive and fecal material. Mesenteric tissue that surrounds the intestinal tract was removed and weighed separately. Gut fill was calculated as the difference in the weight of the full intestinal tract and the sum of the empty sections. Visceral mass was expressed as the absolute weight of the organ or contents and as a percentage of ending live weight.

Carcass Characteristics and Fresh meat Quality

Carcasses were weighed approximately 45-min postmortem to determine HCW. Carcass yield was calculated by dividing HCW by ending live weight. Carcasses were then allowed to chill at 4°C for approximately 24 h. Fresh meat quality was determined on the left side of the carcass at approximately 24-h postmortem. The left side of each chilled carcass was cut between the 10th and 11th rib interface to expose the LM. The surfaces of the LM were allowed to bloom for at least 20 min before quality evaluations were conducted. Ultimate pH was determined using an MPI hand-held pH meter (MPI pH-Meter, Topeka, KS; 2 point calibration: pH 4 and 7). Subjective color, marbling, and firmness scores were conducted by a single individual according to standards established by the National Pork Producers Council (NPPC, 1991, 1999). Objective L*, a*, and b* values were collected with a Minolta CR-400 utilizing a D65 light source, a 0° observer, and an aperture size of 8 mm. Tenth-rib backfat was measured at 3/4 the distance of the LM from the dorsal process of the vertebral column. Loin eye area (**LEA**) was measured by tracing the surface of the LM on double-matted acetate paper. Longissimus muscle tracings were measured in duplicate using a digitizer tablet (Wacom, Vancouver, WA) and Adobe Photoshop CS6 and the average of the 2 measurements was reported. A section of the LM, posterior to the 10th rib, was excised and cut into one 1.25-cm chop and three 2.54-cm-thick chops to determine water holding capacity, proximate composition, and Warner–Bratzler shear force. Estimated carcass lean was calculated using the following equation developed by Burson and Berg (2001): estimated carcass lean, % = [8.588 + (0.465 × HCW, lb.) – (21.896 × 10th rib backfat, in.) + (3.005 × 10th rib LEA, in.^{2})] ÷ HCW, lb.

Water Holding Capacity

Water holding capacity was estimated using the drip-loss method as described by Leick et al. (2010). Briefly, a 1.25-cm chop was suspended from a fish hook in a Whirl-Pak (Nasco, Fort Atkinson, WI) bag for approximately 24 h at 4°C. Chops were weighed before and immediately after suspension. Results were reported as weight loss as a percentage of initial weight.

Loin Proximate Composition

Before analysis, chops (2.54 cm) for proximate composition were individually packaged in Whirl-Pak bags and stored at -2°C. Chops were trimmed of all subcutaneous fat and homogenized using a Cuisinart Food Processor (Model DLC 5-TX, Cuisinart, Stamford, CT). Duplicate 10-g samples of each homogenized chop were weighed, placed in aluminum pans, and covered with Whatman #1 filter paper. Each sample was oven-dried at 110°C for approximately 24 h to determine percent moisture. The dried sample was washed multiple time in an azeotropic mixture of warm chloroform:methanol as described by Novakofski et al. (1989) and weighed to determine extractable lipid content.

Warner–Bratzler Shear Force

Chops (2.54 cm) were vacuum packaged and stored at 4°C until d 7 post mortem. Chops were frozen at the end of the aging period and held until analysis. Twenty-four h before analysis, chops were removed from the freezer and thawed in a 4°C cooler. Chops were trimmed of subcutaneous fat and cooked on a Farberware Open Hearth grill (Model 455N, Walter Kidde, Bronx, NY). Chops were cooked on 1 side to an internal temperature of 35°C, flipped, and cooked to a final internal temperature of 70°C. Internal temperature was monitored using copper-constantan thermocouples (Type T, Omega Engineering, Stanford, CT) connected to a digital scanning thermometer. Next, chops were allowed to cool to 25°C and four 1.25-cm diameter cores were removed parallel to the orientation of the muscle fibers. Cores were sheared using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/Stable Microsystems, Godalming, UK) with a blade speed of 3.3 mm/sec and a load capacity of 100 kg. Shear force was determined on each core and the average of 4 cores was reported. Cook loss was determined by weighing chops used for shear force immediately before and after cooking. Values were reported as moisture lost during cooking as a percentage of raw weight.

Carcass Fabrication

Chilled right sides were fabricated in the same manner as described by Boler et al. (2011), with the only exception being shoulder fabrication. The whole shoulder was fabricated into an NAMP #406 bone-in Boston butt and an NAMP #405 bone-in picnic shoulder. Each piece was then boned out to meet specifications of an NAMP #406A boneless Boston butt and an NAMP #405A boneless picnic shoulder. The following equations were used to assess cutting yields:

Lean cutting yield, % = [(trimmed ham, kg + trimmed loin, kg + Boston butt, kg + picnic, kg) ÷ right side chilled weight, kg] × 100.

Boneless lean cutting yield, % = [(inside ham, kg + outside ham, kg + knuckle, kg + light butt, kg + shank, kg + Canadian back, kg + tenderloin, kg + sirloin, kg + boneless Boston butt, kg + boneless picnic, kg) ÷ right side chilled weight, kg] × 100.

Carcass cutting yield, % = [(trimmed ham, kg + trimmed lion, kg + Boston butt, kg + picnic, kg + trimmed belly, kg) ÷ right side chilled weight, kg] × 100.

Boneless carcass cutting yield, % = [(inside ham, kg + outside ham, kg + knuckle, kg + light butt, kg + shank, kg + Canadian back, kg + tenderloin, kg + sirloin, kg + boneless Boston butt, kg + boneless picnic, kg + trimmed belly, kg) ÷ right side chilled weight, kg] × 100.

Chemical Analysis

The 2 sources of canola meal and soybean meal and all diets were analyzed for DM (Method 930.15; AOAC, 2007), CP by combustion (Method 999.03; AOAC, 2007) using a Rapid N cube (Elementar Americas Inc, Mt. Laurel, NJ), ADF (Method 973.18; AOAC, 2007), NDF (Holst, 1973), Ca and P (Method 985.01; AOAC, 2007), and AA (Method 982.30 E [a, b, c]; AOAC, 2007). Soybean meal and the 2 sources of canola meal were also analyzed for acid-hydrolyzed ether extract, which was determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (Method 2003.06, AOAC, 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Acid-hydrolyzed ether extract concentrations were 1.60 and 2.10% (as-fed basis) in CM-CV and CM-HP respectively (Table 4).

Table 4. Analyzed nutrient composition of high-protein canola meal (CM-HP), conventional canola meal (CM-CV), and soybean meal (SBM), as-fed basis

	Ingredient		
Item	CM-HP	CM-CV	SBM
DM, g/kg	894.0	889.0	890.0
CP, g/kg	450.3	405.2	494.8
Acid-hydrolyzed ether extract g/kg	20.9	16.4	6.7
NDF, g/kg	151.0	188.8	67.4
ADF, g/kg	92.2	143.2	38.3
P, g/kg	12.0	10.4	6.2
Ca, g/kg	5.8	6.1	3.3
Indispensable AA, g/kg			
Arg	25.4	23.1	34.7
His	11.2	10.1	12.4
Ile	15.4	14.6	21.0
Leu	28.4	26.7	36.5
Lys	23.3	21.1	28.8
Met	8.3	7.3	6.5
Phe	16.6	15.2	23.9
Thr	16.3	15.6	18.0
Trp	6.2	5.3	6.4
Val	20.4	18.6	22.2
Dispensable AA, g/kg			
Ala	18.0	16.6	20.4
Asp	27.4	25.5	52.0
Cys	10.7	9.0	5.9
Glu	76.5	66.6	84.9
Gly	20.7	19.2	20.2
Pro	24.6	23.4	23.2
Ser	14.8	13.6	20.0
Tyr	10.7	10.7	17.6

Statistical Analysis

Data were analyzed with the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) in a randomized complete block design with pen as the experimental unit. Block was defined as farrowing group, which corresponded with slaughter date. For all measurements, the statistical model included the fixed effects of dietary treatment and the random effect of block. Polynomial contrast statements were used to test linear and quadratic effects of increasing proportions of CM-HP or CM-CV in the diets. Another single degree of freedom contrast statement was used to compare the pooled effects of CM-HP with the pooled effects of CM-CV. Normality of data was confirmed and outliers were tested using the UNIVARIATE procedure of SAS. Statistical significance and tendencies were accepted at $P \leq 0.05$ and $0.05 < P \leq 0.10$, respectively.

Table 5. Effects of high-protein canola meal (CM-HP) and conventional canola meal (CM-CV) on growth performance of finishing pigs

	Diet								*P*-value				
		CM-HP[1]			CM-CV[1]				CM-HP		CM-CV		CM-HP vs.
Item	Control[1]	33%	66%	100%	33%	66%	100%	SEM	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Pen,[4] n	10	10	10	10	10	10	10						
d 0 to 35													
ADG, kg/d	0.84	0.84	0.82	0.82	0.84	0.87	0.86	0.02	0.23	0.94	0.25	0.84	0.03
ADFI, kg/d	1.95	1.95	1.91	1.93	2.00	2.07	1.97	0.05	0.57	0.81	0.55	0.15	0.03
G:F	0.43	0.43	0.43	0.42	0.42	0.42	0.44	0.01	0.59	0.76	0.55	0.21	0.97
d 35 BW, kg	57.1	57.0	56.3	55.9	57.6	58.0	57.8	1.7	0.45	0.91	0.68	0.80	0.20
d 35 to 63													
ADG, kg/d	1.00	1.00	0.97	1.00	1.04	1.01	1.03	0.02	0.51	0.54	0.67	0.66	0.04
ADFI, kg/d	2.68	2.69	2.63	2.72	2.78	2.93	2.87	0.11	0.77	0.54	0.02	0.21	< 0.01
G:F	0.38	0.37	0.37	0.37	0.37	0.36	0.36	0.01	0.22	0.93	0.09	0.76	0.46
d 63 BW, kg	86.7	85.1	83.3	83.7	86.6	86.3	85.8	1.7	0.13	0.52	0.67	0.91	0.09
d 63 to 91													
ADG, kg/d	0.98	0.93	0.91	0.95	0.96	0.93	0.98	0.02	0.21	0.05	0.61	0.18	0.12
ADFI, kg/d	3.07	3.07	3.00	3.07	3.12	3.14	3.23	0.11	0.76	0.57	0.07	0.78	0.02
G:F	0.32	0.30	0.30	0.31	0.31	0.30	0.30	0.01	0.40	0.18	0.08	0.33	0.69
d 91 BW, kg	114.2	111.1	108.8	110.2	113.9	112.7	113.1	1.7	0.06	0.19	0.57	0.83	0.03
d 0 to 91													
ADG, kg/d	0.93	0.92	0.89	0.91	0.94	0.94	0.94	0.01	0.20	0.29	0.70	0.88	0.01
ADFI, kg/d	2.49	2.52	2.46	2.52	2.59	2.67	2.63	0.07	0.89	0.70	0.03	0.19	< 0.01
G:F	0.37	0.37	0.36	0.36	0.36	0.35	0.36	0.01	0.15	0.57	0.02	0.17	0.20

[1]Percentage of canola meal as a replacement for soybean meal.

[2]Quadratic effects of increasing canola meal.

[3]Pooled effects of CM-HP vs. pooled effects of CM-CV.

[4]There were 2 barrows and 2 gilts in each pen.

RESULTS AND DISCUSSION

Growth Performance

In phase 1 (d 0 to d 35), no linear or quadratic effects on ADG, ADFI, G:F, or final BW were observed as a CM-HP or CM-CV were included in the diet (Table 5). However, ADG and ADFI were greater ($P < 0.05$) for pigs fed CM-CV compared with pigs fed CM-HP. In phase 2 (d 35 to d 63), no effect of inclusion of CM-HP were observed, but as CM-CV was included in the diet, ADFI increased (linear, $P < 0.05$) and there was a tendency for a reduction in G:F ($P = 0.09$). However, ADG and final BW were not affected by the inclusion of CM-CV in the diet, but ADG and ADFI were greater ($P < 0.05$) for pigs fed diets containing CM-CV compared with pigs fed diets containing CM-HP. There also was a tendency ($P = 0.09$) for pigs fed CM-CV to be heavier at the end of phase 2 than pigs fed diets containing CM-HP.

In phase 3 (d 63 to d 91), a reduced ADG (quadratic, $P = 0.05$) and a tendency ($P = 0.06$) for a reduced final BW were observed as the inclusion of CM-HP increased in the diets, whereas ADFI and G:F were not affected by CM-HP. There were, however, tendencies ($P = 0.07$ and 0.08, respectively) for ADFI to increase and G:F to decrease as CM-CV was included in the diets, whereas ADG and final BW were not affected by CM-CV. Average daily feed intake and final BW also were greater ($P < 0.05$) for pigs fed CM-CV than for pigs fed CM-HP.

During the entire feeding period (d 0 to d 91), there were no effects of inclusion of CM-HP in the diets, but a linear increase ($P < 0.05$) in ADFI and a linear decrease ($P < 0.05$) in G:F were observed as CM-CV inclusion rate increased. Average daily gain and ADFI also were greater ($P < 0.05$) for pigs fed diets containing CM-CV compared with pigs fed diets containing CM-HP. The reduction in G:F that was observed as CM-CV inclusion in the diets increased is most likely a consequence of the reduced NE in the diets containing CM-CV compared with the control diet and diets containing CM-HP. Pigs fed the diets containing CM-CV responded to the reduced NE by increasing ADFI, which resulted in the reduced G:F.

The presence of glucosinolates in canola meal has caused increased thyroid gland size and hypothyroidism, which has decreased ADG and muscle protein accretion (Spencer, 1985; Mullan et al., 2000). However, the varieties of canola used in this study contained <30 μmol/g glucosinolates (Appendix Table A1), which is the amount generally accepted as below the threshold to cause potential effects, based on the thyroid gland weights reported in previous research (Bell, 1993; Gonzalez-Vega and Stein, 2012). In several previous experiments, it has been demonstrated that between 15 and 30% canola meal can be included in diets fed to growing-finishing pigs without changing growth performance (Busboom et al., 1991; Mullan et al., 2000; King et al., 2001). However, reduced growth performance of pigs fed diets containing up to 18 or 22.5% canola meal has also been reported (Vvan et al. (1996;; Seneviratne et al., 2010). One of the reasons for these differences may be that the canola meals used differ among studies. However, the diets used in this experiment containing the greatest levels of canola meal contained 5 to 6 micromol glucosinolates per gram and this did not appear to have major negative effects on pig growth performance. It is, therefore, likely that other characteristics of canola meal are responsible for the different results obtained among different experiments. Nevertheless, results from this experiment demonstrated that both CM-HP and CM-CV can fully replace SBM in diets fed to growing-finishing pigs without impairing performance. We are not aware of any previous experiments that have provided such results. Based on these data, we conclude that if diets are formulated to contain equal quantities of digestible P and digestible AA, both CM-HP and CM-CV may be used as the major protein source in maize-based diets fed to growing-finishing pigs.

Viscera Mass Differences

To avoid confounding effects of live pig weights on weights of the viscera, only visceral mass as a percentage of ending live weight is discussed. A linear increase ($P < 0.05$) was observed for kidney weights as a percentage of live weight as inclusion of CM-HP or CM-CV increased in the diets (Table 6) and there was a linear increase ($P < 0.01$) in liver weights as a percentage of live weight as CM-CV inclusion in the diets increased. There also was a tendency for an increase (quadratic, $P = 0.09$) in stomach weights as CM-HP inclusion in the diets increased, and there were both linear ($P = 0.07$) and quadratic ($P = 0.06$) tendencies for increased stomach weight as CM-CV inclusion increased. However, no differences in organ weights between pigs fed diets containing CM-HP and diets containing CM-CV were observed.

Busato et al. (1991) reported liver enlargement in pigs fed 5 or 10% of high glucosinolate canola meal (86.5 mmol/g) but reported no liver enlargement in pigs fed 10% of low glucosinolate meal (1.9 mmol/g). In the current experiment, diets containing CM-CV had the greatest levels of glucosinolates (6.7 mmol/g for phase 1, 5.2 mmol/g for phase 2, and 4.5 for phase 3), which may be the reason liver weight increased as CM-CV was included in the diets. However, CM-HP contained much less glucosinolates than CM-CV, which may be the reason pigs fed diets containing CM-HP did not have increased liver weights. The liver enlargement observed as greater levels of glucosinolates are included in the diets is a result of cell hypertrophy rather than hyperplasia, with the cytoplasmic fraction being particularly increased (Busato et al., 1991).

Rundgren (1983) summarized multiple studies and concluded that glucosinolates in rapeseed products fed to pigs had no significant effects on kidney weights. It is, however, possible that the increased kidney weights observed in this experiment are a result of increased fiber in the diets because diet ADF and NDF concentrations increased as dietary canola meal inclusion increased and increased kidney weights have been reported as a consequence of increasing the concentration of fiber in the diets (Pond et al., 1988). With the exception of liver and kidney weight, viscera content weights as a percentage of live weight were not impacted by inclusion of CM-HP or CM-CV in the diets, although concentrations of fiber and glucosinolates increased in the diets as canola meal inclusion increased. This observation indicates that the additional fiber provided by the canola meals used in this experiment did not reach a level that impacted viscera weights other than liver weights.

Carcass Characteristics

There were no differences in ending live weight, HCW, LEA, 10th-rib backfat thickness, and estimated carcass lean among pigs fed CM-HP or CM-CV compared with pigs fed control diets, nor were there differences between pigs fed CM-HP and pigs fed CM-CV (Table 7). There was, however, a tendency (quadratic, $P = 0.07$) for reduced carcass yield when pigs were fed increasing levels of CM-CV. The lack of differences in carcass yield was unexpected because dietary fiber increased with increasing inclusion of CM-HP and CM-CV in the diets, and previous data have indicated that increased fiber in pig diets may reduce carcass yield (Hochstetler et al., 1959; Pond et al., 1988; Pluske et al., 1998). However, it appears that the increases in dietary fiber that were a result of increased inclusion of CM-HP or CM-CV were too small to have a measurable impact on carcass yield.

Hypothyroidism caused by glucosinolates can reduce T_3 and inhibit calpain activity, potentially leading to greater 10th-rib backfat thickness and reduced carcass lean percentage (Du and McCormick, 2009). Shelton et al. (2001) reported that pigs fed CM-CV as the sole source of supplemental intact protein tended to have greater 10th-rib backfat thickness

Table 6. Effects of high-protein canola meal (CM-HP) and conventional canola meal (CM-CV) on viscera mass and proportional differences of finishing pigs

	Diet								*P*-value				
		CM-HP[1]			CM-CV[1]				CM-HP		CM-CV		
Item	Control[1]	33%	66%	100%	33%	66%	100%	SEM	Linear	Quad[2]	Linear	Quad[2]	CM-HP vs. CM-CV[3]
Heart, kg	0.37	0.38	0.36	0.36	0.37	0.36	0.35	0.02	0.54	0.53	0.38	0.63	0.43
Kidney, kg	0.42	0.42	0.45	0.43	0.42	0.44	0.43	0.02	0.31	0.40	0.42	0.50	0.93
Liver, kg	1.80	1.76	1.89	1.78	1.80	1.83	1.91	0.06	0.82	0.56	0.17	0.45	0.40
Thyroid gland, g	11.89	11.30	13.15	11.80	12.78	12.81	11.36	0.75	0.64	0.61	0.64	0.12	0.70
Full intestinal tract, kg	7.84	7.46	8.00	7.47	7.68	7.62	7.67	0.36	0.67	0.80	0.68	0.72	0.94
Esophagus, g	70.63	57.63	71.14	65.01	67.02	66.65	65.88	3.96	0.84	0.37	0.38	0.71	0.53
Stomach, kg	0.63	0.55	0.60	0.57	0.60	0.57	0.58	0.02	0.05	0.18	0.01	0.26	0.52
Small intestine, kg	1.57	1.46	1.47	1.37	1.54	1.46	1.55	0.10	0.05	0.88	0.63	0.37	0.12
Large intestine, kg	1.58	1.41	1.48	1.47	1.58	1.55	1.41	0.12	0.38	0.18	0.04	0.23	0.24
Empty intestinal tract, kg	3.84	3.47	3.63	3.48	3.79	3.64	3.59	0.21	0.06	0.30	0.08	0.96	0.10
Gut fill, kg	4.00	3.98	4.29	3.99	3.89	3.98	4.08	0.23	0.79	0.54	0.75	0.66	0.59
Heart, % live wt	0.31	0.33	0.31	0.32	0.31	0.31	0.31	0.01	0.86	0.60	0.85	0.97	0.11
Kidney, % live wt	0.36	0.36	0.39	0.38	0.36	0.38	0.38	0.01	0.03	0.41	0.05	0.76	0.50
Liver, % live wt	1.55	1.54	1.63	1.59	1.53	1.58	1.70	0.03	0.14	0.67	< 0.01	0.07	0.57
Thyroid gland, % live wt	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.77	0.47	0.59	0.13	0.82
Full intestinal tract, % live wt	6.71	6.53	6.93	6.67	6.51	6.59	6.80	0.22	0.74	0.85	0.68	0.30	0.65
Esophagus, % live wt	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.003	0.61	0.20	0.95	0.32	0.73
Stomach, % live wt	0.54	0.49	0.52	0.51	0.51	0.49	0.51	0.01	0.25	0.09	0.07	0.06	0.99
Small intestine, % live wt	1.33	1.27	1.27	1.23	1.30	1.26	1.38	0.07	0.15	0.78	0.70	0.12	0.15
Large intestine, % live wt	1.35	1.23	1.29	1.32	1.35	1.34	1.25	0.09	0.87	0.15	0.18	0.44	0.49
Empty intestinal tract, % ve wt	3.29	3.04	3.15	3.12	3.21	3.15	3.19	0.15	0.30	0.19	0.37	0.48	0.23
Gut Fill, % live wt	3.42	3.49	3.72	3.55	3.29	3.43	3.61	0.17	0.43	0.51	0.37	0.39	0.33

[1]Percentage of canola meal as a replacement for soybean meal.

[2]Quadratic effects of increasing canola meal.

[3]Pooled effects of CM-HP vs. pooled effects of CM-CV.

compared with pigs fed SBM. However, Castell and Falk (1980) reported no differences in 10th-rib backfat thickness and other carcass characteristics in pigs fed 15% canola seeds compared with pigs fed SBM. Data from the current experiment are also in agreement with Busboom et al. (1991), who fed diets containing SBM, 20% intact canola, or 20% ground canola (conventional; meal form) and reported no differences in carcass measurements. It is possible that these conflicting observations may have been caused by different inclusion levels, different types of canola meal, different canola seed processing techniques, different concentrations of fiber and glucosinolates among sources of canola meal, or differences in AA supplementation among experiments. The fact that diets within each phase used in the current experiment were formulated to contain similar concentrations of standardized ileal

Table 7. Effects of high-protein canola meal (CM-HP) and conventional canola meal (CM-CV) on carcass characteristics of finishing pigs

	Diet								*P*-value				
		CM-HP[1]			CM-CV[1]				CM-HP		CM-CV		
Item	Control[1]	33%	66%	100%	33%	66%	100%	SEM	Linear	Quad[2]	Linear	Quad[2]	CM-HP vs. CM-CV[3]
Ending live wt, kg	116.7	114.3	115.6	111.7	117.8	115.6	112.8	2.6	0.21	0.76	0.20	0.42	0.43
HCW, kg	91.0	89.6	89.8	87.3	92.6	90.5	87.8	2.0	0.21	0.77	0.18	0.27	0.38
Carcass yield, %	78.01	78.41	77.68	78.22	78.58	78.27	77.84	0.28	0.94	0.80	0.51	0.07	0.57
Loin eye area, cm^2	50.81	51.62	51.22	52.22	50.03	49.52	49.49	1.58	0.59	0.95	0.53	0.81	0.12
10th rib backfat, cm	2.03	1.77	1.69	1.78	1.89	1.78	1.88	0.15	0.11	0.13	0.27	0.31	0.27
Estimated carcass lean[4], %	53.89	53.82	53.95	52.87	54.67	53.77	52.37	0.98	0.51	0.61	0.22	0.27	0.95

[1]Percentage of canola meal as a replacement for soybean meal.

[2]Quadratic effects of increasing canola meal.

[3]Pooled effects of CM-HP vs. pooled effects of CM-CV.

[4]Estimate carcass lean, % = [8.588 + (0.465 HCW, lb.) − (21.896 10th rib backfat, in.) + (3.005 loin eye area, in.2)] ÷ CWH, lb (Burson and Berg, 2001).

Table 8. Effects of high-protein canola meal (CM-HP) and conventional canola meal (CM-CV) on LM quality of finishing pigs

	Diet								*P*-value				
		CM-HP[1]			CM-CV[1]				CM-HP		CM-CV		CM-HP vs.
Item	Control[1]	33%	66%	100%	33%	66%	100%	SEM	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Shear force, kg	3.34	3.31	3.68	3.44	3.80	3.68	3.57	0.23	0.52	0.64	0.57	0.22	0.27
Cook Loss, %	22.28	22.12	24.20	22.71	24.89	21.80	22.99	1.61	0.61	0.64	0.88	0.61	0.82
pH	5.48	5.47	5.51	5.53	5.51	5.51	5.52	0.03	0.01	0.38	0.10	0.34	0.35
Objective Color													
L*	49.30	51.35	47.72	46.69	49.52	47.73	47.81	0.85	< 0.01	0.07	0.10	0.93	0.74
a*	7.81	8.57	8.23	8.48	8.49	7.68	8.96	0.45	0.39	0.56	0.18	0.49	0.90
b*	2.93	3.96	2.91	2.45	3.17	2.42	3.54	0.40	0.17	0.07	0.55	0.27	0.84
Subjective evaluations													
Color	3.0	3.0	2.9	3.1	3.0	3.0	3.2	0.09	0.63	0.25	0.15	0.28	0.38
Marbling	1.3	1.3	1.2	1.4	1.3	1.3	1.6	0.19	0.78	0.53	0.21	0.35	0.45
Firmness	2.8	2.4	2.9	2.7	2.7	2.8	2.9	0.19	0.78	0.53	0.21	0.35	0.45
Loin Composition													
Moisture, %	74.23	74.05	74.65	74.38	74.27	74.47	74.2	0.22	0.29	0.84	0.91	0.50	0.78
Lipid, %	2.37	2.53	1.99	2.04	2.58	2.19	2.55	0.26	0.19	0.84	0.89	0.78	0.23
Drip Loss, %	4.38	5.21	3.73	4.01	4.51	4.40	4.73	0.56	0.31	0.63	0.71	0.86	0.62

[1]Percentage of canola meal as a replacement for soybean meal.

[2]Quadratic effects of increasing canola meal.

[3]Pooled effects of CM-HP vs. pooled effects of CM-CV.

digestible AA may also have contributed to a lack of differences in carcass composition among treatments.

Meat Quality

There were no effects of CM-HP or CM-CV on shear force, cook loss, ultimate LM pH, subjective color, subjective marbling, subjective firmness, LM composition (moisture and lipid), or drip loss, nor were there differences between pigs fed CM-HP and pigs fed CM-CV (Table 8). There was a linear increase ($P < 0.05$) in ultimate LM pH, a linear decrease ($P < 0.01$) in objective L*, a tendency for a quadratic reduction ($P = 0.07$) for objective L*and for objective b* as inclusion of CM-HP increased. There was a tendency for a linear increase ($P = 0.10$) in ultimate LM pH and a tendency for a linear decrease ($P = 0.10$) in objective L* as CM-CV inclusion rate increased. Data for fresh ham quality (ultimate pH and objective L*, a*, and b*) on 6 ham muscles are presented in supplementary Table S1.

The potential for hypothyroidism to reduce calpain activity may result in decreased tenderness (Marple et al., 1975; Küchenmeister and Kuhn, 2003). However, lack of differences in shear force provided evidence that glucosinolates levels in the canola meal used in this experiment did not cause negative effects on tenderness. Decreased L* values indicated darker LM color, which agree with results from Dransfield et al. (1985), who reported LM from pigs fed canola meal were darker compared with LM from pigs fed SBM. More research is needed to investigate why meat from pigs fed canola meal becomes darker. The lack of other quality differences among treatments in the current study is in agreement with previous research (Busboom et al., 1991), which indicated that pork quality in pigs fed canola meal compared with pigs fed SBM was not changed.

Carcass Cutability

Pigs fed CM-CV tended (linear, $P = 0.08$) to have reduced right side chilled weight and tendencies (quadratic, $P = 0.10$ and 0.09, respectively) for reduced lean cutting yield and carcass cutting yield were observed as the inclusion of CM-CV increased in the diets (Table 9). There was also a tendency (quadratic, $P = 0.07$) for an increase and then a decrease in boneless carcass cutting yield as inclusion of CM-HP increased in the diets. Boneless lean cutting yield and boneless carcass cutting yield were greater ($P < 0.05$) in pigs fed diets containing CM-HP than in pigs fed diets containing CM-CV, and tendencies ($P = 0.06$ and 0.08, respectively) for greater lean cutting yield and carcass cutting yield were observed for pigs fed diets containing CM-HP compared with pigs fed diets containing CM-CV. Limited published data are available to compare cutting yields of pigs fed diets containing alternative protein sources, particularly canola meal. Differences in cutability was not anticipated. In this experiment, pigs were fed diets with similar CP and NE levels. Hinson et al. (2012) reported that increasing CP from 13% to nearly 18% (energy levels were the same) in finishing diets resulted in a tendency ($P = 0.10$) for a 1.65-kg

Table 9. Effects of high-protein canola meal (CM-HP) and conventional canola meal (CM-CV) on carcass cutability of finishing pigs

	Diet								P-value				
		CM-HP[1]			CM-CV[1]				CM-HP		CM-CV		CM-HP vs.
Item	Control[1]	33%	66%	100%	33%	66%	100%	SEM	Linear	Quad[2]	Linear	Quad[2]	CM-CV[3]
Right side chilled weight, kg	44.46	43.64	43.86	42.86	45.16	44.25	42.23	0.99	0.29	0.92	0.08	0.16	0.59
Lean cutting yield[4], %	58.63	59.56	58.51	58.21	57.22	57.34	58.32	1.40	0.47	0.39	0.79	0.10	0.06
Boneless lean cutting yield[5], %	39.44	40.88	39.38	39.09	38.32	38.25	38.96	0.90	0.38	0.18	0.60	0.16	0.02
Carcass cutting yield[6], %	70.76	71.72	70.63	70.27	69.56	70.02	70.66	1.25	0.30	0.22	0.95	0.09	0.08
Boneless carcass cutting yield[7], %	51.56	53.04	51.50	51.14	50.66	50.93	51.30	0.75	0.22	0.07	0.82	0.21	0.03

[1]Percentage of canola meal as a replacement for soybean meal.

[2]Quadratic effects of increasing canola meal.

[3]Pooled effects of CM-HP vs. pooled effects of CM-CV.

[4]Lean cutting yield, % = [(trimmed ham, kg + trimmed loin, kg + Boston butt, kg + picnic, kg) ÷ right side chilled weight, kg] × 100.

[5]Boneless lean cutting yield, % = [(inside ham, kg + outside ham, kg + knuckle, kg + light butt, kg + shank, kg + Canadian back, kg + tenderloin, kg + sirloin, kg + boneless Boston butt, kg + boneless picnic, kg) ÷ right side chilled weight, kg] × 100.

[6]Carcass cutting yield, % = [(trimmed ham, kg + trimmed lion, kg + Boston butt, kg + picnic, kg + trimmed belly, kg) ÷ right side chilled weight, kg] × 100.

[7]Boneless carcass cutting yield, % = [(inside ham, kg + outside ham, kg + knuckle, kg + light butt, kg + shank, kg + Canadian back, kg + tenderloin, kg + sirloin, kg + boneless Boston butt, kg + boneless picnic, kg + trimmed belly, kg) ÷ right side chilled weight, kg] × 100.

heavier carcass that also had 0.6% units greater (P = 0.03) carcass lean estimates. Even so, this did not result in differences in cutability of any primal or subprimal component of the carcass (Kutzler et al., 2011). Carcass cutability was also not influenced by dietary fiber differences of finishing barrows. A 1.7% unit increase in crude fiber did not alter ($P \geq 0.44$) cutability of barrows weighing approximately 118 kg at the time of slaughter (Asmus et al., 2014; Tavárez et al., 2014). Additional primal and subprimal cutout weights and primal and subprimal percentages are presented in supplementary Tables S2 and S3, respectively.

CONCLUSION

Replacement of SBM by CM-HP in diets fed to growing-finishing pigs did not result in any changes in ADG, ADFI, or G:F, but the final BW tended to be reduced as inclusion of CM-HP increased. If SBM was replaced by CM-CV, ADG and final BW were not changed, but overall ADFI was increased and G:F was reduced, which is likely a result of the reduced NE in diets containing CM-CV compared with the control diets. With the exception of kidney weights and liver weights, the 2 sources of canola meal did not substantially influence any measurement for organ weights. There was a tendency (linear, $P = 0.07$) for a decrease in stomach percentage as CM-CV increased. Carcass characteristics and LM tenderness were not affected when pigs were fed canola meal. Boneless cutting yields were improved in pigs fed CM-HP compared with pigs fed CM-CV, but in general, cutting yields of pigs fed CM-HP and pigs fed CM-CV were similar to cutting yields of pigs fed control diets. Therefore, these data indicate that SBM can be completely replaced by CM-HP or CM-CV without considerable changes in growth performance, visceral mass, carcass characteristics, fresh meat quality, or carcass cutability, provided that diets are formulated to contain similar quantities of standardized ileal digestible AA.

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Appendix Table A1. Analyzed glucosinolates of high-protein canola meal (CM-HP) and conventional canola meal (CM-CV), as-fed basis

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

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