Digestibility of amino acid in full-fat canola seeds, canola meal, and canola expellers fed to broiler chickens and pigs[1]

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ABSTRACT: Canola products including full-fat canola seeds (**FFCS**), canola meal (**CM**), and canola expellers (**CE**) have been used in diets for both broiler chickens and pigs. However, their ability to utilize the AA in canola products might be different from each other. Therefore, this study was conducted to compare the apparent ileal digestibility (**AID**) and standardized ileal digestibility (**SID**) of CP and AA in broiler chickens and growing pigs fed FFCS, CM, and CE. Three diets were prepared to contain FFCS, CM, or CE as a sole source of nitrogen. A nitrogen-free diet was prepared. In Exp. 1, a total of 272 twenty-one-day-old male broiler chickens with an initial BW of 932 ± 80.6 g were assigned to diets in a randomized complete block design with BW as a blocking factor. After 5 d of feeding, birds were euthanized by sodium pentobarbital, and ileal digesta samples were collected from distal two-third of the ileum. In Exp. 2, 16 barrows were surgically fitted with T-cannulas at the distal ileum. After 8-d recovery period, pigs (initial BW = 18.9 ± 1.17 kg) were divided into 4 blocks based on BW and assigned to a quadruplicate 4 × 2 incomplete Latin Square design with 4 diets and 2 periods. Each period consisted of 5-d adaptation and 2-d ileal digesta collection periods. Data were analyzed as a 2 × 3 factorial treatment arrangement with effects of species (broiler chickens or pigs) and diets (FFCS, CM, or CE). There were interactions ($P < 0.05$) between species and experimental diets in the AID of all indispensable AA except for Lys. The AID of indispensable AA in FFCS for broiler chickens was greater ($P < 0.05$) than for pigs. Broiler chickens also had greater ($P < 0.05$) AID of Arg, His, Leu, Phe, and Val in CM compared with pigs; however, there were no differences in the AID of indispensable AA in CE between broiler chickens and pigs. The basal ileal endogenous losses of CP and AA, except Trp, in pigs were greater ($P < 0.05$) than in broiler chickens. There were also interactions ($P < 0.05$) between species and experimental diets in the SID of all indispensable AA except for Lys. Broiler chickens fed the diet containing FFCS had greater ($P < 0.05$) SID of indispensable AA compared with pigs fed the same diet; however, the SID of indispensable AA in CM or CE were not different between broiler chickens and pigs. In conclusion, differences in digestibility of AA in canola products were affected by nonruminant animal species.

Key words: amino acid, canola meal, digestibility, full-fat canola seeds, poultry, swine

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INTRODUCTION

Commercial diets for both broiler chickens and pigs have been formulated with similar feed ingredients due to ingredient commonality and similarity of gastrointestinal tract and digestive physiology. Moreover, experimental procedures to evaluate the digestibility of AA in feed ingredients are similar (Kong and Adeola, 2014). Differences in the digestion process, especially in the foregut, may affect the utilization of AA even though both broiler chickens and pigs have similar digestive physiology. In addition, physiochemical properties of feed ingredients may differently act on the utilization of AA in broiler chickens and pigs. Park et al. (2017) reported that the standardized ileal digestibility (**SID**) of most AA in full-fat soybean, hulled soybean meal (**SBM**), dehulled SBM, and peanut flour for pigs were greater than for broiler chickens but both species had differences in the SID of AA among test ingredients that were consistent between the species. However, it is unclear if the SID of AA for pigs is greater than that for broiler chickens in other feed ingredients and if the SID of AA in other feed ingredients shows similar pattern of differences within species.

Canola meal (**CM**), which is the coproduct of solvent extraction of oil from full-fat canola seeds (**FFCS**), has been widely used in diets for both broiler chickens and pigs as a protein supplement, whereas canola expellers (**CE**) is the coproduct from double pressing using expeller for oil extraction from FFCS (Canola Council of Canada, 2015). In addition, FFCS has also been considered as an alternative feed ingredient for both broiler chickens and pigs due to its high energy and CP contents (Woyengo et al., 2014; Barekatain et al., 2015). However, digestibility of CP and AA in canola products may be influenced by processing procedure. Studies have been conducted to compare the digestibility of AA in canola products for broiler chickens (Woyengo et al., 2010; Adewole et al., 2017b) and for pigs (Maison and Stein, 2014; Adewole et al., 2017a). However, most of previous studies have been used canola products originating from different crushing plants with a variety of canola seeds from different locations, but not from solvent or expeller extracted of the same canola seeds. Furthermore, the magnitude of influences from processing of canola products on digestibility of AA may be different between broiler chickens and pigs. Therefore, this study was conducted to test the hypothesis that the apparent ileal digestibility (**AID**) and SID of CP and AA in FFCS, CM, and CE, derived from solvent or expeller extracted of the same canola seeds, are not affected by canola seed processing in broiler chickens and pigs.

MATERIALS AND METHODS

Experimental procedures using broiler chickens and pigs were reviewed and approved by the Purdue University Animal Care and Use Committee.

Ingredients and Experimental Diets

Full-fat canola seeds, CM, and CE originated from the same batch of canola seeds from University of Alberta (Edmonton, Alberta, Canada; Table 1). One batch of canola seeds was divided into 3 sub-batches. One sub-batch was used without oil removal as FFCS, one sub-batch had oil removed via expelling followed by solvent extraction to produce CM, and the last sub-batch had oil removed via expelling to produce CE. The FFCS was finely ground (<0.75 mm) with dry ice using a centrifugal grinder (ZM 200; Retsch GmbH, Haan, Germany) before making the experimental diets. Three experimental diets containing FFCS, CM, or CE as a sole source of nitrogen (**N**) were prepared for both broiler chickens and pigs (Table 2). These diets were formulated to contain the same concentration of CP (N × 6.25) at 160 g/kg. Sucrose and cornstarch were added as energy sources. Soybean oil was added in the diet containing CM but not in the other diets due to the high concentration of acid-hydrolyzed ether extract (**AEE**) in FFCS and CE. An N-free diet (**NFD**) was also prepared to determine the basal ileal endogenous losses (**BEL**) of CP and AA for broiler chickens and pigs. All diets were prepared to meet or exceed the estimated vitamin and mineral requirements for both broiler chickens and pigs in National Research Council (NRC, 1994, 2012). Chromic oxide at 5 g/kg was added in all diets as an indigestible marker.

Experiment 1: Digestibility of CP and AA for Broiler Chickens

Two-hundred and seventy-two male broiler chickens (Cobb 500; Cobb-Vantress Inc., Siloam Springs, AR) with a mean BW of 42.5 g at day 0 post-hatching were obtained from a commercial hatchery. Birds were tagged and housed in electrically heated battery brooders (model SB 4 T; Alternative Design Manufacturing, Siloam Springs,

Table 1. Analyzed nutrient composition of full-fat canola seeds (FFCS), canola meal (CM), and canola expellers (CE), g/kg as-fed basis

	Ingredient		
Item	FFCS	CM	CE
DM	949	905	926
GE, kcal/kg	6,378	4,415	5,141
CP (nitrogen × 6.25)	248	436	365
Acid-hydrolyzed ether extract	339	24	166
Crude fiber	73.3	104.0	88.1
Ash	39.4	63.5	53.1
NDF	194	213	179
ADF	155	180	150
Indispensable AA			
Arg	14.6	25.0	21.0
His	6.4	11.0	9.2
Ile	10.0	16.7	14.1
Leu	17.0	28.9	24.3
Lys	14.0	24.3	20.6
Met	4.8	7.9	6.7
Phe	10.0	16.8	14.2
Thr	9.9	16.9	14.3
Trp	2.7	4.9	4.0
Val	12.3	21.3	18.3
Dispensable AA			
Ala	10.4	18.4	15.3
Asp	17.1	28.2	23.9
Cys	5.8	10.2	8.6
Glu	40.3	72.0	59.5
Gly	12.0	20.3	17.0
Pro	9.2	15.8	13.5
Ser	12.9	23.4	18.6
Tyr	6.7	10.9	9.5

AR) with temperature at 35°C from days 0 to 7, at 31°C from days 7 to 14, and at 27°C from days 14 to 25. Before the experimental period, birds were fed a corn–SBM-based standard starter diet (210 g CP/kg) for 20 d. On day 21, individual BW of birds were obtained (mean initial BW = 932 ± 80.6 g), and then birds were allotted to 4 dietary treatments in a randomized complete block design with BW as a blocking factor using a spreadsheet program (Kim and Lindemann, 2007). Eight replicate cages were assigned to each diet with 8 birds per cage except for the NFD treatment, which had 10 birds per cage. Birds had ad libitum access to feed and water during the experimental period. After feeding experimental diets for 5 d, birds were euthanized by the injection of sodium pentobarbital (156 mg/kg BW; Fatal-Plus; Vortech Pharmaceuticals, Ltd., Dearborn, MI). Collection of ileal digesta and sample processing were as previously described by Park et al. (2017).

Experiment 2: Digestibility of CP and AA for Pigs

Sixteen barrows were surgically fitted with T-cannulas at the distal ileum by following the procedure by Dilger et al. (2004). Pigs were moved into individual metabolism crates (1.22 × 1.22 m) equipped with a feeder and a nipple drinker and received a corn–SBM-based standard grower diet (194 g CP/kg) for 8 d of recovery period. After the recovery period, pigs with an initial BW of 18.9 ± 1.17 kg were divided into 4 blocks based on BW and allotted to a quadruplicate 4 × 2 incomplete Latin Square design with 4 experimental diets and 2 periods using a spreadsheet program (Kim and Kim, 2010).

Feeding, collection of ileal digesta, and sample processing were conducted by following the procedures described by Park et al. (2017).

Chemical Analysis

Ileal digesta samples from broiler chickens and pigs were freeze-dried before further analyses. Test ingredients, experimental diets, and ileal digesta samples were finely ground (<0.75 mm) using a centrifugal grinder and analyzed for DM by drying at 105°C for 24 h in a forced-air drying oven [Precision Scientific Co., Chicago, IL; method 934.01; Association of Official Analytical Chemists (AOAC), 2006]. Nitrogen concentrations in test ingredients, experimental diets, and ileal digesta samples were analyzed by combustion method (TruMac N; LECO Corp., St. Joseph, MI; method 990.03; AOAC, 2000), and the CP concentration was obtained by multiplying the N concentration by 6.25. The concentrations of AA in test ingredients, experimental diets, and ileal digesta samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO). Briefly, test ingredients, diets, and ileal digesta samples were hydrolyzed in 6 M HCl (or BaOH for the analysis of Trp) at 110°C for 24 h under N atmosphere. For Met and Cys analyses, samples were oxidized by performic acid before acid hydrolysis. Hydrolyzed samples were analyzed for AA concentration by high-performance liquid chromatography after postcolumn derivatization [method 982.30 E (a, b, c); AOAC, 2006]. Test ingredients were analyzed for GE using an isoperibol bomb calorimeter (model 6200; Parr Instrument Co., Moline, IL) and ash (method 942.05; AOAC, 2006). The concentration of AEE (method 954.02; AOAC, 2006) was analyzed at the University of Missouri Agricultural Experiment

Table 2. Ingredient composition of experimental diets, g/kg as-fed basis

	Diet[1]			
Item	FFCS	CM	CE	NFD
Sucrose	121.0	390.5	350.0	500.0
Cornstarch	100.0	100.0	100.0	316.0
Full-fat canola seeds	720.0	0.0	0.0	0.0
Canola meal	0.0	421.0	0.0	0.0
Canola expellers	0.0	0.0	494.0	0.0
Soybean oil	0.0	30.0	0.0	50.0
Cellulose[2]	0.0	0.0	0.0	50.0
Ground limestone	10.0	8.5	8.0	13.0
Monocalcium phosphate	15.0	16.0	14.0	23.5
Salt	4.0	4.0	4.0	0.0
Potassium carbonate	0.0	0.0	0.0	2.6
Magnesium oxide	0.0	0.0	0.0	2.0
Sodium bicarbonate	0.0	0.0	0.0	7.5
Choline chloride	0.0	0.0	0.0	2.5
Potassium chloride	0.0	0.0	0.0	2.9
Vitamin–mineral premix[3]	5.0	5.0	5.0	5.0
Chromic oxide premix[4]	25.0	25.0	25.0	25.0
Total	1,000	1,000	1,000	1,000

[1]FFCS = full-fat canola seeds; CM = canola meal; CE = canola expellers; NFD = nitrogen-free diet.

[2]Solka-Floc 40 FCC, International Fiber Corporation, North Tonawanda, NY.

[3]Provided the following quantities per kilogram of complete diet: vitamin A, 8,575 IU; vitamin D_3, 4,300 IU; vitamin E, 28.6 IU; menadione, 7.30 mg; riboflavin, 9.15 mg; $_D$-pantothenic acid, 18.3 mg; niacin, 73.5 mg; choline chloride, 1,285 mg; vitamin B_{12}, 0.02 mg; biotin, 0.09 mg; thiamine mononitrate, 3.67 mg; folic acid, 1.65 mg; pyridoxine hydrochloride, 5.50 mg; I, 1.85 mg; Mn, 180 mg; Cu, 7.40 mg; Fe, 73.5 mg; Zn, 180 mg; Se, 0.43 mg.

[4]Provided 5 g chromic oxide per kilogram of complete diet.

Station Chemical Laboratories. Test ingredients were also analyzed for crude fiber (method 978.10; AOAC, 2006), NDF (Van Soest et al., 1991), and ADF [method 973.18 (AD); AOAC, 2006] using a fiber analyzer (Ankom 2000 Fiber Analyzer, Ankom Technology, Macedon, NY) after extraction of fat for 12 h in the analyses of NDF and ADF and for 24 h in the analysis of crude fiber. Experimental diets and ileal digesta samples were analyzed for the concentrations of Cr using a spectrophotometer (Spark 10M; Tecan Group Ltd., Männedorf, Switzerland) at 450 nm of absorption after wet digestion in nitric acid and 70% perchloric acid (Fenton and Fenton, 1979).

Calculations and Statistical Analysis

Calculations for the AID and SID of CP and AA as well as the BEL of CP and AA for broiler chickens and pigs were as previously described by Park et al. (2017).

Data from Exp. 1 and 2 were pooled and considered a 2 × 3 factorial arrangement with effects of species (broiler chickens or pigs) and experimental diets (FFCS, CM, or CE). Before statistical analysis, outlier was tested using 2.5 times interquartile range, and one pig fed NFD in period 1 of Exp. 2 was removed as outlier. Data were analyzed by ANOVA using general linear model procedure of SAS (SAS Inst. Inc., Cary, NC). Independent variables in the model were species, experimental diets, interaction between species and experimental diets, and block within species. To match the blocking factors of Exp. 2 with Exp. 1, the components of Latin square design were rearranged. The experimental design of Exp. 2 was a quadruplicate 4 × 2 incomplete Latin Square design with 4 blocks of BW (i.e., 4 pigs per block), 4 columns of 4 pigs on 4 diets in each of 4 blocks, and 2 periods in each of 4 blocks. The 4 columns of 4 pigs on 4 diets were merged into diets to remove column effects from the statistical model, and 2 periods were multiplied with 4 blocks to generate 8 blocks. With this, the effects of the 4 blocks in each of the 2 periods are unrelated. Block effects in Exp. 2 were consistent with those in Exp. 1, but were considered separately in the model (i.e., block nested within species as independent variable). Least squares means were separated by pairwise comparison with the Tukey's adjustment if there was an interaction. Data for the BEL of CP and AA were analyzed by 2-sample, 2-tailed *t* tests to compare values between broiler chickens and pigs. In all statistical analyses, the experimental unit was cage for Exp. 1 and pig for Exp. 2, and the significance was determined at $P < 0.05$.

RESULTS

In Exp. 1, one bird receiving the diet containing FFCS was removed from the experiment because of abnormal health condition. All other birds were in good condition during the experimental period. In Exp. 2, all pigs were in good condition during the experimental period.

Chemical Analysis

The analyzed concentration of CP in test ingredients ranged from 248 g/kg in FFCS to 436 g/kg in CM on an as-fed basis (Table 1). The AEE concentration in FFCS was 339 g/kg as-fed basis, but it was 24 g/kg as-fed basis in CM. The analyzed concentrations of CP and AA in experimental diets were close to the values calculated by the analyzed concentration of CP and AA in test ingredients (Table 3).

Table 3. Analyzed concentration of DM, CP, and AA in experimental diets, g/kg as-fed basis

	Diet[1]			
Item	FFCS	CM	CE	NFD
DM	949	951	953	960
CP (nitrogen × 6.25)	178	171	179	6.43
Indispensable AA				
Arg	10.4	10.1	10.2	0.0
His	4.6	4.5	4.6	0.0
Ile	7.1	7.0	7.1	0.1
Leu	12.2	12.0	12.2	0.2
Lys	10.1	10.1	10.3	0.1
Met	3.2	3.1	3.2	0.0
Phe	7.0	7.0	7.1	0.1
Thr	7.0	7.0	7.0	0.0
Trp	2.8	2.2	2.1	0.0
Val	8.9	8.8	8.8	0.1
Dispensable AA				
Ala	7.6	7.6	7.7	0.1
Asp	12.3	11.7	11.9	0.2
Cys	4.1	4.2	4.2	0.0
Glu	31.2	30.1	30.1	0.2
Gly	8.6	8.4	8.5	0.1
Pro	6.7	6.6	6.5	0.1
Ser	9.0	9.4	9.8	0.0
Tyr	4.5	4.2	4.4	0.1

[1]FFCS = full-fat canola seeds; CM = canola meal; CE = canola expellers; NFD = nitrogen-free diet.

Apparent Ileal Digestibility of CP and AA

There were interactions ($P < 0.05$) between experimental diets and species in the AID of AA except Lys, Gly, Pro, and Ser (Table 4). The AID of indispensable AA in FFCS for broiler chickens were greater ($P < 0.05$) than for pigs. Broiler chickens also had greater ($P < 0.05$) AID of Arg, His, Leu, Phe, and Val in CM compared with pigs; however, there were no differences in AID of indispensable AA in CE between broiler chickens and pigs. The AID of CP and Lys for broiler chickens was greater ($P < 0.001$) than for pigs regardless of the experimental diets. Broiler chickens fed FFCS or CM had greater ($P < 0.05$) AID of Ala, Asp, Glu, and Tyr compared with pigs. The AID of Ala in CE for broiler chickens was greater ($P < 0.05$) than for pigs. The AID of Gly, Pro, and Ser for broiler chickens were greater ($P < 0.001$) than for pigs regardless of the experimental diets.

Standardized Ileal Digestibility of CP and AA

The BEL of CP and AA, except Trp, in pigs were greater ($P < 0.05$) than in broiler chickens (Table 5). The BEL of indispensable AA ranged from 44 mg/kg DMI for Trp to 446 mg/kg DMI for Thr in broiler chickens and from 58 mg/kg DMI for Trp to 703 mg/kg DMI for Leu in pigs.

Similar to the results for AID values, interactions ($P < 0.05$) between experimental diets and species were observed for the SID of AA except Lys, Gly, Pro, and Ser (Table 6). Broiler chickens fed the diet containing FFCS had greater ($P < 0.05$) SID of indispensable AA compared with pigs fed the same diet; however, the SID of indispensable AA in CM or CE were not different between broiler chickens and pigs. Within broiler chickens, the SID of all indispensable AA, except Trp, was not different from values calculated for CM and CE. However, within pigs, the SID of all indispensable AA, except Trp, in FFCS was less ($P < 0.05$) than in CE, but the SID of all indispensable AA, except Met, in FFCS was not different from values obtained for CM. The SID of CP and Lys for broiler chickens was greater ($P < 0.001$) than for pigs regardless of experimental diet. The SID of Ala, Asp, Cys, Glu, and Tyr in FFCS fed to broiler chickens was greater ($P < 0.05$) than for pigs; however, values in CM or CE for broiler chickens were not different from pigs.

DISCUSSION

The analyzed concentration of CP in FFCS was similar to values reported by González-Vega and Stein (2012) and NRC (2012) but was greater than values in other reports (Sauvant et al., 2004; Seneviratne et al., 2011; Barekatain et al., 2015; Eklund et al., 2015). In addition, the analyzed concentration of CP in CM was also greater than values by Sauvant et al. (2004), NRC (2012), Maison and Stein (2014), and Adewole et al. (2016, 2017a). These differences may be due to the low concentration of AEE in the FFCS used in this experiment. The analyzed AEE concentration in FFCS was less than previously reported values (González-Vega and Stein, 2012; NRC, 2012; Barekatain et al., 2015). Barthet and Daun (2011) reported that the general oil content in canola seeds is usually greater than 440 g/kg and there is a negative correlation between protein and oil contents in canola seeds, which agreed with the high CP and low AEE concentrations in FFCS used in this study. Therefore, the CP in FFCS might be concentrated when producing CM, which led to increased CP concentration in CM used in this study. This is also in accordance with the low concentration of AEE in CM compared with values reported by Maison and Stein (2014). However, the concentration of CP in CE was within the range of values in previous studies (NRC, 2012; Maison

Table 4. Apparent ileal digestibility (%) of CP and AA in full-fat canola seeds (FFCS), canola meal (CM), and canola expellers (CE) for broiler chickens and pigs[1]

	Broiler chickens			Pigs				*P*-value		
Item	FFCS	CM	CE	FFCS	CM	CE	SD	Diet	Species	Diet × species
CP	75.9	73.3	75.1	65.7	66.4	71.0	3.46	0.037	<0.001	0.055
Indispensable AA										
Arg	87.3^{a}	85.5^{a}	86.5^{a}	78.7^{c}	80.0^{bc}	83.4^{ab}	2.85	0.077	<0.001	0.035
His	85.5^{a}	82.9^{a}	84.3^{a}	76.8^{c}	78.8^{bc}	82.0^{ab}	2.66	0.043	<0.001	0.006
Ile	78.3^{a}	75.8^{ab}	76.6^{a}	68.5^{c}	70.8^{bc}	75.2^{ab}	3.40	0.062	<0.001	0.006
Leu	81.9^{a}	79.4^{a}	80.3^{a}	71.0^{c}	72.8^{bc}	77.6^{ab}	3.37	0.051	<0.001	0.007
Lys	82.0	79.6	80.8	70.5	72.2	74.6	3.24	0.278	<0.001	0.064
Met	86.2^{a}	85.0^{ab}	85.9^{a}	78.1^{c}	81.9^{b}	84.6^{ab}	2.32	0.003	<0.001	<0.001
Phe	81.0^{a}	79.7^{a}	80.4^{a}	69.9^{c}	73.1^{bc}	77.4^{ab}	3.38	0.021	<0.001	0.008
Thr	72.4^{a}	69.3^{ab}	70.7^{ab}	62.8^{c}	64.5^{bc}	69.5^{ab}	4.14	0.095	<0.001	0.026
Trp	94.9^{a}	85.5^{b}	87.9^{b}	88.0^{b}	83.9^{b}	86.7^{b}	2.94	<0.001	<0.001	0.018
Val	75.1^{a}	72.6^{a}	73.1^{a}	64.4^{c}	66.2^{bc}	71.3^{ab}	3.93	0.105	<0.001	0.013
Dispensable AA										
Ala	81.4^{a}	79.2^{ab}	79.9^{a}	69.4^{d}	71.9^{cd}	75.2^{bc}	2.91	0.083	<0.001	0.004
Asp	79.0^{a}	76.1^{ab}	77.5^{ab}	67.2^{c}	68.1^{c}	72.5^{bc}	3.74	0.098	<0.001	0.048
Cys	80.0^{a}	74.8^{bc}	76.2^{ab}	70.9^{c}	70.9^{c}	74.3^{bc}	3.38	0.071	<0.001	0.016
Glu	88.4^{a}	86.9^{ab}	87.7^{ab}	81.6^{d}	82.6^{cd}	84.9^{bc}	2.09	0.093	<0.001	0.035
Gly	80.1	75.9	77.5	64.7	63.9	66.8	4.07	0.175	<0.001	0.251
Pro	77.4	75.0	75.6	67.3	67.5	71.5	3.49	0.215	<0.001	0.069
Ser	77.5	74.0	77.1	64.1	65.5	68.4	5.15	0.268	<0.001	0.329
Tyr	79.1^{a}	75.5^{a}	77.0^{a}	68.3^{c}	70.0^{bc}	75.0^{ab}	3.30	0.029	<0.001	0.003

[a–d]Means within a row with different superscripts differ ($P < 0.05$).

[1]Each least squares mean represents 8 observations.

Table 5. Basal ileal endogenous losses of CP and AA for broiler chickens and pigs, mg/kg DMI[1]

Item	Broiler chickens	Pigs	SED	*P*-value
CP, g/kg DMI	8.00	17.32	0.957	<0.001
Indispensable AA				
Arg	206	497	35.7	<0.001
His	105	238	16.2	<0.001
Ile	239	378	24.5	<0.001
Leu	374	703	46.3	<0.001
Lys	275	483	35.2	<0.001
Met	62	86	7.9	0.010
Phe	237	427	26.6	<0.001
Thr	446	686	45.6	<0.001
Trp	44	58	17.2	0.427
Val	394	621	48.3	<0.001
Dispensable AA				
Ala	255	551	36.7	<0.001
Asp	487	958	69.0	<0.001
Cys	155	293	22.5	<0.001
Glu	580	1,164	85.3	<0.001
Gly	289	1,240	74.1	<0.001
Pro	318	609	60.0	0.003
Ser	302	1,934	306.8	0.003
Tyr	180	280	17.1	<0.001

[1]Each mean represents 8 observations for broiler chickens and 7 observations for pigs.

and Stein, 2014; Woyengo et al., 2016). This may be due to the greater concentration of AEE in CE that remains after oil extraction. The analyzed concentration of AEE in CE was greater than the range of values reported by Maison and Stein (2014).

Although the low concentration of AEE in FFCS used in this experiment is partly explained by the greater concentration of CP in both FFCS and CM, it was considerably less than the standard value at minimum 440 g/kg suggested in Barthet and Daun (2011). This may be due to the loss of oil during grinding. The concentration of NDF and ADF in FFCS were in agreement with values in previous studies (Sauvant et al., 2004; González-Vega and Stein, 2012; NRC, 2012; Barekatain et al., 2015). However, the concentrations of NDF and ADF in CM were less than previously reported values (Sauvant et al., 2004; NRC, 2012; Li et al., 2015; Adewole et al., 2017a), and the concentrations of NDF and ADF in CE were also less than values reported by NRC (2012) and Woyengo et al. (2016). This may be due to the differences in oil extraction process among studies. It may be speculated that there was a loss of cell wall components during the oil extraction process for CM and CE used in the

Table 6. Standardized ileal digestibility (%) of CP and AA in full-fat canola seeds (FFCS), canola meal (CM), and canola expellers (CE) for broiler chickens and pigs[1]

	Broiler chickens			Pigs				*P*-value		
Item	FFCS	CM	CE	FFCS	CM	CE	SD	Diet	Species	Diet × species
CP	80.2	77.7	79.4	74.9	76.0	80.3	3.46	0.055	0.050	0.054
Indispensable AA										
Arg	89.2^{a}	87.5^{abc}	88.4^{ab}	83.2^{c}	84.7^{bc}	88.0^{ab}	2.85	0.074	<0.001	0.032
His	87.7^{a}	85.2^{ab}	86.5^{a}	81.7^{b}	83.8^{ab}	86.9^{a}	2.66	0.048	0.006	0.006
Ile	81.5^{a}	79.0^{ab}	79.8^{ab}	73.5^{c}	75.9^{bc}	80.3^{ab}	3.40	0.065	0.001	0.006
Leu	84.8^{a}	82.4^{ab}	83.2^{ab}	76.5^{c}	78.4^{bc}	83.1^{ab}	3.37	0.055	<0.001	0.007
Lys	84.6	82.2	83.3	75.0	76.8	79.1	3.24	0.304	<0.001	0.065
Met	88.0^{a}	86.9^{a}	87.8^{a}	80.7^{b}	84.5^{a}	87.2^{a}	2.32	0.003	0.001	<0.001
Phe	84.2^{a}	82.9^{ab}	83.6^{ab}	75.7^{c}	78.9^{bc}	83.1^{ab}	3.38	0.023	<0.001	0.008
Thr	78.5^{a}	75.3^{ab}	76.7^{ab}	72.1^{b}	73.9^{ab}	78.8^{a}	4.14	0.093	0.119	0.026
Trp	96.4^{a}	87.4^{b}	89.9^{b}	89.9^{b}	86.4^{b}	89.3^{b}	2.94	<0.001	0.004	0.015
Val	79.3^{a}	76.8^{abc}	77.4^{ab}	71.1^{c}	72.9^{bc}	78.0^{ab}	3.93	0.099	0.002	0.013
Dispensable AA										
Ala	84.6^{a}	82.4^{ab}	83.0^{ab}	76.2^{c}	78.8^{bc}	82.1^{ab}	2.91	0.093	<0.001	0.005
Asp	82.8^{a}	80.1^{abc}	81.4^{ab}	74.5^{c}	75.8^{bc}	80.2^{abc}	3.74	0.100	<0.001	0.043
Cys	83.6^{a}	78.3^{b}	79.8^{ab}	77.7^{b}	77.6^{b}	80.9^{ab}	3.38	0.062	0.067	0.017
Glu	90.2^{a}	88.7^{ab}	89.5^{a}	85.1^{c}	86.3^{bc}	88.6^{ab}	2.09	0.081	<0.001	0.031
Gly	83.3	79.1	80.7	78.4	78.0	80.7	4.07	0.218	0.095	0.222
Pro	81.9	79.6	80.2	75.9	76.3	80.4	3.49	0.182	0.005	0.062
Ser	80.7	77.1	80.1	84.5	85.1	87.2	5.15	0.392	<0.001	0.483
Tyr	82.9^{a}	79.6^{ab}	80.9^{ab}	74.2^{c}	76.4^{bc}	81.0^{ab}	3.30	0.038	<0.001	0.003

[a–c]Means within a row with different superscripts differ ($P < 0.05$).

[1]Each least squares mean represents 8 observations.

current study, which may also explain the fact that the concentration of NDF and ADF in FFCS was similar to values in CE.

The BEL of CP and AA, except Trp, in pigs were greater than in broiler chickens, which is not consistent with the results reported in Park et al. (2017). However, the BEL of CP and AA agreed with the values reported in previous studies for broiler chickens (Kong and Adeola, 2013; Toghyani et al., 2015; Park et al., 2017) and for pigs (Park et al., 2013; Maison and Stein, 2014; Wang et al., 2018). The reason for the greater BEL of CP and AA in pigs compared with broiler chickens may be due to the shorter absolute length of small intestine in broiler chickens compared with pigs. Although the length of small intestine relative to BW in broiler chickens is longer than in pigs (Park et al., 2017), pigs have greater physical area to lose the intestinal cells compared with broiler chickens. Nyachoti et al. (1997) reported that majority of the BEL of N in pigs is contributed from tissues of the small intestine. Therefore, the BEL of CP and AA in broiler chickens may contain less sloughed cells or mucin proteins compared with pigs.

Interactions between experimental diets and species were observed in both AID and SID of AA except Lys, Gly, Pro, and Ser. These observations were mainly due to the greater digestibility of AA in FFCS for broiler chickens compared with pigs. However, Park et al. (2017) reported that there were no interactions for digestibility of CP and most AA between broiler chickens and pigs fed semi-purified diets containing full-fat soybean, SBM, and peanut flour and that the digestibility of CP and AA for pigs was greater than for broiler chickens. The reason for this discrepancy remains unclear; however, it may be due to the altered digestive functions in foregut of broiler chickens from increased intake of dietary fiber from FFCS. Birds fed diets containing 30 g/kg sugar beet pulp or oat hulls as a source of soluble or insoluble fiber, respectively, had increased weight of gizzard relative to BW and decreased pH of the digesta in proventriculus and gizzard compared with birds fed the control diet and the diet containing 30 g/kg cellulose (Jiménez-Moreno et al., 2009). Also, Jiménez-Moreno et al. (2010) found similar observations using finely ground (<0.2 mm) sugar beet pulp or oat hulls at 30 g/kg of the diet. It is unclear whether fiber components and structure in FFCS have a beneficial effect on gizzard similar to sugar beet pulp or oat hulls and whether this beneficial effect appears after short-term feeding (i.e., 5 d) of the diet containing FFCS. However, it may be speculated that the digestive function of gizzard improved the digestibility of AA in FFCS, which is not applicable to pigs due to the absence of gizzard. On the other hand, increased intake of fiber in pigs fed the diet containing FFSC might reduce digestibility of AA. Fan et al. (1996) reported negative correlations between the concentration of NDF and the AID of CP and AA, except Arg, in pigs fed diets containing 6 CM originating from different processing plants. Compared with the results reported in Park et al. (2017) where all the experimental diets were prepared as semi-purified diets based on dextrose, the diet containing FFCS used in the current experiment was prepared to contain 720 g/kg FFCS, which resulted in increased consumption of fiber to animals compared with other diets in the current experiment as well as the diets used by Park et al. (2017). Therefore, the effect of the concentration of fiber in the diet containing FFCS may have resulted in the interactions between species (broiler chickens or pigs) and diets (FFCS, CM, or CE). Further research is needed to verify the effects of fiber contents in canola products on traits of digestive organs in broiler chickens.

There were no differences in the AID and SID of CP and most AA among FFCS, CM, and CE fed to broiler chickens. The observation is in agreement with observations by Lee et al. (1995) who reported that the true digestibility of most AA in FFCS was not different from values for CM if measured using the force-fed rooster assay. Woyengo et al. (2010) also reported that the SID of CP and indispensable AA, except Thr, in CM were not different from those in CE. The SID of AA in full-fat rapeseed reported by Szczurek (2010) were less than the SID of AA in FFCS observed in the present study, which may be due to differences in variety of seeds. The SID of CP and indispensable AA in CM for broiler chickens obtained in this experiment were in agreement with reported values (Woyengo et al., 2010; Adewole et al., 2017b; Rad-Spice et al., 2018). The SID of CP and indispensable AA in CE obtained in this experiment were also comparable to values reported in previous studies (Woyengo et al., 2010; Bryan et al., 2017).

In pigs, however, the SID of most AA in FFCS were less than in CE, which were not different from CM. Similar with the possible reason for the interactions, it may be speculated that increased intake of fiber in pigs fed the diet containing FFCS negatively affected the digestibility of AA in FFCS. However, it remains unclear why the SID of CP and most AA in FFCS were not different from those in CM. González-Vega and Stein (2012) reported that the SID of CP, Arg, His, Lys, and Trp in FFCS were not different from those in CM, but the SID of the remaining indispensable AA in FFCS were less than in CM. This discrepancy may be due to the differences in sources of FFCS used in the studies. In addition, the differences for FFCS among studies may also be due to differences in grinding procedures. In the current experiment, the same batch of FFCS was used to produce CM; however, in González-Vega and Stein (2012), FFCS and CM were obtained from different plants. Moreover, the SID of CP and AA in FFCS observed in the current study were also greater than values reported in González-Vega and Stein (2012), which may also be due to the differences in sources of FFCS used in studies. The SID of AA, except Trp, in FFCS were in agreement with values reported by NRC (2012).

In the current experiment for pigs, the SID of CP and AA in CM were not different from those in CE. However, Maison and Stein (2014) reported that the mean values for the SID of CP and most AA in 10 samples of 00-rapeseed meal were less than mean value for 5 samples of 00-rapeseed expellers. Woyengo et al. (2016) also reported that the SID of CP and most AA in CM were less than in CE in which both CM and CE originated from the same genus but different plants. Maison and Stein (2014) and Woyengo et al. (2016) suggested that lower SID of AA in CM than CE might be due to the heat damage of CM during desolventizing process. Therefore, it may be speculated that CM used in the current experiment were not damaged by heat during oil extraction process. Thus, the oil extraction process did not affect the SID of CP and AA in canola coproducts that originated from the same batch of FFCS used in the present study. In addition, soybean oil was added to the diet containing CM, but not in the diet containing FFCS and CE to prevent the potential effect of the dietary concentration of oil on digestibility of CP and AA in the current experiment. The SID of indispensable AA in CM observed in the current experiment were within the range of the previously reported values (NRC, 2012; Maison and Stein, 2014; Li et al., 2015; Woyengo et al., 2016; Adewole et al., 2017a). The SID of indispensable AA in CE were also comparable with the values reported in the previous studies (NRC, 2012; Woyengo et al., 2016) and the values reported by Maison and Stein (2014) despite greater concentration of AEE. Kil and Stein (2011) reported that pigs fed diets containing

50 g/kg soybean oil or choice white grease had greater AID of Arg, Leu, and Val than pigs fed control diet possibly due to the increased retention time of digesta in gastrointestinal tract due to fat addition. However, the concentration of AEE in CE used in the present study was 44% greater than mean value (115.2 g/kg) of 5 CE used by Maison and Stein (2014). Therefore, it may be concluded that the greater concentration of AEE in CE used in the present study was not enough to increase the digestibility of AA in CE.

In conclusion, there were interactions between canola products and species. The SID of AA, except Lys, Gly, Pro, and Ser, in FFCS for broiler chickens was greater than for pigs. In broiler chickens, there were no differences in the SID of CP and indispensable AA, except Trp, among FFCS, CM, and CE. However, in pigs, the SID of all indispensable AA, except Lys and Trp, in FFCS was less than CE, but not different from those in CM.

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