Nutritive value of multienzyme supplemented cold-pressed camelina cake for pigs

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ABSTRACT: Cold-pressed camelina cake (CPCC) is a fibrous co-product of camelina seed pressing and available for livestock feeding. However, information is lacking on the effect of supplementing fiber-degrading enzymes to CPCC-based diets on nutrient utilization by pigs. Experiment 1 determined the effect of multienzyme supplementation on standardized ileal digestibility (SID) of amino acid (AA) and net energy (NE) value of CPCC for pigs. Six ileal-cannulated barrows (average initial body weight [BW] = 36 kg) were fed five diets in 5 × 5 Latin square design with 1 added column to give six replicates per diet. The diets were a corn-soybean meal (SBM)-soybean oil-based diet and the basal diet with corn, SBM, and soybean oil replaced by 25% CPCC with or without multienzyme (600 U of xylanase, 75 U of glucanase, 250 U of cellulose, 30 U of mannanase, 350 U of invertase, 2,500 U of protease, and 6,000 U of amylase/kg of diet; Superzyme-CS, 0.5 g/kg) in a 2 × 2 factorial arrangement. The fifth diet was a low-casein cornstarch-based diet. The ratio of corn to SBM and soybean oil in the basal diet was identical to the CPCC-containing diets to allow calculation of nutrient digestibility of CPCC by the difference method. On a dry matter (DM) basis, CPCC

contained 42% crude protein, 10.5% ether extract, 25.4% neutral detergent fiber (NDF), 2.07% Lys, 0.73% Met, 1.64% Thr, 0.51% Trp, and 22.1 trypsin inhibitor units per milligram, respectively. The SID of Lys, Met, Thr, and Trp for CPCC were 43.5%, 70.7%, 44.8%, and 55.3%, respectively. The digestible energy (DE) and NE values for CPCC were 3,663 and 2,209 kcal/kg of DM, respectively. Multienzyme supplementation did not affect the SID of AA, and DE and NE values for the corn-SBM-CPCC-based diet, and for the CPCC. In experiment 2, the effects of multienzyme dosage (0.5 or 50 g/kg of treated feedstuff) on porcine in vitro digestibility of DM (IVDDM) of CPCC was determined. The IVDDM of CPCC was increased ($P < 0.001$) with an increase in multienzyme dosage. Multienzyme at 0.5 g/kg did not affect IVDDM of CPCC. However, multienzyme at 50 g/kg increased ($P < 0.01$) IVDDM for CPCC by at least 16%. In conclusion, multienzyme at 0.5 g/kg did not affect SID of AA and NE values, and IVDDM for CPCC. However, multienzyme at 50 g/kg improved IVDDM of CPCC, implying that the efficacy of the multienzyme with regard to improving nutrient digestibility of CPCC in pigs is dosage dependent.

Key words: cold-pressed camelina cake, multienzyme, nutrient digestibility, pig

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INTRODUCTION

Cold-pressed camelina cake (CPCC) has a relatively high content of protein and residual oil and can be added in swine diets as a source of energy and amino acid (AA; Almeida et al., 2013; Kahindi et al., 2014). However, the use of CPCC in formulating pig feeds is partly limited by

its low nutrient digestibility. For instance, standardized ileal digestibility (SID) of Lys (58%) for CPCC (Kahindi et al., 2014) was lower than the values that were reported by NRC (2012) for soybean meal (SBM; 89%) and canola meal (74%) for pigs, the most widely used AA sources in swine diets. The low nutrient digestibility of CPCC can partly be due to its high-fiber content. For instance, the neutral detergent fiber (NDF) content in camelina cake ranged from 32% to 43% (Kahindi et al., 2014; Pekel et al., 2015; Woyengo et al., 2016a), which is greater than the values that were reported by NRC (2012) for dehulled solvent extracted SBM (8.21%) and canola meal (22.6%). Thus, there is a need for reducing the negative effects of fiber in CPCC to increase its utilization in formulating swine diets.

The negative effects of fiber in fibrous oilseed products such as CPCC can potentially be alleviated by dietary supplementation with fiber-degrading enzymes (multicarbohydases). This is because the nutritive value of CPCC for broilers was improved by supplemental multicarbohydases (Woyengo et al., 2016a). Also, the NE value of cold-pressed soybean cake (Woyengo et al., 2016b), and SID of AA and digestible energy (DE) value for full-fat soybean (Ayoade et al., 2012) for pigs were improved by supplemental multicarbohydases. However, information is lacking on the effect of multicarbohydase supplementation on the nutritive value of the CPCC for pigs. The objectives of this study were to determine the effect of multienzyme supplementation on NE and SID of AA for the CPCC fed to growing pigs; and the effect of supplemental multienzyme dosage on porcine in vitro digestion of CPCC.

MATERIALS AND METHODS

Experimental procedures were reviewed and approved by the Institutional Animal Care and Use Committee at South Dakota State University (No. 15-029A).

Experiment 1

The experiment was conducted to determine the effect of multienzyme supplementation on NE and SID of AA for the CPCC fed to growing pigs. Six crossbred ileal-cannulated barrows (initial body weight [BW] of 35.6 ± 1.69 kg; Large White-Landrace female $\times$ 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 metabolic crates ($1.5 \times 0.6 \times 0.8$ m) with smooth polyvinyl chloride walls and plastic-covered expanded metal flooring in a temperature-controlled room ($22 \pm 2^\circ\text{C}$). Each metabolic crate had smooth sides, plastic-covered expanded metal flooring, a single-space dry feeder, and a nipple drinker.

Experimental diets (Table 1) included a basal diet (corn-SBM-soybean oil-based diet) and the basal diet with corn, SBM, and soybean oil replaced by 25% CPCC without or with multienzyme (Superzyme-CS, Canadian Bio-System Inc., Calgary, AB, Canada; 0.5 g/kg) in a 2×2 factorial arrangement; a low-casein cornstarch-based diet; and sixth diet (cornstarch-based diet containing corn stover; diet formulation not presented). The sixth diet had initially been included in the study for characterizing SID of AA for corn stover; due to poor consumption of this diet throughout the feeding periods, data were excluded from the study. The multienzyme supplement supplied 600 U of xylanase, 75 U of glucanase, 250 U of cellulose, 30 U of mannanase, 350 U of invertase, 2,500 U of protease, and 6,000 U of amylase per kilogram of diet. The diets contained titanium dioxide (0.4%) as an indigestible index. The low-casein cornstarch-based diet was fed to estimate basal endogenous AA losses for determining SID of AA. The ratio of corn to SBM, and soybean oil in the basal diet was identical to the CCPC-containing diets to allow calculation of nutrient digestibility of CPCC by the difference method (Kong and Adeola, 2014). The CPCC was obtained from Dakota Lakes Research Farm, South Dakota State University and had been produced by pressing of the camelina seed at less than 42°C (barrel temperature) using an expeller (Model KEK-P0020, Remscheid, Germany).

The six pigs were fed six diets in 6×6 Latin square design to give six 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 digesta collection. Pigs were fed diets at three times maintenance energy requirement (3×110 kcal of DE/kg of $\text{BW}^{0.75}$; NRC, 1998) based on BW at the beginning of each period. Daily feed allowance was offered in two equal portions at 0800 and 1600 h. Representative 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 .

Table 1. Ingredient composition and analyzed nutrient content of corn– SBM and corn–SBM–CPCC diets,* and low casein cornstarch (CCS)-based diet

Item	Corn-SBM diet	Corn-SBM-CPCC diet	CCS diet
Ingredient, % as fed			
Corn	64.05	47.55	0.00
SBM	30.00	22.27	0.00
CPCC	0.00	25.00	0.00
Soybean oil	3.00	2.23	1.00
Cornstarch	0.00	0.00	42.75
Sugar	0.00	0.00	42.75
Casein	0.00	0.00	5.00
Cellulose	0.00	0.00	5.00
Calcium carbonate	0.85	0.85	1.00
Dicalcium phosphate	1.00	1.00	1.40
Salt	0.50	0.50	0.50
Vitamin premix [†]	0.05	0.05	0.05
Mineral premix [‡]	0.15	0.15	0.15
Titanium dioxide	0.40	0.40	0.40
Analyzed nutrients, % DM basis			
Moisture	11.41	10.43	4.34
CP	21.38	26.28	5.28
GE, kcal/kg	4,552	4,674	4,026
EE	3.32	4.45	0.45
Ash	6.04	6.79	3.25
Indispensable AA			
Arg	1.33	1.83	0.16
His	0.56	0.66	0.15
Ile	0.94	1.07	0.27
Leu	1.85	2.02	0.49
Lys	1.19	1.39	0.41
Met	0.30	0.40	0.12
Phe	1.05	1.20	0.26
Thr	0.77	0.99	0.21
Trp	0.25	0.30	0.07
Val	1.02	1.28	0.33
Dispensable AA			
Ala	1.05	1.21	0.17
Asp	2.11	2.37	0.36
Cys	0.30	0.45	0.01
Glu	3.65	4.33	1.11
Gly	0.85	1.16	0.11
Pro	1.22	1.44	0.52
Ser	0.92	1.12	0.27
Tyr	0.72	0.77	0.13

*The corn and CPCC diets were either unsupplemented or supplemented with multienzyme (Superzyme-CS at 0.5 g/kg of diet, Canadian Bio-System Inc., Calgary, AB, Canada). The multienzyme preparation supplied 600 U of xylanase, 75 U of glucanase, 250 U of cellulase, 30 U of mannanase, 350 U of invertase, 2,500 U of protease, and 6,000 U of amylase/kg of diet.

[†]Provided the following per kilogram of diet: 2,226 IU vitamin A, 340 IU vitamin D3, 11.3 IU vitamin E, 0.01 mg vitamin B12, 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.

[‡]Provided the following per kilogram of diet: 75 mg Zn as ZnSO₄, 75 mg Fe as FeSO₄, 7 mg Cu as CuSO₄, and 20 mg Mn as MnSO₄.

Experiment 2

The experiment was conducted to determine the effect of dosage of multienzyme on porcine in vitro digestion of dry matter (DM) for CPCC. The CPCC was ground to pass through 0.75 mm screen.

The ground CPCC was subjected to in vitro digestion with multienzyme at three levels (0, 0.5, and 50 g/kg of CPCC) as described by [Jha et al. \(2011\)](#) with some modifications. Briefly, 4 g samples were weighed in conical flasks. A phosphate buffer solution (200 mL, 0.1 M, pH 6.0) and an HCl solution

(80 mL, 0.2 M) were poured into the flasks. Two milliliters of a chloramphenicol solution (0.5 g/100 mL ethanol) was added to prevent bacterial growth during hydrolysis. Fresh pepsin solution (8 mL, 20 g/L porcine pepsin, P-0609; Sigma-Aldrich Corp., St. Louis, MO) was added and the flasks were placed in a water-bath at 39 °C for 2 h under gentle agitation (50 rpm). Later, 80 mL of phosphate buffer (0.2 M, pH 6.8) and 40 mL of 0.6 M NaOH were added into the solution. Fresh pancreatin solution (8 mL, 100 g/L pancreatin; P-1750, Sigma-Aldrich Corp.) was added and hydrolysis was continued for 4 h under the same conditions. After hydrolysis, the residues were collected by filtration on a nylon cloth with pore size of 50 µm (ANKOM R1021 filter bags; ANKOM Technology, Macedon, NY), washed with ethanol (2 × 25 mL 95% ethanol) and acetone (2 × 25 mL 99.5% acetone), dried for 12 h at 60 °C, and weighed. The experimental design was as follows: three replicates each of the three treatments (CPCC with multienzyme at 0, 0.5, and 50 g/kg) per batch in each of two batches. The undigested residues were dried for determining in vitro digestibility of DM (IVDDM).

Sample Preparation and Analyses

Feedstuffs (corn, SBM, and CPCC) were analyzed for DM, gross energy (GE), crude protein (CP), NDF, ether extract (EE), and AA, whereas diets, ileal digesta, and feces were analyzed for DM, CP, and titanium dioxide. The SBM was additionally analyzed for trypsin inhibitor (TI) activity, whereas CPCC was additionally analyzed for starch, acid detergent fiber (ADF) and TI activity. Diets and ileal digesta were additionally analyzed for AA. Feces were additionally analyzed for GE.

Samples were analyzed for DM (method 930.15), CP (method 984.13A-D), EE (method 920.39A), AA (method 982.30E), ADF (method 973.18), and NDF (method 2002.04) by 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). Samples were analyzed for TI activity according to the method Ba 12–75 of AOCS (2011).

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 (equation 2; Stein et al., 2007). Each pig fed the low casein cornstarch diet was used to calculate its basal endogenous AA losses (equation 3; Stein et al., 2007). The SID for AA in diets was calculated from AID corrected for basal endogenous AA loss (equation 7; Stein et al., 2007). The AA and energy digestibilities in the CPCC were determined by difference method (Fan and Sauer, 1995) with corn-SBM basal diet. The DE value of CPCC was calculated by multiplying GE by its ATTD. The NE value of CPCC was calculated from the determined DE value and analyzed macronutrient content using equation 5 that was developed by Noblet et al. (1994) and has been adopted by NRC (2012):

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

The IVDDM (%) of CPCC after pepsin and pancreatin hydrolysis was calculated as follows:

$$\text{IVDDM} = \left(\frac{\text{dry weight of intact sample} - \text{dry weight of hydrolysed residue}}{\text{dry weight of intact sample}} \right) \times 100$$

In vivo data were analyzed using the MIXED procedure (SAS Version 9.4; SAS Institute Inc., Cary, NC) with the diet as a fixed factor, and pig and period as random factors. Pig was the experimental unit. For nutrient and energy digestibility, and DE and NE values for diets, main effects of diet and multienzyme and their interactions were determined. For nutrient and energy digestibility, and DE and NE values for CPCC, treatment means (CPCC without multienzyme vs. CPCC with multienzyme) were separated by probability of difference. To test the hypotheses, the level of significance was set at 5%.

In vitro data were also analyzed using the MIXED procedure (SAS Institute Inc.) with the CPCC as a fixed factor, batch as random term and flask as experimental unit. Treatment means were separated by the probability of difference. Also, linear and quadratic contrasts for unequally spaced levels were performed to assess the effect of increasing supplemental multienzyme. Like for in vivo data, the level of significance for testing the hypotheses was set at 5%.

RESULTS

All animals used in the study remained healthy and consumed all the feed offered to them throughout the trial. Arginine, Leu, Lys, and Val were the most abundant indispensable AA in CPCC, whereas Met and Trp were the least abundant (Table 2). The TI activities in CPCC and SBM were 22.1 and 5.66 TIU/mg, respectively.

Multienzyme supplementation did not affect AID of AA, AID and ATTD of GE, and DE and NE values (Table 3), and SID of AA (Table 4) for corn-SBM-based diet and corn-SBM-CPCC-based diet. The basal endogenous AA losses values ranged from 115 mg/kg DM intake (for Met) to 6,792 mg/kg DM intake (for Pro; Table 5). The SID of indispensable AA for CPCC ranged from 44.6% (for Ile) to 74.4% (for Arg; Table 6). Multienzyme supplementation did not affect SID of AA, AID and ATTD of GE, and DE and NE values for CPCC (Table 6). The IVDDM was linearly increased ($P < 0.05$) by an increase in the level of supplemental multienzyme (Figure 1).

Table 2. Analyzed composition (on DM basis) of corn, SBM, and CPCC

Item	Corn	SBM	CPCC
Moisture, %	11.70	8.09	8.58
CP, %	9.06	52.3	42.0
GE, kcal/kg	4,307	4,922	5,057
EE, %	5.63	2.27	10.52
Ash, %	1.47	6.75	6.52
NDF, %	10.7	9.24	25.4
ADF, %	—	—	17.2
Starch, %	—	—	2.40
TI activity, TIU/mg	—	5.66	22.1
Indispensable AA, %			
Arg	0.37	3.79	3.45
His	0.25	1.39	1.00
Ile	0.35	2.51	1.62
Leu	1.03	4.07	2.70
Lys	0.32	3.42	2.07
Met	0.16	0.73	0.73
Phe	0.42	2.67	1.74
Thr	0.29	2.01	1.64
Trp	0.07	0.73	0.51
Val	0.41	2.60	2.17
Dispensable AA, %			
Ala	0.62	2.22	1.87
Asp	0.59	5.88	3.35
Cys	0.17	0.72	0.90
Glu	1.52	9.15	6.81
Gly	0.33	2.18	2.14
Pro	0.71	2.61	2.11
Ser	0.39	2.38	1.74
Tyr	0.23	1.91	1.14

However, multienzyme addition at 50 g/kg, but not at 0.5 g/kg, increased ($P < 0.05$) the IVDDM for CPCC.

DISCUSSION

The CPCC is co-product of camelina (a crop of *Brassica* family) seed crushing plants to obtain oil for food and biofuel industries. Oil is extracted from oilseeds such as camelina by solvent extraction, expeller pressing or cold pressing. Solvent extraction involves heating the seeds to rupture the seed coat and cells, pressing the heated seeds to remove some oil, and solvent extracting the pressed seeds to remove most of the remaining oil, followed by desolventizing and toasting the meal; whereas expeller pressing involves heating the seeds followed by pressing the heated seeds without solvent extraction. Cold-pressing process is similar to expeller-pressing process except that the seeds are not heated and less pressure is applied to the seeds to keep oil extraction at less than 50 °C. Thus, CPCC has a relatively high content of oil because cold pressing is a less efficient method of oil extraction than solvent- or expeller-pressing methods.

The EE content of CPCC (10.52%) was similar to the values that were reported by Cherian et al. (2009), Pekel et al. (2009), Kahindi et al. (2014), and Woyengo et al. (2016a) for camelina co-products, which ranged from 11.9% to 13.55%. The CP content in CPCC was similar to the values that were reported by Kahindi et al. (2014; 41.2%) and Woyengo et al. (2016a; 39.8%) for CPCC, but lower than the values that were reported by Almeida et al. (2013) for expeller-pressed camelina meal, which ranged from 34.0% to 38.3%. Also, the NDF content in CPCC fed in the current study was similar to the values that were reported by Almeida et al. (2013) and Kahindi et al. (2014) for camelina co-products that ranged from 23.7% to 33.9%, but lower than the values that were reported by Woyengo et al. (2016a; 38.3%) for CPCC. It should be noted that the composition of oilseed co-products can vary depending on the oilseed variety, and growing and oil extractions conditions. Thus, the differences in CP and NDF contents between the camelina products among the studies could have been due to differences in camelina variety, and growing and oil extractions conditions. The AA composition of CPCC fed in the current study was similar to the AA composition that was reported by Woyengo et al. (2016a) for CPCC. The Lys to CP ratio (4.93%) of the CPCC was similar to the values (4.23% and

Table 3. AID of N, and AA, ATTD of GE and DE value for the corn–SBM- and corn–SBM–CPCC diets without and with multienzyme*

Item	Corn-SBM diet		Corn-SBM-CPCC diet		SEM	P-value		
	–Enzyme	+Enzyme	–Enzyme	+Enzyme		Diet	Enzyme	Diet × Enzyme
N, %	78.0	78.5	64.1	65.2	1.25	<0.001	0.770	0.951
Indispensable AA, %								
Arg	88.6	88.6	80.0	79.6	1.10	<0.001	0.637	0.714
His	84.7	85.4	72.3	74.5	1.49	<0.001	0.668	0.756
Ile	83.6	84.1	67.3	69.7	1.64	<0.001	0.655	0.677
Leu	84.7	84.5	71.1	70.4	1.55	<0.001	0.915	0.754
Lys	82.9	82.8	66.5	65.9	1.60	<0.001	0.952	0.764
Met	86.3	86.4	77.8	74.8	1.08	<0.001	0.234	0.244
Phe	84.1	83.7	70.0	69.1	1.44	<0.001	0.790	0.718
Thr	74.7	74.9	58.8	61.9	1.72	<0.001	0.490	0.579
Trp	81.7	81.7	69.4	74.1	1.39	<0.001	0.196	0.194
Val	79.9	79.8	65.7	65.7	1.35	<0.001	0.909	0.952
Dispensable AA, %								
Ala	81.3	80.0	65.8	68.6	1.56	<0.001	0.791	0.174
Asp	81.6	81.4	66.8	67.2	1.32	<0.001	0.964	0.944
Cys	74.2	74.8	55.6	59.5	1.97	<0.001	0.357	0.506
Glu	86.6	87.0	73.7	74.6	1.19	<0.001	0.644	0.899
Gly	66.7	68.6	55.0	58.8	2.56	<0.001	0.523	0.959
Pro	76.3	76.6	65.4	67.1	2.33	<0.001	0.896	0.996
Ser	81.8	81.1	65.4	66.3	1.24	<0.001	0.911	0.700
Tyr	85.2	85.1	69.3	70.4	1.35	<0.001	0.671	0.801
ATTD of GE, %	87.5	88.2	83.5	82.7	0.83	<0.001	0.894	0.587
DE, kcal/kg of DM	3,551	3,574	3,504	3,462	43.1	0.058	0.718	0.570

*–Enzyme = without multienzyme; +Enzyme = with multienzyme.

Table 4. SID of AA for corn–SBM- and corn–SBM–CPCC diets without and with multienzyme

Item, %	Corn-SBM diet*		Corn-SBM-CPCC diet		SEM	P-value		
	–Enzyme	+Enzyme	–Enzyme	+Enzyme		Diet	Enzyme	Diet × Enzyme
Indispensable AA								
Arg	95.8	96.5	84.7	84.8	2.00	<0.001	0.826	0.668
His	90.5	91.9	76.8	79.6	1.89	<0.001	0.634	0.964
Ile	89.4	90.7	72.4	74.9	1.87	<0.001	0.550	0.856
Leu	89.1	89.4	75.1	74.4	1.60	<0.001	0.932	0.618
Lys	88.0	88.4	70.9	70.3	1.64	<0.001	0.939	0.658
Met	90.4	90.8	80.9	78.2	1.22	<0.001	0.321	0.301
Phe	88.4	88.6	73.7	72.9	1.48	<0.001	0.983	0.600
Thr	85.3	86.2	66.8	70.2	2.08	<0.001	0.480	0.772
Trp	88.4	89.0	74.6	79.3	1.46	0.078	0.173	0.330
Val	87.0	87.6	71.4	71.3	1.44	<0.001	0.863	0.797
Dispensable AA								
Ala	88.8	89.0	72.1	75.6	1.92	<0.001	0.759	0.468
Asp	87.2	87.5	71.8	72.3	1.26	<0.001	0.893	0.923
Cys	82.2	82.7	60.9	64.8	2.42	<0.001	0.411	0.556
Glu	91.3	92.2	77.8	78.6	1.31	<0.001	0.590	0.977
Gly	93.8	98.0	74.3	78.9	6.86	0.028	0.758	0.802
Pro	138.6	143.2	117.7	118.7	21.7	0.510	0.951	0.897
Ser	91.8	92.0	73.2	74.5	1.98	<0.001	0.910	0.968
Tyr	90.1	90.6	73.9	75.0	1.44	<0.001	0.572	0.995

*–Enzyme = without multienzyme; +Enzyme = with multienzyme.

Table 5. Basal ileal endogenous losses of AA of growing pigs

Item	Average*
Indispensable AA	
Arg	853
His	291
Ile	493
Leu	721
Lys	541
Met	115
Phe	405
Thr	731
Trp	146
Val	652
Dispensable AA	
Ala	769
Asp	1,061
Cys	214
Glu	1,546
Gly	2,055
Pro	6,792
Ser	823
Tyr	315

*Data are expressed as milligrams per kilogram of DM intake.

4.59%) that have been reported for camelina seed by (Almeida et al., 2013) implying that AA were not damaged during the production of CPCC from the camelina seed. The Lys to CP ratio in feedstuffs is an indicator of heat damage of AA in the same feedstuff during its thermal processing (Kim et al., 2012; Woyengo et al., 2015).

TI, which reduces AA digestibility, is one of the antinutritive factors present in soybean and camelina products that limit the inclusion of these products in swine diets (Woyengo et al., 2016b). The CPCC had 3.9 times greater TI activity than SBM. Raw soybean has a very high TI activity. For instance, TI activity in raw soybean ranged from 70.5 to 112 TIU/mg (Chohan et al., 1993; Leeson and Atteh, 1996). However, during the production of the SBM, the TI activity in the soybean is significantly reduced due to heat treatment of the soybean during the cooking, pressing, and toasting stages of producing the SBM. Thus, the greater TI activity in CPCC than in SBM could be due to the fact that CPCC was subjected to less heat during its production. The TI activity of the CPCC was higher than the values that were reported by Almeida et al. (2013) for expeller-pressed camelina meals (6.2–20 TIU/mg), which could have been

Table 6. SID of AA, ATTD of GE, and DE and NE values for CPCC without and with multienzyme

	CPCC ¹			
Item	–Enzyme	+Enzyme	SEM	<i>P</i> -value
Indispensable AA, %				
Arg	74.4	73.3	2.69	0.795
His	58.3	57.3	3.55	0.863
Ile	44.6	44.5	2.76	0.979
Leu	47.6	46.8	4.01	0.916
Lys	43.5	41.9	2.14	0.655
Met	70.7	62.7	2.42	0.106
Phe	48.4	47.1	3.45	0.827
Thr	44.8	45.7	3.41	0.861
Trp	55.3	63.1	3.63	0.239
Val	50.6	50.7	2.71	0.986
Dispensable AA, %				
Ala	46.4	51.5	2.47	0.249
Asp	43.1	45.8	2.61	0.526
Cys	42.0	46.1	6.44	0.690
Glu	56.3	58.0	3.78	0.771
Gly	55.5	57.9	5.80	0.797
Pro	91.9	86.6	16.2	0.837
Ser	48.0	51.3	2.91	0.502
Tyr	39.6	45.2	4.43	0.481
ATTD of GE, %	72.4	72.3	2.27	0.974
DE, kcal/kg of DM	3,663	3,657	114.4	0.972
NE, kcal/kg of DM	2,213	2,209	87.5	0.972

*Enzyme = without multienzyme; +Enzyme = with multienzyme.

Figure 1. Effect of multi-enzyme dosage on IVDDM for CPCC. Linear effect ($P < 0.001$), quadratic effect ($P = 0.492$).

due to differences in oil extraction methods between the CPCC fed in the current study and the expeller-pressed camelina meals fed in the study by Almeida et al. (2013). Also, the TI activity of the CPCC was higher than the value (<1.0 TIU/mg) that was reported by Almeida et al. (2013) for canola meal, which is another co-product of the *Brassica* family. The TI activity of the SBM was similar to the values (3.20–6.21 TIU/mg) that were reported by others (Valencia et al., 2008; Goebel and Stein, 2011; Perryman and Dozier III, 2012; Woyengo et al., 2014).

In addition to TI activity, camelina co-products, like most of the other co-products of the *Brassica* family, contain high levels of glucosinolates (Almeida et al., 2013; Kahindi et al., 2014), which reduces voluntary feed intake because of their bitterness (Lee and Hill, 1983; Mailer et al., 2008). Energy and nutrient digestibility of feedstuffs (such as camelina co-products) that have relatively high content of antinutritive factors can be determined by difference or regression method, but not direct method (Mosenthin et al., 2000). Corn and SBM are palatable and are the most widely used sources of energy and AA in swine diets, respectively. Thus, the energy and nutrient digestibility of CPCC was determined by difference method using corn–SBM-based diet as basal diet. The CP, EE, NDF, and AA contents of corn used in the current study were similar to its values in NRC (2012). Also, the CP, EE, NDF, and AA contents of SBM used in the current study were similar to its values in NRC (2012).

The ATTD of GE (72.4%), DE (3,663 kcal/kg), and NE (2,213 kcal/kg) values for CPCC fed in the current study were lower than the values (82% ATTD of GE and 4,183 kcal/kg DE, 2,439 kcal/

kg NE, respectively) that were reported by Kahindi et al. (2014) for CPCC. However, the ATTD of GE and DE values for CPCC fed in the current study were greater than the values (52% ATTD of GE and 2,683 kcal/kg DE) that were reported by Kiarie et al. (2016) for CPCC. Digestibility of energy in test feedstuff for pigs can vary depending on several factors including: 1) method of estimating energy digestibility, 2) composition of test feedstuffs, 3) dietary level of test feedstuff, and 4) age or BW of pigs. Energy digestibility of CPCC fed in the current study and in the studies by Kahindi et al. (2014) and Kiarie et al. (2016) was determined using the same method (difference method) of estimating nutrient digestibility. The CPCC fed in the study by Kahindi et al. (2014) was the same as that fed in the study by Kiarie et al. (2016). The CPCC fed in the current study and in the studies by Kahindi et al. (2014) and Kiarie et al. (2016) were similar in CP and EE content. However, dietary level of CPCC fed in the current study was 30%, whereas dietary level of CPCC in the studies by Kahindi et al. (2014) and Kiarie et al. (2016) was 20%. Finally, the initial BW of pigs used in the current study was 36 kg, whereas the initial BW of pigs fed in the studies by Kahindi et al. (2014) and Kiarie et al. (2016) were 80 and 33 kg, respectively. Thus, the differences in energy digestibility of CPCC between studies could partly be attributed to differences in dietary level of CPCC and BW of pigs at the initiation of feeding CPCC.

The basal ileal endogenous AA losses were within the range of values that were reported by Dilger et al. (2004), Opapeju et al. (2006), and Woyengo et al. (2010) for growing pigs fed low casein cornstarch-based diet. Also, basal ileal endogenous AA losses were comparable to values reported by Shi et al. (2015) for growing pigs fed N-free diet. However, the basal ileal endogenous AA losses were greater than the values that were reported by Zhai and Adeola (2011), Woyengo et al. (2014), and Woyengo et al. (2016b) for growing pigs fed N-free diet. Recently, Adeola et al. (2016) reviewed the methods of estimation of basal ileal endogenous AA losses in pigs, and concluded that basal ileal endogenous AA loss values from pigs fed N-free diet are lower than those from pigs fed low casein cornstarch-based diet. Thus, the differences between the current study and those of Zhai and Adeola (2011), Almeida et al. (2013), Woyengo et al. (2014), and Woyengo et al. (2016b) with regard to basal ileal endogenous AA losses could have been due to differences in composition of diets fed in the studies.

The SID of Pro for diets was greater than 100%, which was similar to results of [Dilger et al. \(2004\)](#), [Opapeju et al. \(2006\)](#), [Woyengo et al. \(2010\)](#), and [Woyengo et al. \(2016b\)](#) who reported SID of Pro values that were greater than 100%. [Dilger et al. \(2004\)](#) attributed this high SID of Pro to higher basal ileal endogenous loss of the Pro when pigs are fed low-protein diets. Because basal ileal endogenous AA loss values from pigs fed low casein cornstarch-based diets can be greater than those from pigs fed N-free diets, the SID of AA values that are estimated using basal ileal endogenous AA loss values from pigs fed low casein cornstarch-based diets could be greater than those that are estimated using basal ileal endogenous AA loss values from pigs fed N-free diets. However, the SID of AA values for CPCC fed in the current study were generally lower than the values (which were estimated using basal ileal endogenous AA loss values from pigs fed N-free diet) reported by [Almeida et al. \(2013\)](#) for expeller-pressed camelina meal. Also, SID of AA values for CPCC fed in the current study were generally lower than the values (which were estimated using basal ileal endogenous AA loss values from various studies in which pigs were fed low casein diets) reported by [Kahindi et al. \(2014\)](#) for CPCC. Thus, the differences between the current study and those of [Almeida et al. \(2013\)](#) and [Kahindi et al. \(2014\)](#) with regard to basal SID of AA for camelina co-products could not have been due to differences in methods of estimating basal ileal endogenous AA losses. As previously mentioned, the CPCC fed in the current had greater TI activity than expeller-pressed camelina meal fed in the study by [Almeida et al. \(2013\)](#). Also, the AA digestibility of expeller-pressed camelina meal fed in the study by [Almeida et al. \(2013\)](#) was estimated by direct method. Thus, the differences in SID of AA for CPCC between studies could partly be attributed to differences in antinutritional factor content of CPCC, dietary level of CPCC, and method of estimating AA digestibility of CPCC. The IVDDM of CPCC (46%) was lower than the values that were reported by [Woyengo et al. \(2016c\)](#) for solvent-extracted canola meal (63%), expeller-pressed canola meal (68%), and cold-pressed canola cake (70%), which could partly be attributed to the greater fiber content and TI activity in camelina co-products than in canola co-products.

The negative effects of dietary fiber can be reduced partly through dietary supplementation with multienzyme preparations that degrade dietary fiber. In the current study, multienzyme supplementation did not affect energy and AA digestibility in

corn-SBM diet, which could have been due to the low-fiber content in corn and SBM. [Thacker \(2005\)](#) also reported insignificant effect of fiber-degrading enzymes on nutrient digestibility in corn-SBM-based diets for pigs. As previously mentioned, CPCC has a greater fiber content than SBM, implying that the fiber-degrading enzymes can be more effective in CPCC-based diets than in SBM-based diets. The AID of GE and AMEn value for CPCC for broilers were improved by multienzyme supplementation ([Woyengo et al., 2016a](#)). The NE value and SID of some AA for cold-pressed soybean cake for pigs were improved by supplementation of multienzyme product used in a previous study at 0.5 g/kg ([Woyengo et al., 2016b](#)). In the current study, however, multienzyme supplementation at 0.5 g/kg did not improve energy and AA digestibilities and hence, DE and NE values. Also, multienzyme supplementation at 0.5 g/kg did not affect IVDDM for CPCC. However, multienzyme supplementation at a greater dosage (50 g/kg) improved IVDDM for CPCC, implying that in the current study, the lack of effect of multienzyme on NE value and SID of AA for CPCC was likely due to the fact that multienzyme at 0.5 g/kg was not adequate to improve the digestibility of CPCC for pigs. The TI activity in CPCC fed in the current study was 22 TIU/mg, whereas the TI activity in cold-pressed soybean cake fed in the study by [Woyengo et al. \(2016b\)](#) was 2.25 TIU/mg because it had been derived from heated soybean seeds. TIs can reduce the activities of proteases and carbohydrases ([Zhang et al., 2010](#)), leading to greater requirement of proteases and carbohydrases for nutrient digestion. Thus, the difference between the current study and that of [Woyengo et al. \(2016b\)](#) with respect to the effect of multienzyme on nutrient digestibility could partly be due to differences in the TI activity in the evaluated feedstuffs, and hence optimal multienzyme dosage. Thus, there is a need to identify optimal dosage of the multienzyme product used in the current study for CPCC-based diets for pigs.

The differences between the current study and that of [Woyengo et al. \(2016b\)](#) in which multienzyme supplementation improved nutrient digestibility of CPCC broilers could partly have been due to differences in digestive physiology of pigs and poultry. The multienzyme products used in the current study and that of [Woyengo et al. \(2016b\)](#) contained protease activity, and have optimum pH of 4.8, which is found in the crop of chickens. Dietary proteolytic enzymes can degrade TI ([Bedford, 1996](#)), implying that TI in CPCC can be degraded by protease that is present in the supplemental

multienzyme in the crop before it (TI) arrives in the upper part of small intestine, where it binds to digestive enzymes. However, in pigs, the optimal pH for the multienzyme used in the current study is only found in the upper part of the small intestine, where TI exerts its negative effects. Thus, the confounding effect of TI on the effect of multienzyme on nutrient digestibility in pigs can be greater than that in poultry.

In conclusion, CPCC can be included in swine diets as a source of energy and AA. Multienzyme supplementation at 0.5 g/kg did not affect energy and nutrient digestibility, DE and NE values. Also, multienzyme supplementation at 0.5 g/kg did not affect porcine IVDDM for CPCC. However, multienzyme at 50 g/kg improved porcine IVDDM of CPCC, implying that efficacy of the multienzyme used in the current study with regard to improving nutrient digestibility of CPCC in pigs is dosage dependent.

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