Canola meal produced from high-protein or conventional varieties of canola seeds may substitute soybean meal in diets for gestating and lactating sows without compromising sow or litter productivity

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ABSTRACT: An experiment was conducted to test the hypothesis that productivity of sows fed diets containing canola meal produced from high-protein or conventional varieties of canola seeds is not different from that of sows fed corn–soybean meal (**SBM**) diets. A total of 180 sows (initial BW: 207.8 ± 29.11 kg) were randomly allotted to 1 of 5 diets with 36 to 40 sows per diet. A 2-phase feeding program was used with gestation diets fed from day 7 of gestation to farrowing and lactation diets fed during the lactation period and from weaning to first estrus. The 5 diets within each phase consisted of a control diet based on corn and SBM, 2 diets were based on corn and high-protein canola meal (**CM-HP**) that was included to replace 50 or 100% of the SBM in the control diet, and 2 diets contained conventional canola meal (**CM-CV**) included to replace 50 or 100% of the SBM in the control diet. Soybean hulls were included in diets fed during gestation to standardize the concentration of NDF to approximately 13% in all diets. However, no soybean hulls were used in lactation diets resulting in increased concentrations of NDF as the dietary concentration of CM-HP or CM-CV increased. Results of the experiment indicated that there were no differences in sow BW changes during gestation, in sow BW on day 1 post-farrowing, or at weaning due to dietary treatments. No differences were observed among diets in ADFI during gestation or lactation or in the number of total pigs born, pigs born alive, still-born pigs, or weaned pigs per litter. Likewise, no differences were observed among diets in litter birth weight, live litter birth weight, litter BW at weaning, or litter ADG. As the inclusion level of CM-HP or CM-CV increased, the percentage of pigs surviving during the lactation period increased (linear, $P < 0.05$), but the wean to first estrus interval also increased as the dietary concentration of CM-CV increased (linear, $P < 0.05$). Average pig BW at weaning and pig ADG decreased (linear, $P < 0.05$) as the inclusion level of CM-HP increased. No differences were observed between CM-HP and CM-CV with the exception that pigs born from sows fed CM-CV during gestation had greater ($P < 0.05$) average live pig birth weight compared with pigs born from sows fed CM-HP during gestation. Results of this experiment indicate that CM-HP or CM-CV may replace all SBM in diets fed to sows during gestation and lactation.

Key words: conventional canola meal, high-protein canola meal, sows, soybean meal

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INTRODUCTION

Canola meal, which is produced after oil is extracted from canola seeds, is the second most used protein source in animal diets (King et al.,

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2001; Arntfield and Hickling, 2011). Compared with soybean meal (**SBM**), canola meal has relatively low concentration of digestible amino acids and DE because it contains 10 to 20% less protein and approximately 3 times more fiber (Berrocoso et al., 2015). Inclusion of canola meal in diets for growing–finishing pigs is restricted by the relatively high concentration of fiber (Newkirk, 2009; Barthet and Daun, 2011) and also by the concentration of glucosinolates in the meal (Schöne et al., 2001), but limited research has been reported to determine the utilization of canola meal in diets fed to sows. The recommended maximum inclusion rate of canola meal in lactation diets is 20%, but no limit has been reported for gestation diets (King et al., 2001; Canola Council of Canada, 2015). However, Smiricky-Tjardes et al. (2003) indicated that including canola meal in gestation and lactation diets reduced the number of pigs born alive, lactation feed intake, the number of pigs weaned per litter, and litter weaning weight.

New varieties of black-seeded canola (*Brassica napus*) with increased concentration of protein and reduced concentration of fiber have been identified, and canola meal produced from these varieties also contains more protein and less fiber compared with conventional canola meal (**CM-CV**; Berrocoso et al., 2015; Liu et al., 2016). There is, however, no information about feeding high-protein canola meal (**CM-HP**) to sows during gestation and lactation. Therefore, the objective of this research was to test the hypothesis that 50 or 100% of the SBM in diets for gestating and lactating sows may be replaced by CM-HP or CM-CV without affecting sow or litter productivity.

MATERIALS AND METHODS

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois at Urbana-Champaign, and the experiment was conducted at the Swine Research Center at the University of Illinois.

One source of SBM was obtained from the University of Illinois feed mill (Champaign, IL) and CM-HP and CM-CV were provided by Dow AgroScience LLC (Indianapolis, IN; Table 1). All 3 ingredients were analyzed in duplicate for DM (Method 930.05; AOAC International, 2007), ash (Method 942.05, AOAC International, 2007), CP (Method 990.03; AOAC International, 2007), and acid hydrolyzed ether extract, which was determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (Method 2003.06, AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Ingredients were also analyzed in duplicate for GE using an isoperibol bomb calorimeter (Model 6300; Parr Instruments, Moline, IL), crude fiber (Method 978.10; AOAC International, 2007), ADF (Method 973.18; AOAC International, 2007), NDF (Holst, 1973), lignin [Method 973.18 (A-D); AOAC International, 2007], sucrose, raffinose, stachyose, fructose, and glucose (Janauer and Englmaier, 1978), Ca and P (Method 985.01; AOAC International, 2007), phytate (Ellis et al., 1977), and amino acids [Method 982.30 E (a, b, c); AOAC International, 2007]. The concentration of phytate P in each ingredient was calculated as 28.2% of phytate (Tran and Sauvant; 2004), and nonphytate P was calculated as the difference between the concentration of total P and phytate P. Both sources of canola meal were also analyzed for glucosinolates using high-performance liquid chromatography (Lee et al., 2008). The same batches of SBM, CM-HP, and CM-CV were used in all diets.

A 2-phase feeding program was used with gestation diets fed from day 7 of gestation to farrowing, and lactation diets were fed during the lactation period and from weaning to breeding. The 5 diets that were used in gestation included a control diet based on corn, SBM, and soybean hulls, 2 diets containing CM-HP in quantities sufficient to replace 50 or 100% of the SBM in the control diet, and 2 diets containing CM-CV in quantities needed to replace 50 or 100% of the SBM in the control diets (Tables 2 and 3). Inclusion of soybean hulls was adjusted as CM-HP or CM-CV increased to maintain ADF and NDF constant among diets. Diets used in lactation were formulated using the same principles as diets used in gestation with the exception that no soybean hulls were used, and as a consequence, dietary concentration of ADF and NDF increased with increased inclusion of CM-HP or CM-CV in the diets. All diets were formulated based on the digestibility values for energy, amino acids, and P that had been determined in SBM, CM-HP, and CM-CV in previous research (Berrocoso et al., 2015; She et al., 2017) and all diets were formulated to meet current estimates for nutrient requirements for gestating or lactating sows (NRC, 2012).

A total of 180 sows (Camborough, Pig Improvement Company; Hendersonville, TN; average parity: 2.3; initial BW: 207.8 ± 29.11 kg) were used in the experiment. Sows were randomly

Table 1. Analyzed composition of soybean meal, high-protein canola meal, and conventional canola meal, as fed-basis

Item	Soybean meal	Canola meal, high protein	Canola meal, conventional
DM, %	89.00	89.40	88.90
Ash, %	5.74	7.64	7.14
CP, %	49.48	45.03	40.52
GE, kcal/kg	4,245	4,306	4,267
AEE,[1] %	0.67	2.09	1.64
Crude fiber, %	3.58	7.66	9.90
ADF, %	3.83	9.22	14.32
NDF, %	6.74	15.10	18.88
Lignin, %	0.06	3.73	8.45
Ca, %	0.33	0.58	0.61
P, %	0.62	1.20	1.04
Phytate,%	1.36	3.08	2.65
Phytate P,[2] %	0.38	0.87	0.75
Nonphytate P,[3] %	0.24	0.33	0.29
Carbohydrates, %			
Fructose	0.11	0.02	0.02
Glucose	0.12	0.03	0.04
Sucrose	7.45	5.34	6.00
Raffinose	1.07	0.52	0.35
Stachyose	3.07	0.65	0.80
Indispensable AA, %			
Arg	3.47	2.54	2.31
His	1.24	1.12	1.01
Ile	2.10	1.54	1.46
Leu	3.65	2.84	2.67
Lys	2.88	2.33	2.11
Met	0.65	0.83	0.73
Phe	2.39	1.66	1.52
Thr	1.80	1.63	1.56
Trp	0.64	0.62	0.53
Val	2.22	2.04	1.86
Total	21.04	17.15	15.76
Dispensable AA, %			
Ala	2.04	1.80	1.66
Asp	5.20	2.74	2.55
Cys	0.59	1.07	0.90
Glu	8.49	7.65	6.66
Gly	2.02	2.07	1.92
Pro	2.32	2.46	2.34
Ser	2.00	1.48	1.36
Tyr	1.76	1.07	1.07
Total	24.42	20.34	18.46
Glucosinolates (µmol/g)	–	10.2	19.1

[1]AEE = acid hydrolyzed ether extract.

[2]Calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[3]Calculated as the difference between phytate P and total P.

allotted to 1 of the 5 dietary treatments on day 7 of gestation. There were 36 to 40 replicate sows per diet. All sows, regardless of parity, were fed approximately 7,400 kcal ME/d from the start of the experiment and until they were moved to the farrowing facility and fed approximately 10,200 kcal ME/d from entering the farrowing facility until farrowing. Because of the slightly lower ME in the diets containing CM-CV compared with diets containing CM-HP, sows fed CM-CV diets were offered slightly more feed than sows fed the CM-HP diets to maintain constant ME intake. After parturition, all sows were fed 4.5 kg/d for 4 d and after that they were allowed ad libitum access to feed

Table 2. Ingredient composition of experimental diets, gestation

		High-protein canola meal		Conventional canola meal	
Item	Control	50%	100%	50%	100%
Ground corn	67.95	68.37	68.70	68.32	68.71
High-protein canola meal	–	10.10	20.30	–	–
Conventional canola meal	–	–	–	11.65	23.30
Soybean hulls	10.00	8.50	7.00	7.00	4.00
Soybean meal, 48% CP	18.00	9.00	–	9.00	–
Soybean oil	1.00	1.00	1.00	1.00	1.00
Limestone	0.80	0.80	0.78	0.78	0.76
Dicalcium phosphate	1.45	1.38	1.32	1.40	1.32
L-Lysine HCl, 78% Lys	-	0.05	0.10	0.05	0.11
Salt	0.40	0.40	0.40	0.40	0.40
Choline	0.10	0.10	0.10	0.10	0.10
Vitamin–mineral premix[1]	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00
Calculated composition					
ME, kcal/kg[2]	3,178	3,208	3,240	3,181	3,185
NE, kcal/kg[2]	2,344	2,343	2,342	2,312	2,281
CP, %	15.53	15.51	15.52	15.52	15.51
ADF, %	6.80	6.78	6.76	6.89	6.98
NDF, %	13.34	13.41	13.48	13.19	13.03
Ca, %	0.78	0.78	0.78	0.78	0.78
P, %	0.57	0.62	0.68	0.63	0.67
Digestible P,[3] %	0.34	0.34	0.34	0.34	0.34
Amino acids,[4] %					
Arg	0.87	0.79	0.70	0.79	0.70
His	0.36	0.35	0.34	0.35	0.34
Ile	0.53	0.48	0.43	0.48	0.44
Leu	1.22	1.15	1.08	1.16	1.10
Lys	0.62	0.61	0.61	0.61	0.61
Met	0.22	0.24	0.26	0.24	0.25
Met + Cys	0.46	0.52	0.58	0.51	0.56
Phe	0.65	0.59	0.53	0.59	0.53
Thr	0.46	0.44	0.43	0.45	0.44
Trp	0.14	0.15	0.15	0.14	0.14
Val	0.60	0.58	0.57	0.58	0.56

[1]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D3 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 B12, 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.

[2]Values for ME and NE were calculated based on ME and DE in each energy contributing ingredient. Values for ME and NE in corn, soybean hulls, and soybean oil were based on NRC (2012), and values for ME and NE in soybean meal, high-protein canola meal, and conventional canola meal were from Berrocoso al. (2015).

[3]Standardized total tract digestible (STTD) P. Values were calculated based on standardized total tract digestibility of P in corn, soybean hulls, and dicalcium phosphate published by NRC (2012), and values for standardized total tract digestibility of P in soybean meal, high-protein canola meal, and conventional canola meal were from She et al. (2017).

[4]Amino acids are indicated as standardized ileal digestible AA. Values were calculated based on values for standardized ileal digestibility of AA in corn, soybean hulls, and L-Lys HCL published by NRC (2012), and standardized ileal digestibility values for AA in soybean meal, high-protein canola meal, and conventional canola meal were from Berrocoso et al. (2015).

until weaning. The weight of the feed added to the feeders was recorded, and the feed left in the feeder on the last day of lactation was recorded as well. During gestation, sows were individually housed in gestation stalls (2.1 × 0.6 m) with a feeder and a nipple waterer, and in the farrowing unit, sows were housed in farrowing crates (2.1 × 1.5 m) that had plastic-coated slatted floors. Room temperature was moderated with exhaust fans in the summer months and with whole-room heaters for the winter months. Each crate contained a stainless steel feeder and 2 nipple waterers.

Table 3. Ingredient composition of experimental diets, lactation

	Diet				
		High-protein canola meal		Conventional canola meal	
Item	Control	50%	100%	50%	100%
Ground corn	66.65	65.68	64.42	62.25	56.48
High-protein canola meal	–	14.83	29.90	–	–
Conventional canola meal	–	–	–	16.90	35.10
Soybean meal, 48% CP	27.00	13.50	–	13.50	–
Soybean oil	3.00	2.70	2.43	4.10	5.30
Limestone	0.77	0.72	0.67	0.66	0.55
Dicalcium phosphate	1.70	1.60	1.50	1.62	1.53
L-Lys HCl, 78% Lys	0.08	0.17	0.25	0.17	0.24
L-Thr	–	–	0.03	–	–
Salt	0.40	0.40	0.40	0.40	0.40
Choline	0.10	0.10	0.10	0.10	0.10
Vitamin–mineral premix[1]	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00
Calculated composition					
ME, kcal/kg[3]	3,404	3,404	3,404	3,404	3,404
NE, kcal/kg[3]	2,505	2,462	2,417	2,420	2,323
CP, %	18.85	18.77	18.77	18.66	18.88
ADF, %	2.95	3.78	4.61	4.73	6.65
NDF, %	7.89	9.13	10.38	9.77	11.77
Ca, %	0.80	0.80	0.80	0.80	0.80
P, %	0.66	0.73	0.81	0.73	0.80
Digestible P,[3] %	0.40	0.40	0.40	0.40	0.40
Amino acids,[4] %					
Arg	1.12	0.99	0.87	0.99	0.88
His	0.44	0.43	0.41	0.42	0.41
Ile	0.67	0.59	0.52	0.60	0.53
Leu	1.45	1.34	1.23	1.33	1.23
Lys	0.87	0.87	0.87	0.87	0.87
Met	0.26	0.29	0.31	0.28	0.30
Met + Cys	0.53	0.62	0.70	0.60	0.67
Phe	0.81	0.72	0.63	0.71	0.62
Thr	0.58	0.55	0.55	0.56	0.55
Trp	0.19	0.19	0.20	0.19	0.19
Val	0.75	0.72	0.69	0.71	0.69

[1]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D3 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 B12, 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.

[2]Values for ME and NE were calculated based on ME and DE in each energy contributing ingredient. Values for ME and NE in corn and soybean oil were based on NRC (2012), and values for ME and NE in soybean meal, high-protein canola meal, and conventional canola meal were from Berrocoso al. (2015).

[3]Standardized total tract digestible (STTD) P. Values were calculated based on standardized total tract digestibility of P in corn and dicalcium phosphate published by NRC (2012), and values for standardized total tract digestibility of P in soybean meal, high-protein canola meal, and conventional canola meal were from She et al. (2017).

[4]Amino acids are indicated as standardized ileal digestible AA. Values were calculated based on values for standardized ileal digestibility of AA in corn and crystalline AA published by NRC (2012), and standardized ileal digestibility values for AA in soybean meal, high-protein canola meal, and conventional canola meal were from Berrocoso et al. (2015).

The BW of sows was recorded at the start of the experiment, at entry into the farrowing unit (day 107 of gestation), on day 1 post-farrowing, and at weaning. Average daily feed intake was also calculated for the gestation period and for the lactation period. The number of pigs born alive, stillborn pigs, mummies, and total pigs born per litter were recorded. To equalize litter size, a total of 55 pigs were cross fostered to another sow on day 1 post-farrowing, but pigs were always transferred to a sow within the same treatment. Live pig BW at birth, after cross-fostering, and at weaning (21 days post-partum) were also recorded. Average daily gain per litter and per pig, and pig survival rate from cross-fostering to weaning, were calculated.

Normality of data was confirmed and outliers were tested using the UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC). Outliers were identified as values that deviated from the diet mean by more than 3 times the interquartile range, but no outliers were removed from the data set. Data were analyzed using the PROC MIXED of SAS. The statistical model included the fixed effect of diet and the random effect of group. Least square means were calculated for each independent variable. Contrast statements were used to test linear effects of including graded levels of CM-HP or CM-CV to the diets and to test the difference between CM-HP and CM-CV. Statistical significance and tendencies were considered at $P < 0.05$ and $0.05 \leq P < 0.10$, respectively.

RESULTS

The concentration of CP in SBM was 49.48%, whereas CM-HP and CM-CV contained 45.03 and 40.52% CP, respectively (Table 1). The concentration of ADF, NDF, and lignin were 9.22, 15.10, and 3.73% in CM-HP, 14.32, 18.88, and 8.45% in CM-CV, but SBM contained 3.83% ADF, 6.74% NDF, and 0.06% lignin.

No differences among diets were observed in sow BW on day 7 of gestation, day 107 of gestation, day 1 post-farrowing, or at weaning (Table 4). No effects of CM-HP or CM-CV were observed for sow BW changes during lactation or during the overall experiment period and no differences were observed in ADFI during gestation or lactation. Increasing the inclusion of CM-CV linearly increased ($P < 0.05$) wean to first estrus interval and sows fed CM-CV diets tended to have greater ($P = 0.06$) ADFI during gestation compared with sows fed CM-HP diets.

No effects of CM-HP or CM-CV were observed on the number of total born pigs, pigs born alive, still-born pigs, litter birth weight, live litter birth weight, litter BW at weaning, litter ADG, average pig birth weight, or average live pig birth weight (Table 5). Average pig BW at weaning and pig ADG was linearly decreased ($P < 0.05$) as the inclusion of CM-HP increased. However, as inclusion of CM-HP or CM-CV increased, the percentage of pigs surviving to weaning was linearly increased ($P < 0.05$). There was also a tendency (linear, $P = 0.09$) for average number of pigs at weaning to increase as the inclusion of CM-HP increased in the diets. Sows fed CM-CV diets tended ($P = 0.07$) to have less still-born pigs compared with sows fed CM-HP diets. In addition, pigs from sows fed CM-CV diets during gestation had greater ($P < 0.05$) average live birth weight and had greater ($P < 0.05$) average BW at weaning than pigs from sows fed diets containing CM-HP.

DISCUSSION

Canola meal has been improved by selection of new varieties of canola seeds that have increased

Table 4. Effects of high-protein canola meal (CM-HP) or conventional canola meal (CM-CV) on sow productivity

	Diet						*P* value		
		CM-HP		CM-CV		SEM	CM-HP	CM-CV	CM-HP vs. CM-CV
Item	Control	50%	100%	50%	100%		Linear	Linear	
No. of sows	38	37	36	34	35				
Parity	2.33	2.38	2.22	2.32	2.33	0.31	0.79	1.00	0.93
Sow BW at d 7 gestation, kg	211.3	205.3	210.0	207.7	204.5	5.05	0.84	0.33	0.76
Sow BW at d 107 gestation, kg	271.3	264.9	266.0	268.1	266.8	4.59	0.36	0.45	0.64
Sow BW at d 1 post-farrowing, kg	262.2	250.4	253.1	256.4	252.8	4.46	0.14	0.12	0.52
Sow BW at weaning, kg	243.3	235.6	235.6	240.9	233.6	4.95	0.26	0.15	0.73
Sow lactation BW change,[1] kg	−19.02	−15.04	−17.55	−15.68	−19.09	2.27	0.60	0.98	0.60
Sow overall BW change,[2] kg	−28.23	−29.89	−30.56	−27.23	−32.75	3.20	0.52	0.22	0.93
ADFI in gestation, kg	2.41	2.37	2.37	2.41	2.42	0.03	0.24	0.65	0.06
ADFI in lactation, kg	4.76	4.56	4.71	4.66	4.52	0.25	0.81	0.26	0.78
Wean to first estrus interval, d	5.42	5.33	5.35	5.22	5.80	0.15	0.62	<0.05	0.12

[1]Sow lactation BW change was calculated as the difference between sow weaning weight and sow BW at day 1 post-farrowing.

[2]Sow overall BW change was calculated as the difference between sow weaning weight and sow BW at day 107.

Table 5. Effects of high-protein canola meal (CM-HP) or conventional canola meal (CM-CV) on litter performance

	Diet						*P* value		
	Control	CM-HP		CM-CV		SEM	CM-HP	CM-CV	CM-HP vs. CM-CV
Item		50%	100%	50%	100%		Linear	Linear	
Total pigs born	13.97	14.05	14.27	12.94	13.78	0.62	0.73	0.82	0.20
Pigs born alive	12.46	12.36	12.76	11.92	12.22	0.56	0.71	0.76	0.39
Still-born pigs	1.26	1.59	1.41	0.86	1.17	0.26	0.68	0.81	0.07
Pigs after cross fostering	12.51	12.36	12.81	12.08	12.25	0.51	0.68	0.72	0.42
Litter birth wt, kg	20.40	21.36	21.38	20.26	20.66	0.78	0.34	0.80	0.22
Live litter birth wt, kg	18.68	18.88	19.52	19.12	19.13	0.76	0.39	0.65	0.92
Live litter birth wt after cross fostering, kg	15.74	16.10	17.28	17.27	17.14	0.71	0.09	0.12	0.42
Litter BW at weaning, kg	64.49	63.24	65.90	66.20	66.91	2.47	0.67	0.47	0.41
Litter ADG,[1] kg	2.32	2.25	2.32	2.33	2.37	0.09	0.96	0.71	0.44
Average pig birth wt,[2] kg	1.51	1.71	1.53	1.63	1.55	0.10	0.86	0.76	0.73
Average live pig birth wt,[3] kg	1.54	1.56	1.56	1.66	1.63	0.04	0.83	0.17	<0.05
Average pig BW at weaning,[4] kg	6.52	6.43	6.08	6.53	6.58	0.17	<0.05	0.78	<0.05
Pig ADG,[5] kg	0.23	0.23	0.21	0.23	0.23	0.007	<0.05	0.96	0.10
Pigs per litter at weaning	10.00	9.91	10.98	10.31	10.40	0.42	0.09	0.49	0.83
Pigs survival to weaning,[6] %	80.20	81.64	86.68	86.98	87.03	2.20	<0.05	<0.05	0.20

[1]Litter ADG = (litter weaning weight – litter live birth weight after cross fostering)/days of lactation.
[2]Average pig birth weight = total pig birth weight/total pigs born.
[3]Average live pig birth weight = total live pig birth weight/total live pigs born.
[4]Average pig BW at weaning = total pig weight at weaning/total pigs at weaning.
[5]Pig ADG = (average pig weaning weight – average live birth weight)/days of lactation.
[6]Survivability (%) = (pigs weaned/pigs born alive after cross fostering) × 100.

CP and decreased NDF and ADF (Berrocoso et al., 2015; Liu et al., 2016). Canola meal from these new varieties may, therefore, be used as an alternative protein source in pig diets. Concentrations of CP and amino acids in CM-HP, CM-CV, and SBM used in this experiment are within the range of reported values (Berrocoso et al., 2015; Liu et al., 2016). The reason for the increased concentrations of CP and amino acids in CM-HP compared with CM-CV is that the increased size and thinner hull of high-protein canola seeds reduce the proportion of canola hulls in the meal (Slominski et al., 2012; Trindade Neto et al., 2012). Because the hulls have a lower concentration of amino acids, but a greater concentration of fiber, than other parts of the seed, the meal from larger seeds contains more CP and less fiber than meal from conventional seeds. The difference in fiber content between CM-HP and CM-CV mainly is due to differences in the concentration of lignin with associated polyphenols (Slominski et al., 1994, 2012). The analytical data for the ingredients used in this experiment also demonstrated that the concentration of lignin was much lower in CM-HP compared with CM-CV, which is in agreement with the observation by Slominski et al. (1994). The lower concentrations of CP in CM-CV than in soybean meal are also consistent with published data (González-Vega and Stein, 2012; NRC, 2012; Maison and Stein, 2014; Liu et al., 2016).

Canola meal from newer varieties of canola seeds contains less glucosinolates compared with canola meal from older varieties (Liu et al., 2016). The concentration of glucosinolates in CM-HP used in this experiment was less than in meals used in previous experiments (Slominski et al., 2012; Liu et al., 2014; Berrocoso et al., 2015), which may have contributed to the fact that ADFI was not reduced by sows fed diets containing canola meal compared with sows fed the control diet.

King et al. (2001) suggested that canola meal may be included by up to 20% in diets for lactating sows without adversely affecting lactation or reproductive performance. Recently, Velayudhan and Nyachoti (2017) demonstrated that up to 30% conventional canola meal may be included in diets for lactating sows without changing sow BW or ADFI during lactation, and no differences in weaning to estrus interval, in litter size at weaning, piglet BW at birth, pig BW at weaning, or pig ADG was observed. Thus, results from the present experiment are in agreement with the results by Velayudhan and Nyachoti (2017).

Results of this experiment also confirmed the hypothesis that CM-HP or CM-CV can be used in sow diets to partially or fully replace SBM without negative effects on reproductive and litter performance, except for wean to first estrus that increased by including CM-CV in the diets. It is possible that the small increase in wean to first estrus interval is a result of the sows fed the diet in which CM-CV replaced all soybean meal had a slightly increased loss of BW in lactation compared with sows fed the control diet. The reduced ADG of pigs from sows fed diets with 100% CM-HP is likely a result of the tendency for an increased number of pigs per litter at weaning due to the increased pig survival rate of pigs from sows fed diets with 100% CM-HP. It is not clear why pig survival during lactation was greater for sows fed diets containing CM-HP or CM-CV instead of SBM. Increased fiber in gestation diets may increase litter size at weaning (Reese et al., 2008), but in this experiment the inclusion of soybean hulls in gestation diets was adjusted to maintain a constant concentration of NDF among diets. However, because no soybean hulls were included in lactation diets, NDF increased as canola meal was included in the diets fed during lactation, and it is possible that the increased fiber resulted in calmer sows that were less likely to crush pigs during lactation. However, we do not have data to support this theory so additional research is needed to address this question.

Previous data indicate that feeding canola meal to sows may reduce the number of pigs born alive, lactation feed intake, and the number of pigs weaned (Smiricky-Tjardes et al., 2003). It is possible that the reason for these observations is that diets in the above study were formulated based on total CP and DE values, whereas diets in the present experiment were formulated based on values for digestible amino acids and ME. The energy value of diets rich in protein or fiber is overestimated when expressed on a DE basis (Velayudhan et al., 2015), which may partly explain the results in the experiment by Smiricky-Tjardes et al. (2003).

The greater concentrations of glucosinolates in CM-CV than in CM-HP appears to have no negative impact, because pigs from sows fed diets containing CM-CV had greater live birth weight and had greater BW at weaning than pigs from sows fed CM-HP although CM-HP contained less glucosinolates. Overall, only small differences in pig birth weight and average weight of pigs at weaning between CM-HP and CM-CV were observed, and no other differences in production parameters between the 2 sources of canola meal were observed. This indicates that both sources of canola meal may be used in diets for gestating and lactating sows.

In conclusion, no negative effects of CM-HP or CM-CV were observed on sow and litter performance. To our knowledge, this is the first time it has been demonstrated that both CM-HP and CM-CV may fully replace SBM in diets fed to gestating and lactating sows without negatively affecting sow or litter productivity. However, future studies using diets based on CM-HP or CM-CV over several parities are needed to confirm results from this experiment.

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