Amino acid digestibility in camelina products fed to growing pigs

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Almeida, F. N., Htoo, J. K., Thomson, J. and Stein, H. H. 2013. **Amino acid digestibility in camelina products fed to growing pigs**. Can. J. Anim. Sci. **93**: 335–343. Camelina seed production has increased in North America because of demand for camelina oil for biofuel production. Camelina expellers (CE) is the co-product that remains after oil has been expelled, and CE usually contains approximately 35% crude protein (CP), 14% ether extract, 10% crude fiber, and 5% ash making it an attractive feedstuff for livestock. An experiment was conducted to determine the standardized ileal digestibility (SID) of CP and amino acids (AA) in two sources of camelina seeds [CS-1 and CS-2; average: 39% acid hydrolyzed ether extract (AEE), 28% CP, 27% neutral detergent fiber (NDF), 12% acid detergent fiber (ADF), 4% ash] and in three sources of CE (CE-1, CE-2, and CE-3; average: 35% CP, 24% NDF, 15% AEE, 14% ADF, 6% ash) and to compare the SID of CP and AA in camelina products with the SID of CP and AA in solvent-extracted canola meal fed to pigs. Seven growing pigs (initial BW 43.5 kg) were randomly allotted to a 7×7 Latin square design with seven diets fed to individually housed pigs over seven periods. Six of the diets contained CS, CE, or canola meal as the sole source of CP and AA and a N-free diet was used to determine basal endogenous losses of CP and AA. The SID of CP in CS-1 and CE-2 was less ($P < 0.01$) than the SID of CP in canola meal, but the SID of CP in CS-2, CE-1, and CE-3 was not different from the SID of CP in canola meal. The SID of Lys in CS-1 and CS-2 was less ($P < 0.01$) than in canola meal, but the SID of Lys was not different among CE-1, CE-2, CE-3, and canola meal. Results from this experiment indicate that the SID of AA in CE is mostly comparable with that of canola meal, but the digestibility of CP and AA in the two camelina seeds was somewhat less than in CE and canola meal. Camelina expellers may, therefore, be included in diets fed to pigs.

Key words: Smino acids, camelina, digestibility, pig

Almeida, F. N., Htoo, J. K., Thomson, J. et Stein, H. H. 2013. **La digestibilité des acides aminés des produits de caméline utilisés pour nourrir les porcs en croissance**. Can. J. Anim. Sci. **93**: 335–343. La production de graines de caméline a augmenté en Amérique du Nord en raison de la demande d'huile de caméline pour la production de biocombustibles. Le tourteau de presse de caméline (CE) est le co-produit qui reste après que l'huile ait été extraite. Le CE contient habituellement environ 35% de protéines brutes (CP), 14% d'extrait à l'éther, 10% de fibres brutes et 5% de cendres ce qui en fait un aliment prometteur pour le bétail. Une expérience a été menée pour déterminer la digestibilité iléale standardisée (SID) des CP et des acides aminés (AA) de deux sources de graines de caméline [CS-1 et CS-2; moyenne: 39% d'extrait à l'éther hydrolysé à l'acide (AEE), 28% CP, 27% de fibres de détergent neutre (NDF), 12% de fibres de détergent acide (ADF), 4% de cendres] et dans trois sources de CE (CE-1, CE-2, et CE-3; moyenne: 35% CP, 24% NDF, 15% AEE, 14% ADF, 6% cendres) et pour comparer la SID des CP et AA des produits de caméline avec la SID des CP et AA du tourteau de canola extrait au solvant et utilisé pour nourrir les porcs. Sept porcs en croissance (poids corporel initial 43.5 kg) ont été distribués au hasard dans un carré Latin de 7×7 avec chaque porc logé individuellement et nourri avec une des sept diètes durant les sept périodes. Six des diètes contenaient CS, CE ou le tourteau de canola comme seule source de CP et AA et une diète sans N a été utilisée pour déterminer les pertes endogènes de base des CP et AA. La SID des CP de CS-1 et CE-2 a été moindre ($P < 0{,}01$) que la SID des CP du tourteau de canola, mais la SID des CP de CS-2, CE-1, et CE-3 n'était pas différente de celle des CP du tourteau de canola. La SID de la Lys de CS-1 et CS-2 était moindre ($P < 0{,}01$) que celle du tourteau de canola, mais la SID de la Lys n'était pas différente entre CE-1, CE-2, CE-3 et le tourteau de canola. Les résultats de cette expérience indiquent que la SID des AA de CE est généralement comparable à celle du tourteau de canola, mais la digestibilité des CP et AA des deux graines de caméline était un peu moindre que dans le CE et le tourteau de canola. Les tourteaux de presse de caméline peuvent donc être inclus dans les diètes pour les porcs.

Mots clés: Acides aminés, caméline, digestibilité, porc

Abbreviations: **AA**, amino acid; **ADF**, acid detergent fiber; **AEE**, acid hydrolyzed ether extract; **AID**, apparent ileal digestibility; **BW**, body weight; **CE**, camelina expellers; **CP**, crude protein; **CS**, camelina seed; **NDF**, neutral detergent fiber; **SID**, standardized ileal digestibility

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Camelina sativa L. Crantz, a member of the *Brassica* family, is an oilseed that has been cultivated in Europe for many years. More recently, camelina production has increased in North America because of demand for the oil in camelina seeds for biofuel production (Murphy 2011). Camelina seeds contain approximately 40% oil, and 34 to 40% of total fatty acids are ω-3 fatty acids (Zubr 1997; Hurtaud and Peyraud 2007). Camelina expellers that are produced after the oil has been mechanically expelled from the seeds, usually contain approximately 35% crude protein (CP), 14% ether extract, 10% crude fiber, and 5% ash (Pekel et al. 2009). Camelina expellers also contain glucosinolates, which may negatively affect palatability and growth of broilers (Ryahänen et al. 2007). Research has been conducted to evaluate both camelina seeds and camelina expellers in diets fed to poultry (Rokka et al. 2002; Ryhänen et al. 2007; Pekel et al. 2009) and dairy cows (Hurtaud and Peyraud 2007). To our knowledge, no research has been conducted to evaluate the nutritional value of camelina seeds and camelina expellers fed to pigs.

Brassica napus seeds (canola), also a member of the Brassica family, is expeller-pressed and the oil solvent-extracted for human oil consumption, whereas the co-product meal is included in diets for pigs. No research, however, has been conducted to determine how the nutritional value of camelina seeds or co-products compares with that of canola co-products fed to growing pigs. Therefore, the objectives of this experiment were to determine the apparent ileal digestibility (AID) and the standardized ileal digestibility (SID) of CP and amino acids (AA) in two sources of camelina seeds and in three sources of camelina expellers fed to growing pigs, and to compare the SID of CP and AA in camelina products with the SID of CP and AA in solvent-extracted canola meal.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol (IACUC 10218) for this experiment. One variety of camelina seeds (CS-1) was obtained from Montana State University, Moccasin, MT, and the other variety (CS-2) was sourced from Sustainable Oils, Great Falls, MT (Tables 1 and 2). Camelina expellers were sourced from Penn State Cooperative Extension, Meadville, PA (CE-1); Willamette Biomass Processors, Rickreall, OR (CE-2); and from Sustainable Oils, Great Falls, MT (CE-3). Solvent-extracted canola meal was obtained from the University of Illinois Feed Mill, Champaign, IL.

Seven growing pigs (initial BW 43.5 ± 3.5 kg) had a T-cannula surgically implanted in the distal ileum (Stein et al. 1998) and were randomly allotted to a 7 × 7 Latin square design with seven diets fed to individual pigs over seven periods as described by Kim and Stein (2009). Pigs were the offspring of G-performer boars that were mated to F-25 females (Genetiporc, Alexandria, MN). Pigs were housed in individual pens (1.2 × 1.5 m) with slatted tri-bar floors and solid sided pen walls. Each pen was equipped with a nipple drinker and a feeder.

Two camelina seed diets, three camelina expeller diets, and one canola meal diet were formulated to contain 40% of the test ingredient as the sole source of CP and AA in the diet (Tables 3 and 4). A N-free diet was also formulated to measure the endogenous losses of CP and AA. All diets contained vitamins and minerals in concentrations that exceeded the requirements for growing pigs [National Research Council (NRC) 1998]. Chromic oxide (0.4%) was added to all diets as an indigestible marker.

Pigs were fed each day at 0800 at a rate of 2.5 times the estimated energy requirement for maintenance (i.e., 106 kcal metabolizable energy $kg^{-0.75}$ of BW; NRC 1998). Water was available at all times throughout the experiment.

Pigs were weighed at the beginning of each experimental period, which consisted of 5 d adaptation to diets followed by 2 d of ileal digesta collection. Ileal digesta collection was initiated at 0800 and ceased at 1600 on days 6 and 7. A 240-mL bottle liner was attached to the opened cannula barrel using an auto-locking cable tie (Stein et al. 1998). Bottle liners were removed at least once every 30 min or whenever they were filled with digesta, and stored at −20°C to prevent bacterial degradation of the AA in the digesta.

Digesta samples were mixed, lyophilized and finely ground to pass a 1-mm screen prior to chemical analysis. Diets and ileal samples were analyzed for chromium (method 990.08; AOAC International 2007), and diets, ingredients, and ileal samples were analyzed for AA by ion-exchange chromatography with postcolumn derivatization with ninhydrin. Cysteine and methionine were oxidized with performic acid, which was neutralized with Na metabisulfite (Llames and Fontaine 1994; Commission Directive 1998). Amino acids were liberated from the protein by hydrolysis with 6 N HCL for 24 h at 110°C and quantified with the internal standard by measuring the absorption of reaction products with ninhydrin at 570 nm. Tryptophan was determined by HPLC with fluorescence detection (extinction 280 nm, emission 356 nm), after alkaline hydrolysis with barium hydroxide octahydrate for 20 h at 110°C (Commission Directive 2000). Diets, ingredients, and ileal samples were also analyzed for dry matter (method 935.29; AOAC International 2007), and for N following the Dumas procedure (method 968.06; AOAC International 2007). Ingredients were analyzed for gross energy using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL), ash (method 942.05; AOAC International 2007), glucosinolates (method MGLUC-01, SunWest Food Laboratory Ltd, Saskatoon, SK), trypsin inhibitors (method Ba 12-75; American Oil Chemists Society 2006), ADF (method 973.18; AOAC International 2007), NDF (Holst 1973), Ca and P by inductively coupled plasma (ICP) spectroscopy (method 985.01; AOAC International 2007), and for total fat by acid hydrolysis using

Table 1. Analyzed nutrient composition of test ingredients (as-is basis)

	Ingredient[z]					
	Camelina seeds		Camelina expellers			
Item	CS-1	CS-2	CE-1	CE-2	CE-3	Canola meal
Gross energy (kcal kg^{-1})	6328	6344	4766	5054	5126	4242
Dry matter (%)	94.1	94.9	91.8	92.7	93.6	90.0
Crude protein (N × 6.25) (%)	26.6	29.2	35.2	31.5	32.7	36.4
Acid hydrolyzed ether extract (%)	39.2	39.5	11.3	18.6	17.5	3.7
Acid detergent fiber (%)	13.7	11.9	13.8	13.3	15.2	19.0
Neutral detergent fiber (%)	25.3	29.9	26.3	22.0	26.5	34.8
Ash (%)	4.0	3.3	5.8	6.5	5.4	7.7
Calcium (%)	0.3	0.2	0.5	0.4	0.4	0.7
Phosphorus (%)	0.7	0.6	1.0	0.8	0.9	1.0
Lys:crude protein ratio[y] (%)	4.6	4.4	4.7	5.0	4.1	5.3
Trypsin inhibitors (TIU mg^{-1})	10.8	13.4	18.4	14.6	5.8	<1.0
Indispensable AA (%)						
Arg	2.28	2.45	2.91	2.54	2.58	2.24
His	0.64	0.69	0.84	0.78	0.77	1.00
Ile	0.96	1.04	1.26	1.20	1.20	1.47
Leu	1.73	1.86	2.25	2.12	2.12	2.60
Lys	1.22	1.28	1.64	1.58	1.35	1.93
Met	0.47	0.49	0.63	0.53	0.57	0.74
Phe	1.10	1.20	1.43	1.39	1.35	1.49
Thr	1.04	1.12	1.40	1.28	1.30	1.59
Trp	0.35	0.36	0.43	0.43	0.38	0.50
Val	1.35	1.46	1.74	1.59	1.65	1.89
Dispensable AA (%)						
Ala	1.17	1.26	1.61	1.42	1.47	1.64
Asp	2.19	2.36	2.79	2.78	2.65	2.64
Cys	0.61	0.65	0.83	0.64	0.65	0.87
Glu	4.48	4.90	5.82	5.30	5.29	6.29
Gly	1.35	1.45	1.81	1.58	1.66	1.88
Pro	1.43	1.53	1.87	1.73	1.71	2.34
Ser	1.19	1.30	1.58	1.48	1.46	1.54

[z]CS-1 = Blaine Creek, obtained from Montana State University, Moccasin, MT; CS-2 = Sustainable Oils – 30, sourced from Sustainable Oils, Great Falls, MT; CE-1 = Pennsylvania, sourced from Penn State Cooperative Extension, Meadville, PA; CE-2 = Willamette, sourced from Willamette Biomass Processors, Rickreall, OR; CE-3 = Sustainable Oils, obtained from Sustainable Oils, Great Falls, MT. Canola meal was obtained from the University of Illinois, Urbana, IL.
[y]Calculated by expressing the concentration of Lys in each ingredient as a percentage of the concentration of CP (Stein et al. 2009).

3 N HCl (Sanderson 1986) followed by crude fat extraction with petroleum ether (method 2003.06; AOAC International 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN).

The AID of CP and AA in all diets were calculated using previously published equations (Stein et al. 2007). Camelina seeds, camelina expellers, and canola meal were the sole source of CP and AA in each diet, thus, the AID of CP and AA in each diet represented the AID of CP and AA in the ingredient that was included in that diet. The basal endogenous loss of CP and AA was determined from pigs fed the N-free diet. Values for the SID of CP and AA were calculated by correcting values for the AID of CP and AA for the basal endogenous losses of CP and AA (Stein et al. 2007).

The Proc Mixed procedure of SAS software (Version 9.1; SAS Institute, Inc. Carry, NC) was used to analyze all data. Diet was included in the model as a fixed effect while pig and period were included as random effects. The Univariate procedure was used to test for the presence of outliers. The LSMeans option was used to calculate mean values for each diet and the PDIFF option was used to separate means if they were different. Potential carryover effects were tested as described by Kuehl (1994). The pig was the experimental unit. An alpha level of 0.05 was used to consider significance among dietary treatments.

RESULTS

Pigs remained healthy throughout the experiment. No outliers were observed for any of the response criteria evaluated. The results for carryover effects were not significant.

The total concentration of glucosinolates in CS-1 and CS-2 was 28.4 and 32 μmol g^{-1}, respectively, whereas CE-1, CE-2, and CE-3 contained 42.3, 27.5, and 26.6 μmol g^{-1}, respectively (Table 2). The concentration of 10-methylsulfinyldecyl was 17.3 and

Table 2. Glucosinolate concentration in ingredients (as-fed basis)

	Ingredient[z]					
	Camelina seeds		Camelina expellers			
Item (μmol g^{-1})	CS-1	CS-2	CE-1	CE-2	CE-3	Canola meal
Total glucosinolates	28.4	32.0	42.3	27.5	26.6	1.55
Alkenyl	0.96	0.87	2.43	1.79	1.02	1.33
9-Methylsulfinylnonyl	6.47	6.57	10.4	6.91	5.49	–
10-Methylsulfinyldecyl	17.3	19.5	25.8	14.9	15.8	–
11-Methylsulfinylundecyl	3.39	4.83	3.23	3.63	4.06	–
Indol	0.26	0.28	0.43	0.28	0.30	0.13

[z]CS-1 = Blaine Creek, obtained from Montana State University, Moccasin, MT; CS-2 = Sustainable Oils – 30, sourced from Sustainable Oils, Great Falls, MT; CE-1 = Pennsylvania, sourced from Penn State Cooperative Extension, Meadville, PA; CE-2 = Willamette, sourced from Willamette Biomass Processors, Rickreall, OR; CE-3 = Sustainable Oils, obtained from Sustainable Oils, Great Falls, MT. Canola meal was obtained from the University of Illinois, Urbana, IL.

19.5 μmol g^{-1} in CS-1 and CS-2, respectively, but CE-1, CE-2, and CE-3 contained 25.8, 14.9, and 15.8 μmol g^{-1} of 10-methylsulfinyldecyl, respectively. The total glucosinolates concentration in canola meal was 1.55 μmol g^{-1}.

The AID of CP in CS-1, CS-2, and CE-2 was less ($P < 0.01$) than the SID of CP in canola meal, but the AID of CP in CE-1, and CE-3 was not different from the AID of CP in canola meal (Table 5). The AID of all AA in CS-1 was less ($P < 0.05$) than the AID of all AA in CS-2 and in the 3 sources of CE and in canola meal, except for the AID of Cys, which was not different between CS-1 and CE-2. The AID of all AA in CE-2, except Arg, Asp, Gly and Pro, was less ($P < 0.01$) than the AID of all AA in canola meal. The AID of AA was not different between CE-1 and canola meal, except for the AID of Thr, Cys, and Ser in CE-1, which were less than in canola meal. The AID for AA in CE-3 was not

Table 3. Ingredient composition of experimental diets[z]

	Diets						
	Camelina seeds		Camelina expellers				
Ingredient (%)	CS-1	CS-2	CE-1	CE-2	CE-3	Canola meal	N-free
Camelina seed	40.00	40.00	–	–	–	–	–
Camelina expellers	–	–	40.00	40.00	40.00	–	–
Canola meal	–	–	–	–	–	40.00	–
Cornstarch	45.20	45.20	45.20	45.20	45.20	45.37	67.71
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00	4.00
Sucrose	10.00	10.00	10.00	10.00	10.00	10.00	20.00
Solka floc[y]	–	–	–	–	–	–	5.00
Limestone	0.75	0.75	0.75	0.75	0.75	0.66	0.61
Monocalcium phosphate	0.95	0.95	0.95	0.95	0.95	0.87	–
Dicalcium phosphate							1.08
Magnesium oxide	–	–	–	–	–	–	0.10
Potassium carbonate	–	–	–	–	–	–	0.40
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[x]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[z]CS-1 = Blaine Creek, obtained from Montana State University, Moccasin, MT; CS-2 = Sustainable Oils – 30, sourced from Sustainable Oils, Great Falls, MT; CE-1 = Pennsylvania, sourced from Penn State Cooperative Extension, Meadville, PA; CE-2 = Willamette, sourced from Willamette Biomass Processors, Rickreall, OR; CE-3 = Sustainable Oils, obtained from Sustainable Oils, Great Falls, MT. Canola meal was obtained from the University of Illinois, Urbana, IL.

[y]Fiber Sales and Development Corp., Urbana, OH.

[x]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11 128 IU; vitamin D_3 as cholecalciferol, 2204 IU; vitamin E as DL-alphatocopheryl acetate, 66 IU; vitamin K as menadionenicotinamide bisulfate, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide, 1.0 mg, and nicotinic acid, 43.0 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 4. Analyzed nutrient composition of diets (as-fed basis)[z]

	Diet					
	Camelina seeds		Camelina expellers			
Item	CS-1	CS-2	CE-1	CE-2	CE-3	Canola meal
Dry matter (%)	92.7	93.3	91.7	92.1	92.8	91.7
Crude protein (%)	8.1	11.9	13.7	12.0	13.2	15.7
Glucosinolates[y] (μmol g^{-1})	11.4	12.8	16.9	11.0	10.6	0.6
Indispensable AA (%)						
Arg	0.64	0.98	1.11	0.95	1.02	0.85
His	0.20	0.28	0.32	0.30	0.31	0.38
Ile	0.28	0.41	0.48	0.44	0.47	0.55
Leu	0.55	0.76	0.88	0.82	0.86	1.01
Lys	0.36	0.51	0.63	0.61	0.54	0.74
Met	0.13	0.20	0.24	0.20	0.22	0.27
Phe	0.35	0.49	0.56	0.53	0.54	0.58
Thr	0.31	0.46	0.54	0.50	0.53	0.62
Trp	0.11	0.14	0.17	0.15	0.15	0.19
Val	0.40	0.58	0.67	0.58	0.65	0.71
Dispensable AA (%)						
Ala	0.36	0.52	0.63	0.55	0.60	0.63
Asp	0.70	0.97	1.09	1.08	1.07	1.03
Cys	0.15	0.27	0.30	0.24	0.26	0.34
Glu	1.31	2.00	2.26	2.03	2.13	2.42
Gly	0.42	0.59	0.70	0.61	0.67	0.72
Pro	0.42	0.63	0.73	0.66	0.70	0.91
Ser	0.36	0.54	0.62	0.59	0.60	0.61

[z]CS-1 = Blaine Creek, obtained from Montana State University, Moccasin, MT; CS-2 = Sustainable Oils – 30, sourced from Sustainable Oils, Great Falls, MT; CE-1 = Pennsylvania, sourced from Penn State Cooperative Extension, Meadville, PA; CE-2 = Willamette, sourced from Willamette Biomass Processors, Rickreall, OR; CE-3 = Sustainable Oils, obtained from Sustainable Oils, Great Falls, MT. Canola meal was obtained from the University of Illinois, Urbana, IL.
[y]Calculated concentration.

different ($P > 0.05$) from the AID of AA in canola meal. There were no differences ($P > 0.05$) in the AID of Lys among the three sources of camelina expellers and canola meal, but the AID of Lys in CS-2 was less ($P < 0.01$) than the AID of Lys in CE-1 and in canola meal. However, the AID of Lys in CS-2 was greater ($P < 0.01$) than the AID of Lys in the CS-1.

The SID of CP (Table 6) in CS-1 and CE-2 was less ($P < 0.01$) than the SID of CP in canola meal, but the SID of CP in CS-2, CE-1, and CE-3 was not different from the SID of CP in canola meal. The SID of all AA, except Pro, in CS-1 was less ($P < 0.05$) than the SID of AA in all other ingredients. The SID of most AA in CE-2 was less ($P < 0.05$) than in canola meal, but no differences ($P > 0.05$) were observed between the SID of AA in CE-1 and CE-3 and the SID of AA in canola meal, except that the SID of Cys and Ser in CE-1 was less ($P < 0.01$) than in canola meal. The SID of Lys in canola meal was greater ($P < 0.01$) than the SID of Lys in CS-1 and CS-2, but not different from the SID of Lys in CE-1, CE-2, and CE-3.

DISCUSSION

Demand for biodiesel in the United States has contributed to increasing the demand for camelina oil, which has resulted in an increase in the production of camelina seeds (Murphy 2011). Another reason for the increased production of camelina is that it can be grown in marginal soils with little input costs making it economically attractive to growers (Ehrensing and Guy 2008). Approximately 50 000 acres of camelina are grown in the United States (Voegele 2012), and the majority is grown in Montana, Washington, North Dakota, and South Dakota. In these States, camelina may be grown in areas that would otherwise remain uncultivated (Voegele 2012). Camelina is also cultivated in the four westernmost provinces in Canada (Daly 2011).

As is the case for other oilseeds, if oil is mechanically expelled from camelina, the residual material is called ''expellers'', whereas the residual material that is left if oil has been solvent-extracted from oilseeds is called ''meal'' (NRC 2012). Oil removal by solvent extraction after mechanical expelling is more efficient than mechanically expelling alone; therefore, expellers usually have a greater concentration of oil than solvent-extracted meals (NRC 2012). As a consequence, it was expected that the camelina expellers would have a greater concentration of AEE than the canola meal used in this experiment, which turned out to be the case. The high energy and nutrient contents of camelina expellers make this ingredient attractive to the livestock industry not only as a source of dietary protein, but also as a source of energy.

Table 5. Apparent ileal digestibility (%; AID)[z] of CP and AA in camelina seeds, camelina expellers, and canola meal fed to growing pigs[y]

	Camelina seeds		Camelina expellers					
Item	CS-1	CS-2	CE-1	CE-2	CE-3	Canola meal	SEM	*P* value
CP	31.9*c*	53.6*b*	59.7*ab*	52.9*b*	60.1*ab*	65.1*a*	2.80	<0.01
Indispensable AA								
Arg	51.2*c*	71.3*b*	82.7*a*	75.1*ab*	82.5*a*	78.9*ab*	2.59	<0.01
His	48.0*d*	66.2*c*	75.6*ab*	68.5*bc*	75.2*ab*	78.1*a*	2.61	<0.01
Ile	33.4*c*	55.9*b*	67.5*a*	57.4*b*	70.3*a*	73.5*a*	3.05	<0.01
Leu	41.6*c*	60.1*b*	72.3*a*	62.1*b*	75.5*a*	77.2*a*	2.87	<0.01
Lys	40.4*c*	57.7*b*	67.9*a*	63.6*ab*	63.9*ab*	71.0*a*	3.10	<0.01
Met	48.4*d*	67.8*c*	81.0*a*	71.9*bc*	78.6*ab*	82.6*a*	2.36	<0.01
Phe	37.5*d*	58.4*c*	70.4*ab*	62.0*bc*	73.5*a*	75.2*a*	2.93	<0.01
Thr	21.3*d*	44.8*c*	53.9*bc*	48.6*bc*	56.6*ab*	64.9*a*	3.27	<0.01
Trp	32.8*c*	47.6*b*	59.5*a*	49.1*b*	62.3*a*	67.7*a*	3.37	<0.01
Val	34.9*c*	56.4*b*	68.4*a*	58.3*b*	70.0*a*	70.7*a*	2.96	<0.01
Mean	39.9*c*	60.0*b*	71.2*a*	62.9*b*	72.2*a*	74.1*a*	2.81	<0.01
Dispensable AA								
Ala	26.0*d*	51.2c	63.3*ab*	56.0*bc*	62.9*ab*	69.1*a*	2.97	<0.01
Asp	41.4*b*	59.9*a*	67.6*a*	62.2*a*	66.6*a*	66.5*a*	2.55	<0.01
Cys	37.0*d*	56.8*bc*	56.7*bc*	45.6*cd*	64.4*ab*	72.7*a*	3.78	<0.01
Glu	49.8*c*	67.7*b*	77.8*a*	68.7*b*	79.0*a*	80.9*a*	2.50	<0.01
Gly	15.2*b*	39.6*a*	48.4*a*	43.1*a*	49.5*a*	54.2*a*	4.66	<0.01
Pro	−53.3*b*	−6.15*a*	19.9*a*	11.4*a*	4.08*a*	7.8*a*	14.28	<0.05
Ser	27.4*d*	50.9*c*	57.0*bc*	52.4*bc*	60.3*ab*	66.7*a*	3.02	<0.01
Mean	27.7*c*	51.1*b*	61.6*ab*	54.4*ab*	60.7*ab*	63.0*a*	3.69	<0.01
Total AA	33.4*c*	55.3*b*	66.1*a*	58.4*ab*	66.1*a*	68.2*a*	3.16	<0.01

[z]Data are least-square means of seven observations per treatment; AID = 1 – (CP or AA in digesta/CP or AA in feed) × (Cr in feed/Cr in digesta) × 100%.
[y]CS-1 = Blaine Creek, obtained from Montana State University, Moccasin, MT; CS-2 = Sustainable Oils – 30, sourced from Sustainable Oils, Great Falls, MT; CE-1 = Pennsylvania, sourced from Penn State Cooperative Extension, Meadville, PA; CE-2 = Willamette, sourced from Willamette Biomass Processors, Rickreall, OR; CE-3 = Sustainable Oils, obtained from Sustainable Oils, Great Falls, MT. Canola meal was obtained from the University of Illinois, Urbana, IL.
a–d Means within a row lacking a common superscript letter differ ($P < 0.05$).

The values for the AID of CP and AA in canola meal determined in the present experiment are in agreement with values previously reported (Fan and Sauer 1995). Likewise, values for the SID of CP and AA in canola meal determined in this experiment are in agreement with values for the SID of CP and AA reported by Stein et al. (2001) and Woyengo et al. (2010). To the best of our knowledge, the AID and SID of CP and AA in camelina seeds and camelina expellers fed to pigs have not been reported. The reason for the negative AID for Pro in both sources of CS is that the concentration of Pro is greater in endogenous protein than the concentration of any other AA (Stein et al. 1999). The pigs may, therefore, excrete more Pro at the end of the ileum than what they consumed, which resulted in a negative value for the AID of Pro. However, when SID values are calculated, the endogenous losses of AA are included in the calculation, which is the reason there are no negative values for the SID of Pro. Negative values for the AID of Pro are not uncommon as has been previously discussed (Stein et al. 1999, 2007).

Glucosinolates are typically present in crucifers such as *C. sativa*. The total concentration of glucosinolates in 10 varieties of camelina seeds was reported in a range of 18.0 to 31.4 μmol g^{-1} (Schuster and Friedt 1998). The concentrations of glucosinolates in the two sources of camelina seeds used in the present experiment were greater than the values in the reported range. These differences among seeds may be a result of differences in environment and type of soil in which the camelina seeds were grown. Biosynthesis of glucosinolates is related to the concentration of sulphur AA in camelina seeds, which depends on the concentration of sulphur in the soil where cultivars are grown (Schuster and Friedt 1998).

Camelina seeds and camelina expellers are usually not included in poultry diets at more than 15%, because products from glucosinolate metabolism may reduce diet palatability and decrease animal performance (Pekel et al. 2009). It has been suggested that glucosinolate levels in swine diets should be in a range of 1.5 to 2.0 μmol g^{-1} of diet to avoid deleterious effects on pigs performance (Tripathi and Mishra 2007; Canola Council of Canada 2009). In the present experiment, however, camelina products were included in diets at 40%, which resulted in calculated concentrations of glucosinolates in diets ranging from 10.6 to 16.9 μmol g^{-1}. Although the concentration of glucosinolates in the diets was above recommended levels, we did not observe any feed refusal, which indicates that palatability of the

Table 6. Standardized ileal digestibility (%; SID)[z] of CP and AA in camelina seeds, camelina expellers, and canola meal fed to growing pigs[y]

	Camelina seeds		Camelina expellers					
Item	CS-1	CS-2	CE-1	CE-2	CE-3	Canola meal	SEM	*P* value
CP	48.6*c*	65.1*ab*	69.5*ab*	64.1*b*	70.4*ab*	73.7*a*	2.80	<0.01
Indispensable AA								
Arg	58.1*c*	75.8*b*	86.6*a*	79.7*ab*	86.8*a*	84.0*a*	2.59	<0.01
His	55.6*d*	71.7*c*	80.4*ab*	73.5*bc*	80.2*ab*	82.1*a*	2.61	<0.01
Ile	42.2*c*	61.9*b*	72.6*a*	62.9*b*	75.6*a*	77.9*a*	3.05	<0.01
Leu	49.1*c*	65.6*b*	76.9*a*	67.1*b*	80.3*a*	81.3*a*	2.87	<0.01
Lys	47.9*c*	63.0*b*	72.1*ab*	68.0*ab*	68.9*ab*	74.6*a*	3.10	<0.01
Met	54.1*d*	71.5*c*	84.0*a*	75.5*bc*	81.9*ab*	85.3*a*	2.36	<0.01
Phe	46.0*d*	64.5*c*	75.6*ab*	67.6*bc*	79.0*a*	80.3*a*	2.93	<0.01
Thr	38.3*d*	56.3*c*	63.6*abc*	59.1*bc*	66.6*ab*	73.3*a*	3.27	<0.01
Trp	44.9*c*	57.2*b*	67.3*ab*	57.9*b*	71.2*a*	74.6*a*	3.37	<0.01
Val	43.9*c*	62.7*b*	73.8*a*	64.5*b*	75.6*a*	75.7*a*	2.96	<0.01
Mean	48.6*d*	66.1*c*	76.3*ab*	68.6*bc*	77.7*a*	78.9*a*	2.81	<0.01
Dispensable AA								
Ala	39.0*d*	60.3*c*	70.6*ab*	64.4*bc*	70.7*ab*	76.4*a*	2.97	<0.01
Asp	50.5*b*	66.5*a*	73.4*a*	68.1*a*	72.6*a*	72.6*a*	2.55	<0.01
Cys	47.8*d*	62.9*bc*	62.1*bc*	52.3*cd*	70.7*ab*	77.4*a*	3.78	<0.01
Glu	55.5*c*	71.4*b*	81.1*a*	72.4*b*	82.6*a*	84.0*a*	2.50	<0.01
Gly	48.7*b*	63.5*a*	68.3*a*	65.9*a*	70.5*a*	73.5*a*	4.66	<0.05
Pro	51.1	63.9	79.3	77.3	66.8	55.4	14.28	0.67
Ser	40.5*c*	59.7*b*	64.6*b*	60.4*b*	68.2*ab*	74.4*a*	3.02	<0.01
Mean	49.9*b*	66.2*a*	74.6*a*	68.6*a*	74.5*a*	75.3*a*	3.69	<0.01
Total AA	49.3*c*	66.2*b*	75.4*ab*	68.6*ab*	76.0*ab*	77.0*a*	3.16	<0.01

[z]Data are least-square means of seven observations per treatment; SID = standardized ileal digestibility; SID = apparent ileal digestibility of diet + (endogenous losses/intake) × 100%. Endogenous losses (g kg^{-1} of dry matter intake) of CP and AA were calculated as the following quantities: CP, 14.65; Arg, 0.48; His, 0.17; Ile, 0.27; Leu, 0.44; Lys, 0.29; Met, 0.08; Phe, 0.32; Thr, 0.57; Trp, 0.14; Val, 0.39; Ala, 0.51; Asp, 0.69; Cys, 0.17; Glu, 0.81; Gly, 1.52; Pro, 4.73; Ser, 0.51.

[y]CS-1 = Blaine Creek, obtained from Montana State University, Moccasin, MT; CS-2 = Sustainable Oils – 30, sourced from Sustainable Oils, Great Falls, MT; CE-1 = Pennsylvania, sourced from Penn State Cooperative Extension, Meadville, PA; CE-2 = Willamette, sourced from Willamette Biomass Processors, Rickreall, OR; CE-3 = Sustainable Oils, obtained from Sustainable Oils, Great Falls, MT. Canola meal was obtained from the University of Illinois, Urbana, IL.

a–d Means within a row lacking a common superscript letter differ ($P < 0.05$).

diets was not an issue in this short term experiment, although the fact that pigs were fed restrictedly may have contributed to this observation. This observation is in agreement with Mathäus and Zubr (2000) who suggested that detrimental effects of glucosinolates from *C. sativa* oilseed cake are less compared with the detrimental effects of glucosinolates from rapeseed products. The reason for this hypothesis is that hydrolysis of glucosinolates in camelina yields only non-volatile isothiocyanates and camelina seeds do not contain progoitrin, which forms the toxic compound goitrin (Mathäus and Zubr 2000).

The AA concentrations in the three sources of camelina expellers used in this experiment are in close agreement with values previously reported for the concentrations of AA in camelina expellers (Pekel et al. 2009). Likewise, the concentrations of AA in the two sources of camelina seeds are in agreement with the concentrations of AA in 16 sources of camelina seeds (Zubr 2003), and the concentrations of AA in canola meal are also in agreement with the concentrations of AA in canola meal reported by Stein et al. (2001).

The analyzed nutrient compositions in the two sources of camelina seeds were somewhat similar, although CS-1 camelina seed was grown in Montana under wetter and cooler conditions than average and ripened around 2 wk later than average (D. Wichman, Central Ag Research Center, Moccasin, MT, personal communication).

All three sources of camelina expellers fed in this experiment were produced by a cold press process to expell the oil. For cold-pressed canola expellers, it has been demonstrated that the digestibility of Lys increases if a non-heated barrel with a faster screw speed is used, but this was not the case for other AA (Seneviratne et al. 2011).

The Lys:CP ratio of heat damaged feed ingredients is reduced compared with that of non-heat damaged feed ingredients because Maillard reactions cause a reduction in the concentration of Lys, but not in the concentration of CP (González-Vega et al. 2011). Values for the Lys:CP ratio calculated in this experiment for camelina seeds and camelina expellers were similar, which indicates that differences observed in CP and AA digestibilities among camelina products were not due to heat damage. Camelina is a relatively new crop in the United States and breeding programs have been limited (Grady and Nleya 2010). Therefore, it is possible that genetic differences between the two varieties of camelina seeds

contributed to the differences observed for the digestibility of CP and AA. Antinutritional factors other than glucosinolates, such as tannins, may also affect the digestibility of AA in camelina products.

The average concentration of trypsin inhibitors in camelina seeds was 12.1 TIU mg^{-1}, which is less than the average of 13 varieties (18.0 TIU mg^{-1}) of camelina seeds grown in MN (Budin et al. 1995). The relatively greater concentration of trypsin inhibitors in camelina expellers compared with the concentration of trypsin inhibitors in canola meal indicates that it may be desirable to apply a certain degree of heating when processing camelina expellers to reduce the concentration of trypsin inhibitors. If such a reduction is achieved, the nutritional value of camelina expellers may be improved.

In conclusion, results from this experiment indicate that the digestibility of CP and AA in at least one source of camelina seeds was less than in camelina expellers and canola meal. The digestibility values determined for camelina expellers, however, indicates that camelina expellers may be included in diets fed to pigs, because these values are comparable to the digestibility values determined for canola meal. However, the presence of antinutritional factors, such as glucosinolates and trypsin inhibitors in camelina expellers, needs to be taken into consideration when including camelina products in diets fed to pigs. Although the digestibility of CP and AA in camelina expellers is less than in canola meal, camelina expellers contain more gross energy than solvent-extracted canola meal because of the greater concentration of oil. However, concentrations of digestible and metabolizable energy in camelina expellers have not yet been determined. Likewise, inclusion levels of camelina expellers in diets fed to pigs and effects of camelina expellers on growth performance of pigs have not yet been reported.

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