Nutritive value of expeller/cold-pressed canola meal and pre-pressed solvent-extracted carinata meal for broiler chicken

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ABSTRACT A study was conducted to evaluate standardized ileal digestibility (**SID**) of amino acids (**AA**) and nitrogen-corrected apparent metabolizable energy (**AMEn**) values of pre-pressed solvent-extracted carinata meal (**SE-carinata meal**) and expeller/cold-pressed canola meal (**ECP-canola meal**) for broilers. Two hundred and forty broiler chicks were divided into 40 groups of 6 birds/group and fed 4 diets in a completely randomized design (10 groups/diet) from 14 to 21 d of age. The diets were cornstarch-based containing SE-carinata meal, ECP-canola meal, or pre-pressed solvent-extracted canola meal (SE-canola meal; reference feedstuff) as the sole protein source, and N-free diet. Digestibility of AA and N retention for feedstuffs was determined by the direct method, whereas energy retention of feedstuffs was determined by difference from the N-free diet. On DM basis, SE-canola meal, ECP-canola meal, and SE-carinata meal contained 43, 36, and 50% CP; 2.60, 2.21, and 1.82% Lys; 32, 29, and 27% neutral detergent fiber, and 1.1, 15.3, and 0.88% ether extract, respectively. On DM basis, the AMEn value was lowest ($P < 0.05$) for SE-carinata meal (1,295 kcal/kg), intermediate ($P < 0.05$) for SE-canola meal (1,608 kcal/kg), and greatest ($P < 0.05$) for ECP-canola meal (1,994 kcal/kg). The SID values of indispensable AA for ECP-canola meal were greater ($P < 0.05$) than those for SE-canola meal or SE-carinata meal. The SID values of all indispensable AA (except Gly, Lys, and Trp) for SE-carinata meal were greater ($P < 0.05$) than those for SE-canola meal. The SE-canola meal and SE-carinata meal did not differ in SID of Gly and Trp; however, SE-carinata meal had lower ($P < 0.05$) SID of Lys than SE-canola meal. The results indicate that ECP-canola meal fed in this study could be a good source of AA and energy for broilers. Results also indicate that SE-carinata meal fed in this study could be an attractive AA source for broiler diet, but could benefit from Lys fortification due it its low SID Lys value.

Key words: amino acid digestibility, apparent metabolizable energy, broiler, expeller/cold-pressed canola meal, pre-press solvent-extracted carinata meal

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INTRODUCTION

Oilseed crops belonging to the *Brassic*a family are grown for the production of oil that can be used in the food and biofuel industries. Oil can be extracted from oilseeds by solvent extraction, expeller pressing, or expeller/cold pressing (Lee et al., 2020). Solvent extraction is the most widely used method of oil extraction from oilseed crops in North America (Cheng et al., 2019) and canola is the most widely grown oilseed crop of the *Brassic*a family (Unger, 1990; Cheng et al., 2019; Lee et al., 2020). Therefore, pre-pressed solvent-extracted canola meal (**SE-canola meal**) is the most commercially available feedstuff from canola (Leming and Lember, 2005; Lee et al., 2020). Cold pressing method is used to extract oil from canola in the human food and biofuel industries, and hence the availability of expeller/cold-pressed canola meal (**ECP-canola meal**) for livestock feeding is increasing. Carinata, another oilseed crop from the *Brassic*a family, is grown mainly for the production of oil for the biofuel industry (Bouaid et al., 2009; Chu et al., 2017). Therefore, the availability of carinata co-products such as pre-pressed solvent extracted carinata meal (**SE-carinata meal**) for livestock feeding is increasing (Tadelle et al., 2003; Xin and Yu, 2014; Ban et al., 2017; Ndou and Woyengo, 2020).

The nutritive value of SE-canola meal for poultry has been determined in several previous studies (Adewole et al., 2017; Zhong and Adeola, 2019) and is

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increasingly used as protein and amino acids (**AA**) sources in poultry diets (Canola Council of Canada, 2019). Ndou and Woyengo (2020) recently reported the standardized ileal digestibility (**SID**) of AA and net energy values of ECP-canola meal and SE-carinata meal for growing pigs, whereas the net energy and SID of AA for ECP-canola meal for pigs has also been reported in some previous studies (Seneviratne et al., 2011; Woyengo et al., 2016). However, information is lacking on the nutritive value of ECP-canola meal and SE-carinata meal for poultry. Although pigs and poultry are monogastric animals, some differences in the digestion process between these species may differentially affect the digestibility and utilization of energy and nutrients in their feedstuffs (Park et al., 2017; Zhong and Adeola, 2019). Determining the available energy and SID AA values for a new feedstuff is necessary to provide useful information about the utilization of the energy and AA in such an ingredient for energy and protein retention in the body. It is, therefore, imperative to determine the nitrogen-corrected apparent metabolizable energy (**AMEn**) and SID of AA values for ECP-canola meal and SE-carinata meal for poultry as this would provide valuable information for their incorporation into poultry diet formulations for optimal performance and minimal nutrient excretion into the environment. The objective of this study was to determine the SID of AA and AMEn values of ECP-canola meal and SE-carinata meal for broilers.

MATERIALS AND METHODS

Experimental procedures were reviewed and approved by the Institutional Animal Care and Use Committee at South Dakota State University (18-087E).

Experimental Ingredients and Diets

Diets included cornstarch-based diets with SE-canola meal, ECP-canola meal or SE-carinata meal as the sole source of AA, and N-free diet (Table 1). The ECP-canola meal fed in this study was derived from *Brassica napus* seed and was sourced from Dakota Lakes Field Station (Pierre, SD) in one lot. Further, the ECP-canola meal had been produced by processing canola seed at less than 50°C (barrel temperature) for 2 min using a screw press expeller (Model KEK-P0020; Egon Keller GMBH & Co Remscheid, Germany). The SE-carinata meal was produced at the Archer Daniels Midland (**ADM**) facility in Red Wing (MN). The carinata seeds were pre-pressed and solvent-extracted using processing conditions similar to those that are typically used for production of the conventional SE canola meal. The typical processing conditions at which the conventional SE canola meal is produced have previously been described (Woyengo et al., 2010a). In summary, the extraction temperature for the conventional SE canola meal is 100 to 120°C for about 1 h. The SE-canola meal fed in this study was obtained from a local feed mill (Brookings, SD) and was included as a reference in the study. The N-free diet was fed to estimate basal endogenous AA losses for determining the SID of AA (Stein et al., 2007). The ratio of cornstarch to sugar, cellulose, and soybean oil in the test diets was identical to the N-free diet to allow calculation of energy retention of the test feedstuffs using the difference method (Fan and Sauer, 1995). The diets contained titanium dioxide (0.3%) as an indigestible marker.

Birds, Housing, and Experiment Procedure

A total of 240 one-day-old male broiler chicks of Ross 308 strain were acquired from a commercial hatchery. The chicks were distributed to electrically heated Petersime battery brooders (Petersime Incubator Co., Gettysburg, OH) so that each cage (34 cm wide, 102 cm long, and 24 cm high) housed approximately 14 birds. Room temperature was following the programs recommended for the Ross strain. Light was provided for 24 h daily throughout the experiment. Chicks were fed a drug-free commercial starter diet (3,050 kcal/kg ME, 22% CP, 1.00% Ca, and 0.45% non-phytate P) from d 1 to 14 d of age. On d 14, the birds were redistributed into 40 cages (6 birds/cage) and group-weighed.

The 4 experimental diets were randomly assigned to the cages in a completely randomized design (10 cages per diet) and fed from d 14 to 21 of age. Fresh water and feed were given ad libitum throughout the experiment. On d 19 and 20, excreta samples were collected from each cage and stored frozen at −20°C for later laboratory analyses. On d 21, birds were euthanized via cervical dislocation, and ileum contents were gently squeezed out and stored frozen at −20°C for later laboratory analyses.

Sample Preparation and Analyses

The collected excreta and ileal digesta samples were, respectively, pooled for each cage. The pooled excreta samples were oven-dried for 4 d at 60°C, whereas the pooled ileal digesta samples were freeze-dried. Thereafter, the dried excreta, ileal digesta, test feedstuffs, and diet samples were finely ground using a centrifugal mill (model ZM200; Retsch GmbH, Haan, Germany) to pass through a 0.75 mm screen. All samples were analyzed for DM, gross energy (**GE**), and CP (N × 6.25). Samples were further analyzed as follows: test feedstuffs for neutral detergent fiber (**NDF**), acid detergent fiber (**ADF**), ether extract (**EE**), and AA; diet and ileal digesta samples for AA and titanium content; and excreta samples for titanium content.

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) by the AOAC (2006); and for the GE using an adiabatic bomb calorimeter (model 1261, Parr Instrument Co., Moline, IL) with benzoic as the standard. Samples were analyzed for AA (method 982.30 E) at the University of Missouri Experiment Station laboratories (Colombia, MO) using

Table 1. Ingredient composition and analyzed nutrient content of pre-pressed solvent-extracted canola meal (SE-canola meal), expeller/cold-pressed canola meal (ECP-canola meal), and pre-pressed solvent-extracted carinata meal (SE-carinata meal) and N-free diets.

Item	SE-canola meal	ECP-canola meal	SE-carinata meal	N-free diet
Ingredient, % as fed				
SE-canola meal	50.00			
CP-canola meal		50.00		
SE-carinata			30.00	
Cornstarch	37.50	37.50	54.10	78.20
Sucrose	3.84	3.84	5.53	8.00
Cellulose (sulkafloc)	1.44	1.44	2.08	3.00
Soybean oil	2.40	2.40	3.46	5.00
Limestone	0.98	0.98	0.98	1.00
Dicalcium phosphate	1.95	1.95	1.95	2.40
Poultry vitamin premix[1]	0.25	0.25	0.25	0.25
Poultry mineral premix[2]	0.25	0.25	0.25	0.25
Choline chloride	0.50	0.50	0.50	0.50
Salt	0.30	0.30	0.30	0.30
Potassium carbonate				0.40
Magnesium sulphate				0.10
Chromic oxide[3]	0.30	0.30	0.30	0.30
Titanium oxide	0.30	0.30	0.30	0.30
Analyzed nutrients, dry matter basis				
Dry matter, %	92.8	94.4	95.1	95.2
Crude protein, %	20.7	18.3	15.1	0.51
Gross energy, kcal/kg	4,357	4,282	4,255	4,143
Indispensable amino acids, %				
Arg	1.26	1.15	1.02	0.01
His	0.58	0.49	0.39	0.01
Ile	0.89	0.80	0.61	0.02
Leu	1.49	1.32	1.04	0.03
Lys	1.28	1.12	0.57	0.02
Met	0.41	0.35	0.27	0.01
Phe	0.85	0.76	0.60	0.02
Thr	0.87	0.76	0.58	0.01
Trp	0.26	0.20	1.02	0.002
Val	1.11	1.01	0.73	0.02
Dispensable amino acids, %				
Ala	0.92	0.82	0.65	0.02
Asp	1.37	1.32	0.98	0.03
Cys	0.57	0.44	0.38	0.01
Glu	3.74	3.24	2.80	0.04
Gly	1.10	0.95	0.76	0.01
Pro	1.31	1.08	0.89	0.02
Ser	0.76	0.66	0.52	0.01
Tyr	0.54	0.50	0.33	0.01

[1]Provided the following per kg of diet: 50,094 IU vitamin A, 22,556 IU vitamin D3, 226 IU vitamin E, 15 mg thiamine, 33 mg riboflavin, 90 mg pantothenic acid, 10 mg folic acid, 301 mg niacin, 16 mg pyridoxine, 15 mg menadione, 90 mg cyanocobalamin, and 0.9 mg biotin.

[2]Provided the following per kg of diet: 300 mg manganese, 50 mg iron, 40 mg copper, 275 mg zinc, 3.13 iodine, and 0.75 mg selenium.

[3]We use titanium oxide as the indigestibility marker in our laboratory for digestibility studies. However, we had issues with the equipment for analyzing titanium when starting this study. Therefore, we included chromic oxide to have the option of analyzing for chromium in case the equipment for titanium analysis was still not functional after our experiment.

the AOAC (2006). Titanium 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

Apparent ileal digestibility (**AID**) of AA, and apparent retention of nitrogen and energy for diets were calculated using the indicator method (Stein et al., 2007) as follows:

$$\% \text{ apparent digestibility or retention of nutrient or energy} = [1 - (N_f/N_d) \times (M_d/M_f)] \times 100$$

where: N_f = nutrient or energy concentration in excreta or ileal digesta (% DM); N_d = nutrient or energy concentration in the diet (% DM); M_d = titanium concentration in diet (% DM); C_f = titanium concentration in excreta or ileal digesta (% DM).

SID of AA for diets was calculated from AID of AA corrected for basal endogenous losses of AA (Stein et al., 2007) using the following equation:

$$\text{SID}, \% = \text{AID} + [(\text{basal IAA}_{end}/\text{AA}_{diet}) \times 100$$

where IAA_{end} is the basal endogenous loss of an AA in grams per kilogram of DM intake and AAdiet represent the AA concentrations (g/kg) in diet DM.

The AID and SID of AA and N retention for the test feedstuffs were determined by the direct method. The energy retention for the test feedstuffs was determined by difference method (Fan and Sauer, 1995) using N-free diet as basal diet as follows:

$$DA = (DD - DB \times SB)/SA$$

where: DA = retention of energy (%) in an assay feedstuff (SE-canola meal, ECP-canola meal or SE-carinata

meal); DD = retention of energy (%) in an assay diet (cornstarch-SE-canola meal-, cornstarch-ECP-canola meal-based or cornstarch-SE-carinata meal-based diets); DB = retention of energy (%) in the basal diet (N-free diet); SB = contribution level of energy (decimal percentage) from energy-yielding ingredients (cornstarch, sucrose, cellulose and soybean oil) in N-free diet to the assay diet; and SA = contribution level of energy (decimal percentage) from SE-canola meal, ECP-canola meal or SE-carinata meal to the cornstarch-SE-canola meal-, cornstarch-ECP-canola meal-based or cornstarch-SE-carinata meal-based diets.

The AME values for test feedstuffs were calculated by multiplying GE by apparent retention of GE. The AMEn for test feedstuffs were calculated as AME value (per gram test feedstuff) minus 8.22 multiplied by grams of N retained per gram test feedstuff according to Hill et al. (1960).

Data were subjected to analysis of variance using the MIXED procedure of SAS (SAS version 9.3; SAS Inst. Inc., Cary, NC) for a completely randomized design with cage as the experimental unit. Before ANOVA, all data were tested for normality using the univariate procedure of SAS and for homogeneity of variance using residual plots to remove outliers. Four outliers (1 for SE-canola meal, 1 for ECP-canola meal, and 2 for SE- carinata meal) were removed. Treatment means were separated using the PDIFF option with adjustment for the Tukey−Kramer test in SAS when a significant effect was detected. To test the hypotheses, $P < 0.05$ was considered significant.

RESULTS

The SE-carinata meal had lower content of EE, NDF, and ADF, but greater content of CP and AA (except Lys) than SE-canola meal or ECP-canola meal (Table 2). The ECP-canola meal had lower content of CP, AA, NDF, and ADF, but the greater content of EE than SE-canola meal.

The apparent N retention was lower ($P < 0.05$) for SE-carinata than that of the 2 canola co-products, which did not differ in N retention (Table 3). The apparent GE retention was also lowest ($P < 0.05$) for the SE-carinata meal, greatest ($P < 0.05$) for the ECP-canola meal, and intermediate ($P < 0.05$) for SE-canola meal. Similarly, the AMEn was lowest ($P < 0.05$) in the SE-carinata meal, greatest ($P < 0.05$) in the ECP-canola meal, and intermediate ($P < 0.05$) for SE-canola meal.

The AID values of indispensable AA for ECP-canola meal were greater ($P < 0.05$) than those for SE-canola meal or SE-carinata meal (Table 4). The AID values of Arg, Ile Leu, Phe, and Val for SE-carinata meal were greater ($P < 0.05$) than those for SE-canola meal. The SE-carinata meal and SE-canola meal did not differ in AID of Gly, His, Met, Ser, Thr, and Trp. The AID of Lys for SE-carinata meal was lower ($P < 0.05$) than that for SE-canola meal. The SID values of indispensable AA for ECP-canola meal were greater ($P < 0.05$) than those for SE-canola meal or SE-carinata meal (Table 5). The SID values of all indispensable AA (except of Gly, Lys, and Trp) for SE-carinata meal were greater ($P < 0.05$) than those for SE-canola meal. The SID of Lys for SE-

Table 2. Analyzed composition of pre-pressed solvent-extracted canola meal (SE-canola meal), expeller/cold-pressed canola meal (ECP-canola meal), and pre-pressed solvent-extracted carinata meal (SE-carinata meal), on dry matter basis.

Item	SE-canola meal[1]	ECP-canola meal[2]	SE-carinata meal[3]
Dry matter, %	88.2	93.1	92.5
Crude protein, %	42.86	35.93	50.2
Gross energy, kcal/kg	4,377	4,969	4,853
Ether extract, %	1.12	15.3	0.88
Neutral detergent fiber, %	31.54	28.5	26.7
Acid detergent fiber, %	20.49	19.7	15.4
Indispensable amino acids, %			
Arg	2.60	2.32	3.55
Gly	2.23	1.87	2.43
His	1.19	0.96	1.30
Ile	1.83	1.57	2.07
Leu	3.10	2.60	3.45
Lys	2.60	2.21	1.82
Met	0.88	0.71	0.96
Phe	1.72	1.51	2.04
Ser	1.55	1.36	1.61
Thr	1.78	1.54	1.89
Trp	0.51	0.38	0.64
Val	2.28	1.96	2.51
Dispensable amino acids, %			
Ala	1.92	1.61	2.09
Asp	2.99	2.79	3.43
Cys	1.17	0.91	1.35
Glu	7.56	6.33	9.07
Pro	2.70	2.15	3.01
Tyr	1.15	1.04	1.33

[1]All values for SE-canola meal were analyzed in the current study.

[2]Source of the values for ECP-canola meal (except gross energy) is Lee et al. (2020) who analyzed and fed (in their study) the same ECP-canola meal fed in the current study. The gross energy value for ECP-canola meal was analyzed in the current study.

[3]Sources of the values for SE-carinata meal is Hong et al. (2019) who analyzed and fed (in their study) the same SE-carinata meal fed in the current study.

Table 3. Nitrogen and energy retention and nitrogen-corrected metabolizable energy (AMEn) of pre-pressed solvent-extracted canola meal (SE-canola meal), expeller/cold-pressed canola meal (ECP-canola meal), and pre-pressed solvent-extracted carinata meal (SE-carinata meal).

Item	SE-canola meal	ECP-canola meal	SE-carinata meal	SEM	*P* value
Retention, %					
Nitrogen	59.1[a]	62.4[a]	36.3[b]	1.36	<0.001
Gross energy	44.1[b]	46.7[a]	31.6[c]	0.39	<0.001
AMEn, kcal/kg of dry matter	1,608[b]	1,994[a]	1,295[c]	17.1	<0.001

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

Table 4. Apparent ileal digestibility of amino acids in pre-pressed solvent-extracted canola meal (SE-canola meal), expeller/cold-pressed canola meal (ECP-canola meal) and pre-pressed solvent-extracted carinata meal (SE-carinata meal).

Item, %	SE-canola meal	ECP-canola meal	SE-carinata meal	SEM	*P* value
Indispensable amino acids					
Arg	86.1[c]	92.1[a]	89.3[b]	0.30	<0.001
Gly	76.2[b]	84.9[a]	75.6[b]	0.61	<0.001
His	82.8[b]	90.1[a]	84.3[b]	0.40	<0.001
Ile	75.3[c]	84.1[a]	78.8[b]	0.57	<0.001
Leu	79.3[c]	87.3[a]	81.6[b]	0.49	<0.001
Lys	75.7[b]	85.8[a]	67.0[c]	0.68	<0.001
Met	85.6[b]	91.1[a]	87.0[b]	0.39	<0.001
Phe	79.2[c]	87.3[a]	81.5[b]	0.48	<0.001
Ser	68.4[b]	78.2[a]	69.9[b]	0.94	<0.001
Thr	65.7[b]	76.8[a]	67.3[b]	0.85	<0.001
Trp	89.1[b]	91.7[a]	88.1[b]	0.35	<0.001
Val	70.1[c]	80.3[a]	73.1[b]	0.75	<0.001
Dispensable amino acids					
Ala	78.4[b]	86.6[a]	79.6[b]	0.51	<0.001
Asp	70.8[b]	85.6[a]	71.3[b]	0.63	<0.001
Cys	73.1[b]	82.0[a]	74.1[b]	0.65	<0.001
Glu	86.8[b]	91.9[a]	86.6[b]	0.35	<0.001
Pro	70.6[c]	79.8[a]	75.5[b]	0.72	<0.001
Tyr	76.7[b]	84.9[a]	76.8[b]	0.61	<0.001

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

Table 5. Standard ileal digestibility of amino acids in pre-pressed solvent-extracted canola meal (SE-canola meal), expeller/cold-pressed canola meal (ECP-canola meal) and pre-pressed solvent-extracted carinata meal (SE-carinata meal).

Item	SE-canola meal	ECP-canola meal	SE-carinata meal	SEM	*P* value
Indispensable amino acids					
Arg	88.4[c]	94.6[a]	92.1[b]	0.30	<0.001
Gly	79.7[b]	88.9[a]	80.6[b]	0.61	<0.001
His	85.0[c]	92.8[a]	87.5[b]	0.40	<0.001
Ile	78.8[c]	87.9[a]	83.8[b]	0.57	<0.001
Leu	82.2[c]	90.5[a]	85.7[b]	0.49	<0.001
Lys	78.7[b]	89.1[a]	73.5[c]	0.68	<0.001
Met	88.0[c]	94.1[a]	90.4[b]	0.39	<0.001
Phe	82.7[c]	91.2[a]	86.4[b]	0.48	<0.001
Ser	74.6[c]	85.3[a]	78.9[b]	0.94	<0.001
Thr	72.2[c]	84.2[a]	77.0[b]	0.85	<0.001
Trp	91.3[b]	94.5[a]	91.2[b]	0.36	<0.001
Val	75.5[c]	86.1[a]	81.1[b]	0.75	<0.001
Dispensable amino acids					
Ala	82.0[c]	90.7[a]	84.9[b]	0.51	<0.001
Asp	75.1[b]	90.1[a]	77.4[b]	0.63	<0.001
Cys	76.7[c]	86.5[a]	79.4[b]	0.65	<0.001
Glu	88.9[b]	94.3[a]	89.3[b]	0.35	<0.001
Pro	74.1[c]	84.0[a]	80.5[b]	0.72	<0.001
Tyr	80.5[c]	88.9[a]	82.9[b]	0.61	<0.001

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

carinata meal was lower ($P < 0.05$) than that for SE-canola meal. However, the SE-canola meal and SE-carinata meal did not differ in SID of Gly and Trp.

DISCUSSION

The purpose of this study was to evaluate the nutritive value of ECP-canola meal and SE-carinata meal for broiler chickens, in terms of SID of AA and AMEn. We also determined the retention of energy and nitrogen for these feed ingredients. All data were expressed on DM basis to facilitate data comparison with those obtained from the literature. Herein, SE-canola meal was used as the reference feedstuff because it is the most commercially available feedstuff from canola and is increasingly used as a protein-source alternative for soybean meal in poultry diets as previously mentioned because it has a good balance of essential AA. The SE-carinata meal was included in the test diet at 30%, which was a lower level than the level (50%) at which the SE-canola meal or ECP-canola meal was included in the test diet because of the greater content of glusosinolates in the former than in the latter 2 test feedstuffs; glucosinolates reduces feed palatability. Thus, the test diets differed with regard to CP content. However, our intention was not to equalize CP content among the diets, but to determine AID of AA values for test feedstuffs by direct method and correct them for basal endogenous losses of AA to estimate SID of AA values. It should be noted that SID of AA values do not depend on dietary CP level, as is the case for AID of AA. Hence, the difference among the test diets with regard to dietary CP level is not a concern as the objective of this study was to compare the 3 test feedstuffs with regard to SID of AA and not AID of AA.

Nutrient Composition

The CP, AA, EE, NDF, and ADF contents of the SE-canola meal fed in the current study were similar to the values reported by Woyengo et al. (2010b) and Adewole et al. (2017) for SE-canola meal. The nutrient composition of ECP-canola meal and its comparison with other canola co-products have been previously discussed (Lee and Woyengo, 2018). The ECP-canola meal fed in this study had greater CP, AA, and NDF contents than that reported by Woyengo et al. (2016), which could be ascribed to the lower EE content of the former (15.3%) than for the latter (31.3%) reported by Woyengo et al. (2016). However, the ECP-canola meal fed in this study had lower content of CP, AA, and EE but greater NDF and ADF content than the ECP-canola meal reported by Ndou and Woyengo (2020). The ECP-canola meal fed in this study was produced by processing canola seed at less than 50°C (barrel temperature) compared to the temperature (70°C) reported by Ndou and Woyengo (2020). Therefore, the Lys to CP ratio value for the ECP-canola meal fed in this study was slightly greater than the value reported by Ndou and Woyengo (2020); 6.15 vs. 5.86%), implying the latter had a slightly lower protein quality due to heat damage through the formation of Maillard reaction products. Different processing conditions employed for oil extraction can differentially affect the chemical composition of ECP-canola meal (Seneviratne et al., 2011). The ECP-canola meal used in this study also had lower CP, AA, NDF, and ADF contents but greater EE content than the SE-canola meal reported herein. Oil extraction using cold pressing is not as efficient as solvent extraction and thus, resulting in ECP-canola meal having greater residual oil content than SE-canola meal. It should be noted that the Maillard reaction results in the formation of proteins, which are neutral-detergent insoluble (Van Soest, 1994) and thus contribute to the NDF content. Therefore, the observed greater NDF content in the SE-canola meal relative to the ECP-canola meal could suggest the presence of Maillard reaction products. It is also possible that the greater NDF content in the SE-canola meal than ECP-canola meal is due to the difference sources of canola seeds used for producing those meals.

The nutrient composition of the SE-carinata meal fed in this study in comparison with other carinata meals has been previously discussed (Ndou and Woyengo, 2020). The SE-carinata meal had greater CP, AA (except Lys), but lower EE, NDF, and ADF contents than the values reported for the 2 canola-coproducts reported in this study, and these differences may be ascribed to the differences in the oil, CP, and fiber contents between the 2 oil seeds from the *Brassica* family. The lower Lys to CP ratio value for the SE-carinata meal, albeit greater CP and the remaining AA contents, relative to the 2 canola products used herein could be due to heat damage because of the processing conditions that were employed for oil extraction from the carinata seeds.

Amino Acid Digestibility

The AID and SID of AA for the SE-canola meal in this study were similar to the values reported by Adewole et al. (2017) but, in general, slightly greater than values reported by others (Newkirk et al., 2003a,b; Adedokun et al., 2008; Woyengo et al., 2010b) for SE-canola meal in broilers. A possible reason for the differences in the AID and SID of AA reported for SE-canola meal among the abovementioned studies could be due to the difference in SE-canola meal sources and processing conditions during oil extraction from the canola seeds.

To the best of our knowledge, neither the AID nor SID of AA in ECP-canola meal or SE-carinata meal has been reported for broiler for comparison. However, a recent study with pigs indicated that the AID and SID of indispensable AA, except Lys, for SE-carinata meal, were greater than those for ECP-canola meal despite the greater NDF content in the SE-carinata meal than for the ECP-canola meal (Ndou and Woyengo, 2020). The authors attributed the greater AA digestibility values for SE-carinata meal than for ECP-canola meal to the

differences in the protein intrinsic structures (α-helix and β-sheets arrangements of secondary proteins) between the former and the latter. Carinata co-products have been reported to have a higher α-helix and β-sheets ratio, which results in their higher protein digestibility in ruminants because a higher proportion of β-sheets in protein decreases the accessibility of gastrointestinal enzymes for digesting the protein (Yu, 2005; Theodoridou et al., 2014; Ban et al., 2017). Ban (2016) also reported that, compared to canola meal, carinata meal has a higher proportion of soluble protein, indicating that the protein in carinata meal is more digestible than that in canola meal. However, in this study, whereas SE-carinata meal had greater digestibility values of most AA than SE-canola meal, those digestibility values were lower relative to ECP-canola meal contrary to the previously mentioned results of Ndou and Woyengo (2020) in pigs. The ECP-canola meal also had greater NDF and ADF contents than SE-carinata meal in this study. Therefore, the reason for the contrasting reports on AA digestibility in SE-carinata meal and ECP-canola meal between this study and that of Ndou and Woyengo (2020) is not clear, although it could be attributed to the differences in the digestion processes, particularly the foregut, between pigs and broiler chickens. Nonetheless, a comparative digestibility study between poultry and pigs is warranted to establish the utilization of AA in ECP-canola meal and SE-carinata for the 2 species. The greater digestibility values for most the AA for SE-carinata meal relative to SE-canola meal could be mainly due to the greater AA but lower fiber contents in the former than in the latter. Fiber components cannot be broken down by endogenous enzymes in monogastric animals and are reported to encapsulate dietary protein, increase endogenous nitrogen and AA loss, and then result in a lower nitrogen and AA digestibility (Adeola and Cowieson, 2011; Agyekum and Nyachoti, 2017). The lower Lys digestibility in the SE-carinata meal relative to the 2 canola co-products in this study agrees with the results from the study with pigs (Ndou and Woyengo, 2020), where the Lys digestibility value was lower for SE-carinata meal than for ECP-canola meal. The preceding finding could be mainly ascribed to the rather low Lys to CP ratio for SE-carinata meal (3.6%) when compared to the 2 canola co-products (around 6%) and indicate that the SE-carinata meal was likely to be heat-damaged. Indeed, both Lys content and its digestibility were reported to be reduced by the desolventization and toasting process when the meal temperature and moisture content were at least 105°C and 10%, respectively (Newkirk et al., 2003a; Classen et al., 2004), leading to the formation of Maillard reaction products. The greater digestibility of AA for ECP-canola meal and of most AA for SE-carinata meal relative to SE-canola meal is expected to result in improving broiler performance. Therefore, it would be imperative to evaluate the effect of inclusion of the ECP-canola meal and SE-carinata meal in broiler diets on growth performance. Due to the observed low SID Lys value, fortification with Lys would benefit the SE-carinata meal used in this study when used to replace SE-canola meal in broiler chickens diets.

Retention of N and GE, and AMEn

It is interesting to note that whereas AA digestibility values were generally lowest in SE-canola meal in this study, nitrogen retention for SE-canola meal was greater than that for SE-carinata meal but similar to that for ECP-canola meal. Carinata seed has been reported to have greater erucic acid and glucosinolate contents than canola seed (Xin and Yu, 2014). Therefore, meals generated from carinata seeds are expected to have greater contents of the aforementioned secondary metabolites than meals from canola seeds. Indeed, the reported total glucosinolate contents for SE-carinata meal and ECP-canola meal from the same batches as those used in this study were 23.7 μmol/g (Kasiga et al., 2020) and 11.1 μmol/g (Lee et al., 2020), respectively. Glucosinolates are biologically inactive and nontoxic but the endogenous enzyme myrosinase present in the seeds and meals from the genus *Brassica* and the activities of the microflora enzyme in the digestive tract can degrade glucosinolates into products that have antinutritional effects in animals (Tripathi and Mishra, 2007; Khajali and Slominski, 2012; Woyengo et al., 2017). However, the negative effects of glucosinolates on animals are relative to their concentrations in the diet and tolerance of the animal species to dietary glucosinolate content. In this context, there are reports indicating that poultry can generally tolerate total dietary glucosinolate content up to 2.5 μmol/g (Woyengo et al., 2017). Above tolerance levels, adverse effects such as impaired functioning of the thyroid, enlarged kidney and liver, necrosis of the liver and kidney cells, and reduced feed intake and growth have been reported (Tripathi and Mishra, 2007; Khajali and Slominski, 2012; Woyengo et al., 2017). Therefore, the reported hepatotoxicity and nephrotoxicity upon consumption of high dietary glucosinolate could lead to rechanneling of absorbed nutrients and breakdown of body protein to support the maintenance of these organs thereby reducing the protein retained for body growth. Thus, the foregoing could explain the observed low nitrogen retention value for SE-carinata meal relative to the 2 canola co-products owing to the reportedly higher glucosinolate content of the former than the latter as previously mentioned. It could also be argued the low Lys to CP ratio together with the low SID of Lys value observed for the SE-carinata meal contributed to its low nitrogen retention compared to the 2 canola co-products. The low lysine digestibility will imply low incorporation of it into body protein. However, based on the concept of ideal protein, the other absorbed indispensable AA will be deemed excess and have to be ultimately deaminated and excreted (Emmert and Baker, 1997; Baker, 2009), leading to low retained nitrogen and AA.

It is not apparent why SE-canola meal and ECP-canola meal had similar nitrogen retention as the former had less AA digestibility values than the latter.

However, it has been reported that heat treatment could detoxify some glucosinolates (Tripathi and Mishra, 2007; Lee et al., 2020) and SE-canola meal is exposed to higher temperatures than ECP-canola meal during the production process. Therefore, it follows that any adverse effect of glucosinolate on nitrogen retention would be less in the SE-canola meal relative to the ECP-canola meal in this study and thus, could explain the similarity observed in their nitrogen retention. The greater nitrogen retention for ECP-canola meal than for SE-carinata meal implies improved N utilization and reduced excretion of N for the former than for the latter.

The AMEn value of the SE-canola meal reported in this study was consistent with the values reported by Adewole et al. (2017) for conventional SE-canola meals obtained from different canola processing plants in Canada. The main components that contribute to metabolizable energy in oilseed meals, such as canola meal and carinata meal, are oil and protein (Khajali and Slominski, 2012) and to a lesser extent, digestible carbohydrates (Slominski and Campbell, 1990). The EE compared with protein or carbohydrates have greater GE value. The EE content in the ECP-canola meal used in this study was almost 15 times greater, while having the lowest CP content when compared to that in SE-canola meal and SE-carinata meal. Therefore, the observed greatest energy retention along with the greatest AMEn value for ECP-canola meal was due mainly to its EE content. Glucosinolates are detoxified by the liver and kidney, and then excreted mainly via urine (Kristensen et al., 2007). Glucosinolates are organic compounds, implying that their excretion via urine results in increased GE concentration in urine. Thus, the low GE retention and AMEn value observed for the SE-carinata meal relative to SE-canola meal or ECP-canola meal could be due to the reportedly greater glucosinolate content of carinata meals relative to the canola coproducts. It could also be due to lower N retention for SE-carinata meal than for SE-canola meal or ECP-canola meal since uric acid and urea that are forms of which N is excreted via urine, are organic compounds that contribute to GE in urine. In this study, the fiber contents could not have contributed to the observed low energy retention and AMEn value for SE-carinata meal because it had the lowest NDF and ADF contents. It is also possible the observed low EE content in the SE-carinata relative to the 2 canola co-products used in this study contributed to its observed low energy retention and AMEn value.

In conclusion, the SID of AA for ECP-canola meal and the SID of most AA for SE-carinata meal were greater when compared to those for SE-canola meal. However, the results of this study show that energy retention and AMEn values were greater only for ECP-canola meal relative to SE-canola meal. Thus, the results indicate that ECP-canola meal may be a better source of AA and energy for broiler than SE-canola meal. The results also indicate that the SE-carinata meal used in this study could be an attractive alternative dietary AA source and could benefit from Lys fortification when used for broiler diets due to its low SID lysine value. Also, the SID of AA and AMEn values of ECP-canola meal and SE-carinata meal fed in the current study could be used when formulating broiler chicken diets.

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DISCLOSURES

The authors declare no conflicts of interest

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