Camelina sativa cake for broiler chickens: effects of increasing dietary inclusion on clinical signs of toxicity, feed disappearance, and nutrient digestibility

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ABSTRACT: The effect of feeding diets with increasing dietary inclusions of *Camelina sativa* cake (CC; 22% ether extract, 34% crude protein) on safety, feed disappearance, and nutrient digestibility was evaluated in a 42-day (d) broiler study. Day-old male chicks (Ross 308; *n* = 744) were divided among 24 test cages in a randomized complete block design with six replicate cages per dietary regimen. Dietary regimens consisted of feeding test diets containing 0, 8, 16, or 24% CC over three growth phases of 2-week duration each. Diets fed from d 14–21 included an indigestible marker. Pen body weight, feed added, and leftover orts for each phase were measured on d 0, 14, 28, and 42 to calculate average daily feed disappearance, average daily weight gain, and gain-to-feed ratio. On d 14, 28, and 42, three broilers per test cage were euthanized by intravenous injection. A gross post mortem examination was conducted and select organs were weighed. Blood was drawn from broilers removed on d 42 to measure serum parameters. Excreta from d 19 to 21 and ileal digesta (10 birds per cage) on d 21 were collected to yield a single pooled sample of each per test cage. Dietary CC inclusion up to 24% did not affect broiler mortality or the incidence of abnormal gross findings. Differences ($P < 0.05$) in serum levels of P, uric acid, T3, and T4 are explained by differential digestible nutrient intake among broilers fed increasing CC inclusion levels. Organ weight as proportion of body weight was not affected by treatment, except for pancreas on d 28 and 42, which both linearly increased ($P < 0.01$) with increasing CC inclusion. Daily feed disappearance did not differ among CC inclusion levels for the overall 42-d study. Increasing dietary CC inclusion level linearly reduced nutrient digestibility of test diets ($P < 0.01$). In conclusion, CC is a safe feedstuff for broilers that can be fed at dietary inclusions up to and including 24% without adverse effects on broiler health.

Key words: broiler chickens, camelina cake, dietary inclusion, nutrient digestibility, safety

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INTRODUCTION

Camelina sativa is an oilseed containing 35–40% oil (Budin et al., 1995). It belongs to the *Brassica* family and is closely related to mustard (*B. juncea*), rapeseed (*B. napus*), and canola (*B. napus*; low erucic acid, reduced glucosinolates). Although camelina has been cultivated since the Bronze Age, there is renewed interest in camelina as a feedstock for bio-fuel production. A life-cycle analysis determined that camelina-derived biofuels compare favorably with biofuels derived from

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other oil crops (Li and Mupondwa, 2014), due in large part to several advantageous agronomic characteristics (Shonnard et al., 2010). Camelina is early maturing (<100 days [d]; Gugel and Falk, 2006), can be grown successfully under a wide range of soil and moisture conditions, and requires little or no fertilizer or pesticide to realize acceptable yields (Zubr, 1997). Camelina's tolerance of low moisture conditions make it particularly well suited to the soil zones of the Canadian Prairies and the central Great Plains of the United States (Gugel and Falk, 2006).

The major co-product of camelina oil extraction is camelina cake (CC), which has value as a potential feedstuff for livestock and poultry. CC contains 30% to 40% crude protein, so is a potential dietary source of amino acids for pigs and poultry. Most importantly, the remaining oil in cake (10% to 20%) increases its dietary energy value compared to solvent-washed meal. Its oil comprises a high proportion of polyunsaturated fatty acids, in particular α-linolenic acid (>35% of total fatty acids; Zubr, 2003; Nain et al., 2015).

The US Food and Drug Administration has accorded CC "generally recognized as safe" status and allows feeding diets containing up to 10% CC to broiler chickens and laying hens. Feeding CC to food-producing animals is presently not allowed in Canada except for egg layers (10% inclusion) and broiler chickens (12% inclusion), which implies that the cake has otherwise limited economic value to oilseed crushers. The sale of the cake or solvent-extracted meal resulting from oil extraction into the animal feed sector would be a major revenue stream for commercial oilseed processors. In Canada, a prerequisite for listing of novel feedstuffs is the evaluation of data relating to feeding safety and efficacy.

The purpose of this experiment was to generate information pertaining to the safety of feeding CC to broiler chickens at dietary inclusions up to 24%. We tested the hypothesis that clinical indicators of toxicity, feed disappearance, and nutrient digestibility would not differ among broilers fed increasing dietary CC inclusions compared with those fed a diet with no CC. The objectives were therefore to evaluate the effect of feeding increasing dietary inclusions of CC on clinical appearance of organ tissues, as well as on organ weights, serological parameters, feed disappearance, and nutrient digestibility of CC.

MATERIALS AND METHODS

Trial procedures were reviewed and animal usage was approved by the University of Alberta's Animal Care and Use Committee for Livestock and followed principles established by the Canadian Council on Animal Care (2009).

Experimental Design and Management

Male chicks (n = 744; Ross 308) were brought to the Poultry Research and Technology Centre at the Edmonton Research Station (Edmonton, Alberta, Canada) on the day of hatch. Upon arrival, chicks were neck-tagged for individual identification and weighed. Chicks were then randomly distributed among 24 test cages (53.3 cm width × 119.4 cm length × 43.2 cm height) in a 3-tiered pullet battery (Specht Ten Elsen GmbH & Co.; Sonsbeck am Niederrhein, Germany) for 31 chicks per test cage. Test cages were grouped into six blocks based on location within the test battery. Each dietary regimen appeared once per block for a randomized complete block design with six replicate cages per treatment.

Chicks had continuous access to water via an adjustable height nipple drinker line and feed from a trough that ran the front length of the cage. Room temperature and lighting were under automated control and conformed to programs recommended for this strain (Aviagen, 2018). Actual temperature, relative humidity, and maximum/minimum temperatures over the preceding 24 h were recorded daily and temperature setpoints for the room were adjusted accordingly.

Beginning at placement (d 0), chicks had *ad libitum* access to phase diets corresponding to the dietary regimen assigned to each cage. Test diets included 0, 8, 16, or 24% CC for each of three, 2-week phases (starter, d 0–14; grower; d 15–28; finisher; d 29–42). Individual broiler weights were measured on d 0, 7, 14, 21, 28, 35, and 42. Feed added each week and remaining orts in feeders at the end of the week were determined for each cage to calculate feed disappearance.

Excreta was collected on trays placed on cleaned manure belts under each cage for a 48-h period beginning at 0800 h of d 19 of the study. On d 21, 10 broilers from each test cage were euthanized by cervical dislocation and digesta was collected from the region of the ileum spanning approximately 3 cm distal to the vitelline (Meckel's) diverticulum to approximately 3 cm proximal to the ileo-caecal junction. Excreta and digesta were pooled to produce a single sample of each per test cage.

After weighing on d 14, 28, and 42, blood samples were drawn from three broilers per cage, which were then euthanized by intravenous embutramide (T61; Intervet Canada, Kirkland, QC) injection via the wing vein to prevent physical trauma to the thyroid gland that might result from cervical dislocation. Euthanized birds were placed on ice and transported to Alberta Agriculture and Forestry's Post Mortem Laboratory (Airdrie, Alberta) for clinical examination of intact carcasses and assessment of organ appearance that could indicate gross toxicity. The Veterinary Pathologist and technicians were kept blind to treatment assigned to individual broilers. The heart, liver, pancreas, and spleen were excised and weighed. Carcasses and remaining viscera from birds participating in this study were disposed of by incineration.

Test Ingredient and Experimental Diets

Camelina seed (spring var. Celine) was sourced from a commercial supplier (Mercer Seeds; Lethbridge, AB, Canada). Seed was pressed at Agri-Food Discovery Place at the Edmonton Research Station using a Komet CA 59 screw press (IBG—Monforts Oekotec GmbH & Co.Kg; Monchengladbach, Germany), yielding oil and screw-pressed cake (Table 1). Cake was then milled in a Jacobson model P160 hammermill (Carter Day International; Minneapolis, MN) through a 3.2 mm screen to produce a coarse mash.

Test diets for each of the three growth phases consisted of 76% of a phase-specific concentrate and reciprocal amounts of CC and cornstarch in 8%-point increments to make up the remaining 24% of each test diet (Table 2). Diets fed during the grower phase contained 0.4% chromic oxide to calculate nutrient digestibility.

Experimental diets were mixed at the Environment and Metabolism Unit at the Edmonton Research Station in a model SPC 2748 horizontal paddle mixer (Marion Mixers; Marion, IA). Diets were hydrated to 15% moisture and cold-pelleted using a model PM1230 flat-die pellet press (Buskirk Engineering; Ossian, IN).

Table 1. Nutrient content (% as-is unless otherwise noted) and fatty acid composition (% of total fatty acids) of the two batches of screw-pressed camelina cake fed to broiler chickens

Item	Batch 1 (Phases 1 and 2 diets)	Batch 2 (Phase 3 diets)
Moisture	8.05	7.90
Gross energy, kcal/kg	5,730	5,777
Crude protein	34.25	34.40
Neutral detergent fibre	26.32	26.63
Acid detergent fibre	15.04	14.37
Crude fiber	9.37	9.37
Ash	5.38	5.01
Phosphorus	1.01	0.74
Calcium	0.23	0.19
Ether extract	21.00	22.71
Fatty acids, % of total fatty acids		
Myristic acid (C14:0)	0.08	0.08
Palmitic acid (C16:0)	6.44	6.28
Stearic acid (C18:0)	2.68	2.37
Arachidic acid (C20:0)	1.39	1.33
Behenoic acid (C22:0)	0.30	0.31
Palmitoleic acid (C16:1)	0.02	0.16
Oleic acid (C18:1)	15.28	17.17
Gonodic acid (C20:1)	15.34	14.04
Erucic acid (C22:1)	0.00	2.38
α-Linolenic acid (C18:3 $n-3$)	28.82	27.73
Eicosatrienoic acid (C20:3 $n-3$)	1.17	0.98
EPA (C20:5 $n-3$)	0.09	0.08
DHA (C22:6 $n-3$)	0.02	0.02
Linoleic acid (C18:2 $n-6$)	21.13	22.63
γ-Linolenic acid (C18:3 $n-6$)	0.24	0.25
Arachidonic acid (C20:4 $n-6$)	2.47	-
Glucosinolates, μmol/g		
9-methyl-sulfinyl-nonyl glucosinolate	7.73	8.89
10-methyl-sulfinyl-decyl glucosinolate	28.5	28.2
11-methyl-sulfinyl-undecyl glucosinlolate	6.79	5.38
Total glucosinolates	44.90	44.10
Trypsin inhibitor activity, mg/g	9.6	9.8

Sample Analysis

Blood serum was sent to Prairie Diagnostic Services (Saskatoon, Saskatchewan, Canada). Samples were analyzed for phosphorus, calcium, glucose, creatine kinase, aspartate aminotransferase, and uric acid content using a Cobas c3 analyzer (Hitachi Canada; Mississauga, Ontario, Canada). Triiodothyronine (T3) and thyroxine (T4) levels in serum were determined using T3 and T4 coat-a-count test kits (Siemens Canada; Oakville, Ontario, Canada).

Excreta samples were oven dried at 65°C for 24 h, whereas digesta samples were freeze-dried. Test ingredient, diets, lyophilized digesta, and dried excreta samples were then ground in a model ZM200 centrifugal mill (Retsch GmbH; Haan, Germany) through a 1 mm screen. Moisture content was determined by drying in a forced air oven at 135°C for 2 h (method 930.15, AOAC, 2006; Table 3). Gross energy was measured using a model 5003 adiabatic oxygen calorimeter (Ika-Werke GMBH & Co. KG; Staufen, Germany) using benzoic acid as a standard at the Department of Agricultural Food and Nutritional Sciences (University of Alberta; Edmonton, Alberta, Canada). Crude protein ([CP];method 990.03; AOAC, 2006), crude fiber

Table 2. Ingredient composition of test diets (as fed) fed to broiler chickens

	Camelina cake inclusion level											
	Starter phase (d 0–14)				Grower phase (d 14–28)				Finisher phase (d 28–42)			
Ingredient	0%	8%	16%	24%	0%	8%	16%	24%	0%	8%	16%	24%
Cornstarch	24.00	16.00	8.00	0.00	24.00	16.00	8.00	0.00	24.00	16.00	8.00	0.00
Camelina cake (22% fat)	0.00	8.00	16.00	24.00	0.00	8.00	16.00	24.00	0.00	8.00	16.00	24.00
Wheat, ground	32.05	32.05	32.05	32.05	39.92	39.92	39.92	39.92	43.51	43.51	43.51	43.51
Soybean meal	20.10	20.10	20.10	20.10	12.17	12.17	12.17	12.17	11.33	11.33	11.33	11.33
Corn, ground	13.47	13.47	13.47	13.47	13.51	13.51	13.51	13.51	11.26	11.26	11.26	11.26
Canola oil	2.82	2.82	2.82	2.82	2.52	2.52	2.52	2.52	3.10	3.10	3.10	3.10
Fish meal	2.24	2.24	2.24	2.24	3.75	3.75	3.75	3.75	2.63	2.63	2.63	2.63
Mono-/di-calcium phosphate	1.55	1.55	1.55	1.55	1.01	1.01	1.01	1.01	1.08	1.08	1.08	1.08
Limestone	1.50	1.50	1.50	1.50	1.06	1.06	1.06	1.06	1.07	1.07	1.07	1.07
Vitamin/mineral premix[a]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Choline chloride premix[b]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.43	0.43	0.43	0.43	0.34	0.34	0.34	0.34	0.36	0.36	0.36	0.36
Vitamin E[c] premix	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
D,L-Methionine	0.17	0.17	0.17	0.17	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07
L-Lysine HCl	0.17	0.17	0.17	0.17	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
L-Threonine	0.04	0.04	0.04	0.04	0.08	0.08	0.08	0.08	0.02	0.02	0.02	0.02
Enzyme[d]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Coccidiostat[e]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Antibiotic[f]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

[a]Provided the following per kg of diet: 10,000 IU vitamin A; 4,000 IU vitamin D3; 50 IU vitamin E; 4 mg thiamine; 10 mg riboflavin; 15 mg pantothenic acid; 2 mg folic acid; 65 mg niacin; 5 mg pyridoxine; 4 mg menadione; 120 mg manganese; 80 mg iron; 20 mg copper; and 100 mg zinc.

[b]Provided 100 mg of choline per kg of diet.

[c]Provided 15 IU of tocopherol per kg of diet.

[d]Provided the following enzyme activities per kg of diet: 150 units xylanase; 125 units glucanase; 4,000 units amylase; 1,750 units protease; and 5,000 units invertase.

[e]Coban, Elanco (Guelph, ON, Canada), Canadian Food Inspection Agency, Medicating Ingredient Brochure #57, Claim 1.

[f]BMD 110, Alpharma (Leduc, AB, Canada). Canadian Food Inspection Agency, Medicating Ingredient Brochure #48, Claim 2.

([CF]; method 978.10; AOAC, 2006), ether extract ([EE]; method 920.39; AOAC, 2006), neutral detergent fiber ([NDF]; Holst, 1973), acid detergent fiber ([ADF]; method 973.18; AOAC, 2006), ash (method 942.05; AOAC, 2006), chromium (method 990.08; AOAC, 2006), and amino acid ([AA]; method 982.30; AOAC, 2006) analysis were conducted at the Experiment Station Chemical Laboratories (ESCL), University of Missouri (Columbia, MO).

The two batches of camelina cake fed in this study were also assayed for fatty acid profile (method Ce 1d-91; AOCS, 2017) at ESCL, trypsin inhibitor activity (CEN-EN-ISO 14902, 2001) at Nutrilab B.V. (Giessen, the Netherlands), and glucosinolate content (Raney and McGregor, 1990) at Intertek-SunWest Labs (Saskatoon, Saskatchewan, Canada).

Calculations

Apparent digestibility of nutrients in grower phase test diets was established using marker and nutrient content in digesta or excreta relative to the corresponding assay diet, as per the following equation:

$$\text{Apparent digestibility, \%} = \left(\begin{array}{l} 1 - (\text{\% Nutrient in digesta} \\ \quad \text{or excreta / \% Nutrient in diet}) \\ \quad \times (\text{\% Marker in diet/} \\ \quad \text{\% Marker in digesta or excreta}) \end{array} \right) \times 100$$

The difference method was then used to estimate AID in the test ingredient. Digestibility of AA in assay diets can be described as

$$D_{\text{assay}} = D_{\text{conc}} \times \text{RC}_{\text{conc}} + D_{\text{test}} \times \text{RC}_{\text{test}}$$

where D_{assay} is the observed digestibility of nutrient in the assay diet; D_{conc} is digestibility of a nutrient in the concentrate; RC_{conc} is the relative contribution of the concentrate to the content of a nutrient in the assay diet; D_{test} is the digestibility of a nutrient in the test ingredient; and RC_{test} is the relative contribution of the test ingredient to the content of a nutrient in the assay diet. The above equation can be rearranged as follows to solve for D_{test}:

$$D_{\text{test}} = \frac{D_{\text{assay}} - D_{\text{conc}} \times \text{RC}_{\text{conc}}}{\text{RC}_{\text{test}}}.$$

Statistical Analyses

Statistical models included the fixed effect of dietary inclusion level of CC (0, 8, 16 or 24%). Growth performance, digestibility, tissue weight, and serological data were transformed (natural logarithm, where required) and then analyzed using the MIXED procedure of SAS (v 9.2, SAS Institute; Cary, NC). Models included block as a random effect and inclusion level of CC was tested using a linear contrast.

Proportional incidence of mortality, culls, and pathological post-mortem findings were analyzed using the LOGISTIC procedure of SAS as binary response data (e.g., abnormal/total) using a binary logit link function. The results for mortality and post-mortem variables are presented in frequency table format. The reported *P*-values for these data are those yielded by a Type 3 analysis of the effect of CC inclusion level (Kaps and Lamberson, 2009).

RESULTS AND DISCUSSION

Test Ingredient and Experimental Diets

The two batches of CC averaged 34.3% CP, 26.5% NDF, 14.7% ADF, 9.4% CF, and 5.2% ash (Table 3), which was lower content than cake of the same cultivar (Celine) fed to nursery and growout pigs (Smit and Beltranena, 2017a, 2017b). The reason for the difference was an oil dilution effect of 11.8%-units greater EE content given the lower seed pressing efficiency comparing cold vs. expeller pressing (Bullerwell et al., 2016; Popa et al., 2017). Alpha-linolenic acid (C18:3, *n*−3; 28.8%) was the most abundant fatty acid in camelina cake batches, followed by linoleic acid (C18:2, *n*−6; 21.9%), oleic acid (C18:1–9c; 16.2%), and gonodic acid (C20:1; 14.7%). Total CC glucosinolate content averaged 44.5 μmol/g camelina with 10-methyl-sulfinyl-decyl accounting for 64% (also called glucocamelinin; Russo and Reggiani, 2017), 9-methyl-sulfinyl-nonyl for 19%, and 11-methyl-sulfinyl-undecyl for14%. Trypsin inhibitor activity in CC batches averaged 9.7 mg/g.

In diets (Table 3), each 1% increase in camelina cake inclusion replacing cornstarch, increased gross energy by 17 kcal/kg, CP by 0.36 percentage points, NDF by 0.17 percentage points, EE by 0.23 percentage points, and lysine by 0.02 percentage points, respectively.

Safety of Feeding Camelina Cake

Increasing dietary CC inclusion level did not affect broiler mortality, number of broilers culled, or gross post-mortem organ (thyroid, heart, liver, etc.) findings that might suggest toxicity (Tables 4 and 5, respectively). All mortalities were subject to

Table 3. Analyzed nutrient content of test diets (% as fed unless otherwise indicated) fed to broiler chickens

	Camelina cake inclusion level											
	Starter				Grower				Finisher			
Nutrient	0%	8%	16%	24%	0%	8%	16%	24%	0%	8%	16%	24%
Moisture	10.99	10.20	10.32	10.26	11.49	12.18	12.45	12.65	16.91	16.62	16.56	11.91
Gross energy, kcal/kg	4,420	4,555	4,643	4,781	4,375	4,508	4,637	4,771	4,333	4,470	4,624	4,803
Crude protein	15.64	18.79	21.75	24.25	17.47	20.95	23.32	26.98	17.11	19.82	22.78	24.72
Neutral detergent fiber	8.66	10.44	11.73	14.02	10.34	12.58	12.99	14.31	10.83	11.00	13.57	13.89
Acid detergent fiber	2.44	3.60	4.90	5.95	3.02	4.20	5.26	6.73	2.63	3.72	4.62	5.57
Crude fiber	1.73	2.24	2.75	3.48	2.13	3.17	3.63	4.57	1.88	2.25	2.87	3.43
Ether extract	4.47	5.56	6.76	8.73	3.11	3.89	4.87	6.53	0.37	1.21	4.25	9.21
Calcium	1.04	1.02	1.20	1.17	1.54	1.65	1.61	1.62	1.15	1.13	1.06	1.06
Phosphorus	0.62	0.74	0.82	0.89	0.76	0.83	0.94	0.98	0.68	0.76	0.79	0.88
Indispensable amino acids												
Arginine	0.87	1.09	1.40	1.64	0.87	1.30	1.53	1.74	0.90	1.18	1.49	1.60
Histidine	0.35	0.41	0.51	0.58	0.34	0.50	0.55	0.61	0.39	0.46	0.59	0.57
Isoleucine	0.63	0.72	0.89	1.00	0.58	0.87	0.94	1.03	0.66	0.76	0.87	0.95
Leucine	1.13	1.30	1.61	1.78	1.05	1.56	1.70	1.90	1.18	1.44	1.65	1.77
Lysine	0.81	0.95	1.17	1.31	0.90	1.17	1.34	1.47	0.81	0.96	1.16	1.27
Methionine + cysteine	0.48	0.59	0.76	0.86	0.43	0.61	0.78	0.84	0.49	0.66	0.77	0.83
Methionine	0.25	0.30	0.38	0.43	0.21	0.31	0.39	0.41	0.26	0.35	0.40	0.42
Phenylalanine	0.71	0.81	1.01	1.13	0.69	1.00	1.10	1.19	0.77	0.90	1.03	1.12
Threonine	0.56	0.68	0.85	0.96	0.53	0.75	0.89	0.98	0.60	0.73	0.87	0.99
Tryptophan	0.17	0.19	0.21	0.23	0.20	0.23	0.25	0.26	0.19	0.22	0.25	0.26
Valine	0.78	0.89	1.10	1.25	0.70	1.05	1.13	1.28	0.85	0.94	1.09	1.21

post mortem examination. Culling criteria for this experiment were exclusive to leg problems, traumatic injury (e.g., lacerations and bone breakage) and weakness/unthriftiness. Only three birds died or were removed after d 22 of the study, casting doubt on a causal relationship between CC inclusion level and mortality.

Though the number of birds in our study was small (186 birds per treatment), our findings are consistent with observed mortality by both Ryhänen et al. (2007) and Thacker and Widyaratne (2012) that fed broilers up to 10% and 15% expeller-pressed camelina cake, respectively. The present study is the first to demonstrate that dietary inclusion of camelina cake in excess of 15% does not affect broiler chicken mortality. The results of this study also indicated that dietary inclusion of up to 24% CC does not affect the occurrence of gross pathological findings, most notably the thyroid, liver, and heart.

We have previously reported that increasing expeller-pressed CC inclusions up to 18% in nursery and up to 15% in growout pig diets did not result in gross pathological findings or indicators of organ function that affected overall pig health (Smit and Beltranena, 2017a, 2017b). In the current study, other than incidence of tibial dyschondroplasia (TD), dietary CC inclusion did not affect the incidence of gross post-mortem findings on any sampling day (d 14, 28, or 42) or for the overall study (Table 5). The total incidence of TD was greater among broilers fed either 16% or 24% CC compared with those fed 0% or 8% (P = 0.014). The pathogenesis of TD in chickens is incompletely defined. Numerous physiological factors have been implicated in the etiology of TD, including genetics (Riddell, 1976), reduced levels of alkaline phosphatase or collagen type X (Farquharson and Jeffries, 2000; Webster et al., 2003) and down-regulation of certain proteins associated with signal transduction, energy metabolism, and secretory functions (Rath et al., 1994). A review by Leach and Monsonego-Ornan (2007) summarized the understanding of the physiology implicated in the development of TD in broilers. It has also long been recognized that dietary mineral status, in particular Ca:P ratio, is a key aggravating factor that can increase incidence of TD in growing broilers. Edwards (1984) reported that high dietary P and or narrow Ca:P ratios resulted in a greater incidence of TD in broilers. One of the effects of increasing dietary CC inclusion was an increase in P content of the diet (1g/kg per each 1% CC inclusion) and a decrease in Ca:P ratio in test diets (Table 3). The ratios of Ca:Total P in all test diets fed during this study was 2 or less. The decrease in dietary Ca:P with increasing CC inclusion was most pronounced in the starter and grower phases, where Ca:P declined from 2.0 to 1.7 and from 1.7 to 1.2 (0% vs. 24% diet), respectively. In addition, Ca content remained relatively constant across CC inclusion levels within phase, as limestone was the primary dietary Ca source in test diets. The greater incidence of TD among broilers fed 16% or 24% CC in

Table 4. Incidence of mortality and culls among broiler chickens fed test diets containing increasing dietary inclusions of screw-pressed *Camelina sativa* cake replacing cornstarch[a]

	Camelina cake inclusion level				P-value[b]
,	0%	8%	16%	24%	Inclusion level
Mortality					
d 0–7	1	3	2	4	0.608
d 8–14	1	1	2	1	0.905
d 15–21	0	1	2	2	0.939
d 22–28	0	0	1	1	0.999
d 29–35	0	0	0	0	1.000
d 36–42	0	0	0	1	0.999
Culls					
d 0–7	4	4	3	1	0.618
d 8–14	3	0	4	3	0.978
d 15–21	0	0	0	0	1.000
d 22–28	0	0	0	0	1.000
d 29–35	0	0	0	0	1.000
d 36–42	0	0	0	0	1.000

[a]Number of mortalities or birds culled per week.

[b]Reported P-values are for the Type 3 analysis of the effect of camelina cake inclusion from the LOGISTIC procedure, based on proportional mortality (#mortality/total) and proportion of birds culled (#culled/total) per week.

Table 5. Incidence of gross post mortem findings among broiler chickens fed test diets containing increasing dietary inclusions of screw-pressed *Camelina sativa* cake replacing cornstarch[a]

	Camelina cake inclusion level				*P*-value[b]
	0%	8%	16%	24%	Inclusion level
Ascites					
d 14	0	0	0	0	0.999
d 28	0	0	0	0	0.999
d 42	0	0	1	1	0.997
Total	0	0	1	1	0.997
Right ventricular dilation					
d 14	0	0	0	0	0.999
d 28	0	0	0	0	0.999
d 42	0	1	2	0	0.949
Total	0	1	2	0	0.953
Left ventricular dilation					
d 14	0	0	0	0	0.999
d 28	0	0	0	0	0.999
d 42	0	1	1	0	0.999
Total	0	1	1	0	0.999
Osteomyelitis					
d 14	0	1	0	2	0.949
d 28	0	0	2	2	0.999
d 42	0	0	3	3	0.999
Total	0	1	5	7	0.303
Arthritis					
d 14	0	0	0	0	0.999
d 28	0	0	0	0	0.999
d 42	1	0	0	0	0.999
Total	1	0	0	0	0.999
Tibial dischondroplasia					
d 14	0	0	1	3	0.792
d 28	0	0	7	8	0.988
d 42	3	0	7	7	0.458
Total	3[b]	0[b]	15[a]	18[a]	0.014
Enlarged thyroid					
d 14	0	0	0	0	0.999
d 28	0	1	0	1	0.999
d 42	0	0	0	0	0.999
Total	0	1	0	1	0.999

[a]Number of abnormal findings based on 3 individuals from each of 6 replicates per treatment per sampling day.

[b]Reported *P*-values are for the Type 3 analysis of the effect of camelina cake inclusion from the LOGISTIC procedure, based on proportional incidence of pathological conditions (#pathological/total).

the present study could potentially be explained by macro-mineral imbalances caused by CC contributing disproportionately more total P than Ca to test diets as inclusion level increased.

Feeding increasing dietary inclusion of CC did affect serological parameters of broiler chickens measured in the present study (Table 6). Increasing dietary CC inclusion linearly increased blood phosphorus, uric acid and thyroxine (T4) levels ($P < 0.01$). Serum triiodothyronine (T3) levels were greater in broilers fed 8% or 16% CC compared with those fed 24% CC ($P < 0.04$). The linear increases in serum P and uric acid were likely related to increased digestible P and CP intake, respectively, as CC replaced cornstarch in diets.

The observed patterns in serum T3 and T4 may be again due to differences in digestible nutrient levels resulting from increasing CC inclusion level in test diets. Serum T3 and T4 levels are closely related. The less bioactive T4 form is generally present in serum in greater concentrations than the more bioactive T3 form (May, 1977; Stojević et al., 2000; Moravej et al., 2006). Moravej et al. (2006) studied the effect of graded protein levels in diets formulated to either 2.8 or 3.2 Mcal/kg AME on serum T3 and T4 in growing broilers. As dietary protein content increased, serum levels of T3 decreased and T4 increased. Dietary AME, in contrast, did not affect serum levels of either T3 or T4. The absence of response of thyroid hormones to AME is in agreement with Giachetto et al. (2003), who reported that T3 and T4 levels were unchanged in growing broilers fed rations containing either 2.9 or 3.2 Mcal/kg AME after a 7-d restriction to 30% of *ad libitum* intake. It would therefore appear that serum T3 and T4 trends in the present study were due to differential intake of digestible AA among test diets with increasing CC inclusion level.

Glucosinolates (34.4–36.3 mmol/kg) and trypsin inhibitor (12–28 TIU/mg) are the major antinutritional factors (ANF) in camelina coproducts (Woyengo et al., 2016). Glucosinolate content in the CC samples studied was greater than for solvent-extracted canola meal (Newkirk, 2009). Camelina meal had greater level of glucosinolates than camelina seed (Sizmaz et al., 2016). After mechanically damaging the intact plant cell, myrosinase in the vacuole is released to hydrolyze glucosinolates to form isothiocyanates, thiocyanates, nitriles, and oxazolidinethiones. Thacker and Widyaratne (2012) reported that the glucosinolate profile in camelina is different from that of canola. Long-chain glucosinolates predominate in camelina compared with short-chain glucosinolates that comprise the majority of glucosinolates in canola meal. This finding is of relevance because the enzymatic metabolites of short-chain glucosinolates, such as sinigrin and pro-goitrin, are responsible for most of the toxic and anti-nutritive effects attributed to glucosinolates (Matthäus and Zubr, 2000). The absence of gross pathological findings or size of the thyroid or liver at the CC inclusion levels tested in the present study confirmed that the dominant glucosinolates in camelina do not induce the same toxic effects as those found in rapeseed.

Organ Weights

Feeding increasing dietary CC inclusion had no effect on proportional weight (wt; g/kg body weight [BW]) of most organs (Table 7). Heart wt on d 28 and pancreas wt on d 28 and 42 linearly increased ($P < 0.01$) in response to increasing dietary inclusion of CC. Post mortem examinations confirmed the absence of gross pathological abnormalities in all organs. The linear increase in heart wt on d 28 may be the result of the linear increase in ADFI over the d 14–28 phase feeding increasing dietary CC inclusions. In a previous pig nursery trial, proportional heart and kidney weights linearly decreased, but liver weight linearly increased with increasing expeller-pressed CC inclusion level up to 18% (Smit and Beltranena, 2017a).

At the time this study was initiated, an increase in pancreas wt in response to increasing CC inclusion was not anticipated. None of the anti-nutritional factors known to be present in *Brassica* family oilseeds including glucosinolate, erucic acid, and condensed tannins have been reported to cause such effects (Papas et al., 1979; Vermorel et al., 1986; Blytt et al., 1988; Mawson et al., 1994). Increases in pancreas wt are, however, an effect associated with the presence of trypsin inhibitor activity as it has previously been reported for soybean products fed to broiler chicks (Clarke and Wiseman, 2005). Budin et al. (1995) reported 12–28 units of trypsin inhibitor activity in camelina seed, raising the possibility that trypsin inhibitor levels in the batches of CC fed in our study was sufficiently high to induce the observed increase in pancreas wt. We confirmed that trypsin inhibitor activity in the two samples of

Table 6. Serological parameters of broiler chickens fed test diets containing increasing dietary inclusions of screw-pressed *Camelina sativa* cake replacing cornstarch (42 days of age)[a]

	Camelina cake inclusion level					*P*-value	
	0%	8%	16%	24%	SEM	Level	Linear
Calcium, mmol/L	2.12	1.95	2.10	2.09	0.08	0.735	0.727
Phosphorus, mmol/L	2.13[b]	2.16[b]	2.40[a]	2.48[a]	0.09	< 0.001	< 0.001
Glucose, mmol/L	14.58	14.46	14.26	13.87	0.36	0.539	0.161
Creatine kinase, U/L	2,893	6,488	4,467	3,737	859	0.192	0.591
Aspartate aminotransferase, U/L	197	217	213	221	12	0.200	0.090
Uric Acid, mmol/L	174[c]	214[bc]	254[b]	308[a]	17	< 0.001	< 0.001
T4, nmol/L	2.13[b]	1.91[b]	4.16[a]	2.88[ab]	0.66	0.027	0.020
T3, nmol/L	3.00[ab]	3.27[a]	3.21[a]	2.45[b]	0.22	0.033	0.104

a,b,c: Different superscripts within rows denote statistically different means ($P < 0.05$).

[a]Least-squares means based on 3 individual samples from each of 6 replicates per camelina cake inclusion level on d 42 of the study.

cake were 9.6 and 9.8 mg/g compared with 1.8 mg/g in the reference sample of soybean meal (Table 1). The presence of trypsin inhibitor has implications for AA digestibility in CC, as reduced AA digestibility is a documented effect of trypsin inhibitor (Wiseman et al., 2003). The presence of trypsin inhibitor in CC may explain the large numerical decrease in apparent AA digestibility in our 24% inclusion test diets relative to the 8 or 16% levels.

Feed Disappearance and Growth Performance

Dietary CC inclusion level affected broiler performance in the present study (Table 8). For the starter phase (d 0–14), cage average daily feed disappearance (ADFI) was greater ($P < 0.01$) for broilers fed 8, 16, and 24% CC inclusion compared with the 0% control. Feeding increasing CC inclusion linearly increased ($P < 0.01$) ADFI for phase 2 (d 15–28), but then linearly reduced ADFI for phase 3 ($P < 0.01$). The net result was no effect of dietary CC inclusion on ADFI for the overall 42-d study. Body wt for broilers fed the 8 and 16% CC inclusion levels were greater than for broilers fed either 0% or 24% CC on d 14, 28, and 42 ($P < 0.01$). Overall (d 0–42) average daily BW gain (ADG) increased linearly with increasing dietary inclusion of CC ($P < 0.05$). For all three phases of the study, ADG for broilers fed 0% and 24% CC was lower compared with those fed the 16% inclusion diet ($P < 0.01$). Likewise, gain-to-feed ratio (G:F) in phases 2 and 3 and for the overall 42-d study was greater for broilers fed 16% CC compared with those fed 0% or 24% CC ($P < 0.01$).

Test diets in the present study were not formulated with the intent to compare growth performance. Substitution of CC for cornstarch increased digestible AA and mineral content and reduced AME content as dietary CC inclusion level increased. Observed patterns in ADG, G:F, and BW were therefore most likely explained as the product of differential digestible nutrient content and intake among increasing dietary CC inclusion levels.

The observed patterns in feed disappearance in the present study are of great interest, increasing with inclusion level for the starter and grower periods, decreasing with inclusion level for the finisher period. Previous reports on the effect of camelina cake inclusion on feed intake in growing broilers are inconsistent and none exceeded 15% dietary inclusion. Increasing camelina cake (5% EE) inclusion up to 10% did not affect feed consumption by broilers in a 42-d experiment (Aziza et al., 2010). Ryhänen et al. (2007) observed no difference in ADFI from d 15 to 37 in broilers fed up to 10% camelina cake (18% EE), but did report reduced ADFI at either 5% or 10% inclusion levels from d 1 to 14. Pekel et al. (2009) observed a reduction in feed intake in broilers fed 10% camelina cake

Table 7. Weight (g/kg of body weight [BW]) of selected organs from broiler chickens fed test diets containing increasing dietary inclusions of screw-pressed *Camelina sativa* cake replacing cornstarch at 14, 28 and 42 days (d) of age[a]

	Camelina cake inclusion level					*P*-value	
Organ weight, g/kg BW	0%	8%	16%	24%	SEM	Level	Linear
Liver							
d 14	37.20[a]	34.51[b]	33.99[b]	34.21[b]	0.69	0.009	0.005
d 28	28.81	30.43	28.85	28.34	0.72	0.199	0.288
d 42	24.28	25.57	23.64	24.28	0.60	0.146	0.301
Heart							
d 14	7.18	7.22	6.77	7.16	0.22	0.371	0.491
d 28	6.29[b]	6.76[a]	7.00[a]	6.98[a]	0.16	0.004	0.001
d 42	5.84	5.89	6.13	6.13	0.20	0.629	< 0.001
Spleen							
d 14	0.73	0.72	0.78	0.76	0.05	0.810	0.427
d 28	0.82	0.89	0.93	0.83	0.06	0.561	0.593
d 42	1.11	1.13	1.24	1.21	0.06	0.343	0.105
Pancreas							
d 14	4.10	4.48	4.32	4.52	0.18	0.234	0.181
d 28	2.43[c]	2.70[c]	3.28[b]	3.89[a]	0.15	< 0.001	< 0.001
d 42	1.70[c]	1.89[c]	2.23[b]	2.70[a]	0.09	< 0.001	< 0.001

a,b, c: Different superscripts within rows denote statistically different means ($P < 0.05$).

[a]Least-squares means based on 3 individuals sampled from each of 6 replicates per camelina cake inclusion level per sampling day.

Table 8. Average daily feed disappearance (ADFI), body weight (BW), average daily weight gain (ADG), and gain-to-feed ratio (G:F) of broiler chickens fed test diets containing increasing dietary inclusions of screw-pressed *Camelina sativa* cake replacing cornstarch[a]

	Camelina cake inclusion level					*P*-value	
	0%	8%	16%	24%	SEM	Level	Linear
ADFI, g							
d 0–14	38.7[b]	40.6[a]	40.9[a]	40.5[a]	0.7	0.009	0.011
d 15–28	115.1[c]	117.9[bc]	120.6[ab]	123.2[a]	2.0	0.015	0.002
d 29–42	266.6[a]	266.8[a]	260.9[ab]	253.5[b]	3.8	0.042	0.008
d 0–42	140.1	141.8	140.8	139.1	1.6	0.557	0.477
BW, g							
d 0	45.5	45.6	45.0	45.2	0.2	0.279	0.113
d 14	396.2[b]	423.9[a]	416.8[a]	398.7[b]	5.0	0.002	0.893
d 28	1,134.1[c]	1,323.9[a]	1,332.0[a]	1,240.1[b]	26.5	< 0.001	0.002
d 42	2,226.6[b]	2,561.1[a]	2,735.1[a]	2,332.2[b]	66.0	< 0.001	0.079
ADG, g							
d 0–14	25.1[b]	27.0[a]	26.6[a]	25.3[b]	0.4	0.002	0.954
d 15–28	52.7[c]	64.3[ab]	65.4[a]	60.1[b]	1.9	< 0.001	0.003
d 29–42	78.0[b]	88.4[b]	100.3[a]	78.0[b]	3.9	0.002	0.349
d 0–42	51.9[c]	59.9[b]	64.1[a]	54.5[c]	1.5	< 0.001	0.046
G:F, g:g							
d 0–14	0.649	0.667	0.649	0.624	0.012	0.063	0.054
d 15–28	0.458[b]	0.547[a]	0.542[a]	0.488[b]	0.016	< 0.001	0.159
d 29–42	0.293[b]	0.332[b]	0.384[a]	0.307[b]	0.014	< 0.001	0.091
d 0–42	0.466[b]	0.515[a]	0.525[a]	0.473[b]	0.009	< 0.001	0.362

a,b,c: Different superscripts within rows denote statistically different means ($P < 0.05$).

[a]Least-squares means based on 6 replicates per camelina cake inclusion level.

(13% EE) compared with controls from d 21 to 42 of age. Thacker and Widyaratne (2012) reported a linear reduction in ADFI with increasing dietary inclusion of CC (11% EE) to 15% from d 1 to 21 of age. Camelina is known to contain several anti-nutritive compounds that may adversely affect feed intake, including sinapine, glucosinolates, and condensed tannins (Matthaus and Zubr, 2000; Woyengo et al., 2016). The concentration of these compounds in camelina seed are known to vary by seed origin (Schuster and Friedt, 1998). Levels of these compounds in co-products may also vary as a result of oil extraction (dilution) and subsequent processing (Dçbrowski et al., 1989; Huang et al., 1995). Reports in the literature generally do not describe the source of the seed (cultivar) and only a few describe the processing methodology used to generate cake. The large variation in EE content reported for cakes studied previously is indicative of inconsistency in oil extraction method. It is therefore possible that variation in seed source and oil extraction methodology could be responsible for inconsistent results of effects on feed intake and growth performance when camelina co-products are fed to broilers.

Nutrient Digestibility

Apparent total tract and ileal digestibility of dry matter (DM), gross energy (GE), and nutrients decreased linearly as CC replaced cornstarch in test diets ($P < 0.01$; Table 9). For most nutrients, apparent ileal digestibility was not different between broilers fed 8% and 16% CC, but was lower for those fed 24% CC inclusion ($P < 0.01$). Coefficients of variation for most AA exceeded 20%, which casts doubt on their reliability for the purposes of diet formulation (Table 10). Numerically, AA digestibility coefficients calculated for CC based on 8% and 16% inclusion diets were similar, but those calculated from the 24% inclusion diet were considerably lower.

Total tract digestibility coefficients of GE, DM, and CP for test diets in the present study agree with previous reports. Aziza et al. (2013) reported lower AME (2.26 vs. 2.34 Mcal) and total tract CP digestibility (0.28 vs. 0.40) for a diet containing 10% camelina cake compared with a corn-soybean meal diet fed to laying hens. Thacker and Widyaratne (2012) also reported a linear reduction in apparent total tract digestibility of DM, GE, and nitrogen retention in broilers fed increasing dietary inclusion levels of camelina cake. Further investigation of nutrient digestibility in camelina co-products is required in order to generate digestible nutrient profiles that result in predictable broiler performance. Inconsistencies in broiler performance among the range of camelina cakes tested previously indicate the possibility that the technique used to extract the oil may also influence nutrient digestibility in the cake. Thus, further investigations into the effect that oil extraction methodology has on CC nutrient digestibility are warranted.

In conclusion, the results of the present study indicate that CC can safely be fed at dietary inclusions up to and including 24% without adverse effects on the mortality or indicators of toxicity in broiler chickens. Feed disappearance in the present study further suggests that CC was acceptable to broiler chickens up to 16% dietary inclusion. The present study, however, also underscores the need to better understand the advantages and limitations of dietary CC inclusion in order to optimize its use as a feedstuff for poultry. In particular, more data is needed regarding digestible nutrient content of CC for broiler chickens. Our finding of detectable levels of trypsin inhibitor in CC also suggest further investigations should be undertaken into the relative significance of anti-nutritive factors present in camelina cultivars. The effect that oil extraction

Table 9. Apparent total tract digestibility (ATTD) and apparent ileal digestibility (AID) of gross energy, dry matter and nutrients in test diets containing increasing dietary inclusion levels of screw-pressed *Camelina sativa* cake replacing cornstarch fed to broiler chickens, 21-days of age[a]

	Camelina cake inclusion level					*P*-value	
	0%	8%	16%	24%	SEM	Level	Linear
ATTD, %							
Gross energy	79.68[a]	73.50[b]	65.00[c]	47.81[d]	1.32	< 0.001	< 0.001
Crude protein	70.04[a]	62.67[b]	58.58[c]	42.11[d]	1.22	< 0.001	< 0.001
Dry matter	78.41[a]	71.69[b]	65.06[c]	48.01[d]	1.14	< 0.001	< 0.001
Ether extract	79.33[a]	66.47[b]	41.37[c]	18.16[d]	3.67	< 0.001	< 0.001
Phosphorus	52.74[a]	43.24[b]	42.25[b]	24.28[c]	1.41	< 0.001	< 0.001
AID, %							
Gross energy	73.02[a]	70.27[ab]	66.32[b]	49.67[c]	1.79	< 0.001	< 0.001
Crude protein	83.12[a]	76.91[b]	75.15[b]	61.29[c]	1.69	< 0.001	< 0.001
Dry matter	75.00[a]	69.77[b]	66.79[b]	50.83[c]	1.51	< 0.001	< 0.001
Indispensable amino acids							
Arginine	87.16[a]	82.18[ab]	80.85[b]	69.99[c]	1.83	< 0.001	< 0.001
Histidine	84.70[a]	78.25[b]	77.68[b]	66.37[c]	1.83	< 0.001	< 0.001
Isoleucine	83.42[a]	76.64[b]	76.19[b]	65.43[c]	1.76	< 0.001	< 0.001
Leucine	84.38[a]	78.51[b]	78.12[b]	68.07[c]	1.81	< 0.001	< 0.001
Lysine	85.34[a]	77.83[b]	76.65[b]	64.72[c]	1.78	< 0.001	< 0.001
Methionine	84.64[a]	79.46[a]	79.60[a]	69.94[b]	1.90	< 0.001	< 0.001
Methionine + Cysteine	80.63[a]	73.69[b]	74.44[b]	62.33[c]	2.04	< 0.001	< 0.001
Phenylalanine	85.46[a]	78.82[b]	78.31[b]	68.37[c]	1.79	< 0.001	< 0.001
Threonine	79.88[a]	72.20[b]	72.32[b]	60.89[c]	1.84	< 0.001	< 0.001
Tryptophan	89.26[a]	80.44[b]	73.56[b]	57.70[c]	2.47	< 0.001	< 0.001
Valine	84.76[a]	77.50[b]	77.18[b]	66.16[c]	1.67	< 0.001	< 0.001
Dispensable amino acids							
Alanine	82.68[a]	76.25[b]	75.79[b]	65.07[c]	1.84	< 0.001	< 0.001
Aspartic acid	78.28[a]	71.29[b]	72.66[b]	60.98[c]	1.95	< 0.001	< 0.001
Cysteine	76.42[a]	67.68[b]	69.28[b]	54.52[c]	2.22	< 0.001	< 0.001
Glutamic acid	89.99[a]	86.14[ab]	84.99[b]	75.73[c]	1.42	< 0.001	< 0.001
Glycine	80.03[a]	73.26[b]	72.44[b]	59.92[c]	1.94	< 0.001	< 0.001
Proline	85.70[a]	78.38[b]	76.74[b]	62.82[c]	2.05	< 0.001	< 0.001
Serine	82.34[a]	75.37[b]	74.85[b]	62.25[c]	1.77	< 0.001	< 0.001
Tyrosine	83.84[a]	76.13[b]	75.19[b]	63.16[c]	1.82	< 0.001	< 0.001
Total amino acids	84.35[a]	77.98[b]	77.32[b]	66.33[c]	1.74	< 0.001	< 0.001

a,b,c: Different superscripts within rows denote statistically different means ($P < 0.05$).

[a]Least-squares means based on 6 replicates per camelina cake inclusion level.

Table 10. Apparent ileal digestibility of amino acids in camelina cake, calculated using the difference method and based on 8, 16 and 24% dietary camelina cake inclusion replacing cornstarch fed to broiler chickens, 21-days of age[a]

	Camelina cake inclusion level				*P*-value
	8%	16%	24%	SEM	Level
Indispensable amino acids					
Arginine	71.94	68.97	47.68	6.39	0.082
Histidine	61.35	61.99	36.30	7.68	0.101
Isoleucine	54.42	57.48	31.91	7.98	0.139
Leucine	53.57	57.53	34.40	8.40	0.194
Lysine	43.53	48.34	20.98	8.48	0.140
Methionine	56.51	61.82	41.27	7.85	0.209
Methionine + Cysteine	55.15	60.53	34.76	7.30	0.096
Phenylalanine	54.55	57.61	35.42	8.81	0.220
Threonine	37.96	48.70	25.43	7.16	0.135
Tryptophan	69.65[a]	48.93[ab]	26.69[b]	8.57	0.026
Valine	63.64[a]	64.40[a]	38.94[b]	6.16	0.027
Dispensable amino acids					
Alanine	50.63	55.56	32.19	7.71	0.163
Aspartic acid	51.07	59.71	31.07	8.31	0.114
Cysteine	54.85[a]	60.04[a]	28.57[b]	6.99	0.048
Glutamic acid	71.08	67.58	42.74	7.63	0.076
Glycine	56.47	56.56	28.99	7.19	0.066
Proline	35.47	37.78	6.09	9.22	0.071
Serine	41.84	49.83	28.42	7.10	0.146
Tyrosine	37.12	45.23	24.89	8.43	0.234
Total amino acids	54.82	57.45	32.45	7.59	0.115

a,b,c: Different superscripts within rows denote statistically different means ($P < 0.05$).
[a]Least-squares means based on 6 replicates per camelina cake inclusion levels.

conditions have on feeding value of the resulting CC for poultry also warrants further attention.

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