Nutritional characteristics of camelina meal for 3-week-old broiler chickens

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ABSTRACT Limited information on nutritional characteristics on camelina meal for broiler chickens limits its use in diets of broiler chickens. The objectives of this study were to determine the ileal digestible energy (IDE), ME, and ME∞ contents of 2 different camelina meal (CM1 and CM2) samples for 3-wk-old broiler chickens using the regression method and to determine glucosinolate compounds in the camelina meal samples. The CM1 and CM2 were incorporated into a corn-soybean meal-based reference diet at 3 levels (0, 100, or 200 g/kg) by replacing the energy-yielding ingredients. These 5 diets (reference diet, and 100 and 200 g/kg camelina meal from each of CM1 and CM2) were fed to 320 male Ross 708 broilers from d 21 to 28 post hatching with 8 birds per cage and 8 replicates per treatment in a randomized complete block design. Excreta were collected twice daily from d 25 to 28, and jejunal digesta and ileal digesta from the Meckel’s diverticulum to approximately 2 cm proximal to the ileocecal junction were collected on d 28. The total glucosinolate content for CM1 and CM2 were 24.2 and 22.7 nmol/mg, respectively. Jejunal digesta viscosity was linearly increased (P < 0.001) from 2.2 to 4.1 cP with increasing dietary camelina meal levels. There were linear effects (P < 0.001) of CM1 and CM2 substitution on final weight, weight gain, feed intake, and G:F. The inclusion of CM1 and CM2 linearly decreased (P < 0.001) ileal digestibility of DM, energy, and IDE. The supplementation of CM1 and CM2 linearly decreased (P < 0.001) the retention of DM, nitrogen, and energy; ME, and ME∞. By regressing the CM1 and CM2-associated IDE intake in kilocalories against kilograms of CM1 and CM2 intake, the IDE regression equation was Y = −10 + 1,429 × CM1 + 2,125 × CM2, r2 = 0.55, which indicates that IDE values were 1,429 kcal/kg of DM for CM1 and 2,125 kcal/kg of DM for CM2. The ME regression was Y = 5 + 882 × CM1 + 925 × CM2, r2 = 0.54, which implies ME values of 882 kcal/kg of DM for CM1 and 925 kcal/kg of DM for CM2. ME∞ regression was Y = 2 + 795 × CM1 + 844 × CM2, r2 = 0.52, which implies ME∞ values of 795 kcal/kg of DM for CM1 and 844 kcal/kg of DM for CM2. Based on these results, utilization of energy and nitrogen in camelina meal by broiler chickens is low and the high viscosity observed in jejunal digesta as well as the total glucosinolate in camelina meal may have contributed to the poor energy and nitrogen utilization.

Key words: camelina meal, expeller, metabolizable energy, broiler

INTRODUCTION

Camelina sativa (L. Crantz) or false flax (as it is generally known) originates from the Mediterranean and Central Asia and had been grown for oil before the Middle Ages in Europe (Hurtaud and Peyraud, 2007). The seed of Camelina sativa (L. Crantz) contains between 350 and 400 g oil/kg, which is high in n-3 fatty acids (Kakani et al., 2012). The polyunsaturated fatty acids concentration is approximately 500 g/kg oil (Zubr and Matthias, 2002). The oil, protein, and the fiber found in the seeds of camelina varies among seed varieties, as well as growing conditions (Agegnehu and Honermeier, 1997; Angelini et al., 1997; Zubr, 2003).

Due to the increase in biodiesel production from vegetable oils in recent years, competition among energy, food, and industrial use of these feedstocks has increased. This has increased food prices and the cost of goods and resulted in reduced human consumption of these seeds (Aurore et al., 2003). Camelina can be grown in arid areas and does not affect production of food crops. Also, camelina may be suitable for use in biodiesel production. Therefore, camelina grown in various countries recently is used in biodiesel production. Due to the above-mentioned conditions, the commercial development of camelina in the United States of
America has grown to more than 30,000 hectares mostly for biodiesel production (Pilgeram et al., 2007). Camelina meal is the by-product that remains after the cold pressing of its seeds and might be considered as an alternative feedstuff in poultry diets because of its favorable oil content for poultry, camelina meal has been reported to contain approximately 350 g CP, to its high residual oil (from 50 to 130 g/kg) and its high n-3 fatty acid concentration, which is approximately 25 to 30% of total fatty acids (Cherian et al., 2009; Pekel et al., 2009; Aziza et al., 2010a, b). In addition to its favorable oil content for poultry, camelina meal has been reported to contain approximately 350 g CP, 100 g crude fiber, and 50 g ash/kg (Pekel et al., 2009). Protein in camelina meal is rich in arginine, cysteine, lysine, methionine, and threonine which are indispensable amino acids for poultry. In addition, camelina seed and its byproduct camelina meal can be used in the broiler diets to produce n-3 fatty acid enriched chicken meat because of its high n-3 fatty acid content (Aziza et al., 2010a). It was also observed that expeller extracted camelina meal at 50 or 100 g/kg broiler diet resulted in meat with higher antioxidant capacity (Aziza et al., 2010b). However, detrimental effects on bird performance was also reported by several authors, which was attributed to a variety of reasons including antinutrients like glucosinolates and nonstarch polysaccharides (Ryhänen et al., 2007; Pekel et al., 2009).

In experiments conducted with broiler chickens, several authors reported significant decreases in digestibility of dry matter, nitrogen, and energy with increasing dietary camelina meal concentration (Acamovic et al., 1999; Thacker and Widyaratne, 2012). To our knowledge, there is no current data on ileal digestible and metabolizable energy concentrations of expeller-extracted camelina meal. Therefore, the objective of this study was to determine ileal digestible energy (IDE), ME, and MEₙ of two different expeller camelina meals (CM1 and CM2) for 3-wk-old broiler chickens and glucosinolate content in the camelina meal samples.

**MATERIALS AND METHODS**

**Birds and Management**

Male broiler chicks (Ross 708) were purchased from a local hatchery, weighed and tagged with identification numbers. Birds were reared in electrically heated battery brooders and the temperature was kept at 35°C, 31°C and 27°C from d 1 to 8, d 8 to 15, and d 15 to 28 post-hatching, respectively with continuous fluorescent lighting. The birds were provided ad libitum access to water and a standard starter broiler diet from d 1 to 21 post hatching. The average d 1 post hatching BW, d 21 post hatching BW and 20-d feed intake were 44, 818, and 1029 g, respectively. On d 21, 320 birds were blocked by weight and allocated to 5 treatments. The birds were allocated to diets in such a way that the average initial BW was not different across diets. There were 5 dietary treatments and each diet was replicated 8 times with 8 birds per replicate cage. Birds were provided ad libitum access to water and dietary treatments from d 21 to 28, and the battery cage temperature kept at 27°C.

On d 21 and 28 post-hatching, birds were weighed individually and feed intake per cage recorded. Excreta were collected daily from d 25 to 28. During collection waxed paper was placed in trays under the cages and the excreta on the paper were collected. The collected excreta samples were pooled per cage over a 3-d period and stored in a freezer at −20°C until further processed for analyses. On d 28 post hatching feeders and birds were weighed to determine BW gain and feed intake, followed by asphyxiation using carbon dioxide. Jejunal digesta was collected from the end of the duodenum to the Meckel’s diverticulum. Ileal digesta from the Meckel’s diverticulum to approximately 2 cm proximal to the ileocecal junction were collected. Ileal contents from birds in the same cage were flushed with distilled water into plastic containers and stored at −20°C until dried and ground. All procedures used in the current study were approved by the Purdue University Animal Care and Use Committee.

**Test Ingredients and Diets**

Two camelina meals were evaluated for energy in the current study. The analyzed chemical composition of 2 camelina meal samples are presented in Table 1. Camelina meal from 2 different sources was...
Table 2. Ingredient and nutrient composition of starter diet (d 1 to 21) and experimental diets fed from d 21 to 28.1

<table>
<thead>
<tr>
<th>Ingredient, g/kg</th>
<th>Starter Reference diet</th>
<th>Camelina meal 1</th>
<th>Camelina meal 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>545.2</td>
<td>523.5</td>
<td>466.5</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>360.0</td>
<td>370.0</td>
<td>331.2</td>
</tr>
<tr>
<td>Camelina meal</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Soybean oil</td>
<td>50.0</td>
<td>40.0</td>
<td>35.8</td>
</tr>
<tr>
<td>Chronic oxide-ground corn premix1</td>
<td>0.0</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Monocalcium phosphate2</td>
<td>15.0</td>
<td>17.5</td>
<td>17.5</td>
</tr>
<tr>
<td>Limestone (38% Ca)</td>
<td>15.0</td>
<td>14.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Salt</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Vitamin-mineral premix3</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>DL-Methionine</td>
<td>3.8</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>L-Lysine, HCl</td>
<td>2.9</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>L-Threonine</td>
<td>1.1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
</tr>
</tbody>
</table>

Calculated nutrient content

- CP, g/kg: 227, 229, 241, 253, 239, 249
- ME, kcal/kg: 3,218
- Ca, g/kg: 9.2, 9.0, 9.0, 9.0, 9.0, 9.0
- P, g/kg: 6.9, 7.0, 8.0, 8.0, 8.0, 8.0
- Non-phytate P, g/kg: 4.4, 5.0, 5.0, 5.0, 5.0, 5.0
- Ca:P: 1.3, 1.2, 1.2, 1.1, 1.2, 1.1

Analyzed nutrient content

- DM, g/kg: 888.7, 890.4, 901.4, 896.1, 898.3
- CP, g/kg: 215.1, 234.9, 246.2, 236.5, 246.6
- Gross energy, kcal/kg: 4,095, 4,128, 4,279, 4,169, 4,262
- Ash, g/kg: 64.0, 60.4, 65.1, 60.8, 63.9
- Ca, g/kg: 9.9, 8.9, 9.8, 9.2, 10
- P, g/kg: 7.5, 7.7, 8.3, 7.7, 6.9

1Prepared as 1 g of chromic oxide added to 4 g of ground corn.
216% Ca, 21% P.
3Supplied the following per kilogram of diet: vitamin A, 5,484 IU; vitamin D3, 2,643 IU; vitamin E, 11 IU; menadione sodium bisulfite, 4.38 mg; riboflavin, 5.49 mg; D-pantothenic acid, 11 mg; niacin, 44.1 mg; choline chloride, 771 mg; vitamin B12, 13.2 μg; biotin, 55.2 μg; thiamine mononitrate, 2.2 mg; folic acid, 990 μg; pyridoxine hydrochloride, 3.3 mg; I, 1.11 mg; Mn, 66.06 mg; Cu, 4.44 mg; Fe, 44.1 mg; Zn, 44.1 mg; Se, 300 μg.

 integrates into a corn-soybean meal-based reference diet at 3 levels (0, 100, and 200 g/kg) by replacing the energy-yielding ingredients. The ingredient composition of the 5 diets (reference diet, and 100 and 200 g/kg camelina meal from 2 sources) is presented in Table 2. Corn, soybean meal, and soybean oil have been adjusted at the same ratio to account for substitution. These ratios were 1.47, 13.59, and 9.25 for corn: soybean meal, corn: soybean oil, and soybean meal: soybean oil, respectively. This substitution method was reported to be essential for separating the energy contribution of basal ingredients to the assay diets from that of the test ingredient (camelina meal) when using the regression method in energy utilization studies (Adeola and Ileleji, 2009). The diets had chromic oxide added as an indigestible marker to enable determination of digestibility and retention by the index method.

**Chemical Analysis**

Excreta and ileal digesta samples were placed in a forced-air oven at 55°C for 96 h and subsequently ground to pass through a 0.5-mm screen using a grinder (Retsch ZM 100, GmbH & Co. K. C., Haan, Germany) to ensure a homogeneous mixture. Diets, excreta, and ileal digesta were analyzed for dry matter by drying in an oven (Precision Scientific Co., Chicago, IL) at 105°C for 24 h. Ether extract in camelina meal samples was determined by extracting in petroleum ether using a Soxhlet apparatus (Lab-Line Multi-Unit Extractor, Lab-Line Instruments, Inc., Melrose Park, IL) for approximately 8 h (AOAC, 2000; Method 934.01). Diets, excreta, and ileal digesta were analyzed for gross energy in an adiabatic bomb calorimeter (Model 1261, Parr Instrument Co., Moline, IL) using benzoic acid as a calibration standard. The diets, excreta, and ileal digesta samples were digested (nitric/perchloric wet ash, AOAC Method 935.13 A (a); AOAC International, 2000) chromium concentration was subsequently determined at 440 nm in a spectrophotometer (Spectronic 21D, Milton Roy Co., Rochester, NY). The nitrogen content of the samples was determined by the Kjeldahl method with Kjeltec Auto 1030 Analyzer (Tecator Inc., Herndon, VA 22071). Camelina meal samples were analyzed for neutral detergent fiber and acid detergent fiber |method 973.18 (A, B, C, D);
AOAC International, 2000]. Camelina meal and diet samples were prepared using a nitric-perchloric acid wet ash before the determination of Ca and P contents (AOAC International, 2000). Acid molybdate and Fiske-Subbarow reducer solutions were added to form a phosphomolybdenum complex and concentration of P was determined in a spectrophotometer (Spectronic 21D, Milton Roy Co., Rochester, NY; AOAC Official Method 946.06) at a wavelength of 620 nm. Concentration of Ca in the supernatant was measured using flame atomic absorption spectrometry (Varian FS240 AA Varian Inc., Palo Alto, CA). Camelina meal samples for amino acid analysis were prepared using a 24-h hydrolysis in 6 N HCl at 110°C under an atmosphere of nitrogen. For methionine and cysteine, performic acid oxidation was done before acid hydrolysis. Samples for tryptophan analysis were hydrolyzed using barium hydroxide. Amino acids in hydrolyzates were determined by HPLC after postcolumn derivatization. All amino acid analyses were done at the University of Missouri Experiment Station Chemical Laboratory, Columbia [method 982.30 E (a, b, c); AOAC International, 2000].

**Glucosinolate Analysis**

Desulfoglucosinolate extracts were prepared according to the protocol previously described (Glover et al., 1988). Camelina meal samples were extracted in ether and 20 mg of the ether-extracted samples was incubated in 400 μL of 50% methanol containing 20 μL of 5 mM sinigrin (Sigma) for 10 min at 80°C followed by incubation at 65°C for 2 h. After centrifuging for 10 min, 300 μL of supernatant were mixed with 200 μL of QAE sephadex resin and incubated at room temperature for 5 min. The sephadex resin was washed with 50% methanol and water. Washed resin was incubated in 100 μL of water containing 5 μL of sulfatase for 8 h at 37°C. Sulfatase was prepared as described by Graser et al. (2000). Briefly, 700 mg of aryl sulfatase (Sigma type H-1 from Helix pomatia) was dissolved in 30 mL of water and mixed with 30 mL of absolute ethanol. After centrifugation at 5000 × g for 20 min, the supernatant was mixed with 90 mL of additional absolute ethanol and centrifuged again at 4000 × g for 15 min. The pellet was dissolved in 25 mL of deionized water and stored at −20°C until ready for use. After centrifugation, desulfoglucosinolates were separated by HPLC (Shimadzu) with a Variant Microsorb C18 reversed-phase column using a method described previously (Lee et al., 2012). Desulfoglucosinolates were identified with LC-MS and quantified from peak areas at 229 nm relative to the internal standard in the HPLC chromatogram.

**Jejunal Digesta Viscosity**

Approximately 12 g of digesta sample was placed in a 50 mL plastic centrifuge tube, vortexed for 10 s and centrifuged at 10,000 × g for 10 min at 4°C. The supernatant was transferred into a 2-mL sample cup. The cup containing the supernatant was placed in a water bath (Precision, GCA Corp., College Park, MD) that has been preheated to 40°C until the temperature of the sample equilibrate with that of the water in the water bath (approximately 15 min). Viscosity of these samples were determined using a viscometer (Visbro viscometer, model SV-1A, A&D Company Limited, Japan). The results are reported in centipoises (cP). The same procedure was used for determining the viscosity of diets, except that 30 mL of double distilled water was added to 2.5 g of diet and vortexed prior to centrifugation.

**Calculations and Statistical Analysis**

Metabolizability coefficients (C) of nutrients and energy (ME and IDE) was calculated as previously reported (Bolarinwa and Adeola, 2012) using the following equation: C = 1 − [(Crd/CrO) × (EO/El)], where Crd is the chromium concentration of dietary intake, CrO is the chromium concentration of output (as analyzed in excreta or ileal digesta), EO is the nutrient or energy concentration of output (as analyzed in excreta, and ileal digesta), and El is the nutrient or energy concentration of dietary intake. The product of C and gross energy concentration of (kcal/kg) the diet were used to calculate the ME of the diet. Nitrogen-corrected metabolizable energy (MEn, kcal/kg) of diet was calculated, using the factor 8.22 kcal/g N (Hill and Anderson, 1958), as ME = (8.22 × Nret), where Nret represents N retention in g/kg of DM intake and calculated as Ni − (NO × Crd/CrO); Ni represents nitrogen concentration in the diet, NO represents nitrogen concentration in the excreta in g/kg DM, and Crd and CrO are as defined above. Proportional contribution of energy by the reference diet and the test ingredient to the assay diet, by definition gives: Prd + Pti = 1; where Prd represents proportional energy contribution of reference diet and Pti represents energy contribution by the test ingredient, respectively. The coefficients of (C) ME for reference diet, test diets, and test ingredients are Crd, Ctd, and Cti, respectively. The assumption of additivity in diet formulation implies that: Ctd = (Crd × Prd) + (Cti × Pti); Solving for Cti gives Cti = [(Ctd − (Crd × Prd)) / Pti; Substituting 1− Pti for Prd gives Cti = [Crd + (Ctd − Crd)/Pti].

General linear models procedures of SAS (2006) was used to analyze the growth performance and energy and nutrient utilization data as a randomized complete block design. The effects of increasing levels of camelina meal in assay diets were compared using linear and quadratic contrasts. Regression of the test ingredient-associated IDE, ME, or MEn intake in kilocalories against kilograms of test ingredient intake (on a DM basis) per cage was done using multiple linear regression (Littell et al., 1995). The student t-test was used to compare the differences between mean glucosinolate concentrations in 2 camelina meals.
RESULTS AND DISCUSSION

The camelina meal samples used in this study were analyzed to contain 4,777 and 4,897 kcal of GE/kg, 356 and 337 g of CP/kg, 131 and 135 g of ether extract/kg, 316 and 386 g of NDF/kg, and 51 and 54 g of ash/kg, respectively. Pekel et al. (2009) reported 349 g of CP/kg, and 135 g of ether extract/kg for cold pressed camelina meal, which is in agreement with the current results. Aziza et al. (2010b) reported a mean CP value of 352 g of CP/kg, 49 g of ether extract/kg, 418 g of NDF/kg, and 65 g of ash/kg for camelina meal. The NDF content they reported is considerably higher and the fat content is lower than the samples used in the current study. However, other nutrient levels are generally within the range reported.

Total glucosinolate content for 2 camelina meal samples used in the current study were 24.2 and 22.7 nmol/mg (Figure 1), which is very similar to the 24.4 μmol/g value reported by Aziza et al. (2010b). Ryhänen et al. (2007) reported a total glucosinolate of 22.0 μmol/g, whereas Pekel et al. (2009) observed a total glucosinolate of 20.3 μmol/g for camelina meal, which are in agreement with the results of the current study. Camelina meal 1 (CM1) had significantly higher 9-methylsulfinyl-9-nonyl-glucosinolate (GS9) than the camelina meal 2 (CM2), whereas CM2 had higher 11-methylsulfinylundecyl-glucosinolate (GS11) content than the CM1. This difference between 2 camelina meal samples might be attributed to seed genotypes, climatic or soil conditions including the fertilization of the plant grown (Schuster and Friedt, 1998; Matthäus and Zubr, 2000). Of these factors, sulfur fertilization might be the most important factor influencing glucosinolate content of camelina because it was reported that sulfur fertilization increased plant glucosinolate content by 25% to 500% (Falk et al., 2007). Moreover, 10 methylsulfinyldecyl-glucosinolate (GS10) and total glucosinolate contents were not different between 2 camelina meal samples analyzed in the current study. Schuster and Friedt (1998) reported that GS10 is the main glucosinolate in camelina seed representing approximately 65% of the total glucosinolates in camelina seed, which is confirmed by the result of the current study on camelina meal.

There were linear (P < 0.001) effects of CM1 and CM2 substitution on final weight, weight gain, feed intake, and G:F (Table 3). Moreover, CM1 inclusion also resulted in a quadratic decrease in G:F. Inclusion of camelina meal from the 2 sources reduced (P < 0.01) all the growth performance criteria in the current study. This is in agreement with Ryhänen et al. (2007) and Pekel et al. (2009) that reported impairment on feed efficiency with 50 or 100 g/kg camelina meal inclusion in the starter diet of broiler chickens. On the contrary, Aziza et al. (2010a) reported that camelina meal addition to broiler diet at 50 and 100 g/kg level had no negative effect on carcass weight, BW gain and feed efficiency at 6 wk of age. Thacker and Widyaratne (2012) also showed that the camelina meal inclusion up to 150 g/kg decreased BW gain and impaired the feed conversion of broiler chickens. These authors attributed this negative impact on the growth performance of birds to the presence of glucosinolates in camelina meal. It was indicated that the live performance of birds is compromised if dietary glucosinolate level is more than 2.5 μmol/g (Mushtaq et al., 2007). In the current study, assuming that all glucosinolates in the experimental diets are contributed by camelina meal, the total glucosinolate levels would be 2.42 and 4.84 μmol/g for CM1

Table 3. Growth performance of birds fed experimental diets from d 21 to 28 of age.\(^1\)

<table>
<thead>
<tr>
<th>Item</th>
<th>Reference diet</th>
<th>Camelina meal 1, g/kg</th>
<th>Camelina meal 2, g/kg</th>
<th>SEM</th>
<th>L(^2)</th>
<th>Q(^2)</th>
<th>L(^3)</th>
<th>Q(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial weight, g</td>
<td>840</td>
<td>839</td>
<td>841</td>
<td>840</td>
<td>840</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Final weight, g</td>
<td>1325</td>
<td>1252</td>
<td>1157</td>
<td>1294</td>
<td>1228</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Weight gain, g</td>
<td>485</td>
<td>433</td>
<td>316</td>
<td>454</td>
<td>389</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Feed intake, g</td>
<td>7.41</td>
<td>6.68</td>
<td>6.13</td>
<td>728</td>
<td>672</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>G:F, k/g</td>
<td>655</td>
<td>619</td>
<td>515</td>
<td>625</td>
<td>582</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Jejunum viscosity, cP</td>
<td>2.21</td>
<td>3.03</td>
<td>3.45</td>
<td>3.07</td>
<td>4.10</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

\(^1\)Data are means of 8 replicate cages with 8 birds per cage.
\(^2\)Linear (L) and quadratic (Q) contrasts for camelina meal 1.
\(^3\)Linear (L) and quadratic (Q) contrasts for camelina meal 2.
diets and 2.27 and 4.54 μmol/g for CM2 diets at 100 and 200 g/kg inclusion levels, respectively. Thus, the total glucosinolate level in treatment diets, especially for 200 g/kg inclusion levels, is a lot higher than the suggested upper limit for glucosinolate in broiler diets. This demonstrates that this high glucosinolate levels in the treatment diets explains at least a part of detrimental effects of inclusion of dietary camelina meal on live performance in the current study. It is well known that the myrosinase enzyme in the plant breaks down the whole intact and nontoxic glucosinolates in the bird’s digestive tract. Depending on the seed, the breakdown products of myrosinase catalysis such as goitrin, nitriles, and thiocyanates affect the thyroid gland and causes detrimental effects on the birds performance (Tripathi and Mishra, 2007).

Because jejunal digesta viscosity increased with the addition of camelina meal to the reference diet (Table 3), this higher viscosity might also have contributed to these detrimental effects on growth. Adeola and Bedford (2004) demonstrated that reduction in growth performance is related to increased intestinal digesta viscosity and subsequent decrease in energy and nutrient utilization. The approximate respective increase in the jejunal digesta viscosity in diets with added camelina meal at 100 and 200 g/kg were 37% and 56% for CM1 and 39% and 85% for CM2 when compared to reference diet. Although birds fed 200 g/kg CM2 had higher jejunal digesta viscosity than the birds fed the same amount of CM1 (56 to 85% increase, respectively), it did not cause a further reduction in growth performance of the birds. Viscosity is known to be associated with the nonstarch polysaccharides content of the cereal or oilseed used in animal diets (Bedford and Classen, 1993). To our knowledge, no published data on the nonstarch polysaccharide content of camelina meal is available. However, for canola meal that belongs to the same taxonomic family (Brassicaceae) as camelina, it was reported to contain 16 to 18% nonstarch polysaccharides of which 1.5% is soluble (Bell, 1993; Kocher et al., 2000). Relationship between in vitro diet viscosity and in vivo jejunal viscosity of birds fed two levels (100 and 200 g/kg diet) of camelina meal from CM1 and CM2 was examined. The correlation between in vitro dietary and in vivo jejunal viscosities of birds fed the CM1 (0.995) and CM2 (0.974) was very strong and indicating that higher the dietary camelina meal in the diet, the greater their jejunal digesta viscosity (data not shown). Regression of viscosity of jejunal digesta in cps against total tract energy metabolizability coefficient of broiler chicks fed camelina meal-based diets from d 21 to 28 generated the following equation: $y = -0.0572x + 0.8723$, $r^2 = 0.635$ (Figure 2). The total tract energy metabolizability coefficient of broiler chicks fed camelina meal-based diets decreased as jejunal digesta viscosity increased. This provides evidence that viscosity played a key role in the negative effects on the absorption and utilization of nutrients when birds are fed camelina meal.

There were linear ($P < 0.001$) decreases in the ileal digestibility of DM, nitrogen, energy, and IDE with increasing levels of dietary CM1 supplementation to the reference diet (Table 4). Also, with the supplementation of CM2 to the reference diet, ileal digestibility of DM and energy ($P < 0.001$), nitrogen ($P < 0.05$), and IDE ($P < 0.01$) were linearly decreased. For the total tract utilization, the inclusion of both CM1 and CM2 decreased metabolizability of DM, N, energy, and ME and ME$_n$ linearly ($P < 0.001$). Similarly, Thacker and Widyaratne (2012) reported that increasing levels (30, 60, 90, 120, and 150 g/kg) of camelina meal inclusion to a wheat and soybean meal-based diet linearly decreased the apparent total tract digestibility of DM, energy, and nitrogen retention in 3-wk-old male broiler chicks. Recently Aziza et al. (2013) reported decreased DM, CP digestibility, and dietary AMEn with the inclusion of 100 g/kg camelina meal into a corn-soybean diet in laying hens.

Regression equations relating test ingredient-associated energy intake to intake of CM1 and CM2 in the determination of IDE, ME, and ME$_n$ of CM1 and CM2 are presented in Table 5. The IDE regression equation was $Y = -10 + 1,429 \times CM1 + 2,125 \times CM2$, $r^2 = 0.55$, which indicates IDE values of 1,429 kcal/kg of DM for CM1 and 2,125 kcal/kg of DM for CM2. The ME regression equation was $Y = 5 + 882 \times CM1 + 925 \times CM2$, $r^2 = 0.54$, which indicates ME values of 882 kcal/kg of DM for CM1 and 925 kcal/kg of DM for CM2. For ME$_n$, the regression equation was $Y = 2 + 795 \times CM1 + 844 \times CM2$, which indicates ME$_n$ values of 799 kcal/kg of DM for CM1 and 844 kcal/kg of DM for CM2. The IDE, ME, and ME$_n$ of CM2 were higher ($P < 0.05$) than those of CM1. As discussed earlier, antinutrients and high fiber content of camelina meal may have affected the energy contribution to the diets. Especially high dietary fiber would interfere with absorption of other nutrients (Sklan et al., 2003) and therefore, it can be one reason for the relatively low ME and MEn values obtained for camelina meal in the

![Figure 2. Effect of jejunal digesta viscosity on total tract energy metabolizability coefficient of broiler chicks fed camelina meal-based diets to 28 d of age. Each data point indicates total tract energy metabolizability coefficient of cage plotted against jejunal viscosity of that cage (8 replicates per treatment). $P < 0.001$ (SE = 0.03), R = -0.797.](image-url)
Table 4. Coefficients of ileal digestibility and total tract metabolizability of DM, nitrogen and energy by birds fed experimental diets d 15 to 22 post hatching.¹

<table>
<thead>
<tr>
<th>Item</th>
<th>Reference diet</th>
<th>100</th>
<th>200</th>
<th>100</th>
<th>200</th>
<th>SEM</th>
<th>L²</th>
<th>Q²</th>
<th>L²</th>
<th>Q²</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td></td>
<td>0.699</td>
<td>0.636</td>
<td>0.581</td>
<td>0.637</td>
<td>0.618</td>
<td>0.0410</td>
<td>&lt;0.001</td>
<td>0.795</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Nitrogen</td>
<td></td>
<td>0.826</td>
<td>0.799</td>
<td>0.784</td>
<td>0.806</td>
<td>0.796</td>
<td>0.0226</td>
<td>&lt;0.001</td>
<td>0.550</td>
<td>0.013</td>
</tr>
<tr>
<td>Energy</td>
<td></td>
<td>0.741</td>
<td>0.686</td>
<td>0.637</td>
<td>0.694</td>
<td>0.675</td>
<td>0.0304</td>
<td>&lt;0.001</td>
<td>0.820</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>IDE, kcal/kg DM</td>
<td></td>
<td>3.415</td>
<td>3.181</td>
<td>3.026</td>
<td>3.229</td>
<td>3.206</td>
<td>171</td>
<td>&lt;0.001</td>
<td>0.536</td>
<td>0.007</td>
</tr>
</tbody>
</table>

¹Data are means of 8 replicate cages with 8 birds per cage.
²Linear (L) and quadratic (Q) contrasts for camelina meal 1.
³Linear (L) and quadratic (Q) contrasts for camelina meal 2.

Current study. Previous research have shown that there is strong negative correlations between fiber fractions and energy value of corn DDGS (Melcho et al., 2013; Rochell et al., 2011) and wheat DDGS (Cozannet et al., 2010) which might be the case for camelina meal in the current study. Variations (data not shown) observed in different cages for ME, and MEn values obtained may be a cause of relatively low r² observed for the regression equations obtained in the current study.

From the current results, utilization of energy and nitrogen in camelina meal by broiler chickens is low. The content of glucosinolate and the high viscosity observed in jejunal digesta may have contributed to the poor nutrient digestibility and therefore the detrimental effects on live performance of birds. However, further research with broilers on how glucosinolates, especially their breakdown products in the gastrointestinal tract specifically affects the performance of birds, and a detailed analysis of source of viscosity in camelina meal is required.

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REFERENCES


