Nutritive value of enzyme-supplemented carinata meal for growing pigs[1]

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ABSTRACT: Carinata meal is increasingly available for livestock feeding. However, the effects of supplemental phytase and fiber degrading enzymes on nutritive value of carinata meal for pigs have not been reported. Objective of the study was to evaluate the standardized ileal digestibility (SID) of amino acid (AA), and digestible energy (DE) and net energy (NE) values of phytase- and fiber-degrading enzymes-supplemented carinata meal for growing pigs. Ten ileal-cannulated pigs (initial body weight = 53.9 ± 4.76 kg) were fed 4 diets in a replicated 4 × 4 Latin square design with two additional columns to give 10 replicates per diet. Diets included a corn-soybean meal (SBM)-based basal diet, basal diet with 25% carinata meal, basal diet with 25% carinata meal plus phytase at 2,000 FTU/kg and multi-carbohydrase at 0.2 g/kg, and in addition a nitrogen-free diet. The multicarbohydrase supplied 4 units of xylanase, 10 units of β-glucanase, and 1,000 units of pectinase per kilogram of diet. The ratio of corn to SBM and soybean oil in carinata meal-containing diets was identical to that in the corn-SBM-based basal diet to allow calculation of AA and energy digestibility of carinata meal by the difference method. On a dry matter basis, carinata meal contained 50.2% crude protein, 0.88% ether extract, 15.37% acid detergent fiber, 1.82% Lys, 0.96% Met, 1.89% Thr, and 0.64% Trp, respectively. The SID of Lys, Met, Thr, and Trp for carinata meal were 51.4%, 82.2%, 65.9%, and 85.9%, respectively. The DE and NE values for carinata meal were 3,427 and 1,828 kcal/kg of dry matter, respectively. Supplementation of a combination of phytase and multicarbohydrase did not affect the apparent ileal digestibility of AA and SID of AA for the corn-SBM-carinata meal-based diet, and for the carinata meal. However, the combination of phytase and multicarbohydrase did improve ($P < 0.05$) apparent total tract digestibility, and DE and NE values for carinata meal by 9.4%, 9.5%, and 12.4%, respectively. In conclusion, the enzymes used in the current study could be added in carinata meal-based diets for growing pigs to improve the energy value.

Key words: carinata meal, multicarbohydrase, nutrient digestibility, phytase, pigs

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INTRODUCTION

The increasing demand for biofuel production has triggered an upsurge in research into the development of profitable oil crops (Blackshaw et al., 2011). *Brassica carinata*, also known as Ethiopian mustard, has been used for biofuel production for more than 10 yr (Cardone et al.,

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2003; Xin and Yu, 2013; Schulmeister et al., 2016). Carinata grows well with good lodging and shatter resistance in semi-arid regions of Canadian Prairies and Northern Plains of the United States (Xin and Yu, 2013). Thus, its cultivation for biofuel production is increasing, implying that the carinata co-products are becoming increasingly available for livestock feeding.

Solvent-extracted carinata meal has a high protein content. For instance, its crude protein (CP) content on dry matter (DM) basis was 51.6% (Xin and Yu, 2013), which is close to the value (53% on DM basis) that was reported by NRC (2012) for soybean meal (SBM); SBM is the most widely used source of amino acids (AA) in swine diets. Thus, carinata meal can potentially be a good source of AA in swine diets. However, carinata meal has a relatively high content of fiber. Carinata meal has been reported to contain 18.8% neutral detergent fiber (NDF; Xin and Yu, 2013), which is greater than the value that was reported for SBM (9.1%) by NRC (2012). Dietary fiber reduces nutrient utilization (Woyengo and Nyachoti, 2011), and hence, the high content of fiber in carinata meal can limit its inclusion in swine diets. Carinata meal also, like any other feedstuffs of plant origin, contains phytate which reduces nutrient digestibility and utilization. The negative effects of fiber and phytate in carinata meal can potentially be alleviated by supplementing fiber-degrading enzymes and phytase, respectively. Supplemental fiber-degrading enzymes have been shown to improve the nutritional value of various *Brassica* co-products including canola meal (Zijlstra et al., 2010), rapeseed meal (Fang et al., 2007), and camelina cake (Woyengo et al., 2018).

The nutritive value of carinata meal for pigs has previously been reported (Woyengo, 2019). However, there is a lack of information on the effect of supplementing carinata meal-containing diets with a combination of phytase and fiber-degrading enzymes on its energy value and nutrient availability in pigs. The objective of this study was to determine the effects of phytase and multicarbohydrase supplementation on digestible energy (DE), net energy (NE), and standardized ileal digestibility (SID) of AA values for carinata meal fed to growing pigs.

MATERIALS AND METHODS

Experimental procedures were reviewed and approved by the Institutional Animal Care and Use Committee at South Dakota State University (# 18-013A).

Experimental Animals

Ten crossbred ileal-cannulated barrows (initial body weight [BW] of 53.9 ± 4.76 kg; Large White-Landrace female × Large White-Hampshire male; Pig Improvement Company) were used in the study. Pigs had been surgically fitted with a simple T-cannula at the distal ileum as described by Sauer and Ozimek (1986). Pigs were housed individually in pens (1.2 × 1.8 m) that allowed freedom of movement in a temperature-controlled room (22 ± 2°C). Each pen had a metal slatted flooring, a single-space dry feeder, and a nipple drinker.

Experimental Diets

Diets included a corn-SBM based basal diet, basal diet with 25% carinata meal, and basal diet with 25% carinata meal plus phytase and a multicarbohydrase (Ronozyme Hi-Phos and Ronozyme VP CT, respectively); both products are available from DSM Nutritional Products. The phytase was dosed at 2,000 FTU/kg and the multicarbohydrase at 0.2 g/kg and a N-free diet (Table 1). The phytase product used in the current study was a 6-phytase, which was produced in *Aspergillus oryzae*. The multicarbohydrase was produced via submerged fermentation of a wild type *Aspergillus aculeatus,* and supplied 4 units of xylanase, 10 units of endo-1,3(4)-β-glucanase, and 1,000 units of pectinase per kilogram of diet. The ratio of corn to SBM and soybean oil in carinata meal-containing diets was identical to the corn-SBM based diet to allow calculation of energy and AA digestibility of the carinata meal by the difference method (Fan and Sauer, 1995). The N-free diet was fed to estimate basal endogenous AA losses for determining SID of AA. The carinata meal was obtained from Agrisoma Biosciences Inc. (Saskatoon, Saskatchewan, Canada) and had been produced from carinata seeds by solvent extraction. The diets contained titanium dioxide (0.4%) as an indigestible marker.

Experimental Design and Procedure

The 10 pigs were fed the four diets in a replicated 4 × 4 Latin square design with two additional columns to give 10 replicates per diet. Each period consisted of 9 d; the first 5 d were for adaptation, followed by 2 d of fecal collection and 2 d of ileal

Table 1. Ingredient and analyzed nutrient of experimental diets

Item	Diet[1]		
	Corn-SBM	Corn-SBM-CM	N-free
Ingredient, % as fed			
Corn	71.42	53.07	0.00
Soybean meal	25.39	18.87	0.00
Carinata meal	0.00	25.00	0.00
Soybean oil	0.49	0.36	3.00
Cornstarch	0.00	0.00	80.40
Sucrose	0.00	0.00	10.40
Cellulose	0.00	0.00	3.00
Calcium carbonate	1.10	1.10	1.10
Monocalcium phosphate	0.84	0.84	0.84
Salt	0.16	0.16	0.16
KCO_3	0.00	0.00	0.40
MgO	0.00	0.00	0.10
Vitamin premix[2]	0.05	0.05	0.05
Mineral premix[3]	0.15	0.15	0.15
Titanium dioxide	0.40	0.40	0.40
Analyzed nutrients, DM basis			
Moisture, %	13.53	11.97	10.07
Crude protein, %	18.80	26.65	0.28
Gross energy, kcal/kg	3,851	3,966	3,760
Ether extract, %	1.43	2.00	0.61
Ash, %	5.80	6.87	3.62
Indispensable amino acids, %			
Arg	1.06	1.60	0.02
His	0.46	0.64	0.01
Ile	0.77	1.03	0.02
Leu	1.53	1.93	0.04
Lys	0.90	1.09	0.02
Met	0.25	0.39	0.02
Phe	0.87	1.11	0.02
Thr	0.64	0.92	0.02
Trp	0.21	0.30	<0.02
Val	0.84	1.19	0.02
Dispensable amino acids, %			
Ala	0.88	1.14	0.02
Asp	1.67	2.04	0.05
Cys	0.29	0.51	0.02
Glu	3.04	4.35	0.04
Gly	0.69	1.07	0.02
Pro	1.02	1.47	0.04
Ser	0.71	0.92	0.01
Tyr	0.59	0.74	0.02

[1]SBM = soybean meal; CM = carinata meal; the corn-SBM-CM diet was either unsupplemented or supplemented with phytase and a multi-carbohydrase (Ronozyme Hi-Phos and Ronozyme VP CT, respectively) from DSM Nutritional Products. The phytase was dosed at 2,000 FTU/kg and the multi-carbohydrase at 0.2 g/kg. The multicarbohydrase supplied 4 units of xylanase, 10 units of endo-1,3(4) β-glucanase, and 1,000 units of pectinase per kilogram of diet.

[2]Provided the following per kilogram of diet: 2,226 IU vitamin A, 340 IU vitamin D_3, 11.3 IU vitamin E, 0.01 mg vitamin B_{12}, 0.91 mg menadione, 2.04 mg riboflavin, 12.5 mg pantothenic acid, 11.3 mg niacin, 0.23 mg folic acid, 0.68 mg pyridoxine, 0.68 mg thiamine, and 0.04 mg biotin.

[3]Provided the following per kilogram of diet: 75 mg Zn as $ZnSO_4$, 75 mg Fe as $FeSO_4$, 7 mg Cu as $CuSO_4$, and 20 mg Mn as $MnSO_4$.

digesta collection. Pigs were fed diets at three times maintenance energy requirement (3 × 197 kcal of metabolizable energy/kg of $BW^{0.60}$; NRC, 2012) based on BW at the beginning of each period. Daily feed allowance was offered in two equal portions at 0800 and 1600 h. Fresh fecal samples were collected from each pen between 0800 and 1700 h daily. Ileal digesta was collected continuously for 12 h from 0800 to 2000 h daily (Nyachoti et al., 2002). Collected feces and digesta were pooled for each pig and period and stored frozen at −20°C.

Sample Processing and Analyses

Pooled fecal samples were oven-dried at 60°C for 72 h, whereas pooled ileal digesta samples were freeze-dried for 7 d. Feedstuffs (corn, SBM, and carinata meal), diets, and dried feces samples were ground to pass through a 0.75-mm screen using a centrifugal mill (model ZM200; Retsch GmbH, Haan, Germany). Freeze-dried ileal digesta samples were ground by a coffee grinder (model 80303; Hamilton Beach, Glen Allen, VA) to pass through a 0.70-mm screen.

Feedstuffs were analyzed for DM, gross energy (GE), CP, NDF, acid detergent fiber (ADF), ether extract (EE), and AA. Diets, ileal digesta, and feces were analyzed for DM, GE, CP, and titanium dioxide. Diets and ileal digesta were additionally analyzed for AA. Samples were analyzed for DM (method 930.15), CP (method 984.13A-D), EE (method 920.39A), NDF (method 2002.04), and ADF (method 973.18) according to the AOAC (2006). The GE was analyzed using an adiabatic bomb calorimeter (model AC600, Leco, St. Joseph, MI). Titanium dioxide in samples was determined by spectrophotometry (model Spectra MAX 190, Molecular Devices, Sunnyvale, CA) at 408 nm after ashing at 525°C for 10 h (Myers et al., 2004).

Calculations and Statistical Analysis

The apparent ileal digestibility (AID) and apparent total tract digestibility (ATTD) values of the diets were calculated using the indicator method (Eq. [2]; Stein et al., 2007). The SID for AA in diets was calculated from AID corrected for basal endogenous AA loss (Eq. [7]; Stein et al., 2007). The energy and AA digestibility in the carinata meal were determined by the difference method (Fan and Sauer, 1995) with corn-SBM basal diet. The apparent hindgut digestibility (AHD) of GE was calculated by subtracting the AID value of GE

from the ATTD value of GE. The DE value of carinata meal was calculated by multiplying GE by its ATTD. The NE value of carinata meal was calculated from the determined DE value and analyzed macronutrient content using Eq. 5 that was developed by Noblet et al. (1994) and has been adopted by NRC (2012):

$$NE = 0.700 \times DE + 1.61 \times EE + 0.48 \times \text{starch} - 0.91 \times CP - 0.87 \times ADF.$$

Data were subjected to ANOVA using the MIXED procedure (SAS Inst. Inc., Cary, NC) with the diet as a fixed factor, and pig and period as random factors. Treatment means were separated by probability of difference. To test the hypotheses, the level of significance was set at 5%.

RESULTS

Pigs consumed all the feed offered to them throughout the trial. Leucine, Arg, and Val were the most abundant indispensable AA in carinata meal, whereas Trp, Met, and His were the least (Table 2). Supplementation of a combination of phytase and multicarbohydrase did not affect AID of AA (Table 3), and SID of AA (Tables 4 and 5) for corn-SBM-carinata meal-based diet. However, addition of a combination of phytase and multicarbohydrase to corn-SBM-carinata meal-based diet improved ($P < 0.05$) the ATTD of GE and DE value for the diet (Table 3). The AID of indispensable AA for carinata meal ranged from 50.0% (for Lys) to 86.6% (for Arg; Table 6). The basal endogenous AA losses values ranged from 50 mg/kg DM intake (for Met) to 4,627 mg/kg DM intake (for Pro; Table 4). The SID of indispensable AA for carinata meal ranged from 51.0% (for Lys) to 86.8% (for Arg; Table 7). Supplementation of a combination of phytase and multicarbohydrase did not affect AID of AA (Table 6) or SID of AA (Table 7) for carinata meal. However, the supplementation of a combination of phytase and multicarbohydrase numerically increased the AID of GE and AHD of GE, leading to an improvement ($P < 0.05$) in the ATTD of GE, DE, and NE values for carinata meal (Table 8).

Table 2. Analyzed composition (on dry matter basis) of feedstuffs

Item	Corn	Soybean meal	Carinata meal
Moisture, %	12.11	11.05	7.23
Crude protein, %	7.32	52.60	50.22
Gross energy, kcal/kg	3,875	4,214	4,350
Ether extract, %	2.29	1.11	0.88
Ash, %	1.53	7.08	7.83
Neutral detergent fiber, %	7.61	8.98	23.74
Acid detergent fiber, %	3.01	7.38	15.37
Starch, %	80.94	8.55	8.70
Indispensable amino acids			
Arg	0.35	3.89	3.55
His	0.23	1.39	1.30
Ile	0.28	2.62	2.07
Leu	0.89	4.10	3.45
Lys	0.26	3.36	1.82
Met	0.17	0.74	0.96
Phe	0.38	2.75	2.04
Thr	0.27	2.05	1.89
Trp	0.07	0.82	0.64
Val	0.38	2.69	2.51
Dispensable amino acids			
Ala	0.55	2.27	2.09
Asp	0.52	6.03	3.43
Cys	0.19	0.80	1.35
Glu	1.35	9.51	9.07
Gly	0.32	2.23	2.43
Pro	0.64	2.71	3.01
Ser	0.33	2.20	1.61
Tyr	0.24	2.00	1.33

DISCUSSION

The carinata meal is a co-product from crushing of *Brassica carinata* seeds to obtain oil for the biofuel industry (Gesch et al., 2015). As previously mentioned, the carinata meal fed in the current study was produced from carinata seeds by solvent extraction. The nutritional value of carinata meal fed in the current study was reported by Woyengo (2019). In summary, carinata meal had greater CP, indispensable AA (except for the Lys), SID of most indispensable AA, and NDF values and lower EE value than those reported for solvent-extracted canola meal and cold-pressed canola cake.

The energy and nutrient digestibility of carinata meal were determined by the difference method using corn-SBM-based diet as basal diet because carinata meal contains high levels of glucosinolates, especially sinigrin (Lawrence and Anderson, 2018). Since they are bitter, the glucosinolates can reduce feed palatability (Almeida et al., 2013; Kahindi et al., 2014). Energy and nutrient digestibility of feedstuffs that are potentially less palatable should ideally be determined by the difference or regression methods (Mosenthin et al., 2000). The AID values of Lys (50.0%), Met (80.9%), Thr (65.9%), and Trp (85.4%) for carinata meal determined in the present study were similar to the AID values of Lys (50.7%), Met (83.7%), Thr (64.0%), and Trp (84.1%) for carinata meal that were reported by Woyengo (2019). Solvent-extracted canola meal

Table 3. Apparent digestibility of gross and nutrients, and digestible energy value for the diets

	Diets[1]				*P*	
Item	Corn-SBM	Corn-SBM-CM	Corn-SBM-CM + Enzyme	SEM	Diet	Enzyme
Apparent ileal digestibility, %						
DM[2]	73.5	58.3	58.5	0.86	<0.0001	0.880
N	77.7	70.0	70.6	1.04	<0.0001	0.623
Indispensable amino acids, %						
Arg	89.0	87.5	87.0	0.49	0.0210	0.387
His	86.7	81.8	81.2	0.56	<0.0001	0.316
Ile	83.4	77.1	77.3	0.52	<0.0001	0.776
Leu	85.8	79.6	79.8	0.61	<0.0001	0.834
Lys	82.7	70.3	70.1	0.84	<0.0001	0.829
Met	86.9	83.4	84.3	0.48	<0.0001	0.158
Phe	84.7	79.7	80.0	0.56	<0.0001	0.654
Thr	75.6	70.7	70.6	0.77	0.0001	0.997
Trp	84.9	84.8	84.1	0.98	0.5120	0.481
Val	79.0	73.9	74.3	0.67	<0.0001	0.702
Dispensable amino acids, %						
Ala	79.2	73.9	74.5	0.69	<0.0001	0.332
Asp	81.6	74.6	74.3	0.56	<0.0001	0.612
Cys	77.0	69.4	71.1	1.44	0.0002	0.157
Glu	87.2	82.2	82.0	0.54	<0.0001	0.894
Gly	66.2	65.3	63.4	1.97	0.1814	0.448
Pro	71.7	69.8	71.3	2.73	0.8335	0.724
Ser	81.8	74.7	75.6	0.74	<0.0001	0.557
Tyr	84.8	80.3	80.1	0.48	<0.0001	0.751
ATTD[3] of gross energy, %	86.6	82.1	84.1	0.61	0.0001	0.0063
Digestible energy, kcal/kg of DM	3,319	3,266	3,320	21.5	0.0478	0.0195

[1]SBM = soybean meal; CM = carinata meal; Enzyme = phytase and a multicarbohydrase (Ronozyme Hi-Phos and Ronozyme VP CT, respectively) from DSM Nutritional Products. The phytase was dosed at 2,000 FTU/kg and the multicarbohydrase at 0.2 g/kg. The multicarbohydrase supplied 4 units of xylanase, 10 units of endo-1,3(4) β-glucanase, and 1,000 units of pectinase per kilogram of diet.

[2]DM = dry matter.

[3]ATTD = apparent total tract digestibility.

is the most widely used feedstuff from the *Brassica* family for formulation of swine diets. When compared with NRC (2012), AID values for solvent-extracted canola meal, the carinata meal fed in the current study had higher AID value of Trp (85% vs. 66%), but lower AID of Lys (50% vs. 71%). The carinata meal and solvent-extracted canola meal did not differ in AID of Met. The AID values of Lys, Met, Thr, and Trp for carinata meal were lower than the AID values of Lys (87%), Met (88%), Thr (80%), and Trp (88%) that were reported for solvent-extracted SBM by NRC (2012), which could be attributed to higher fiber content in carinata meal than in SBM. The basal ileal endogenous AA losses were similar to the values that were reported by Woyengo et al. (2016) for growing pigs fed a N-free diet. However, the basal ileal endogenous AA losses were lower than the values reported by Maison and Stein (2014) and Woyengo (2019). The differences in endogenous AA losses between the study of Maison and Stein (2014) and Woyengo (2019), and the current study or the study of Woyengo et al. (2016) could partly be attributed to differences in BW of the pigs. Basal ileal endogenous AA losses in pigs decrease with increasing BW (Pahm et al., 2008; Adeola et al., 2016). The average initial BW of pigs used in the current study and in the study of Woyengo et al. (2016) were 53.9 and 79.8 kg, respectively, whereas the initial BW of pigs used in the study of Maison and Stein (2014) and Woyengo (2019) were 28.8 and 32.7 kg, respectively. The SID values of Lys (51.0%), Met (81.7%), Thr (65.6%), and Trp (86.0%) for carinata meal were less than the SID values of Lys (60.1%), Met (87.8%), Thr (73.2%), and Trp (89.8%) that were reported for carinata meal by Woyengo (2019). The lower basal endogenous AA losses in this study may have resulted in the lower SID values of AA than in the study of Woyengo (2019). The ATTD of GE (73.1%) for carinata meal was greater than the value (67.1%) that was reported for carinata meal by Woyengo (2019), which could be attributed to the

fact that pigs used in the current study were heavier than pigs used in the study of Woyengo (2019). The ability of pigs to digest dietary GE increases with age or BW. For instance, Le Goff and Noblet (2001) reported greater ATTD of GE in sows than in growing pigs and attributed this to greater fermentation of dietary fiber in the hindgut of sows. In the current study, the DE (3,427 kcal/kg) and NE (1,828 kcal/kg) values for carinata meal were greater than the values (3,065 kcal/kg DE and 1,611 kcal/kg NE) that were reported for carinata meal by Woyengo (2019). This was due to a greater ATTD of GE for the carinata meal fed in the current trial.

In the current study, supplementation of a combination of phytase and multicarbohydrase did not affect AA digestibility in carinata meal, which is contrary to results from several studies (Kiarie et al., 2010; Zeng et al., 2018) in which such supplementation of swine diets resulted in increased ileal digestibility of AA. Oilseed co-products contain phytate, which is poorly hydrolyzed by pigs, and reduce AA digestibility by binding to dietary AA and digestive enzymes (Woyengo and Nyachoti, 2013). Also, as previously mentioned, *Brassica* oilseed co-products such as carinata meal and canola meal contain more fiber than found in SBM. Fiber is poorly digested by pigs and can reduce nutrient digestibility by encapsulation (Selle and Ravindran, 2008; Woyengo and Nyachoti, 2011). Pectin is the major NSP present in oilseed co-products (Knudsen, 1997) and pectinase was the major enzyme in the multicarbohydrase

Table 4. Basal ileal endogenous losses of amino acids of pigs

Item	Average[1]
Indispensable amino acids	
Arg	528
His	109
Ile	179
Leu	279
Lys	209
Met	50
Phe	185
Thr	275
Trp	71
Val	284
Dispensable amino acids	
Ala	415
Asp	478
Cys	104
Glu	515
Gly	1,131
Pro	4,627
Ser	279
Tyr	145

[1]Data are expressed as milligrams per kilogram of dry matter intake.

Table 5. Standardized ileal digestibility of amino acids for the diets

	Diets[1]				*P*	
Item, %	Corn-SBM	Corn-SBM-CM	Corn-SBM-CM + Enzyme	SEM	Diet	Enzyme
Indispensable amino acids						
Arg	93.3	90.2	90.1	0.70	0.0012	0.803
His	89.2	83.6	82.9	0.55	<0.0001	0.233
Ile	85.9	78.9	79.1	0.53	<0.0001	0.781
Leu	87.6	80.7	81.2	0.67	<0.0001	0.522
Lys	85.1	71.5	72.0	0.77	<0.0001	0.638
Met	89.0	84.8	85.6	0.48	<0.0001	0.223
Phe	86.9	81.4	81.7	0.58	<0.0001	0.650
Thr	80.2	73.2	73.7	0.82	<0.0001	0.641
Trp	88.6	87.1	86.7	0.99	0.0503	0.724
Val	82.6	73.4	76.7	0.67	<0.0001	0.740
Dispensable amino acids						
Ala	84.1	77.7	78.0	0.71	<0.0001	0.728
Asp	84.7	76.3	76.6	0.68	<0.0001	0.741
Cys	80.7	71.5	73.1	1.51	<0.0001	0.174
Glu	89.0	82.8	83.2	0.57	<0.0001	0.647
Gly	79.2	72.7	73.9	1.93	0.0554	0.590
Pro	103.4	96.4	93.6	6.79	0.0620	0.078
Ser	85.9	77.9	78.5	0.75	<0.0001	0.636
Tyr	87.4	82.3	82.0	0.49	<0.0001	0.720

[1]SBM = soybean meal; CM = carinata meal; Enzyme = phytase and a multicarbohydrase (Ronozyme Hi-Phos and Ronozyme VP CT, respectively) from DSM Nutritional Products. The phytase was dosed at 2,000 FTU/kg and the multi-carbohydrase at 0.2 g/kg. The multicarbohydrase supplied 4 units of xylanase, 10 units of endo-1,3(4) β-glucanase, and 1,000 units of pectinase per kilogram of diet.

Table 6. Apparent ileal digestibility of N and amino acids for carinata meal without and with a combination of phytase and multicarbohydrase

	Carinata meal[1]			
Item, %	−Enzyme	+Enzyme	SEM	*P*
N	61.3	62.1	2.38	0.743
Indispensable amino acids				
Arg	86.6	84.9	1.13	0.202
His	76.9	74.8	1.55	0.260
Ile	69.5	70.0	1.48	0.762
Leu	70.6	71.0	1.83	0.819
Lys	50.0	50.6	3.12	0.896
Met	80.9	82.1	1.08	0.258
Phe	72.8	73.6	1.65	0.631
Thr	65.9	64.9	1.70	0.626
Trp	85.4	84.2	2.03	0.501
Val	68.6	69.1	1.53	0.813
Dispensable amino acids				
Ala	67.5	68.3	1.55	0.711
Asp	64.1	62.5	1.93	0.343
Cys	64.8	66.8	3.41	0.234
Glu	77.4	76.1	1.47	0.218
Gly	65.8	62.3	1.87	0.117
Pro	68.6	68.2	6.29	0.623
Ser	64.8	65.9	2.23	0.684
Tyr	73.9	73.1	1.29	0.616

[1]−Enzyme = without addition of enzymes; +Enzyme = with phytase and a multicarbohydrase (Ronozyme Hi-Phos and Ronozyme VP CT, respectively) from DSM Nutritional Products. The phytase was dosed at 2,000 FTU/kg and the multicarbohydrase at 0.2 g/kg. The multicarbohydrase supplied 4 units of xylanase, 10 units of endo-1,3(4) β-glucanase, and 1,000 units of pectinase per kilogram of diet.

Table 7. Standardized ileal digestibility of amino acids for carinata meal without and with a combination of phytase and multicarbohydrase

	Carinata meal[1]			
Item, %	−Enzyme	+Enzyme	SEM	*P*
Indispensable amino acids				
Arg	86.8	86.1	1.38	0.667
His	77.8	75.6	1.57	0.254
Ile	70.4	70.9	1.47	0.770
Leu	71.4	71.9	1.84	0.817
Lys	51.0	51.7	3.08	0.857
Met	81.7	82.7	1.08	0.344
Phe	73.7	74.5	1.66	0.639
Thr	65.6	66.2	1.92	0.816
Trp	86.0	85.7	2.01	0.821
Val	69.8	70.2	1.54	0.845
Dispensable amino acids				
Ala	69.6	70.3	1.54	0.766
Asp	63.0	63.9	2.28	0.784
Cys	65.9	67.5	3.42	0.346
Glu	76.0	76.5	1.37	0.805
Gly	64.0	66.1	3.09	0.625
Pro	86.0	81.1	2.77	0.311
Ser	66.1	67.4	2.19	0.649
Tyr	75.0	74.1	1.30	0.609

[1]−Enzyme = without addition of enzymes; +Enzyme = with phytase and a multicarbohydrase (Ronozyme Hi-Phos and Ronozyme VP CT, respectively) from DSM Nutritional Products. The phytase was dosed at 2,000 FTU/kg and the multicarbohydrase at 0.2 g/kg. The multicarbohydrase supplied 4 units of xylanase, 10 units of endo-1,3(4) β-glucanase, and 1,000 units of pectinase per kilogram of diet.

used in the current study. Thus, it was assumed that phytase and multicarbohydrase would result in increased ileal AA digestibility. However, it should be noted that the effect of phytase on ileal digestibility of AA in pigs has been variable. Some studies have reported improvements in the digestibility of AA (Fan et al., 2005; Liao et al., 2005), whereas in other studies improvement was not observed (Cervabtes et al., 2011; Morales et al., 2012). The reason why phytase improved ileal digestibility of AA in some pig studies but not in other has not yet been clearly established. Solvent extraction of oilseeds involves flaking and cooking of seeds to rupture cells, to increase the availability of oil for extraction, pressing of the cooked seeds to remove some oil, and finally solvent extraction of the pressed seeds to remove most of the remaining oil (Spragg and Mailer, 2007). In addition to increasing the availability of oil, rupturing of cells during flaking and cooking of the seeds results in increased availability of nutrients that are otherwise encapsulated in fiber and other seed components (Khajali and Slominski, 2012). Indeed, supplementation of a multicarbohydrase that contained pectinase increased ileal nutrient digestibility in poultry or pigs fed diets that were based on full-fat canola seed (Meng et al., 2006), full-fat rapeseed (Jozefiak et al., 2010), and full-fat soybean meal (Ayoade et al., 2012), but did not affect ileal nutrient digestibility in broilers fed diet that was based on solvent-extracted canola meal (Meng and Slominski, 2005). Thus, the lack of effect of multicarbohydrase on ileal AA digestibility in the current study could have been due to the fact that the carinata seed oil extraction process had already resulted in increased availability of AA that are otherwise encapsulated in an intact fiber matrix.

Supplementation of a combination of phytase and multicarbohydrase had limited effect on AID of GE for the carinata meal. Amino acids, carbohydrates, and oil are the major energy-yielding components of oilseed co-products. Carinata meal fed in the current study had a low content of oil and easily available carbohydrates, but high content of AA and fiber. Amino acids are well digested in small intestine of pigs, whereas fiber is poorly

Table 8. Apparent digestibility of gross energy, and digestible energy and net energy values for carinata meal without and with a combination of phytase and multicarbohydrase

	Carinata meal[1]			
Item	−Enzyme	+Enzyme	SEM	*P*
Apparent ileal digestibility of gross energy, %	31.4	33.2	2.08	0.528
Apparent hindgut digestibility of gross energy, %	41.7	46.8	3.36	0.274
Apparent total tract digestibility of gross energy, %	73.1	80.0	2.70	0.015
Digestible energy, kcal/kg of dry matter	3,427	3,751	126.4	0.015
Net energy, kcal/kg of dry matter	1,828	2,054	88.5	0.015

[1]−Enzyme = without addition of enzymes; +Enzyme = with phytase and a multicarbohydrase (Ronozyme Hi-Phos and Ronozyme VP CT, respectively) from DSM Nutritional Products. The phytase was dosed at 2,000 FTU/kg and the multicarbohydrase at 0.2 g/kg. The multicarbohydrase supplied 4 units of xylanase, 10 units of endo-1,3(4) β-glucanase, and 1,000 units of pectinase per kilogram of diet.

digested (Knudsen et al., 2012; Lindberg, 2014). Thus, the limited effect of phytase and multicarbohydrase supplementation on AID of GE could be attributed to the lack of effect of the enzyme supplementation on ileal digestibility of AA. Similarly, supplementation of cold-pressed soybean cake (Woyengo et al., 2016) or cold-pressed camelina cake (Woyengo et al., 2018) with multienzyme did not affect AID of GE in pigs. Supplementation of carinata meal with phytase and multicarbohydrase improved the ATTD of GE, which was due to numerical increase in AID of GE and AHD of GE by the enzyme supplementation. The magnitude of the numerical increase in AHD of GE by the enzyme supplementation was greater than the magnitude by which it numerically increased the AID of GE (5.1 vs. 1.8 percentage points). Multicarbohydrases can degrade complex dietary NSP into oligosaccharides that are highly fermentable (Zijlstra et al., 2010). Thus, multicarbohydrase could have degraded carinata meal NSP (in small intestine) into short fragments that were poorly fermented in the small intestine, but highly fermented in the hindgut of pigs. Results from the current study are contrary to the results from the study of Lu et al. (2016) who did not observe an increase in ATTD of GE in pigs due to supplementation of canola meal-based diet with multicarbohydrase that contained pectinase. However, it should be noted that susceptibility of fiber to enzymatic degradation or microbial fermentation is partly negatively correlated with its degree of lignification (Van Soest, 1994; William et al., 2017). Carinata meal fiber is less lignified than fiber in canola meal. For instance, acid detergent lignin content as percentage of NDF content in carinata meal (15.4%) was lower than that in canola meal (30.9%; Xin and Yu, 2013). Thus, carinata meal fiber is potentially more susceptible to enzymatic degradation than canola fiber. Indeed, Woyengo (2019) reported greater apparent hindgut digestibility of GE for carinata meal than for cold-pressed canola cake. Consequently, the differences between the current study and that of Lu et al. (2016) regarding to the effect of multicarbohydrase on ATTD of GE could be attributed to the differences in the degree of lignification between carinata meal and canola meal. Supplementation of a combination of phytase and multicarbohydrase improved the DE and NE values of carinata meal, which was due to improvement in ATTD of GE. On a DM basis, the enzyme-supplemented carinata meal had higher DE value (3,751 kcal/kg) than the values reported for SBM (3,619 kcal/kg) and canola meal (3,273 kcal/kg) by NRC (2012). Moreover, enzyme supplemented carinata meal had higher NE value (2,054 kcal/kg) than the value that was reported by NRC (2012) for canola meal (1,890 kcal/kg), but a similar NE value to that which was reported by NRC (2012) for SBM (2,087 kcal/kg).

In conclusion, supplementation of a combination of phytase and multicarbohydrase to carinata meal did not affect ileal digestibility of energy or SID of AA. However, supplementation of a combination of phytase and multicarbohydrase did improve the ATTD of GE, DE, and NE values. Thus, a combination of the phytase and multicarbohydrase used in the current study could be added in carinata meal-based diets for pigs to improve the energy value.

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