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Nutrient digestibility of extruded canola meal in ileal-cannulated growing pigs and effects of its feeding on diet nutrient digestibility and growth performance in weaned pigs

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Abstract

Canola meal (**CM**) contains less crude protein (**CP**) and more fiber and anti-nutritional factors such as glucosinolates than soybean meal (**SBM**) and consequently has a lower nutrient digestibility. Therefore, processing strategies that may increase the feeding value of CM warrant study. In two experiments, the effects of extrusion of *Brassica napus* CM on apparent (**AID**) and standardized ileal digestibility (**SID**) of amino acids (**AA**), apparent total tract digestibility (**ATTD**) of gross energy (**GE**) in growing pigs, and growth performance and diet digestibility in weaned pigs were assessed. Solvent-extracted CM was extruded using a single-screw extruder at three screw speeds: 250 (CM-250), 350 (CM-350), or 450 (CM-450) rpm. In exp. 1, in a double 4 × 4 Latin square, eight ileal-cannulated barrows (initial body weight [**BW**], 68.1 kg) were fed corn starch-based diets containing 50% CM or extruded CM. The CM sample contained 43.2% CP, 33.2% total dietary fiber (**TDF**), and 8.9 µmol of total glucosinolates/g on a dry matter (**DM**) basis. Extrusion increased ($P < 0.05$) the AID of CP, reduced ($P < 0.05$) apparent hindgut fermentation of CP, and decreased ($P < 0.05$) predicted net energy (**NE**) value of diets. Extrusion increased diet AID and CM SID of most indispensable AA by 3.1 to 5.3%-units. In exp. 2, 200 weaned pigs (initial BW, 8.3 kg) were fed diets containing 20% SBM, CM, or extruded CM starting 2 wk postweaning for 3 wk. The CM sample contained 42.7% CP, 28.3% TDF, and 5.3 µmol total glucosinolates/g DM. Wheat-based diets provided 2.3 Mcal NE/kg and 5.1 g SID Lys/Mcal NE. Dietary inclusion of extruded CM replacing SBM decreased ($P < 0.05$) diet ATTD of DM, GE and CP, and DE value. Average daily feed intake, average daily gain (**ADG**), and gain:feed (**G:F**) of pigs did not differ between extruded CM and SBM diets and were not affected by extrusion, but increasing extruder screw speed linearly increased ($P < 0.05$) ADG for day 1 to 7 and G:F for the entire trial. In conclusion, extrusion increased diet AID and CM SID of AA but not DE and predicted NE values of CM. However, increasing extruder speed did not further increase the SID of most of the AA of CM in growing pigs. Dietary inclusion of 20% CM or extruded CM did not affect the growth performance in weaned pigs.

Key words: canola meal, digestibility, extrusion, growth performance, pig

Abbreviations

AA	amino acid
ADF	acid detergent fiber
ADFI	average daily feed intake
ADG	average daily gain
AHF	apparent hindgut fermentation
AID	apparent ileal digestibility
ANF	anti-nutritional factors
ATTD	apparent total tract digestibility
BW	body weight
CP	crude protein
DM	dry matter
G:F	gain:feed
GE	gross energy
Iend	ileal endogenous loss
NDF	neutral detergent fiber
NE	net energy
SID	standardized ileal digestibility
TDF	total dietary fiber

Introduction

Annually, over 70 million metric ton of canola or rapeseed is produced globally mostly in temperate climate zones (FAOSTAT, 2021). In Canada, 20 million t canola seed is produced annually (5-yr average), and domestic crushing of canola seed generates 4.6 million metric ton of canola meal (**CM**; AAFC, 2020; Canola Council of Canada, 2021). After soybean meal (**SBM**), CM is the most widely fed alternative supplemental protein meal in diets for pigs (Hansen et al., 2020). However, CM has a lower energy value and contains less digestible amino acids (**AA**) compared with SBM (Newkirk, 2009), partly due to a greater fiber content that reduces digestibility of energy and AA (Bell, 1993).

Dietary inclusion of CM to substitute SBM reduced total tract nutrient digestibility and thus nutrient utilization in weaned pigs (Landero et al., 2011). Nutrient utilization of CM might be enhanced using feed processing (Rojas and Stein, 2017; Lancheros et al., 2020), for example, extrusion. Hydrothermal treatment with high shear force may break weak bonds in polysaccharides, whereas excessive heating may cause protein damage (McDougall et al., 1996). Finally, extrusion decomposes glucosinolates (Huang et al., 1995; Liang et al., 2002); however, extrusion to enhance the nutrient digestibility of CM has rarely been reported.

The null hypotheses of the present study were that: 1) extrusion and extrusion speed would not affect the digestibility of nutrients and energy in growing pigs or glucosinolates content of CM and 2) weaned pigs fed diets containing 20% CM extruded with increasing extruder speeds and formulated to equal net energy (**NE**) and standardized ileal digestible AA content would not differ in diet ATTD of nutrients and growth performance compared with pigs fed diets containing non-extruded CM or SBM. The objectives were to evaluate the effects of extrusion of *Brassica napus* CM at different extrusion speeds on: 1) apparent ileal digestibility (**AID**) and apparent total tract digestibility (**ATTD**) of crude protein (**CP**) and gross energy (**GE**), and digestible energy (**DE**) and predicted NE values; 2) standardized ileal digestibility (**SID**) of AA and CP in growing pigs; 3) growth performance and diet digestibility in weaned pigs; and 4) glucosinolates content.

Materials and Methods

Animal use was approved and procedures were reviewed by the University of Alberta Animal Care and Use Committee for Livestock and followed the principles established by the Canadian Council on Animal Care (CCAC, 2009). The animal study was conducted at the Swine Research and Technology Centre, University of Alberta (Edmonton, AB, Canada).

Test ingredient and processing

Dark-seeded, solvent-extracted *B. napus* CM (exp. 1: Altona, MB, Canada; exp. 2: Lloydminster, AB, Canada) was extruded at the Agri-Food Discovery Place, University of Alberta (Edmonton, AB, Canada), using a single-screw extruder (X-115; Wenger, Sabetha, KS) at three extruder screw speeds: low (250 rpm; **CM-250**), medium (350 rpm; **CM-350**), or high (450 rpm; **CM-450**). The flow rate (300 kg/h), the extruder water to feed rate (1:10), and extrusion temperature (from 80 °C in zone 1 to 100 °C in zone 5) were set for the three extrusion processing conditions. The raw CM and the extruded CM were subsequently ground through a hammer mill fitted with a 2.78-mm screen.

Experimental diets and design

Cannulated pig trial (exp. 1)

Four diets were formulated by replacing 50% of an N-free diet with 50% of one of the four CM samples (Table 1). The four test diets exceeded the NRC (2012) requirements for most of the nutrients. The four CM diets were fed to eight pigs over four periods in a double 4 × 4 Latin square design to achieve eight observations per treatment. The basal ileal endogenous loss (**Iend**) of AA was measured on the same pigs feeding an N-free diet prior to feeding the four test diets. The Cr_2O_3 was included

Table 1. Ingredient composition of experimental diets[1], exp. 1

Item, % as-fed	CM	N-free
Test ingredient[2]	50.00	—
Corn starch[3]	42.19	84.80
Sugar	2.49	5.00
Cellulose[4]	1.49	3.00
Canola oil	1.00	2.00
Monocalcium phosphate	0.80	1.60
Limestone	0.60	1.20
Chromic oxide	0.50	0.50
Vitamin premix[5]	0.25	0.50
Mineral premix[6]	0.25	0.50
K_2CO_3	0.25	0.50
Salt	0.15	0.30
MgO	0.05	0.10

[1]CM, canola meal.
[2]To create four diets, the four test ingredients were: CM (ground and not extruded), CM-250, CM-350, or CM-450.
[3]Melojel (National Starch and Chemical Co., Bridgewater, NJ).
[4]Solka-floc (International Fiber Corp., North Tonawanda, NY).
[5]Provided the following per kilogram of diet: vitamin A, 7,500 IU; vitamin D, 750 IU; vitamin E, 50 IU; niacin, 37.5 mg; pantothenic acid, 15 mg; folacin, 2.5 mg; riboflavin, 5 mg; pyridoxine, 1.5 mg; thiamine, 2.5 mg; choline, 2,000 mg; vitamin K, 4 mg; biotin, 0.25 mg; and vitamin B_{12}, 0.02 mg.
[6]Provided the following per kilogram of diet: Zn, 125 mg as $ZnSO_4$; Cu, 50 mg as $CuSO_4$; Fe, 75 mg as $FeSO_4$; Mn, 25 mg as $MnSO_4$; I, 0.5 mg as $Ca(IO_3)_2$; and Se, 0.3 mg as Na_2SeO_3.

as an indigestible marker. A horizontal paddle mixer (model 3061; Marion Process Solutions, Marion, IA) was used to mix mash diets.

Eight crossbred barrows (initial body weight [**BW**] 68.1 ± 9.4 kg; Duroc × Large White/Landrace F_1; Hypor, Regina, SK, Canada) were housed in individual metabolism pens (1.2 m wide, 1.5 m long, and 0.95 m high) with polyvinyl chloride walls with windows and plastic slatted flooring. All pens were equipped with a stainless-steel feeder attached to the front of the pen and a cup drinker beside the feeder assuring free access to water throughout the experiment. Room temperature was controlled at 20.8 ± 1.3 °C. Pigs were surgically fitted with a simple T-cannula at the distal ileum, approximately 5 cm proximal to the ileocecal sphincter (Sauer et al., 1983; de Lange et al., 1989). After measuring basal Iend of AA, pigs were switched to the first assigned experimental diet. Daily feed allowance was adjusted to 2.8 times the maintenance requirement for DE (2.8 × 110 kcal of DE/kg of $BW^{0.75}$; NRC, 1998) fed in two equal meals at approximately 0800 and 1500 hours. Each 9-d experimental period consisted of a 5-d acclimation to the experimental diet, followed by a 2-d collection of feces and a 2-d collection of ileal digesta.

Feces were collected from 0800 to 1600 hours by using plastic bags within a collection system that was glued to the skin around the anus (van Kleef et al., 1994). Digesta was collected between 0800 to 1600 hours using plastic bags containing 15 mL of 5% formic acid attached to the opened cannula barrel with rubber band (Li et al., 1993). Plastic bags were replaced as soon as filled with digesta or after every 20 min. Feces and digesta samples were pooled for each pig within the experimental period and stored at −20 °C. Upon completion of the trial, digesta and fecal samples were thawed, homogenized, subsampled, and freeze-dried.

Nursery pig performance trial (exp. 2)

In total, 200 pigs were selected from 241 pigs (Duroc × Large White/landrace F1; Hypor, Regina, SK, Canada), weaned in three groups at 21 ± 2 d of age based on postweaning average daily gain (**ADG**) and BW on day 12 after weaning. Pigs within gender were divided into heavy and light BW. One heavy and one light barrow and gilt were then randomly placed in 1 of the 50 pens, 4 pigs per pen. Prior to weaning, all pigs received creep-feeding. After weaning, pigs were fed commercial pre-starter (20.6% CP and 2.5 Mcal NE/kg) for 7 d and starter (22.9% CP and 2.4 Mcal NE/kg) diets (Masterfeeds, Edmonton, AB, Canada) for 5 d, respectively.

Table 2. Ingredient composition and analyzed nutrient content of experimental diets[1], Exp. 2

			Extruded CM		
Item, % as-fed	SBM	CM	CM-250	CM-350	CM-450
Wheat	68.32	65.89	65.89	65.89	65.89
SBM	20.00	—	—	—	—
CM	—	20.00	20.00	20.00	20.00
Menhaden fish meal	5.00	5.00	5.00	5.00	5.00
Soy protein concentrate[2]	2.50	2.50	2.50	2.50	2.50
Canola oil	—	2.12	2.12	2.12	2.12
Limestone	0.80	0.63	0.63	0.63	0.63
Celite[3]	0.80	0.80	0.80	0.80	0.80
Salt	0.75	0.75	0.75	0.75	0.75
Mono/di-calcium phosphate	0.55	0.60	0.60	0.60	0.60
Vitamin premix[4]	0.50	0.50	0.50	0.50	0.50
Mineral premix[5]	0.50	0.50	0.50	0.50	0.50
L-Lys HCl, 78%	0.15	0.46	0.46	0.46	0.46
L-Thr, 99%	0.08	0.15	0.15	0.15	0.15
L-Trp, 99%	—	0.07	0.07	0.07	0.07
DL-Met, 99%	0.03	0.01	0.01	0.01	0.01
Choline chloride, 60%	0.03	0.03	0.03	0.03	0.03
Analyzed nutrient content[6], % DM					
Moisture	11.5	11.5	11.2	11.7	11.4
Starch	39.1	35.8	39.3	38.9	41.8
CP (N × 6.25)	29.6	27.8	26.7	26.2	27.0
NDF	9.6	13.7	14.9	14.6	13.8
ADF	4.2	7.1	7.4	7.4	7.2
Ash	7.04	6.38	6.49	6.68	6.45
Ether extract	1.42	4.16	4.21	3.96	4.08
GE, Mcal/kg DM	4.46	4.60	4.60	4.59	4.61

[1]SBM, soybean meal; CM, canola meal, ground but not extruded; CM-250, CM extruded at 250 rpm screw speed; CM-350, CM extruded at 350 rpm screw speed; CM-450, CM extruded at 450 rpm screw speed.
[2]HP300 (Hamlet Protein Inc., Findlay, OH).
[3]Celite 281 (World Minerals Inc., Santa Barbara, CA) used as acid-insoluble ash.
[4]Provided the following per kilogram of diet: vitamin A, 7,500 IU; vitamin D, 750 IU; vitamin E, 50 IU; niacin, 37.5 mg; pantothenic acid, 15 mg; folacin, 2.5 mg; riboflavin, 5 mg; pyridoxine, 1.5 mg; thiamine, 2.5 mg; choline, 2,000 mg; vitamin K, 4 mg; biotin, 0.25 mg; and vitamin B_{12}, 0.02 mg.
[5]Provided the following per kilogram of diet: Zn, 125 mg as $ZnSO_4$; Cu, 50 mg as $CuSO_4$; Fe, 75 mg as $FeSO_4$; Mn, 25 mg as $MnSO_4$; I, 0.5 mg as $Ca(IO_3)_2$; and Se, 0.3 mg as Na_2SeO_3.
[6]Diets were formulated to provide (as-fed): 2.41 Mcal NE/kg, 1.23% SID Lys, 0.36% SID Met, 0.73% SID Thr, and 0.20% SID Trp.

Commercial diets were based on wheat, SBM, oat groats, lactose, and highly digestible protein sources.

A wheat-based control diet and four diets containing 20% test ingredient were formulated by replacing SBM with one of the four CM samples (Table 2). Diets were formulated to provide 2.3 Mcal NE/kg and 5.1 g SID Lys/Mcal NE, and crystalline Thr, Met, and Trp were formulated as ideal ratios to Lys (NRC, 2012). For main ingredients, tabulated NE values (Sauvant et al., 2004) and SID AA (NRC, 2012) were used. Diets did not contain antimicrobials or growth promoters. Acid-insoluble ash (Celite 281; World Minerals, Santa Barbara, CA) was added as an indigestible marker. Diets in mash form were mixed at the University of Alberta feed mill (Edmonton, AB, Canada). Pigs (initial BW: 8.3 ± 1.7 kg) were fed the experimental diets starting from 2 wk after weaning for 3 wk (day 1 to 21).

The study was conducted as a randomized complete block design with 50 pens divided over three nursery rooms filled 2 wk apart. Each room had three or four blocks representing areas within the room with five pens per block. Pens of pigs within a block were randomly allocated to be fed one of the five diets during the 21-d study for a total of 10 replicate pens per diet. Pens (1.1 × 1.5 m) were equipped with a dry feeder providing four feeding spaces, nipple drinker, polyvinyl chloride partition, and plastic slatted flooring. Rooms were ventilated using negative pressure, maintained within the thermo-neutral zone for the pigs, and provided a 12:12 (L:D) h (0600 to 1800 hours) cycle. Pigs had free access to feed and water.

To calculate average daily feed intake (**ADFI**), ADG and feed efficiency as gain:feed (**G:F**), individual pigs, pen feed added, and orts remaining were weighed weekly. To calculate ATTD of dry matter (**DM**), GE, and CP, freshly voided feces were collected immediately upon defecation from 0800 to 1500 hours by grab sampling from pen floors and pooled by pen (>500 g/pen) on days 19 and 20. Feces were frozen at −20 °C. Upon completion of the study, feces were thawed, homogenized, subsampled, and freeze-dried.

Chemical analyses

The CM, diets, lyophilized feces, and digesta were ground using a 1-mm screen in a centrifugal mill (model ZM200; Retsch, Haan, Germany) and analyzed for moisture (method 930.15; AOAC, 2006), CP (method 990.03; N × 6.25; AOAC, 2006), and GE using an adiabatic bomb calorimeter (model 5003; Ika-Werke, Staufen, Germany). The CM samples and diets were analyzed for ash (method 942.05; AOAC, 2006), ether extract (method 920.39A; AOAC, 2006), starch (assay kit STA-20; Sigma, St. Louis, MO), acid detergent fiber (**ADF**) inclusive of residual ash (method 973.18; AOAC, 2006), and neutral detergent fiber (**NDF**) assayed without heat-stable amylase and expressed inclusive of residual ash (Holst, 1973). The CM samples were analyzed for Ca (method 968.08; AOAC, 2006), P (method 946.06; AOAC, 2006), and total dietary fiber (**TDF**), soluble and insoluble dietary fiber (method 991.43; AOAC, 2006). The AA content in test ingredients, diets, and digesta was analyzed by high-performance liquid chromatography (method 982.30E; AOAC, 2006), and chemically available Lys was analyzed by spectrophotometry (method 975.44; AOAC, 2006). For exp. 1, diets, feces, and digesta were analyzed for Cr_2O_3 by spectrophotometry (model 80-2097-62, KBULtraspec III, Pharmacia, Cambridge, UK) at 440 nm after ashing at 450 °C overnight (Fenton and Fenton, 1979). For exp. 2, diets and feces were analyzed for acid-insoluble ash (Vogtmann et al., 1975 modified by Newkirk et al., 2003). Glucosinolate content in CM was measured by gas-liquid chromatography (Daun and McGregor, 1981) at POS Bio-Sciences (Saskatoon, SK, Canada).

Calculations

The AID and ATTD of DM, CP, and GE in diets were calculated using the index method (Adeola, 2001). The difference between ATTD and AID was considered as apparent hindgut fermentation (**AHF**). Diet NE values were predicted using equation 5 in Noblet et al. (1994) using the determined diet DE value and analyzed content of ADF, starch, CP, and ether extract, as adopted by NRC (2012). Gain:feed was calculated as ADG divided by ADFI for each week and the entire trial.

The basal Iend of AA and CP (g/kg of DM intake) was calculated using the equation for the N-free diet (Stein et al., 2007; equation 3): $\text{basal Iend} = [\text{AA or CP in digesta} \times (Cr_2O_3 \text{ in diet}/\ Cr_2O_3 \text{ in digesta})]$. The SID for AA was calculated by correcting the AID for basal Iend using the equation (Stein et al., 2007; equation): $\text{SID} = [\text{AID} + (\text{basal Iend/AA in diet})]$.

Statistical analyses

Nutrient digestibility and growth performance data were analyzed using the MIXED procedure of SAS (ver. 9.4; SAS Inst. Inc., Cary, NC). Normality (PROC UNIVARIATE) and homogeneity of variance (PROC GLM, Hovtest = Levene) of the residuals of each variable were examined prior to analysis of variance (ANOVA). For exp. 1, diet was the fixed effect, and square, period nested in square, and pig nested in square were random effects. For exp. 2, pen was the experimental unit with diet and week as fixed effects and block as random effect. Multiple comparisons between least squares means were performed using the PDIFF statement with TUKEY adjustment.

Growth performance data were analyzed as repeated measures using weekly pen data with first-order ante-dependence variance–covariance structure based on the Bayesian information criterion fit statistics and initial BW as a covariate if significant. Single degree of freedom contrasts were used to compare the digestibility and performance of the SBM diet vs. extruded CM diets, non-extruded vs. extruded CM diets, and to detect linear or quadratic effects of increasing extruder speed on the digestibility and growth performance for each week and the entire trial (Littell et al., 2006). Data are presented as least squares means with pooled SEM. To test the hypotheses, $P < 0.05$ was considered significant and $0.05 \leq P < 0.10$ was considered as tendency.

Results

Cannulated pig trial (exp. 1)

Pigs remained healthy and consumed their daily feed allowance throughout the trial.

Extrusion did not affect CP and TDF but seemed to increase the ADF content of CM (Table 3). Increasing extruder screw speed to 350 rpm seemed to decrease total glucosinolate content in CM by 1.57 μmol/g DM, with pronounced reduction of 4-methoxy-3-CH_3-indolyl, 4-OH-3-CH_3-indolyl, and phenylethyl content. Among the four CM diets (Table 4), the coefficient of variation (CV) for CP, ADF, NDF, and GE was 1.7%, 2.1%, 2.8%, and 0.1%, respectively.

Extrusion increased ($P < 0.05$; Table 5) the AID of CP, reduced ($P < 0.05$) the AHF of CP, and decreased ($P < 0.05$) predicted NE value of diets. Increasing extruder screw speed did not affect the AID, ATTD, and AHF of DM, CP, and GE, and the DE and predicted NE values of CM diets.

Table 3. Analyzed nutrient profile and glucosinolate content of experimental ingredients[1], exp. 1

Item, % DM	CM	Extruded CM		
		CM-250	CM-350	CM-450
Moisture	7.34	7.49	7.00	6.37
CP (N × 6.25)	43.2	42.5	42.1	42.1
GE, Mcal/kg	4.79	4.81	4.79	4.79
Ether extract	3.2	2.7	2.7	3.6
NDF	26.0	33.9	26.9	28.6
ADF	19.7	23.4	21.8	21.7
TDF	33.2	34.6	33.6	33.9
Insoluble fiber	27.9	27.8	28.1	26.9
Soluble fiber	2.30	2.46	2.39	2.33
Ash	8.05	7.98	7.91	7.97
P	1.15	1.11	1.12	1.10
Ca	0.66	0.69	0.70	0.69
Indispensable AA				
Arg	2.52	2.46	2.44	2.45
His	1.13	1.08	1.07	1.07
Ile	1.79	1.75	1.73	1.75
Leu	2.93	2.87	2.86	2.87
Lys	2.35	2.32	2.32	2.33
Met	0.84	0.73	0.80	0.81
Phe	1.73	1.71	1.67	1.67
Thr	1.72	1.68	1.73	1.74
Trp	0.54	0.51	0.51	0.50
Val	2.21	2.22	2.17	2.17
Dispensable AA				
Ala	1.80	1.78	1.79	1.77
Asp	2.90	2.83	2.84	2.86
Cys	1.05	1.08	1.03	1.03
Glu	6.97	6.77	7.03	7.07
Gly	2.05	2.09	2.07	2.00
Pro	2.50	2.46	2.54	2.58
Ser	1.34	1.31	1.58	1.60
Tyr	1.12	1.13	1.09	1.10
Total AA	38.2	37.5	37.9	38.0
Chemically available Lys	2.26	2.23	2.22	2.23
Glucosinolates, μmol/g				
2-OH-3-Butenyl	3.67	3.54	3.31	3.52
Epi-2-OH-3-butenyl	0.13	0.11	0.10	0.11
4-CH_3-Sulfinyl-butyl	0.13	0.14	0.13	0.13
2-OH-4-Pentenyl	0.10	0.10	0.09	0.10
5-CH_3-Sulfinyl-pentyl	0.61	0.59	0.53	0.58
3-Butenyl	1.85	1.78	1.66	1.78
4-OH-3-CH_3-Indolyl	1.48	0.82	0.78	0.89
4-Pentenyl	0.15	0.15	0.14	0.15
3-CH_3-Indolyl	0.38	0.35	0.31	0.36
Phenylethyl	0.29	0.21	0.17	0.18
4-Methoxy-3-CH_3-indolyl	0.04	0.02	0.02	0.02
1-Methoxy-3-CH_3-indolyl	0.04	0.04	0.03	0.04
Total glucosinolates	8.87	7.84	7.30	7.86

[1]CM, canola meal, ground but not extruded; CM-250, CM extruded at 250 rpm screw speed; CM-350, CM extruded at 350 rpm screw speed; CM-450, CM extruded at 450 rpm screw speed.

Extrusion increased ($P < 0.05$; Table 6) the AID of AA except for Lys, Thr, Cys, Gly, Pro, and Ser of CM diets.

Similar to the changes in AID, extrusion increased ($P < 0.05$; Table 7) the SID of CP and AA except for Lys, Thr, Ala, Cys, Gly, Pro, and Ser in CM. Increasing extruder screw speed did not affect the SID of CP and most of the AA in CM.

Nursery pig performance trial (exp. 2)

Extrusion did not affect CP, TDF, or soluble fiber content of CM (Table 8). Increasing extruder screw speed to 350 rpm seemed to decrease the total glucosinolate content in CM by 0.8 μmol/g DM, with pronounced reduction of 4-OH-3-CH3-indolyl, epi-2-OH-3-butenyl, and 4-CH_3-sulfinyl-butyl content. Among the four CM diets (Table 2), the CV for CP, ADF, NDF, and GE was 2.5%, 2.0%, 4.0%, and 0.2%, respectively.

Compared with SBM diet, extruded CM diets had lower ($P < 0.05$; Table 9) ATTD of DM, GE, and CP, and DE value. Extruded CM diets had lower ($P < 0.01$) ATTD of CP than non-extruded CM diet. Increasing extruder speed did not increase the ATTD of DM, GE, and CP, and DE and predicted NE values of the CM diets.

For growth performance, pigs fed extruded CM diets had ADFI and ADG not different from pigs fed the SBM diet for each week and the entire trial (day 1 to 21; Table 10). Compared with non-extruded CM, extrusion of CM did not affect ADFI, ADG, and G:F for each week and the entire trial. Increasing extruder screw speed linearly increased ($P < 0.05$) ADG for day 1 to 7 and G:F for the entire trail. Final BWs were 19.6, 19.6, 19.2, 19.8, and 19.9 kg for SBM, CM, CM-250, CM-350, and CM-450 diets, respectively, and did not differ between SBM and extruded CM diets nor was final BW affected by extrusion or extruder screw speed.

Discussion

Nutritive value and extrusion of CM

Solvent-extracted CM, a coproduct from crushing canola seed to obtain oil for the food and biofuel industries, is an important protein source used in pig nutrition (Woyengo et al., 2016a). In the present study, the analyzed content of dietary fiber, CP, and AA in CM was similar to table values (NRC, 2012) and values reported by others (Adewole et al., 2017; Wang et al., 2017). CM contains high fiber, mostly insoluble due to high lignification of canola seed hulls (Bach Knudsen, 2014) that is associated with low digestibility and utilization of nutrients such as AA in pigs (Schulze et al., 1994; Stein and Shurson, 2009). In addition, CM contains anti-nutritional factors (**ANF**), mainly glucosinolates that may decrease animal performance by reducing feed intake and affecting thyroid and liver functions (Tripathi and Mishra, 2007). Thus, processing strategies to increase nutrient digestibility and increase the feeding value of CM are important (Zhou et al., 2015).

Extrusion cooking can disrupt cell walls, denature protein, emulsify fat, and reduce ANF, such as trypsin inhibitors and tannins in field pea or lentil grain (Cheftel, 1986; Alonso et al., 1998; Singh et al., 2007; Hugman et al., 2021), and may increase the solubility of the fiber fraction (de Vries et al., 2012). However, in the present study, extrusion did not noticeably increase the solubility of dietary fiber in CM in both exp. 1 and 2. Instead, extrusion slightly increased soluble fiber and TDF content in CM. The nutrient composition of the extruded CM using increasing extruder screw speed did not change greatly, indicating that extrusion of CM in a single-screw extruder at the screw speed settings used in the present study did not affect cell wall structure sufficiently (Liang et al., 2002). However, extrusion in the present study reduced glucosinolates content in CM, similar to previous reports that extrusion reduced glucosinolates content in rapeseed meal mostly due to heating (Huang et al., 1995; Tripathi and Mishra, 2007). Extrusion did not reduce chemically available Lys of CM, indicating that Lys damage due to the Maillard reaction was minimal (Pahm et al., 2008) likely because of low retention time in the barrel of the extruder.

Table 4. Analyzed nutrient profile of experimental diets[1], exp. 1

		Extruded CM			
Item, % DM	CM	CM-250	CM-350	CM-450	N-free
Moisture	8.2	7.6	7.6	7.2	9.36
Starch	38.6	35.1	35.8	36.6	66.5
CP (N × 6.25)	21.9	22.2	22.8	22.3	0.96
NDF	15.2	15.6	14.6	14.9	2.01
ADF	11.8	11.9	12.1	11.5	2.16
Crude fiber	8.27	7.71	7.83	7.42	1.18
Ash	6.43	6.43	6.48	6.41	4.01
Ether extract	2.84	2.81	2.03	2.24	3.71
GE, Mcal/kg	4.42	4.41	4.42	4.42	—
Indispensable AA					
Arg	1.25	1.27	1.27	1.27	0.01
His	0.56	0.56	0.57	0.56	0.00
Ile	0.90	0.91	0.92	0.91	0.02
Leu	1.49	1.52	1.52	1.51	0.04
Lys	1.17	1.22	1.22	1.21	0.03
Met	0.40	0.41	0.42	0.42	0.01
Phe	0.87	0.88	0.88	0.88	0.02
Thr	0.88	0.89	0.90	0.89	0.01
Trp	0.27	0.26	0.25	0.26	0.02
Val	1.08	1.15	1.14	1.14	0.02
Dispensable AA					
Ala	0.91	0.94	0.94	0.93	0.02
Asp	1.48	1.50	1.50	1.50	0.02
Cys	0.53	0.53	0.54	0.53	0.01
Glu	3.60	3.69	3.69	3.67	0.04
Gly	1.03	1.09	1.07	1.06	0.01
Pro	1.35	1.32	1.38	1.29	0.03
Ser	0.72	0.73	0.74	0.74	0.01
Tyr	0.54	0.55	0.56	0.54	0.01

[1]Diets contained 50% canola meal; CM, canola meal, ground but not extruded; CM-250, CM extruded at 250 rpm screw speed; CM-350, CM extruded at 350 rpm screw speed; CM-450, CM extruded at 450 rpm screw speed.

Table 5. AID, ATTD, and AHF of DM, CP, and GE, and the DE and predicted NE value of experimental diets[1], exp. 1

						P-value		
		Extruded CM					Extruder speed[4]	
Item	CM	CM-250	CM-350	CM-450	SEM[2]	Extrusion of CM[3]	Linear	Quadratic
AID, %								
DM	69.6	70.2	67.3	69.6	1.81	0.685	0.735	0.116
CP	73.5	77.0	75.0	76.9	1.57	0.046	0.952	0.190
GE	71.9	72.7	70.0	72.0	1.69	0.795	0.708	0.124
ATTD, %								
DM	79.7	79.5	79.4	79.1	0.60	0.521	0.424	0.794
CP	79.2	78.1	78.8	77.8	0.77	0.151	0.734	0.219
GE	80.3	80.2	80.0	79.6	0.59	0.407	0.360	0.787
AHF[5], %								
DM	10.0	9.3	12.2	9.5	1.92	0.855	0.946	0.118
CP	5.7	1.1	3.8	1.0	1.82	0.023	0.926	0.103
GE	8.4	7.5	10.0	7.6	1.77	0.977	0.960	0.122
DE, Mcal/kg DM	3.55	3.54	3.53	3.52	0.026	0.353	0.477	0.753
NE, Mcal/kg DM	2.42	2.38	2.38	2.38	0.018	0.025	0.676	0.813

[1]Diets contained 50% canola meal; CM, canola meal, ground but not extruded; CM-250, CM extruded at 250 rpm screw speed; CM-350, CM extruded at 350 rpm screw speed; CM-450, CM extruded at 450 rpm screw speed.
[2]Least squares means based on eight observations per diet.
[3]Contrast CM vs. extruded CM.
[4]Analyzed using contrast for the three extruded CM diets.
[5]AHF = ATTD – AID.

Table 6. AID of AA of experimental diets[1], exp. 1

		Extruded CM				*P*-value		
							Extruder speed[4]	
Item, %	CM	CM-250	CM-350	CM-450	SEM[2]	Extrusion of CM[3]	Linear	Quadratic
Indispensable AA								
Arg	84.2	89.6	88.5	89.6	0.93	<0.001	0.985	0.193
His	83.1	86.2	85.3	86.2	0.98	0.005	0.979	0.321
Ile	76.8	80.5	78.5	79.7	1.25	0.023	0.549	0.169
Leu	79.1	83.2	81.3	82.4	1.17	0.005	0.527	0.172
Lys	79.8	82.6	80.2	81.9	1.15	0.086	0.574	0.061
Met	86.0	90.6	89.8	90.7	0.65	<0.001	0.931	0.162
Phe	79.5	83.5	81.7	82.8	1.12	0.004	0.592	0.173
Thr	73.1	75.7	73.8	75.5	1.62	0.184	0.883	0.221
Trp	86.4	89.4	88.3	90.2	0.94	0.002	0.374	0.083
Val	73.8	79.1	76.7	78.3	1.37	0.003	0.564	0.136
Dispensable AA								
Ala	77.9	81.5	79.0	80.7	1.35	0.044	0.594	0.099
Asp	73.7	80.2	77.9	80.1	1.43	<0.001	0.973	0.089
Cys	74.7	75.6	74.4	76.8	2.22	0.667	0.613	0.391
Glu	84.8	88.6	87.7	88.7	0.94	<0.001	0.969	0.248
Gly	71.5	75.1	71.9	74.7	1.63	0.110	0.792	0.060
Pro	71.0	73.2	70.1	72.6	2.45	0.634	0.810	0.217
Ser	76.1	79.0	77.3	79.1	1.59	0.093	0.962	0.213
Tyr	80.6	84.0	82.6	83.5	1.12	0.009	0.617	0.249
Total AA	77.8	81.7	79.7	81.3	1.28	0.013	0.813	0.137

[1]Diets contained 50% canola meal; CM, canola meal, ground but not extruded; CM-250, CM extruded at 250 rpm screw speed; CM-350, CM extruded at 350 rpm screw speed; CM-450, CM extruded at 450 rpm screw speed.
[2]Least square means based on eight observations per treatment.
[3]Contrast CM vs. three extruded CM.
[4]Analyzed using contrast for the three extruded CM diets.

Table 7. SID of CP and AA of experimental diets[1,2], exp. 1

		Extruded CM				*P*-value		
							Extruder speed[5]	
Item, %	CM	CM-250	CM-350	CM-450	SEM[3]	Extrusion of CM[4]	Linear	Quadratic
CP	78.9	82.3	80.2	82.2	1.57	0.056	0.938	0.162
Indispensable AA								
Arg	86.9	92.2	91.0	92.2	0.96	<0.001	0.985	0.193
His	85.9	88.9	88.0	89.0	1.03	0.005	0.979	0.297
Ile	80.3	84.0	81.9	83.2	1.32	0.025	0.549	0.160
Leu	82.6	86.7	84.8	85.9	1.22	0.006	0.539	0.169
Lys	83.1	85.8	83.4	85.2	1.18	0.110	0.589	0.060
Met	88.2	92.7	91.8	92.7	0.68	<0.001	0.988	0.151
Phe	82.9	86.9	85.1	86.2	1.15	0.005	0.592	0.173
Thr	79.2	81.8	79.7	81.5	1.66	0.205	0.883	0.205
Trp	86.4	89.4	88.3	90.3	0.94	0.002	0.374	0.083
Val	77.7	82.8	80.4	82.0	1.43	0.004	0.579	0.139
Dispensable AA								
Ala	82.4	85.8	83.3	85.1	1.38	0.055	0.617	0.096
Asp	78.5	84.9	82.6	84.8	1.46	<0.001	0.973	0.089
Cys	78.5	79.4	78.1	80.5	2.30	0.676	0.613	0.373
Glu	87.0	90.7	89.7	90.8	0.97	0.001	0.960	0.246
Gly	79.0	82.2	79.1	82.0	1.72	0.158	0.882	0.062
Pro	76.7	79.1	75.7	78.6	2.54	0.604	0.851	0.172
Ser	81.7	84.5	82.7	84.5	1.58	0.110	0.999	0.204
Tyr	84.5	87.8	86.3	87.3	1.13	0.011	0.660	0.212
Total AA	83.2	87.9	85.9	87.6	1.41	0.004	0.838	0.142

[1]Diets contained 50% canola meal; CM, canola meal, ground but not extruded; CM-250, CM extruded at 250 rpm screw speed; CM-350, CM extruded at 350 rpm screw speed; CM-450, CM extruded at 450 rpm screw speed.
[2]The SID of CP and AA was calculated by correcting the AID of CP and AA with the measured basal Iend (g/kg DM intake): CP, 11.82; Arg, 0.33; His, 0.15; Ile, 0.31 Leu, 0.53; Lys, 0.39; Met, 0.09; Phe, 0.30; Thr, 0.54; Trp, 0.12; Val, 0.42; Ala, 0.40; Asp, 0.70; Cys, 0.20; Glu, 0.77; Gly, 0.77; Pro, 0.78; Ser, 0.40; Tyr, 0.21; and total AA, 7.50.
[3]Least square means based on eight observations per treatment.
[4]Contrast CM vs. three extruded CM.
[5]Analyzed using contrast for the three extruded CM diets.

Table 8. Analyzed nutrient profile and glucosinolate content of experimental ingredients[1], exp. 2

			Extruded CM		
Item, % DM	SBM	CM	CM-250	CM-350	CM-450
Moisture	11.25	9.01	8.92	8.55	8.66
CP (N × 6.25)	55.9	42.7	42.2	41.3	42.4
TDF	9.0	28.3	29.0	29.4	29.4
Insoluble fiber	8.4	26.7	27.3	27.8	27.8
Soluble fiber	0.55	1.61	1.70	1.63	1.60
Ash	7.6	7.4	7.2	9.6	7.3
Ca	0.72	0.77	0.77	1.85	0.77
P	0.70	1.09	1.09	1.07	1.09
Ether extract	1.6	3.4	3.2	3.2	3.0
GE, Mcal/kg	4.78	4.85	4.82	4.69	4.82
Indispensable AA					
Arg	3.84	2.36	2.32	2.34	2.35
His	1.39	1.07	1.06	1.06	1.07
Ile	2.63	1.71	1.69	1.69	1.71
Leu	4.14	2.83	2.81	2.82	2.82
Lys	3.44	2.38	2.36	2.36	2.39
Met	0.73	0.80	0.79	0.77	0.78
Phe	2.82	1.69	1.67	1.68	1.67
Thr	2.03	1.73	1.71	1.71	1.69
Trp	0.74	0.45	0.46	0.44	0.47
Val	2.69	2.14	2.10	2.11	2.15
Total AA	52.29	37.09	36.63	36.61	36.90
Chemically available Lys	3.36	2.25	2.22	2.24	2.26
Glucosinolates, µmol/g					
2-OH-3-Butenyl	N/A	2.51	2.37	2.25	2.33
Epi-2-OH-3-Butenyl	N/A	0.09	0.07	0.06	0.06
4-CH_3-Sulfinyl-butyl	N/A	0.08	0.07	0.05	0.07
2-OH-4-Pentenyl	N/A	0.05	0.05	0.04	0.04
5-CH_3-Sulfinyl-pentyl	N/A	0.21	0.19	0.16	0.20
3-Butenyl	N/A	1.24	1.17	1.13	1.15
4-OH-3-CH_3-Indolyl	N/A	0.68	0.49	0.42	0.50
4-Pentenyl	N/A	0.07	0.06	0.06	0.07
3-CH_3-Indolyl	N/A	0.25	0.23	0.21	0.24
Phenylethyl	N/A	0.15	0.14	0.11	0.12
4-Methoxy-3-CH_3-indolyl	N/A	<0.02	<0.02	<0.02	<0.02
1-Methoxy-3-CH_3-indolyl	N/A	<0.02	<0.02	<0.02	<0.02
Total glucosinolates	N/A	5.31	4.85	4.51	4.78

[1]SBM, soybean meal; CM, canola meal, ground but not extruded; CM-250, CM extruded at 250 rpm screw speed; CM-350, CM extruded at 350 rpm screw speed; CM-450, CM extruded at 450 rpm screw speed.

Nutrient and energy digestibility of extruded CM (exp. 1)

Extrusion alters the physical and chemical characteristics of feedstuff and may increase the nutritional quality of coproducts such as triticale distillers dried grains with solubles (Oryschak et al., 2010). The dietary fiber components in dark-seeded *B. napus* CM are mainly water-insoluble non-starch polysaccharides, lignin, and polyphenols (Slominski et al., 2012) that might be difficult to degrade in the gut of pigs. In exp.1, extrusion did not increase diet ATTD of DM and GE, likely reflecting similar content or unaltered physicochemical properties of dietary fiber, protein, and fat among the four CM samples. These results contrast with extrusion increasing the nutrient digestibility and energy value of rapeseed meal (Keady and O′Doherty, 2000) and increasing the solubility and fermentability of fiber in wheat flour (Cheftel, 1986). The DM digestibility and fermentability were not affected by extrusion and extruder screw speed in exp. 1. The major energy-yielding components in CM are protein and fiber, and their digestibility determines the DM and GE digestibility of CM. Collectively, the three extruded CM samples had increased AID of CP, similar to extrusion increasing the in vitro CP digestibility of corn dried distillers grain and solubles (de Vries et al., 2013). However, extrusion did not alter ATTD of CP of CM, which could be explained by less CP entering the large intestine for fermentation and possibly reduced fermentability of CP for extruded CM. The overall picture emerging from the present study indicates that cell wall structures of solvent-extracted *B. napus* CM were not disrupted sufficiently, not even with increasing extruder screw speeds.

Heat treatment can disrupt the cell wall structure and denature protein and may thereby increase AA digestibility (Cheftel, 1986; Camire, 1991), as observed in wheat- and barley-based diets containing either SBM or cassava (Vande Ginste and De Schrijver, 1998) or diets containing 93.5% extruded corn fed to growing pigs (Rodriguez et al., 2020). In the present study, extrusion increased AID and SID of most indispensable AA except Lys of solvent-extracted CM, indicating that extruded CM contributed more dietary AA to the pig than non-extruded CM. Several factors such as an increase in susceptibility to digestive enzymes due to protein denaturation during extrusion might contribute to the increased AA digestibility (Hendriks and Sritharan, 2002). In the present study, increasing extruder screw speed from 250 to 450 rpm increased the specific mechanical energy from 111 to 133 kcal/kg. However, increased extruder

Table 9. ATTD of DM, CP, and GE, and the DE and predicted NE values of experimental diets[1], exp. 2

			Extruded CM				P-value		Extruder speed[5]	
Item, %	SBM	CM	CM-250	CM-350	CM-450	SEM[2]	SBM vs. extruded CM[3]	Extrusion of CM[4]	Linear	Quadratic
ATTD										
DM	84.6	81.0	79.3	79.3	80.4	0.87	<0.001	0.077	0.201	0.456
GE	83.8	80.4	78.4	78.6	80.0	1.09	<0.001	0.125	0.162	0.544
CP	83.8	80.8	77.0	77.0	79.4	1.21	<0.001	0.005	0.052	0.268
DE, Mcal/kg of DM	3.73	3.70	3.61	3.61	3.69	0.050	0.024	0.121	0.131	0.383
NE, Mcal/kg of DM	2.52	2.52	2.48	2.48	2.54	0.035	0.472	0.536	0.081	0.296

[1]Diets contained 20% canola meal; CM, canola meal, ground but not extruded; CM-250, CM extruded at 250 rpm screw speed; CM-350, CM extruded at 350 rpm screw speed; CM-450, CM extruded at 450 rpm screw speed; SBM, soybean meal.
[2]Least squares means based on 10 pen observations of 4 pigs per diet.
[3]Contrast SBM diet vs. three extruded CM diets.
[4]Contrast CM diet vs. three extruded CM diets.
[5]Analyzed using contrast for the three extruded CM diets.

Table 10. Growth performance of weaned pigs[1], exp. 2

							P-value[3]			
			Extruded CM						Extruder speed[6]	
Item	SBM	CM	CM-250	CM-350	CM-450	SEM[2]	SBM vs. extruded CM[4]	Extrusion of CM[5]	Linear	Quadratic
ADFI, g										
Day 1 to 7	456	506	489	504	507	37	0.139	0.840	0.622	0.839
Day 8 to 14	802	831	806	811	823	37	0.712	0.568	0.646	0.899
Day 15 to 21	1,080	1,066	1,066	1,073	1,065	37	0.696	0.930	0.971	0.820
Day 1 to 21	780	801	787	796	798	27	0.525	0.761	0.686	0.893
ADG, g										
Day 1 to 7	319	356	309	393	400	45	0.182	0.766	0.044	0.320
Day 8 to 14	607	588	568	548	582	45	0.256	0.556	0.752	0.475
Day 15 to 21	671	675	675	700	673	45	0.752	0.848	0.976	0.507
Day 1 to 21	532	540	517	547	552	26	0.765	0.954	0.183	0.585
G:F										
Day 1 to 7	0.70	0.70	0.63	0.78	0.78	0.076	0.604	0.663	0.058	0.243
Day 8 to 14	0.73	0.71	0.71	0.67	0.70	0.044	0.303	0.724	0.947	0.432
Day 15 to 21	0.59	0.63	0.64	0.65	0.63	0.032	0.090	0.832	0.846	0.445
Day 1 to 21	0.68	0.68	0.66	0.70	0.70	0.023	0.469	0.717	0.046	0.244

[1]Diets contained 20% canola meal; CM, canola meal, ground but not extruded; CM-250, CM extruded at 250 rpm screw speed; CM-350, CM extruded at 350 rpm screw speed; CM-450, CM extruded at 450 rpm screw speed; SBM, soybean meal.
[2]Least squares means based on 10 pen observations of 4 pigs per diet.
[3]For ADFI, ADG, and feed efficiency, a week effect was observed ($P < 0.001$), but an interaction between diet and week was not observed ($P > 0.05$).
[4]Contrast SBM diet vs. three extruded CM diets.
[5]Contrast CM diet vs. three extruded CM diets.
[6]Analyzed using contrast for the three extruded CM diets.

speed did not further increase the SID of most of the AA of CM in growing pigs, indicating that the additional mechanical energy applied to CM did not open up the protein structure further, contrasting to potential better cooking effect due to greater shear force and increased conversion of mechanical energy into thermal energy (Liang et al., 2002).

Extrusion did not increase the DE value of CM because the AID and ATTD of GE of diets were not affected by extrusion or increasing extruder screw speed. In addition, changes in ADF and NDF content or rendering dietary insoluble fiber to soluble fiber due to extrusion were not observed in the present study. This finding is in contrast with extrusion increasing the soluble portion of TDF in wheat, oats, and rice bran that may consequently increase energy digestibility (Gualberto et al., 1997). Fiber is partly fermented in the gastrointestinal tract of pigs and is strongly and negatively correlated with DE value (Fairbairn et al., 1999; Noblet and Le Goff, 2001; Woyengo et al., 2016b). In the present study, extrusion decreased the predicted NE values of CM diets, possibly due to lower measured starch and ether extract content in the diets. The increased extruder screw speed, hence increased mechanical energy, did not further affect the predicted NE values of CM diets.

Diet nutrient digestibility and growth performance in weaned pigs (exp. 2)

Fiber is not only an energy-yielding nutrient in CM but also hinders nutrient digestion. In the present study, CM contained three times more fiber than dehulled SBM (26.7 to 27.8 vs. 8.4% insoluble fiber) that may account for most of the lower ATTD of DM and GE in diets containing CM than SBM (Montoya and Leterme, 2010). In particular, the limited ability of young pigs to digest fiber compared with growing pigs might worsen the situation (Noblet and Shi, 1994). Even though increasing fiber content in CM diets did not affect feed intake, the lower ATTD for GE and CP for extruded CM diets compared with SBM run parallel with the 16% reduction in the ATTD of GE and 9% reduction in the ATTD of CP for rapeseed meal than SBM (Fernández et al., 1986). Extrusion reduced the ATTD of CP of CM diets, possibly due to less CP entering the large intestine for fermentation as shown in exp. 1 and possible lower fermentability for extruded CM. However, extrusion of CM at increasing extruder screw speeds did not increase the nutrient digestibility in CM, likely due to its inability to open up the cell wall structure and alter fiber digestibility.

Pigs maintained growth performance indicating that inclusion of 20% extruded CM can replace SBM in diets for weaned pigs, contrasting earlier studies that reported that young pigs fed diets containing CM had a lower growth rate than pigs fed diets containing SBM (McIntosh et al., 1986; Baidoo et al., 1987). Formulating diets based on equal NE value and SID AA content and achieving equivalent feed intake are the main factors to maintain growth when including high fiber coproducts into pig diets (Woyengo et al., 2014). For example, feeding up to 20% solvent-extracted *B. napus* CM by replacing SBM in diets did not reduce the growth performance of weaned pigs even 1 wk after weaning (Landero et al., 2011). In addition, lower glucosinolate content compared with cultivars of rapeseed offers a better feeding value of CM from modern canola cultivars (Canola Council of Canada, 2009). Indeed, total glucosinolate content in the CM samples (4.51 to 5.31 μmol/g CM) was slightly greater than that in previous studies (3.84 μmol glucosinolates/g CM; Landero et al., 2011) but did not affect feed intake in weaned pigs, indicating that weaned pigs can tolerate the increased glucosinolates in diets. For day 15 to 21, G:F tended to be greater for pigs fed the extruded CM diets than the SBM diet, indicating that weaned pigs can utilize extruded CM to support growth or had greater gut fill due to increased fiber intake. The greater fiber intake and related lower nutrient digestibility might increase the mass of undigested residue in the gut (Jørgensen et al., 1996; de Lange et al., 2003). Among the non-extruded and extruded CM using increasing extruder screw speeds, G:F did not differ, indicating that extrusion or increased extruder screw speed did not result in better conversion efficiencies for CM diets to support growth. However, the linear increase in ADG in day 1 to 7 and G:F for the entire trial with increasing extruder screw speed requires further investigations.

In conclusion, extrusion of dark-seeded, solvent-extracted *B. napus* CM increased the ileal digestibility of most indispensable AA in growing pigs, thereby providing more dietary AA from CM to the pig. However, extrusion did not increase the AID and SID of the first-limiting AA Lys. In addition, increased extruder screw speed and thus increased mechanical energy did not increase energy digestibility in growing pigs and did not improve the growth performance in weaned pigs. Weaned pigs can be fed 20% CM or extruded CM instead of SBM in diets formulated to equal NE and SID AA by adding feed-grade AA without reducing growth performance.

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Conflict of interest statement

All authors declare no real or perceived conflicts of interest.

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