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Low-Fiber Canola. Part 2. Nutritive Value of the Meal

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ABSTRACT: The nutritive value of meals derived from black- and yellow-seeded *Brassica napus* and canola-quality *Brassica juncea* was determined with broiler chickens and young turkeys. A higher apparent ileal digestibility of total amino acids was observed in chickens fed diet containing yellow-seeded *B. napus* than in those fed conventional black-seeded *B. napus* or canola-quality *B. juncea* (88.8 vs 83.4 and 84.2%, $P < 0.05$). Metabolizable energy (AME_n) contents for yellow- and black-seeded *B. napus* and *B. juncea* as determined with broiler chickens were 2190, 1904, and 1736 kcal/kg DM, respectively. In the turkey assay, the AME_n values for yellow- and black-seeded *B. napus* and *B. juncea* canola averaged 2166, 2007, and 1877 kcal/kg DM, respectively. Multicarbohydrase enzyme addition to broiler chicken diets increased energy utilization (from 1943 to 2249 kcal/kg DM, on average), with the most pronounced effect observed for *B. juncea* canola (from 1736 to 2356 kcal/kg DM).

KEYWORDS: *canola meal, metabolizable energy, amino acid digestibility, broiler chicken, turkey*

INTRODUCTION

Canola meal is a commonly used protein supplement in animal diets. However, when compared with soybean meal, its dietary inclusion rates are limited mainly due to the high content of fiber and lower contents of protein and available energy. Early research indicated that yellow seed coat color of canola was associated with the lower fiber content, and a strong negative correlation between dietary fiber and protein contents was observed in meals derived from the earlier forms of *Brassica rapa* (*campestris*) canola.[1−3] When fed to pigs, crude protein and energy of yellow seed coats were more digestible than those of black seed coats.[4] Therefore, breeding for yellow seed coat has been justified as a means to improve the quality of canola meal without compromising oil content in the seed. This has thus led to the development of yellow-seeded *Brassica napus* canola with meals derived from earlier forms of partly yellow-seeded *B. napus* showing quality characteristics superior to those of its conventional black-seeded counterpart.[5,6]

Recently, a new and improved line of yellow-seeded *B. napus* canola (YN01-429) has been developed at the Saskatoon Research Center, Agriculture and Agri-Food Canada, Saskatoon, Canada. This line has improved agronomic characteristics (i.e., increased yield and oil contents) and stabilized yellow seed coat color.[7] In addition, canola-quality (low-glucosinolate, low-erucic acid) forms of *Brassica juncea* mustard, known for its pure yellow seed coat color, have been developed.[8]

As documented in the accompanying part 1 of this series, a comprehensive chemical characterization of meals derived from yellow-seeded *B. napus* and *B. juncea* canola has been completed. Superior quality characteristics (i.e., increased protein and sucrose and reduced dietary fiber contents) of the meal derived from yellow-seeded *B. napus* when compared with its black-seeded counterpart or yellow-seeded *B. juncea* have been observed.[9] The current study was undertaken to evaluate the nutritive value of meals derived from black- and yellow-seeded *B. napus* canola and canola-quality yellow-seeded *B. juncea*. Broiler chickens and turkeys were used to determine how changes and differences in the chemical composition and nutritive contents of the meals would influence the availability of energy, amino acids, growth performance, and gut function.

MATERIALS AND METHODS

Plant Material. Seed samples of yellow-seeded *B. napus* line YN01-429, black-seeded *B. napus* line N89-53, and canola type yellow-seeded *B. juncea* (var. Xceed) were obtained from Agriculture and Agri-Food Canada Research Center, Saskatoon, SK, Canada, and were crushed to produce their respective meals at the POS Pilot Plant in Saskatoon, SK, Canada, using the conventional prepress solvent extraction process.

Broiler Chicken Growth Study. A short-term broiler chicken study was conducted to evaluate the effect of meals from black- and yellow-seeded *B. napus* and yellow-seeded *B. juncea* on growth performance and ileal digestibility of amino acids (AA). One-day-old male Ross-308 broiler chickens were purchased from a local commercial hatchery. Birds were held in electrically heated Jamesway battery brooders (James Mfg. Co., Mount Joy, PA, USA) for a 3 day pre-experimental period to ensure complete yolk sac lipid absorption and were fed commercial chick starter crumbles (21% crude protein). On day 3, birds were fasted for 4 h, individually weighed, and randomly distributed among treatments. There were five birds per pen and nine replicate pens per treatment. Birds were provided with continuous light, had free access to water, and were fed corn/soybean meal-based diets containing 30% of test canola meals (Table 1). Body weight (BW) and feed intake were recorded on day 17 with pen as the experimental unit. Mean BW gain, feed intake, and feed conversion ratio (FCR) were calculated to determine growth performance. On day 17, 2 birds per pen, giving a total of 18 birds per treatment, were

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Table 1. Composition of Experimental Diets Used in Broiler Chicken Growth Performance Study and Apparent Metabolizable Assays with Broiler Chickens and Turkeys

	broiler chicken growth trial			AME_n assay	
item	*B. napus*, black	*B. napus*, yellow	*B. juncea*, yellow	turkey test diet	broiler basal diet
ingredient, % of diet					
corn	43.2	46.4	44.8	–[a]	34.9
wheat	–	–	–	–	17.4
soybean meal	16.1	13.2	14.6	–	24.9
test ingredient	30.0	30.0	30.0	93.1[b]	–
canola meal	–	–	–	–	5.0
canola oil	6.4	6.0	6.2	–	5.1
limestone	1.16	1.08	1.09	1.6	1.7
dicalcium phosphate	1.26	1.45	1.40	–	1.1
monocalcium phosphate	–	–	–	3.5	–
sodium chloride	–	–	–	0.3	–
wheat middlings	–	–	–	–	4.0
spray-dried blood plasma[c]	–	–	–	–	3.9
DL-methionine	0.1	0.1	0.1	–	0.1
mineral premix[d]	0.5	0.5	0.5	–	0.5
vitamin premix[e]	1.0	1.0	1.0	–	1.0
vitamin–mineral premix[f]	–	–	–	1.0	–
titanium dioxide	0.3	0.3	0.3	0.5	0.3
total	100.0	100.0	100.0	100.0	100.0
calculated composition					
CP, %	22.9	23.2	23.3	na[g]	22.9
ME, kcal/kg	3000	3000	3000	na	3092
calcium, %	1.0	1.0	1.0	na	1.02
nonphytate phosphorus, %	0.45	0.45	0.45	na	0.45
methionine	0.5	0.5	0.5	na	0.46
methionine + cysteine, %	1.0	1.0	1.0	na	0.84
lysine, %	1.3	1.3	1.2	na	1.33

[a]Not present. [b]Three canola meal samples derived from black- and yellow-seeded *B. napus* and canola-quality *B. juncea* were used. [c]Hemotech, Minnetonka, MN, USA. [d]Provided Mn, 70 mg; Cu, 10 mg; Fe, 80 mg; Zn, 80 mg; Se, 0.3 mg; I, 0.5 mg; and Na, 1.7 g per kilogram of diet. [e]Provided vitamin A, 8255 IU; vitamin D_3, 3000 IU; vitamin E, 30.0 IU; vitamin B_{12}, 0.013 mg; vitamin K, 2.0 mg; niacin, 24.5 mg; choline, 1081 mg; folic acid, 4.0 mg; biotin, 0.25 mg; riboflavin, 6.0 mg per kilogram of diet. [f]Supplied the following per kilogram of diet: vitamin A (as *all-trans*-retinol acetate), 13000 IU; vitamin D_3 (as cholecalciferol), 3000 IU; vitamin E (as DL-α-tocopheryle acetate), 35 mg; vitamin K_3 (as menadione nicotinamide bisulphite), 2 mg; vitamin B_1 (as thiamin mononitrate), 2 mg; vitamin B_2, 8 mg; vitamin B_6 (as pyridoxine hydrochloride) 3.5 mg; niacin (as nicotinic acid), 65 mg; calcium-D- pantothenate, 18 mg; folic acid, 1.5 mg; biotin, 0.2 mg; choline chloride 60%, 400 mg; Mn (as $MnSO_4 \cdot H_2O$), 100 mg; Zn (as $ZnSO_4 \cdot H_2O$), 80 mg; Fe (as $FeSO_4 \cdot H_2O$), 50 mg; Cu (as $CuSO_4 \cdot 7H_2O$) 8 mg; I (as KI), 0.8 mg; Se, 0.3 mg. [g]Not applicable.

randomly selected and euthanized by cervical dislocation. The ileum (from Meckel's diverticulum and 2 cm before anterior of the ileo–ceco junction) was removed from each bird and cut into two subsections of equal length, and the contents from the second half were collected. Digesta samples were then freeze-dried, finely ground, and pooled to yield four replicate samples per treatment, each sample representing digesta from four or five birds.

Metabolizable Energy (AME_n) Assay with Broiler Chickens. A 3 × 2 factorial arrangement of treatments was used to evaluate the effects of genotype (i.e., meals from black- and yellow-seeded *B. napus* and *B. juncea*) and enzyme supplementation (without or with a multicarbohydrase supplement) on metabolizable energy (AME_n) contents of test ingredients for broiler chickens. A basal diet composed of practical feed ingredients was used (Table 1). The six experimental diets were composed of 70% of basal diet and 30% of test ingredients without or with enzyme supplementation. The enzyme (multi-carbohydrase) supplement Superzyme OM (Canadian Bio-Systems Inc., Calgary, AB, Canada) was used and supplied 1700 units of cellulase, 1100 units of pectinase, 1200 units of xylanase, 360 units of glucanase, 240 units of mannanase, 30 units of galactanase, 1500 units of amylase, and 120 units of protease per kilogram of diet. One-day-old male Ross-308 broiler chickens were purchased from a local commercial hatchery. The management procedures and housing conditions were the same as those described for the growth assay above. A control group was fed the basal diet for the entire trial and was included to calculate the AME_n values of test ingredients. There were 5 birds per pen, 4 replicate pens per treatment (6 for the control group), and 150 birds in total. Birds in experimental groups were fed the basal diet from day 3 to 14, and then the diets containing test ingredients from day 15 to 19. On day 19, excreta samples from each pen were collected over a 3 h period, immediately frozen at −20 °C, freeze-dried, and finely ground. Excreta samples from the same pen were pooled to yield four replicates per treatment (six for the control group).

Metabolizable Energy Assay with Turkeys. Forty-two 21-day-old heavy Large White BIG-6 turkey males, sexed at a local commercial hatchery, were randomly assigned to three dietary treatments, each consisting of seven pens of two birds per pen. Birds had free access to water and were provided with continuous light. From day 21, birds were fed experimental diets containing 93% of test ingredient as the only source of protein and energy (Table 1). The diets were cold pelleted (up to 50 °C; 1.5 mm diameter pellets) using CPM California Lab Pellet Mill model CL-2 (Crawfordsville, IN, USA) and were offered on an ad libitum basis. There was a 4 day adaptation period, and the experimental period lasted for 5 days. On day 30, excreta samples from each pen were collected over a 3 h period and immediately frozen at −20 °C. Upon completion of excreta collection, birds were euthanized by cervical dislocation, and segments of the digestive tract (i.e., gizzard, small intestine, ceca, and colon) with contents were collected, emptied, and weighed. As soon as possible

after euthanasia (ca. 20 min), the pH of digesta was measured using a microelectrode and pH-ion meter (model 301, Hanna Instruments, Vila do Conde, Portugal). Samples of ileal (from Meckel's diverticulum to 2 cm before anterior of the ileo−ceco junction) and cecal contents were used for immediate analysis of dry matter, viscosity, and short-chain fatty acids (SCFA), whereas the rest of the cecal digesta was transferred to the test tubes and stored at −70 °C until needed. Samples of digesta from the last two-thirds of the ileum were collected for amino acid and internal marker (titanium dioxide) analysis. Digesta and excreta samples were then freeze-dried and finely ground. Samples from the same pen were pooled to yield seven replicates per treatment.

Animal Care. All animal procedures were conducted according to the guidelines of the Canadian Council on Animal Care[10] with the animal protocols for the study with broiler chickens and turkeys approved by the Animal Care and Use Committee of the University of Manitoba and the University of Warmia and Mazury, respectively.

Chemical Analyses and Calculations. All excreta or ileal digesta samples were analyzed for titanium dioxide.[11] In addition, digesta samples from broiler chicken growth study and turkey experiment were subjected to AA analysis,[9] whereas the excreta samples from both metabolizable energy assays were analyzed for nitrogen (nitrogen analyzer, model NS-2000, Leco Corp., St. Joseph, MI, USA) and gross energy (Parr 6300 calorimerter, Parr Instrument Co., Moline, IL, USA). The AME_n values of test ingredients were calculated as described by Leeson and Summers.[12] The following equation was used for the calculation of ileal digestibility of AA (%) = $\{1 - [(Ti_{\%diet} \div Ti_{\%digesta}) \times (AA_{\%digesta} \div AA_{\%diet})]\} \times 100$.

For digesta viscosity measurements, the contents of the small intestine were mixed on a vortex mixer and centrifuged at 7211*g* for 10 min at 21 °C. The supernatant (0.5 mL) was placed in a Brookfield LVDV-II+ cone−plate rotational viscometer (CP40; Brookfield Engineering Laboratories Inc., Stoughton, MA, USA), and the viscosity was measured at a fixed temperature of 39 °C and a shear rate of 60 per minute.

The activity of bacterial *β*-glucosidase and *β*-glucuronidase in the cecal digesta was measured by the rate of *p*-nitrophenol release from the nitrophenylglucosides according to the modified method of Djouzi and Andrieux[13] as described by Juskiewicz and Zdunczyk.[14] The following substrates were used: *p*-nitrophenyl-*β*-D-glucopyranoside for *β*-glucosidase and *p*-nitrophenyl-*β*-D-glucuronide for *β*-glucuronidase. The reaction mixture contained 0.3 mL of substrate solution (5 mM) and 0.2 mL of a 1:10 (v/v) dilution of the cecal sample in 100 mM phosphate buffer (pH 7.0). Incubation was carried out at 39 °C, and following the addition of 2.5 mL of 0.25 M cold sodium carbonate and centrifugation at 7211*g* for 15 min at 21 °C, the absorbance was measured at 400 nm. Enzyme activity (IU) was expressed as micromoles of *p*-nitrophenol formed per minute and per gram of digesta.

Cecal digesta samples were subjected to SCFA analysis using gas−liquid chromatography (Shimadzu GC-14A Shimadzu Co., Kyoto, Japan). The samples (0.2 g) were mixed with 0.2 mL of formic acid, diluted with deionized water, and centrifuged at 7211*g* for 5 min at 20 °C. Supernatant was loaded onto the chromatography glass column (2.5 m × 2.6 mm) packed with 10% SP-1200−1% H_3PO_4 on 80/100 Chromosorb W AW (Supelco Co., Bellefonte, PA, USA). The chromatograph was coupled to a flame ionization detector. Column, injector, and detector temperatures were 110, 195, and 180 °C, respectively.

Statistical Analysis. All studies were set up as completely randomized designs, and data were tested by the GLM procedure of the SAS program.[15] Means were separated by Tukey's honestly significant difference. All statements of significance are based on $P \leq 0.05$.

RESULTS

Growth Performance of Broiler Chickens. In the growth performance study, broiler chickens were fed corn/soybean meal-based diets containing 30% of test ingredient over a 2 week period. Similar BW gaind and FCR data were observed in chickens fed meals derived from black- and yellow-seeded *B. napus* canola (Table 2). However, an inferior FCR was observed for birds fed the meal from *B. juncea* canola. Although not different ($P < 0.01$) from that of yellow *B. napus*, the FCR value for the *B. juncea* meal was significantly higher than that of the conventional black-seeded *B. napus* canola.

Table 2. Growth Performance of Broiler Chickens Fed Diets Containing Meals Derived from Black- or Yellow-Seeded Canola (3−17 Days)[a]

diet	feed intake (g/bird/14 days)	BW gain (g/bird/14 days)	FCR (g feed/g gain)
B. napus, black	566.4	427.7	1.326 b
B. napus, yellow	575.5	431.7	1.334 ab
B. juncea, yellow	573.2	416.4	1.380 a
SEM	12.90	12.22	0.013

[a] $n = 9$. Means within a column with no common letters (a, b) differ significantly ($P < 0.05$).

Ileal Amino Acid Digestibility of Canola Meals. In the growth performance study, apparent ileal digestibility of AA was also determined (Table 3). The highest ($P < 0.05$) digestibilities for total and each essential AA, except tryptophan and methionine, were observed in broiler chickens fed diets containing a meal from yellow-seeded *B. napus*. No difference was observed in ileal AA digestibility between the black *B. napus* and *B. juncea* groups, and their total AA digestibility, on average, was lower than that of yellow-seeded *B. napus* by 5% ($P = 0.01$).

There are limited published reports on the contents of digestible AA in canola meals for turkeys. Thus, the assay with turkeys was carried out to determine the apparent ileal AA digestibility of different canola meals when fed (days 21−30) as the only dietary source of protein and energy (Table 4). The digestibility of total and indispensable (essential) AA was similar among the meals evaluated with the exception of methionine. Methionine was more digestible in yellow-seeded *B. napus* than in *B. juncea*, but was not different from that of black-seeded *B. napus*.

Metabolizable Energy (AME_n) Values of Canola Meals. Metabolizable energy contents of canola meals were also determined in broiler chickens and turkeys. In broiler chickens, the preferred by the feed industry AME_n assay was used and involved diets composed of 70% of basal diet and 30% of test ingredient fed to broiler chickens of 15 days of age for 5 days. The ME assay used in the turkey study was somewhat similar to the true metabolizable energy assay (TME_n) with adult roosters, which is often used to determine the available energy content for older birds. It was based on diets containing 93% of test ingredient as the only source of protein and energy and was fed to turkeys of 21 days of age for 9 days.

In the broiler chicken assay (Table 5), the highest AME_n value was found in the meal derived from yellow-seeded *B. napus* (2190 kcal/kg DM), which was similar to that of its black-seeded counterpart (1904 kcal/kg) but higher than the value for *B. juncea* meal (1736 kcal/kg, $P = 0.05$). Enzyme addition increased the AME_n values of experimental diets and test ingredients, with the significant increase observed for *B. juncea* canola ($P < 0.01$). In the turkey assay (Table 4), the

Table 3. Apparent Ileal Digestibility of Indispensable and Total Amino Acids (AA) in Broiler Chickens Fed Diets Containing Meals from Black- or Yellow-Seeded Canola (%, Day 17)[a]

diet	Arg	Cys	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	total AA
B. napus, black	87.6 b	79.5 ab	84.9 b	80.6 b	84.6 b	84.7 b	88.7	80.6 b	76.0 b	70.0	80.3 b	83.4 b
B. napus, yellow	91.5 a	81.1 a	89.8 a	86.5 a	89.5 a	89.2 a	88.8	86.8 a	84.4 a	70.1	87.7 a	88.8 a
B. juncea, yellow	89.2 ab	74.8 b	85.7 b	81.6 b	85.6 b	83.2 b	87.1	82.4 b	77.7 b	74.7	81.9 b	84.2 b
SEM	0.7	1.4	0.8	0.9	0.8	0.9	0.8	1.1	1.4	2.2	1.0	0.9

[a] $n = 4$. Means within a column with no common letters (a, b) differ significantly ($P < 0.05$).

Table 4. Apparent Metabolizable Energy (AME_n) Content and Apparent Ileal Digestibility of Indispensable and Total Amino Acids (AA) in Turkeys Fed Diets Containing Meals Derived from Black- or Yellow-Seeded Canola (Day 30)[a]

		apparent amino acid digestibility (%)										
diet	AME_n (kcal/kg DM)[b]	Arg	Cys	His	Ile	Leu	Lys	Met	Phe	Thr	Val	total AA
B. napus, black	2006.7 b	69.7	52.3	75.8	71.3	74.1	75.9	75.7 ab	75.5	59.9	68.6	69.4
B. napus, yellow	2165.5 a	66.7	52.8	77.6	73.7	75.8	78.9	78.2 a	77.1	61.7	71.3	70.7
B. juncea, yellow	1877.2 b	75.3	58.8	75.4	71.0	73.0	72.5	72.6 b	74.1	58.5	68.5	69.3
SEM	37.4	2.9	3.9	1.3	1.6	1.4	2.2	1.4	1.5	1.7	1.6	1.5

[a] $n = 7$. Means within a column with no common letters (a, b) differ significantly ($P < 0.05$). [b]The DM contents of diets containing black- and yellow-seeded *B. napus* and *B. juncea* were 92.5, 92.7, and 91.9%, respectively.

Table 5. Apparent Metabolizable Energy (AME_n) Contents of Meals Derived from Black- or Yellow-Seeded Canola When Fed to Broiler Chickens without or with Enzyme Supplementation (AME Assay; Day 19)[a]

effect	AME_n (kcal/kg DM)
genotype	
B. napus, black	1961.4 b
B. napus, yellow	2280.9 a
B. juncea, yellow	2045.6 ab
SEM	71.2
enzyme	
no enzyme	1943.2
enzyme	2248.7
SEM	58.2
genotype × enzyme	
B. napus, black	1904.3 bc
B. napus, black + enzyme	2018.5 abc
B. napus, yellow	2189.8 ab
B. napus, yellow + enzyme	2372.0 a
B. juncea, yellow	1735.7 c
B. juncea, yellow + enzyme	2355.5 ab
SEM	100.7
genotype	0.015
enzyme	0.002
genotype × enzyme	0.045

[a] $n = 4$. Means within a column and within a source with no common letters (a–c) differ significantly ($P < 0.05$).

meal derived from yellow-seeded *B. napus* again contained the highest amount of AME_n (2166 kcal/kg DM, $P < 0.01$), whereas no significant difference was observed between those of black-seeded *B. napus* and *B. juncea* (2007 vs 1877 kcal/kg).

In this study, the physiological responses of young turkeys to diets containing meals derived from yellow-seeded *B. napus* canola and canola-quality *B. juncea* were also investigated. In comparison with the conventional black-seeded *B. napus*, feeding the diet containing meal derived from yellow-seeded *B. napus* canola resulted in a significant decrease ($P < 0.05$) in the small intestinal pH and an increase in ceca mass, both tissue and digesta (Table 6). In addition, yellow-seeded *B. napus* meal caused a significant increase in α-glucosidase activity in the ceca, whereas the activities of β-glucosidase, α- and β-galactosidase, and β-glucuronidase remained unchanged when compared with those of black-seeded *B. napus*. In comparison with its black-seeded counterpart, yellow-seeded *B. napus* canola caused a significant decrease in the concentration of cecal SCFA. However, the total cecal SCFA pool, as expressed in micromoles per kilogram of BW (data not shown), did not differ among the treatments.

Feeding *B. juncea* meal, on the other hand, caused more significant changes in the intestinal function, including lower hydration and higher viscosity of the small intestinal contents and increased bacterial α- and β-glucosidase, α-galactosidase, and β-glucuronidase activities in the ceca ($P < 0.05$).

DISCUSSION

Chemical and nutritive characterization of test canola meals presented in part 1 of this series[9] indicated that the meal derived from the newly developed line of yellow-seeded *B. napus* has superior quality characteristics and contains more protein, more sucrose, and less dietary fiber in comparison with its black-seeded counterpart or canola-quality *B. juncea*. Further seed fractionation study clearly demonstrated that yellow-seeded *B. napus* had a bigger seed size, a lower contribution of the hull fraction to the total seed mass, and a lower fiber content of the hull fraction, all contributing to the reduced fiber content of the resulting meal. In addition, the reduction in dietary fiber of the meal derived from yellow-seeded *B. napus* canola resulted from the lower levels of each fiber component, including cell wall/nonstarch polysaccharides (NSP), protein (glycoprotein), minerals, and lignin with associated polyphenols (tannins).

Poultry do not express endogenous enzymes capable of digesting NSP. Total-tract digestibility of NSP from canola meal is negligible in laying hens (i.e., 2%),[16] adult roosters (4%),[17] or broiler chickens fed a corn–canola meal diet (8%).[18] Glycoproteins, which represent the structural protein of the cell walls and Maillard reaction products, often referred to as neutral detergent insoluble nitrogen (NDIN), are also poorly digested by poultry and swine. Although tannins in sorghum bind and precipitate dietary protein,[12] canola tannins would

Table 6. Effect of Meals Derived from Black- and Yellow-Seeded Canola on Tissue Weight, Digesta Viscosity, pH Values, Bacterial Enzyme Activities, and Short-Chain Fatty Acid (SCFA) Contents in the Ceca of Turkeys at 30 Days of Age[a]

item		*B. napus*, black	*B. napus*, yellow	*B. juncea*, yellow	SEM
BW, kg		1.22	1.20	1.23	0.017
gizzard					
	pH of digesta	4.36	4.12	4.21	0.062
small intestine					
	full mass, g/kg BW	128 a	127 a	102 b	3.2
	pH of digesta	6.39 a	5.92 b	6.20 a	0.066
	viscosity, mPa s	1.51 b	1.55 b	2.32 a	0.093
	DM of digesta, %	15.2 b	15.9 b	22.5 a	0.09
	ammonia, mg/g of digesta	0.39	0.40	0.38	0.009
ceca					
	tissue wt, g/kg BW	8.5 b	10.0 a	8.1 b	0.27
	digesta wt, g/kg BW	2.0 b	4.2 a	2.5 b	0.25
	pH of digesta	6.96	7.17	7.04	0.065
	DM of digesta, %	18.2	18.4	20.6	0.55
	enzyme activity, μmol//h/g of digesta				
		α-glucosidase	9.1 c	13.6 b	17.6 a	1.02
		β-glucosidase	2.2 b	2.2 b	14.3 a	1.35
		α-galactosidase	14.0 b	12.2 b	25.1 a	1.70
		β-galactosidase	18.0	19.5	25.1	1.58
		β-glucuronidase	3.1 b	5.5 b	12.7 a	1.04
	SCFA, μmol/g of fresh digesta				
		acetic	43.2 a	21.3 b	38.5 a	2.63
		propionic	3.4 a	1.2 b	3.0 a	0.28
		isobutyric	0.4 a	0.2 b	0.3 ab	0.04
		butyric	8.5 a	3.9 b	8.4 a	0.58
		isovaleric	0.4 b	0.2 c	0.6 a	0.05
		valeric	0.7 a	0.2 b	0.9 a	0.08
		total SCFA	56.4 a	26.9 b	51.8 a	3.46
colon						
	tissue wt, g/kg BW	7.4 a	7.0 ab	6.2 b	0.23
	digesta wt, g/kg BW	7.3	6.2	7.0	0.38
	pH of digesta	6.77	6.78	6.63	0.087

[a] $n = 7$. Means within a row with no common letters (a–c) differ significantly ($P < 0.05$).

have little influence on protein utilization due to their low water solubility and encapsulation within the cells of the hull fraction. Therefore, we hypothesized that the meals derived from yellow-seeded *B. napus* and *B. juncea* canola have an improved nutritive value.

The broiler chicken study (Table 3) confirmed that protein from yellow-seeded *B. napus* meal was more digestible than that from its black-seeded counterpart or *B. juncea*. The values for apparent ileal digestibilities of total and essential AA were highest for a diet containing yellow-seeded *B. napus* meal. In the turkey experiment (Table 4), total AA for all three meals were, on average, 70% digestible. Such values are similar to the results of AA digestibility of commercial canola meals reported by Palander et al.[19] and Adedokun et al.,[20] but slightly lower than those reported by Kluth and Rodehutscord[21] when calculated by multiple linear regression analysis. In contrast to broiler chickens, the difference of AA digestibility between the test ingredients observed in the current study was less in turkeys than in broiler chickens. A significantly higher ileal digestibility (by 5.6%), associated with yellow-seeded *B. napus*, was noticed only in the case of methionine, when compared with that of *B. juncea*. A comparison of results of the turkey trial with those of the broiler chickens studies is difficult because different methodologies were used, and thus factors such as species, age, and the inclusion rate of the test ingredients may have contributed to some discrepancy.

The AME_n values of yellow-seeded *B. napus* determined in the current study averaged 2190 and 2166 kcal/kg DM for broiler chickens and turkeys, respectively, and were similar to that of the commercial canola meal used in feed formulation (i.e., 2000 kcal/kg, as-fed basis; equivalent to 2222 kcal/kg DM).[22] When compared with its black-seeded counterpart or *B. juncea* meal, the improved nutritive value of yellow-seeded *B. napus* was again substantiated by its higher AME_n values for both broiler chickens and turkeys. As previously discussed, higher sucrose, higher protein, and lower dietary fiber contents in yellow-seeded *B. napus* contribute to the improvement in its energy value. However, it is not clear why meal derived from yellow-seeded *B. napus* did not out-perform the other two meals in the growth performance study with broiler chickens (see Table 2). Apart from improved digestibility of select amino acids, which although higher in yellow *B. napus* would most likely not translate into any significant quantitative changes in the diet when formulated on the basis of total amino acid content, which was the case in the current study, the available energy content of yellow-seeded *B. napus* determined in the AME assays with broiler chickens and turkeys was significantly higher than that of its black-seeded counterpart (i.e., by 239 kcal/kg, on average). With 30% of dietary inclusion rate of canola meals, this would translate into 72 kcal/kg increase in available energy content and should have been reflected in improved growth performance and, more specifically, in the decrease in FCR. One definite conclusion from this study is that the low dietary fiber content of yellow-seeded *B. napus* canola may not contribute to the improved nutrient utilization. Therefore, quantitative (i.e., increased protein and amino acid content) more so than qualitative changes (i.e., increased amino acid and energy availability) would be expected from the low-fiber *B. napus* canola. Further research involving the production trials with poultry and swine is needed to determine the benefit of low-fiber canola. Such studies will soon be underway in our facility as large amounts of meal derived from yellow-seeded *B. napus* canola (i.e., 700 kg) have recently been produced as part of the Canola Council of Canada research initiative.

In the broiler chicken study, canola meal-containing diets were used without or with a multicarbohydrase enzyme supplement. This enzyme cocktail has been demonstrated to be effective in canola NSP depolymerization.[17,23] Following enzyme addition, the increase of AME_n values of test ingredients reached significance only for *B. juncea*. It is not clear why this particular meal responded to enzyme supplementation to a much greater extent than the other meals. It appears that such a response is a consequence of the different NSP profile and high pectic polysaccharides content of *B. juncea* meal.

The results of the present study indicate that, in comparison with the conventional black-seeded *B. napus* canola, the meals derived from yellow-seeded *B. napus* and *B. juncea* canola influenced the function of the digestive tract of young turkeys. This may be a result of differences in chemical composition of

the meals. One important factor is the reduced concentrations of polyphenols in yellow-seeded *B. napus* and *B. juncea* compared with black-seeded *B. napus*.

From the chemical composition data presented in part 1 of this series,[9] it is dificult to pinpoint the components responsible for the difference. All three meals contained similar amounts of fat (1.6−1.8%), sugars (i.e., 0.2−0.3%), and starch (i.e., 0.3−0.4%) and relatively high amounts of sucrose, with *B. juncea* meal showing an intermediate value of 9.2% when compared with the black- or yellow-seeded seeded *B. napus* canola (8.8 and 10.2%, respectively). *B. juncea* meal was the highest in oligosaccharides (i.e., 3.6 vs 3.1 and 2.5%, respectively), which, when converted to SCFA by microbial population of the lower gut, should contribute to more rather than less available energy in this ingredient. Jankowski et al.[24] demonstrated changes in cecal concentrations of SCFA in turkeys fed diets with different oligosaccharide contents, with the decrease in SCFA contents coinciding with the proportional decrease in dietary oligosaccharide content. In addition, some increase in β-glucuronidase activity with decreased dietary oligosaccharide content was observed. This was also the case in the current study with the diet containing *B. juncea* meal contributing to the highest activity of bacterial enzymes, including α-glucosidase, β-glucosidase, α-galactosidase, and β-glucuronidase, in the ceca among the meals evaluated. Increased bacterial activity, however, could also be a consequence of increased NSP fermentation in the ceca. However, this does not explain the difference in available energy because all three meals contained similar amounts of NSP, including water-soluble NSP. It is also not clear if the higher viscosity of intestinal contents observed in turkeys fed the *B. juncea* diet would affect energy utilization. It is well-known that high digesta viscosity may have an effect on energy and protein utilization. The fact that the *B. juncea* meal responded to milticarbohydrase supplementation to a much greater extent than the other meals in the broiler chicken assay indicated that the differences in the NSP components are responsible for differences in energy utilization. Further research on the composition of NSP of *B. juncea* meal may allow for better understanding of the physiological responses observed in turkeys and explain the differences in energy utilization.

Another factor responsible for growth depression and low nutrient utilization could be related to the antinutritive properties of glucosinolates, with *B. juncea* meal showing a distinct difference in the glucosinolate profile when compared with the other two meals. However, as recently reviewed by Khajali and Slominski[25] and considering a conservative 4 μmol per gram of diet as the maximum or "no-effect" level of glucosonolate inclusion rate, the broiler chicken *B. juncea* diet contained 5.2 μmol per gram, which was similar to that of yellow-seeded *B. napus* and still much lower than 8.1 μmol per gram for black-seeded *B. napus*. Therefore, it is not clear why this particular meal showed the lowest available AA and energy contents among the meals evaluated.

In conclusion, it appears that the low-fiber meal derived from yellow-seeded *B. napus* canola has superior quality characteristics compared with black-seeded *B. napus* and canola-quality *B. juncea* in terms of available energy and amino acid content. Enzyme supplementation increased the AME_n contents of canola meal-containing diets, with the most pronounced effect observed for *B. juncea* canola.

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Notes

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ABBREVIATIONS USED

AA, amino acid; AME_n, apparent metabolizable energy; BW, body weight; DM, dry matter; FCR, feed conversion ratio; NSP, nonstarch polysaccharides; SCFA, short chain fatty acids

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