Feed preference of weaned pigs fed diets containing soybean meal, *Brassica napus* canola meal, or *Brassica juncea* canola meal

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ABSTRACT: *Brassica napus* and *Brassica juncea* canola meal (**CM**) may replace soybean meal (**SBM**) in pig diets, but differ in fiber, glucosinolates content and profile. Preference of weaned pigs provided double-choice selections to diets containing 20% SBM, *B. napus* CM, or *B. juncea* CM was evaluated in two studies. In experiment 1, 216 pigs (9.4 ± 1.6 kg initial BW) were housed in 27 pens of 8 pigs (four gilts and four barrows). In experiment 2, 144 pigs (8.9 ± 1.1 kg) were housed in 36 pens of 4 pigs (two gilts and two barrows). Pigs were offered three dietary choices: *B. napus* CM with SBM as reference (***B. napus* CM [SBM]**), *B. juncea* CM with SBM as reference (***B. juncea* CM [SBM]**), and *B. juncea* CM with *B. napus* CM as reference (***B. juncea* CM [*B. napus* CM]**) in a replicated 3 × 3 Latin square. Diets were formulated to provide 2.4 Mcal NE/kg and 4.5 g standardized ileal digestible Lys/Mcal NE and were balanced using canola oil and crystalline AA. Each pair of diets was offered in two self-feeders per pen as mash (experiment 1) or pellets (experiment 2) during three test-periods of 4-d, followed by a 3-d non-test period when a common diet was offered in both feeders. Feeders with different diets were rotated daily among pens during preference periods for both experiments, and feeder positions (right or left) were switched daily in experiment 2. Prior to the study and between periods, pigs were fed non-test diets containing SBM (experiment 1) or without test feedstuffs (experiment 2). Overall in both experiments, pigs preferred ($P < 0.001$) SBM over *B. napus* and *B. juncea* CM diets, and preferred ($P < 0.001$) *B. napus* over *B. juncea* CM diet. Dietary choice did not affect ($P > 0.05$) growth performance in both experiments, except for greater G:F ($P < 0.05$) for pigs fed the *B. juncea* CM [*B. napus* CM] diets than pigs fed the *B. napus* CM [SBM] or *B. juncea* CM [SBM] diets in experiment 1. In conclusion, weaned pigs preferred SBM over CM diets when given a choice, and preferred *B. napus* over the *B. juncea* diet that contained more total glucosinolates especially gluconapin. Weaned pigs fed the *B. juncea* CM [*B. napus* CM] diets in the double-choice selection did not reduce feed intake, weight gain, and G:F compared to pigs fed the *B. napus* CM [SBM] or *B. juncea* CM [SBM] diets.

Key words: canola meal, feed preference, growth performance, soybean meal, weaned pig

J. Anim. Sci. 2018.96:600–611
doi: 10.1093/jas/skx052

INTRODUCTION

Many factors including palatability affect feed intake (Nyachoti et al., 2004; Forbes, 2010). Canola meal (**CM**) can be included in pig diets instead of soybean meal (**SBM**) to reduce feed cost (Woyengo et al., 2014) but may affect palatability. In Canada, 95% of CM originates from *Brassica napus* and the balance from *Brassica juncea* and *Brassica rapa* (Newkirk, 2011). Previously, feeding 20% CM containing 10.5 μmol glucosinolates/g reduced ADFI of weaned pigs (Baidoo et al., 1987); however, feeding 20% modern CM containing 3.8 μmol glucosinolates/g did not (Landero

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Received November 8, 2017.
Accepted December 6, 2017.

et al., 2011). Feeding 24% *B. juncea* CM containing 10.8 µmol glucosinolates/g reduced ADFI (Landero et al., 2013).

Glucosinolate and fiber content and type differ among CM samples (Landero et al., 2011, 2013). The CM can have off-flavors that may reduce feed palatability (Frank et al., 2010) as outcome from sensory systems of pigs that involve olfaction and taste (Baldwin, 1976). Historically, starter pigs persistently reduced selection of diets containing 5% to 20% CM over SBM (Baidoo et al., 1986). Thus, feed palatability of modern CM varying in fiber and glucosinolates content and type in weaned pigs warrants study. Double-choice preference tests are widely used to assess feed palatability (Forbes, 2010) for protein feedstuffs (Kim et al., 2012). Whether feeder position affects feed selection in such tests is inconclusive (Forbes, 2010).

The hypotheses were that weaned pigs have equal feed preference for diets containing 20% SBM, *B. napus* CM, or *B. juncea* CM offered in double-choice selections, and feeder position does not affect feed selection. Objectives were to test feed preference of *B. napus* CM with SBM as reference (***B. napus* CM [SBM]**), *B. juncea* CM with SBM as reference (***B. juncea* CM [SBM]**), or *B. juncea* CM with *B. napus* CM as reference (***B. juncea* CM [*B. napus* CM]**), test if feeder position affects diet selection, and compare growth performance of weaned pigs fed the three paired diets.

MATERIALS AND METHODS

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

Experimental Diets and Design

In two experiments, three double-choice dietary treatments were offered to compare feed preference of three diets containing SBM, *B. napus* CM, or *B. juncea* CM over each other: 1) *B. napus* CM with SBM as reference, 2) *B. juncea* CM with SBM as reference, and 3) *B. juncea* CM with *B. napus* CM as reference. Diets were wheat-based and formulated to contain 20% of three test feedstuffs (Table 1). Based on established NE values and SID AA coefficients (Sauvant et al., 2004; NRC, 2012), and calculated NE values and SID Lys content for *B. napus* and *B. juncea* CM (Landero et al., 2011), diets were formulated to provide 2.36 Mcal NE/kg and 4.49 g SID Lys/Mcal NE (as-fed; Table 2) with other AA as an ideal ratio to Lys (NRC, 2012). Premixes were added to meet or exceed trace mineral and vitamin requirements (NRC, 2012). Diets were mixed in a 300-kg horizontal paddle mixer (Marion Mixers; Marion, IA) and fed as mash in experiment 1. For experiment 2, diets were mixed and subsequently cold-pelleted in a pellet mill (model PM1230, Buskirk Engineering, Ossian, IN) powered by a 22.4 kW electric motor. Prior to pelleting, diets were hydrated to approximately 15% moisture through addition of water to ingredients while mixing. Temperature of pelleted diets exiting the pellet die did not exceed 63 °C. Pelleted diets were cooled and air-dried.

Both experiments 1 and 2 were replicated 3 × 3 Latin squares for three periods starting 2 wk after weaning that occurred at 19 ± 2 d of age. Periods included 4 d of double-choice feed preference test followed by 3 d for a preference test on feeder positions with a common non-test diet.

Table 1. Ingredient composition of experimental diets, as-fed basis

Ingredient, %	Soybean meal	*B. napus* CM	*B. juncea* CM
Wheat, ground	68.47	66.31	66.31
Soybean meal	20.00	–	–
B. napus CM[a]	–	20.00	–
B. juncea CM[b]	–	–	20.00
Canola oil	3.00	4.90	4.90
Soy protein concentrate	2.50	2.50	2.50
Herring fish meal	2.50	2.50	2.50
Limestone	1.00	0.91	0.91
Mono/di-calcium phosphate	0.82	0.74	0.74
Vitamin premix[c]	0.50	0.50	0.50
Mineral premix[d]	0.50	0.50	0.50
Salt	0.50	0.50	0.50
L-Lys•HCl	0.10	0.40	0.40
L-Thr	0.04	0.13	0.13
DL-Met	0.04	0.04	0.04
L-Trp	–	0.04	0.04
Choline chloride	0.03	0.03	0.03

[a]Bunge Canada, Fort Saskatchewan, AB, Canada.

[b]Bunge Canada, Altona, MB, Canada.

[c]Supplied per kilogram of diet: 7,500 IU of vitamin A, 750 IU of vitamin D, 50 IU of vitamin E, 37.5 mg of niacin, 15 mg of pantothenic acid, 2.5 mg of folacin, 5 mg of riboflavin, 1.5 mg of pyridoxine, 2.5 mg of thiamine, 4 mg of vitamin K, 0.25 mg of biotin, and 0.02 mg of vitamin B_{12}.

[d]Supplied per kilogram of diet: Zn, 125 mg (as $ZnSO_4$); Fe, 75 mg (as $FeSO_4$); Cu, 50 mg (as $CuSO_4$); Mn, 25 mg (as $MnSO_4$); I, 0.5 mg [as $Ca(IO_3)_2$]; and Se, 0.3 mg (as Na_2SeO_3).

Table 2. Analyzed nutrient content of experimental diets,[a] as-fed basis

Item, %	Soybean meal	*B. napus* CM	*B. juncea* CM
Moisture	10.1	10.0	9.91
CP	21.7	20.3	20.8
Ash	4.97	5.37	5.09
Crude fat	3.58	5.69	5.09
ADF	3.30	5.80	4.08
NDF	11.1	15.3	13.2
GE, Mcal/kg	4.06	4.20	4.19
Indispensable AA			
Arg	1.24	1.10	1.11
His	0.54	0.54	0.52
Ile	0.83	0.75	0.73
Leu	1.53	1.38	1.36
Lys	1.16	1.27	1.10
Met	0.32	0.35	0.34
Phe	1.00	0.85	0.83
Thr	0.75	0.88	0.82
Trp	0.24	0.22	0.21
Val	0.95	0.91	0.89
Total AA[b]	19.8	18.6	18.0
Chemically-available Lys	1.07	1.18	1.01

[a]Diets were formulated to provide (as fed): 2.36 Mcal NE/kg, 1.06% SID Lys, 0.38% SID Met, 0.70% SID Thr, and 0.24% SID Trp.

[b]Soybean meal diet provided the following dispensable AA (%): Ala, 0.85; Asp, 1.74; Cys, 0.31; Glu, 4.45; Gly, 0.88; Pro, 1.45; Ser, 0.89; and Tyr, 0.64. *Brassica napus* CM diet contained (%): Ala, 0.80; Asp, 1.32; Cys, 0.38; Glu, 4.09; Gly, 0.88; Pro, 1.43; Ser, 0.79; and Tyr, 0.55. The *B. juncea* CM diet provided (%): Ala, 0.79; Asp, 1.30; Cys, 0.33; Glu, 4.07; Gly, 0.88; Pro, 1.38; Ser, 0.78; and Tyr, 0.55.

Experimental Procedures

Prior to the start of experiments, pigs were fed a commercial pre-starter diet (2.65 Mcal NE/kg, 6.2 g SID Lys/Mcal NE; Hi-Pro Feeds, Sherwood Park, AB, Canada) in the farrowing room until day 3 after weaning. Pigs had free access to two diets as a pair that was offered separately in two adjacent feeders in each pen immediately after weaning. From day 3 to 14 after weaning and during the 3-d non-test of each experimental period, pigs were offered the same diet in both feeders. During the 3-d non-test period, a commercial non-test diet (2.62 Mcal NE/kg, 4.8 g SID Lys/Mcal NE; Hi-Pro Feeds) that contained SBM was offered in experiment 1 and a diet (2.54 Mcal NE/kg, 5.0 g SID Lys/Mcal NE) that contained faba bean protein, field pea protein, and herring meal as major protein sources was offered in experiment 2.

For both experiments, blocks with three pens each were formed across the ventilation gradient to account for factors such as location within room, temperature, and ventilation rate. Pigs had free access to feed and water throughout the entire study. Pens (2.2 m × 1.5 m wide) were equipped with polyvinyl chloride partitions, slatted plastic flooring, and two nipple drinkers attached to the opposite wall. Two stainless-steel dry feeders with four feeding spaces of 15.2 cm each were placed beside each other and attached to the front of the pen. Rooms were ventilated using negative pressure and were maintained within the thermo-neutral zone for the pigs, with a 12-h light (0600 to 1800 h) and 12-h dark cycle.

For both experiments, individual pigs were weighed on days 0, 4, and 7 of each 7-d period. Feed added to and remaining in the feeder was weighed daily to calculate feed disappearance per pen. The feeder opening was adjusted to ensure proper feed flow, prevent feed bridging, and minimize feed waste (Nemechek et al., 2015). Feed availability was monitored three times per day to ensure adequate feed available in the trough of each feeder.

In experiment 1, 216 weaned pigs (Large White × Duroc; Hypor, Regina, SK, Canada; initial BW, 9.4 ± 1.6 kg) were housed in 27 pens of 8 pigs (four gilts and four barrows) in three nursery rooms filled 2 wk apart. The three dietary double-choice treatments were randomly allocated to pens within each of three blocks per room to achieve nine observations per treatment. Feeders were switched from their original pens to adjacent pens with the same dietary treatment daily, but feeder position (right or left) remained unchanged. Pigs had free access to 0.5 feeding space in each of two feeders.

In experiment 2, 144 weaned pigs (Large White × Duroc; Hypor, Regina, SK, Canada; initial BW, 8.9 ± 1.1 kg) housed in 36 pens of 4 pigs (two gilts and two barrows) in four nursery rooms were used. The three dietary choices were randomly allocated to pens within each of three blocks per room to achieve 12 observations per double-choice treatment. Each test diet was equally assigned to the left or right feeder at the start. Feeder position (right or left) in each pen was switched daily and feeders were also switched from their original pens to adjacent pens with the same dietary treatment daily. Pigs had free access to one feeding space in each of two feeders.

Chemical Analyses

SBM, *B. napus* CM, *B. juncea* CM, and test diets were ground through a 1-mm screen in a centrifugal mill (Retsch GmbH, Haan, Germany). Diets and ingredients were analyzed for DM (method 930.15), CP (method 990.03; N × 6.25), crude fat (method 920.39A), ADF inclusive of residual ash (method 973.18), ash (method 942.05), AA (method 982.30E) and chemically-available Lys (method 975.44) as described by AOAC (2006), GE using an adiabatic bomb calorimeter (model 5003; Ika-Werke GMBH & Co. KG, Staufen, Germany), and NDF assayed without a heat stable amylase and expressed inclusive of residual ash (Holst, 1973). In addition, test ingredients were analyzed for total dietary fiber (method 985.29), Ca (method 968.08), and P (method 946.06) according to AOAC (2006) and starch (assay kit STA-20; Sigma, St. Louis, MO). The *B. napus* and *B. juncea* CM were analyzed for glucosinolates by GLC (Daun and McGregor, 1981).

Calculations and Statistical Analyses

Feed preference for a test diet vs. its reference diet was expressed as a percentage by dividing feed intake of the test diet by total feed intake of test and reference diets (Sola-Oriol et al., 2011). Preference for feeder position (left or right) was expressed as a percentage by dividing feed intake from one feeder by total feed intake from both feeders. Pig BW and weight of consumed feed were used to calculate ADG, ADFI, and G:F for each pen.

Feed preference and growth performance data were analyzed using SAS (Version 9.4; SAS Inst. Inc., Cary, NC) with pen as the experimental unit for both experiments 1 and 2. Paired *t*-test was used to analyze feed preference of a test diet vs. its reference diet. Feed preference among the three paired diet comparisons and preference between feeder positions were analyzed using the GLIMMIX procedure with the Gaussian distribution and Identity link function options. Treatment, period, day, treatment × period, treatment × day, and treatment × day (period) were fixed effects, and block was a random factor in the statistical models. Weekly or daily effects among three paired diet comparisons and between feeder positions were analyzed for each period and day. For growth performance, data were analyzed using the MIXED procedure. Normality and homogeneity of variance of the residual of each variable were confirmed using the UNIVARIATE procedure with "Normal" option and GLM procedure with "Hovtest = Levene" option, respectively. Performance data were analyzed as repeated measures with the SIMPLE variance-covariance structure, except for ADFI in experiment 2 with the first-order ante-dependence variance-covariance structure based on the Bayesian information criterion (**BIC**) fit statistics and with initial BW as a covariate if significant. The *P* values for multiple comparisons were adjusted with the Tukey option in the statistical models. To test the hypotheses, $P < 0.05$ was considered significant and $0.05 \leq P < 0.10$ was considered a trend.

RESULTS

The two CM diets provided similar CP as the SBM diet (Table 2). However, *B. napus* CM and *B. juncea* CM diets contained more crude fat, ADF, and NDF than the SBM diet. The *B. napus* CM and *B. juncea* CM samples contained less CP, but more crude fat, ADF, NDF, total dietary fiber than the SBM sample (Table 3). The *B. juncea* CM contained double the total glucosinolate than *B. napus* CM (Table 3). The dominant glucosinolate in *B. juncea*

Table 3. Analyzed nutrient content of the test ingredients, as-fed basis

Item, %	SBM	*B. napus* CM	*B. juncea* CM
Moisture	7.50	11.8	10.8
CP	46.0	38.6	39.2
Total dietary fiber	20.5	29.3	25.7
NDF	9.54	27.0	19.9
ADF	6.13	18.0	13.5
Starch	3.70	–	1.66
Crude fat	1.14	1.91	1.72
Ash	8.04	7.75	7.34
Ca	1.02	0.66	0.71
P	0.73	1.26	1.40
GE, Mcal/kg	4.25	4.30	4.26
Indispensable AA			
Arg	3.30	2.24	2.53
His	1.35	0.96	1.00
Ile	2.09	1.29	1.57
Leu	3.55	2.59	2.81
Lys	2.95	2.00	2.01
Met	0.60	0.76	0.74
Phe	2.27	1.45	1.55
Thr	1.76	1.61	1.61
Trp	0.62	0.43	0.41
Val	2.18	1.71	1.99
Total AA[a]	43.7	33.5	34.8
Available Lys	2.80	1.81	1.86
Total glucosinolates,[b] µmol/g	–	4.91	10.84

[a]SBM provided the following dispensable AA (%): Ala, 1.92; Asp, 4.95; Cys, 0.61; Glu, 7.53; Gly, 1.85; Pro, 2.26; Ser, 2.04; and Tyr, 1.64. The *B. napus* CM provided (%): Ala, 1.67; Asp, 2.67; Cys, 0.92; Glu, 6.05; Gly, 1.87; Pro, 2.19; Ser, 1.51; and Tyr, 1.03. The *B. juncea* CM provided (%): Ala, 1.76; Asp, 2.95; Cys, 0.83; Glu, 6.14; Gly, 1.96; Pro, 2.05; Ser, 1.45; and Tyr, 1.07.

[b]*Brassica napus* CM provided the following glucosinolates (µmol/g): 3-butenyl, 1.27; 4-pentenyl, 0.11; 2-OH-3-butenyl, 2.30; phenylethyl, 0.10; 3-CH3-indolyl, 0.17; and 4-OH-3-CH3-indolyl, 0.96. *Brassica juncea* CM provided: Allyl, 0.14; 3-butenyl, 9.33; 4-pentenyl, 0.32; 2-OH-3-butenyl, 0.69; phenylethyl, 0.12; 3-CH3-indolyl, 0.07; and 4-OH-3-CH3-indolyl, 0.17.

CM was 3-butenyl (gluconapin), whereas the major glucosinolate in *B. napus* CM was 2-OH-3-butenyl (progoitrin) followed by gluconapin.

In experiment 1, overall the pigs preferred ($P < 0.001$; Table 4) the SBM diet over the *B. napus* and *B. juncea* CM diets, and preferred ($P < 0.001$) the *B. napus* CM diet over the *B. juncea* CM diet. Overall among pairs, the extent of feed preference was strongest ($P < 0.05$) for the SBM diet over the *B. juncea* CM diet, intermediate for the SBM diet over the *B. napus* CM diet, and weakest ($P < 0.05$) for the *B. napus* CM diet over the *B. juncea* CM diet. Diet choice interacted with period ($P = 0.007$). Within period 2, feed preference among pairs was ranked identical as overall, but feed preference for the *B. napus* CM diet over the SBM diet and the *B. juncea* CM diet over the SBM diet did not differ from each other within periods 1 and 3. Among periods, feed preference for the *B. napus* CM diet over the SBM diet was greater for period 2 ($P < 0.05$) than periods 1 and 3. Feed preference for the *B. juncea* CM diet over the SBM diet was lower for periods 1 and 2 ($P < 0.05$) than period 3. Feed preference for the *B. juncea* CM diet over the *B. napus* CM diet did not differ among the three periods. A daily increase in feed preference for any of the three paired diets was not detected.

When pigs were offered one non-test diet in both two feeders within a pen, pigs preferred ($P < 0.001$; Table 5) the feeder positioned on the left side over that on the right side overall and for period 1 ($P < 0.001$), but not for periods 2 or

Table 4. Preference of weaned pigs fed paired mash diets containing of SBM, *B. napus* CM, or *B. juncea* CM,* experiment 1

	Paired diets, test diet [reference diet]‡				*P*-value$			
Feed preference,† %	1. *B. napus* CM [SBM]	2. *B. juncea* CM [SBM]	3. *B. juncea* CM [*B. napus* CM]	SEM‖	Among pairs	Pair 1	Pair 2	Pair 3
Period 1								
Day 1	14.7^{b}	9.7^{b}	39.5^{a}	10.0	0.015	< 0.001	< 0.001	0.329
Day 2	13.5^{b}	5.3^{b}	37.8^{a}	9.3	0.005	< 0.001	< 0.001	0.253
Day 3	9.6^{b}	5.1^{b}	35.4^{a}	7.0	< 0.001	< 0.001	< 0.001	0.081
Day 4	6.9^{b}	6.0^{b}	35.8^{a}	5.8	< 0.001	< 0.001	< 0.001	0.052
Days 1–4	11.2^{by}	6.5^{by}	37.1^{a}	4.0	< 0.001	< 0.001	< 0.001	0.003
Period 2								
Day 1	29.2^{a}	10.9^{b}	37.6^{a}	6.5	0.001	0.001	< 0.001	0.084
Day 2	20.3^{ab}	7.2^{b}	32.1^{a}	6.9	0.006	< 0.001	< 0.001	0.040
Day 3	20.9^{ab}	8.0^{b}	29.9^{a}	6.6	0.010	< 0.001	< 0.001	0.011
Day 4	17.0^{ab}	8.8^{b}	25.9^{a}	6.6	0.052	< 0.001	< 0.001	0.009
Days 1–4	21.8^{bx}	8.7^{cy}	31.4^{a}	3.3	< 0.001	< 0.001	< 0.001	< 0.001
Period 3								
Day 1	12.4^{b}	19.7^{b}	40.1^{a}	8.6	0.011	< 0.001	< 0.001	0.313
Day 2	13.2^{b}	12.5^{b}	37.9^{a}	6.4	0.001	< 0.001	< 0.001	0.146
Day 3	17.8^{b}	13.5^{b}	36.4^{a}	7.8	0.016	< 0.001	< 0.001	0.146
Day 4	17.8^{b}	14.7^{b}	43.1^{a}	7.6	0.002	< 0.001	< 0.001	0.418
Days 1–4	15.3^{by}	15.1^{bx}	39.4^{a}	3.7	< 0.001	< 0.001	< 0.001	0.012
Overall								
Day 1	18.8^{b}	13.4^{b}	39.1^{a}	4.9	< 0.001	< 0.001	< 0.001	0.032
Day 2	15.7^{b}	8.3^{b}	35.9^{a}	4.3	< 0.001	< 0.001	< 0.001	0.006
Day 3	16.1^{b}	8.9^{b}	33.9^{a}	4.1	< 0.001	< 0.001	< 0.001	0.001
Day 4	13.9^{b}	9.8^{b}	34.9^{a}	4.0	< 0.001	< 0.001	< 0.001	0.001
Days 1–4	16.1^{b}	10.1^{c}	36.0^{a}	2.1	< 0.001	< 0.001	< 0.001	< 0.001

$^{a–c}$Within a row, means without a common superscript differ ($P < 0.05$).

^{x,y}Within a column, means for days 1–4 of each period without a common superscript differ ($P < 0.05$).

*Diets were offered in a paired choice as mash in two feeders with four feeding spaces each. Each pig had access to 0.5 feeding space if all pigs were eating simultaneously.

†Feed preference of a test diet was expressed as percentage of sum of feed intake of test diet and its reference diet.

‡A value < 50 means that pigs preferred the reference diet. The lower the value, the stronger the preference for the reference diet over the test diet. Preference of the reference diet (= 100 – Feed preference of test diet) was not shown.

‖Least-squares means based on nine pen observations of eight pigs per double-choice comparison.

$For feed preference, an effect of paired diet comparison ($P < 0.001$) and interaction between paired diet comparison and period ($P = 0.007$) were observed.

Table 5. Preference on feeder position of weaned pigs during non-test periods when feeding a common non-test SBM-based diet in both feeders,[a,b,c] experiment 1

	Feeder position			
Preference, %	Left	Right	SEM	*P*-value
Period 1				
Day 5	62.4	37.6	5.5	< 0.001
Day 6	54.8	45.2	7.1	0.179
Day 7	64.4	35.6	8.5	0.002
Days 5–7	60.5	39.5	4.1	< 0.001
Period 2				
Day 5	53.5	46.5	6.1	0.253
Day 6	54.0	46.0	9.3	0.397
Day 7	51.8	48.2	9.8	0.716
Days 5–7	53.1	46.9	4.9	0.207
Period 3				
Day 5	50.2	49.8	5.1	0.951
Day 6	52.0	48.0	7.5	0.588
Day 7	53.7	46.3	7.7	0.342
Days 5–7	52.0	48.0	3.9	0.319
Overall				
Day 5	55.4	44.6	3.3	0.001
Day 6	53.6	46.4	4.6	0.116
Day 7	56.6	43.4	5.0	0.010
Days 5–7	55.2	44.8	2.5	< 0.001

[a]Least-squares means based on 27 pen-observations of 8 pigs each. Within the pen, the same starter diet was offered for 3 d in three different non-test periods to all pens of pigs. The same diet was offered as mash in two feeders with four feeding spaces. Each pig had access to 0.5 feeding space if all pigs were eating simultaneously. Feeder position within and among pens was not switched.

[b]Feeder preference was expressed as a percentage of feed intake from feeder positioned on left or right out of total intake from the two feeders.

[c]For feeder preference, effects of feeder position and an interaction between feeder position and period were observed ($P < 0.05$), but effects of period and day were not ($P > 0.05$).

3. Overall, ADG and ADFI did not differ among pigs fed the three paired diets (Table 6); however, pigs fed the *B. juncea* CM [*B. napus* CM] diets had greater ($P < 0.05$) G:F compared with pigs fed the *B. napus* CM [SBM] or *B. juncea* CM [SBM] diets. For period 2, pigs fed the *B. napus* CM [SBM] or *B. juncea* CM [SBM] diets had greater ADFI ($P < 0.05$) than pigs fed the *B. juncea* CM [*B. napus* CM] diet. For period 3, pigs fed the *B. juncea* CM [*B. napus* CM] diet had greater G:F ($P < 0.05$) compared with pigs fed the *B. juncea* CM [SBM] diet.

In experiment 2, overall the pigs preferred the SBM diet ($P < 0.001$; Table 7) over the *B. napus* or *B. juncea* CM diets, and preferred ($P < 0.001$) the *B. napus* CM diet over the *B. juncea* CM diet. Overall among pairs, the extent of feed preference did not differ. Diet choice interacted with period ($P < 0.01$). Within period 1, feed preference for the *B. napus* CM diet over the SBM diet was greater ($P < 0.05$) than for the *B. juncea* CM diet over the SBM diet. Within period 3, feed preference for the *B. juncea* CM diet over the SBM diet was greater ($P < 0.05$) than for the *B. napus* CM diet over the SBM diet. Among periods, pigs preferred the SBM diet over the *B. napus* CM diet stronger ($P < 0.05$) for periods 2 and 3 than for period 1, and preferred the SBM diet over the *B. juncea* CM diet stronger ($P < 0.05$) for period 2 than for period 3. Feed preference for the *B. juncea* CM over the *B. napus* CM diet did not differ among the three periods. A daily increase in feed preference within each pair of diets was not observed.

When pigs were offered one non-test diet in both two feeders within a pen, overall preference of pigs for feed position did not differ (Table 8). Within periods, pigs tended to prefer ($P = 0.05$) the feeder positioned on the left side for period 2, but preferred ($P < 0.05$) the feeder on the right side for period 3. Pigs fed the three paired diets did not differ ($P > 0.05$; Table 9) in ADG, ADFI, and G:F overall and for each period.

DISCUSSION

In the present study, weaned pigs preferred the SBM diet over CM diets, and preferred the *B. napus* CM diet over the *B. juncea* CM diet. Glucosinolates, fiber, or other taste factors in CM diets, but not nutrient availability, might have affected diet selection (Kyriazakis and Emmans, 1992, 1995). Interestingly, weaned pigs consuming the *B. juncea* CM [*B. napus* CM] diets did not reduce feed intake or growth compared with pigs consuming the *B. napus* CM [SBM] or *B. juncea* CM [SBM] diets, indicating that young pigs tolerate glucosinolates in *B. napus* (Landero et al., 2011) but not in *B. juncea* CM (Landero et al., 2013).

Chemical Characteristics of CM Samples

With a thinner seed coat, *B. juncea* CM contained less fiber than *B. napus* CM, but *B. juncea* CM still contained double the fiber than SBM (Newkirk et al., 1997; Bell et al., 1998; Slominski et al., 2012). A major concern for including CM in swine diets is that glucosinolates may affect feed palatability in pigs (Rundgren, 1983). Similar to previous data (Landero et al., 2011, 2013; Zhou et al., 2013), *B. juncea* CM contained double the total glucosinolates than *B. napus* CM in the present study. Nevertheless, total glucosinolate content in both CM samples was much lower than 110–150 μmol/g in rapeseed meal (Bell, 1993;

Table 6. Growth performance of weaned pigs fed paired mash diets,*,† experiment 1

	Paired diets, test diet [reference diet]				
Item	1. *B. napus* CM [SBM]	2. *B. juncea* CM [SBM]	3. *B. juncea* CM [*B. napus* CM]	SEM	*P*-value
ADFI, g					
Period 1	619	607	620	21	0.759
Period 2	882[a]	872[a]	813[b]	25	0.025
Period 3	1,192	1,243	1,214	35	0.382
Overall	898	907	882	15	0.267
ADG, g					
Period 1	419	417	432	23	0.759
Period 2	552	561	539	26	0.640
Period 3	735	753	783	24	0.277
Overall	568	577	585	15	0.557
G:F					
Period 1	0.68	0.68	0.70	0.02	0.541
Period 2	0.62	0.64	0.66	0.02	0.293
Period 3	0.62[ab]	0.61[b]	0.64[a]	0.01	0.026
Overall	0.64[b]	0.64[b]	0.67[a]	0.01	0.038

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

*Diets were offered in a paired choice as mash during each experimental period.

†Least-squares means based on nine pen-observations of eight pigs each for each period. For ADFI, an effect of period ($P < 0.05$) and diet combination and period did not interact ($P > 0.05$). For ADG and G:F, an effect of period ($P < 0.05$) was observed.

Newkirk, 2011). Crop breeding has reduced total glucosinolates to below 10 µmol/g in CM from canola seed grown in western Canada since 2009 (Canadian Grain Commission, 2016). The *B. juncea* CM differs from *B. napus* CM in both glucosinolate content and profile. Progoitrin is the main glucosinolate in *B. napus* CM (Fenwick et al., 1982; Bell et al., 1984; Landero et al., 2011), whereas gluconapin is the main glucosinolate in *B. juncea* CM (Newkirk et al., 1997; Bell et al., 1998; Landero et al., 2013).

Preference of Diet and Feeder Position

Many factors can affect feed preference in pigs (Forbes and Kyriazakis, 1995; Forbes, 2010). For example, pigs can select between diets that vary in nutrient density (Edmonds et al., 1987; Fuller et al., 1995; Ferguson et al., 1999). Pigs preferred a diet balanced for AA above a diet containing similar CP but deficient in several AA (Devilat et al., 1970). To minimize effects of unbalanced nutrients or nutrient density, diets were formulated to equal NE value and SID AA content in the present study. Pigs may prefer items at first exposure (Bolhuis et al., 2009). To reduce the early exposure effect, we used a Latin square so each treatment was assigned equally as first exposed item and applied to a pen once in the entire trial. In addition, rotating feeders among pens and switching feeder position in experiment 2 served to minimize the effect of pigs favoring a particular feeder or position following first exposure.

Greater feed preference for SBM diet over CM diets in weaned pigs throughout the present study is consistent with reduced feed intake of CM diets reported previously (Baidoo et al., 1986), but not with equal feed intake between CM and SBM recently (Landero et al., 2011; Sanjayan et al., 2014). The small difference in CP content among the three diets in the present study do not explain the large differences in feed preference (Kyriazakis and Emmans, 1992). CM contains anti-nutritional factors, e.g., glucosinolates, tannins, and sinapine (Bell, 1993; Khattab et al., 2010a; Khattab et al., 2010b) that contribute to bitter flavor (Fenwick et al., 1982; Bell, 1993). Pigs may avoid subsequent consumption of feed with an unpleasant gustatory perception, known as the "Garcia effect" (Revusky, 1971; Breslin and Spector, 2008). Feeding extracts of rapeseed meal to growing pigs revealed that glucosinolates in CM, but not tannins or sinapine, substantially depressed feed intake (Lee et al., 1984). Following disruption of seed cells and low heating, myrosinase that remains intact within the cytoplasm can hydrolyze glucosinolates and yield toxic thiocyanates, nitriles, and isothiocyanates (Mithen et al., 2000). The thiocyanates have strong bitter taste (Fenwick et al., 1982, 1983) that may reduce feed palatability in pigs (Bell et al., 1981; McIntosh et al., 1986; Baidoo et al., 1987; Kyriazakis and Emmans, 1993). Breakdown products of

Table 7. Preference of weaned pigs fed paired cold-pelleted diets containing SBM, *B. napus* CM, or *B. juncea* CM,* experiment 2

	Paired diets, test diet [reference diet][‡]				*P*-value[$]			
Feed preference,[†] %	1. *B. napus* CM [SBM]	2. *B. juncea* CM [SBM]	3. *B. juncea* CM [*B. napus* CM]	SEM[‖]	Among pairs	Pair 1	Pair 2	Pair 3
Period 1								
Day 1	35.0	22.7	33.5	15.2	0.679	0.178	0.016	0.201
Day 2	29.9	10.5	16.4	10.8	0.200	0.022	< 0.001	0.007
Day 3	36.0	14.6	19.6	10.5	0.117	0.101	< 0.001	0.003
Day 4	29.4	9.6	23.9	10.1	0.144	0.007	< 0.001	0.024
Days 1–4	32.6[ax]	14.3[bxy]	23.4[ab]	5.5	0.005	< 0.001	< 0.001	< 0.001
Period 2								
Day 1	11.3	23.9	18.6	10.6	0.503	< 0.001	0.020	0.002
Day 2	14.3	12.1	21.5	9.7	0.597	< 0.001	< 0.001	0.007
Day 3	11.2	6.2	14.9	5.9	0.354	< 0.001	< 0.001	< 0.001
Day 4	15.5	4.9	18.6	6.6	0.108	< 0.001	< 0.001	< 0.001
Days 1–4	13.1[y]	11.8[y]	18.4	3.9	0.204	< 0.001	< 0.001	< 0.001
Period 3								
Day 1	11.1	24.3	21.7	9.5	0.347	< 0.001	0.004	0.009
Day 2	17.5	20.4	9.6	6.8	0.276	< 0.001	0.001	< 0.001
Day 3	7.0	19.0	19.0	7.7	0.211	< 0.001	0.001	< 0.001
Day 4	11.4[ab]	22.2[a]	5.5[b]	6.0	0.029	< 0.001	0.001	< 0.001
Days 1–4	11.8[by]	21.5[ax]	14.0[ab]	3.5	0.016	< 0.001	< 0.001	< 0.001
Overall								
Day 1	19.1	23.6	24.6	7.0	0.706	< 0.001	< 0.001	< 0.001
Day 2	20.6	14.3	15.9	5.3	0.478	< 0.001	< 0.001	< 0.001
Day 3	18.1	13.3	17.8	5.0	0.556	< 0.001	< 0.001	< 0.001
Day 4	18.7	12.2	16.0	4.7	0.383	< 0.001	< 0.001	< 0.001
Days 1–4	19.1	15.8	18.6	2.6	0.413	< 0.001	< 0.001	< 0.001

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[x,y]Within a column, means for days 1–4 of each period without a common superscript differ ($P < 0.05$).

*Diets were offered in a paired choice as pellets in two feeders with four feeding spaces each. Each pig had access to one feeding space if all pigs were eating simultaneously.

[†]Feed preference of a test diet was expressed as percentage of sum of feed intake of test diet and its reference diet.

[‡]A value < 50 means that pigs preferred the reference diet. The lower the value, the stronger the preference for the reference diet over the test diet. Preference of reference diet (= 100 – Feed preference of test diet) was not shown.

[‖]Least-squares means based on 12 pen observations of 4 pigs per paired comparison.

[$]For feed preference, effects of paired diet comparison and day were not observed ($P = 0.413$), but an effect of period and interaction between paired diet comparison and period were observed ($P < 0.01$).

glucosinolates have other biological effects in pigs, e.g., liver and thyroid gland hypertrophy, iodine deficiency, and increased plasma thyroid hormones (Schöne et al., 1990; Bell et al., 1991; Busato et al., 1991; Thomke et al., 1998). As such, pigs are sensitive to dietary inclusion of CM. Inclusion of 5% CM containing 10.5 µmol total glucosinolates/g reduced diet selection when provided a choice, and increasing dietary inclusion of CM linearly reduced feed preference in starter pigs (Baidoo et al., 1986). Similarly, feed preference decreased with increasing *B. napus* rapeseed meal in diets for growing pigs (Sola-Oriol et al., 2011).

Pigs may reduce intake of CM diets differing in glucosinolates content and profile (Baidoo et al., 1986; Landero et al., 2011; Landero et al., 2013). The calculated glucosinolate content was double in the *B. juncea* CM diet than *B. napus* CM diet (2.2 vs. 1.0 µmol/g) that was sufficient to reduce feed preference (Baidoo et al., 1986). Moreover, *B. juncea* contained seven times more gluconapin than *B. napus* CM. Progoitrin is bitter (Fenwick et al., 1983); however, the bitter effect was 9-fold stronger for gluconapin than progoitrin as measured in sensory analysis (Fenwick et al., 1982). Gluconapin content was negatively correlated with feed intake in weaned pigs (Landero et al., 2013). The 3-butenyl isothiocyanate, the main breakdown product of gluconapin, may cause off-flavor of *B. juncea* CM (Frank et al., 2010). The bitter taste and potential toxicity of gluconapin reduced feed palatability in pigs fed *B. juncea* CM (Bell et al., 1981; Landero et al., 2013;

Table 8. Preference on feeder position of weaned pigs during non-test periods when feeding a common non-test diet based on faba bean protein, field pea protein, and herring meal in both feeders,[a,b,c] experiment 2

	Feeder position			
Preference, %	Left	Right	SEM	*P*-value
Period 1				
Day 5	51.1	48.9	7.2	0.761
Day 6	49.0	51.0	6.9	0.768
Day 7	54.4	45.6	7.3	0.235
Days 5–7	51.5	48.5	4.1	0.471
Period 2				
Day 5	52.7	47.3	7.2	0.455
Day 6	55.5	44.5	7.8	0.157
Day 7	54.1	45.9	7.0	0.249
Days 5–7	54.1	45.9	4.2	0.052
Period 3				
Day 5	47.5	52.5	4.8	0.308
Day 6	41.4	58.6	5.9	0.005
Day 7	42.6	57.4	6.2	0.020
Days 5–7	43.9	56.1	3.3	< 0.001
Overall				
Day 5	50.5	49.5	3.7	0.810
Day 6	48.6	51.4	4.0	0.502
Day 7	50.4	49.6	4.0	0.860
Days 5–7	49.8	50.2	2.3	0.870

[a]Least-squares means based on 36 pen-observations of 4 pigs each. Within the pen, the same starter diet was offered for 3 d in three different non-test periods to all pigs. Diet was offered as pellets in two feeders with four feeding spaces. Each pig had access to one feeding space if all pigs were eating simultaneously. Feeder position within and among pens was switched daily.

[b]Feeder preference was expressed as a percentage of feed intake of a SBM diet from feeder positioned on left or right out of total intake from the two feeders.

[c]Effects of feeder position, period, and day were not observed ($P > 0.05$), but an interaction between feeder position and period was observed ($P < 0.05$).

Zhou et al., 2013). Strong avoidance of the *B. juncea* CM diet in weaned pigs indicated that canola breeding needs to reduce bitter gluconapin-type glucosinolates in *B. juncea* canola to prevent reduced feed intake in weaned pigs (Landero et al., 2013).

Another potential factor for greater feed preference for SBM over CM diets is that the *B. napus* and *B. juncea* CM diets contained more fiber than the SBM diet. Increased fiber may increase diet bulkiness, thereby reducing feed intake of young pigs (Kyriazakis and Emmans, 1995; Wilfart et al., 2007). However, *B. juncea* contained less fiber than *B. napus*, but weaned pigs preferred *B. napus* CM diet over *B. juncea* CM diet, indicating that the role of fiber of CM in affecting feed preference was minor (Kyriazakis and Emmans, 1993; Ferguson et al., 2002).

Feed preference of a test diet is relative to its reference diet. When SBM diet was fed as a reference, both *B. napus* CM diet and *B. juncea* CM diet had low feed preference. However, feeding the *B. napus* CM instead of the SBM diet as reference increased feed preference for the *B. juncea* CM diet from 10% to 36% in experiment 1. Vice versa, feeding the *B. juncea* CM diet instead of the SBM diet as a reference increased feed preference for the *B. napus* CM diet from 19 to 81% in experiment 2, indicating that feed preference may be associated with anti-nutritional factors in diets (Forbes and Kyriazakis, 1995; Ferguson et al., 1999). However, similar feed preference of the SBM diet over the *B. napus* CM and *B. juncea* CM diets in experiment 2 does not imply equal feed preference between *B. napus* CM and *B. juncea* CM diets, because pigs preferred the *B. napus* CM over *B. juncea* CM diet.

Older weaned pigs did not increase tolerance of unpleasant characteristics of CM diets compared with younger weaned pigs, because the period effect of feed preference was inconsistent in the present study. Within a short period of time (4 d) in the present study, weaned pigs failed to show adaptation to CM diets because daily increase of feed preference was not observed. The lack of change indicates that anti-nutritional factors in CM may be a concern for weaned pigs, and their effect cannot be avoided by acclimatization to diets in a short time.

Constant position (right or left) of feeders within pens may affect feed preference in double-choice trials. Pigs may habituate to eating from a particular location before starting the study (Devilat et al., 1970; Baldwin, 1976). Feed preference varied when feeder position was switched even though pigs were offered two identical diets (Ferguson et al., 2002). Pigs preferred feeders positioned on the left side during non-test periods in experiment 1. Thus, a new procedure to switch feed positions daily was implemented in experiment 2 to prevent pigs eating from one particular feeder (Forbes, 2010). Consequently, preference of feeder position was not observed during non-test periods in experiment 2. Switching feeder position may assist to achieve better evaluation of feed preference in double-choice trials. However, switching feeder position may confuse pigs and become a confounding factor unless feed can be clearly differentiated by tangible characteristics (Ettle and Roth, 2009; Forbes, 2010). Switching feeder position together with feeding space differences, may partly explain the difference in feed preference between experiments 1 and 2.

Table 9. Growth performance of weaned pigs fed paired cold-pelleted diets,[a,b] experiment 2

	Paired diets, test diet [reference diet]				
Item	1. *B. napus* CM [SBM]	2. *B. juncea* CM [SBM]	3. *B. juncea* CM [*B. napus* CM]	SEM	*P*-value
ADFI, g					
Period 1	487	494	484	16	0.818
Period 2	797	822	761	39	0.331
Period 3	1,088	1,075	1,073	43	0.929
Overall	791	797	773	20	0.446
ADG, g					
Period 1	337	351	342	23	0.853
Period 2	593	577	539	35	0.323
Period 3	724	721	748	31	0.631
Overall	551	549	543	14	0.881
G:F					
Period 1	0.69	0.70	0.71	0.03	0.812
Period 2	0.75	0.70	0.71	0.03	0.261
Period 3	0.66	0.67	0.70	0.02	0.162
Overall	0.70	0.69	0.71	0.02	0.708

[a]Offered in a paired choice as pellets during each experimental period.

[b]Least-squares means based on nine pen-observations of eight pigs each for each period. For all variables, effects of diet and interaction between diet combination and period were not observed ($P > 0.05$). For ADFI and ADG, an effect of period ($P < 0.05$) was observed. For G:F, a trend for effect of period ($0.05 \leq P < 0.10$) was observed.

Feeding space was double in experiment 2 compared with experiment 1 to better evaluate feed preference. In experiment 1, if all eight pigs in one pen had strong feed preference for one of two paired diets, feeding space was limited. In this case, if the feeder with preferred feed is occupied, pigs with a lower social rank might have to eat from the feeder containing the non-preferred feed (Ermer et al., 1994). Conversely, with limiting feeding space in experiment 1, pigs still expressed similar feed preference as in experiment 2, indicating pigs may wait for favored feed rather than consume less favored feed if feeding space is limited. Halving feeding space did not alter overall ranking of feed preference, indicating that differences in feed palatability among the three diets were large. Considering other factors that may affect feed intake, e.g., physical appearance, texture of feed (Forbes, 2010), bulk density, or mash feed bridging in hoppers of feeders (Hancock and Behnke, 2000), diets were pelleted in experiment 2 to minimize these factors affecting feed preference. Nevertheless, switching feed position, increasing feeding space, and pelleting did not alter the outcome of feed preference of CM over SBM or *B. juncea* CM over *B. napus* CM in weaned pigs.

Feed Preference and Growth Performance

Lower feed preference of CM diets over the SBM diet did not affect ADFI and ADG in weaned pigs. Preference of a test diet is relative to a reference diet, but combined intake of feed mostly depends on pigs striving to meet their energy needs (Nyachoti et al., 2004). Maintained growth confirmed that CM can be an alternative feedstuff to SBM for pigs (Woyengo et al., 2014). However, the *B. napus* CM diet was the majority of feed consumed when offering *B. napus* CM or *B. juncea* CM (64% for experiment 1, and 81% for experiment 2). Recent trials confirmed effects of feed preference of *B. napus* and *B. juncea* CM on feed intake and subsequent growth performance. Weaned pigs maintained ADFI and ADG when fed diets containing 20% *B. napus* CM (3.8 µmol total glucosinolates/g) to replace SBM (Landero et al., 2011), but failed to maintain ADFI and ADG when fed diets containing 20% *B. juncea* CM (10.8 µmol total glucosinolates/g) to replace SBM (Landero et al., 2013). The *B. juncea* CM contains less fiber and more NE than *B. napus* CM (Le et al., 2012), but effects of fiber and NE on feed preference might be negligible compared with its glucosinolate content and profile (Ferguson et al., 1999).

In conclusion, weaned pigs strongly preferred the SBM diet over *B. napus* CM or *B. juncea* CM diets. Weaned pigs preferred *B. napus* CM diet over *B. juncea* CM diet indicating that gluconapin in *B. juncea* CM was a major concern affecting CM preference. However, weaned pigs fed *B. juncea* CM [*B. napus* CM] diets did not reduce feed intake compared with pigs fed *B. napus* CM [SBM] or *B. juncea*

CM [SBM] diets, indicating that lower feed preference of a diet does not equate to poorer feed intake. Whether feeder position affected feed selection in double-choice tests remains inconclusive.

ACKNOWLEDGMENTS

We thank Agriculture and Agri-Food Canada and the Canola Council of Canada through the Growing Forward program for the funding for this project. We thank Dr. Rong-Cai Yang for advice on statistical analyses.

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