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Nutritional Evaluation of Canola Protein Concentrate for Broiler Chickens

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ABSTRACT : This trial was conducted to determine the effects of including canola protein concentrate in diets fed to broiler chickens on nutrient digestibility and broiler performance (0-21 days). A total of 180, day-old, male broiler chicks weighing an average of 52.8±0.6 g were assigned to one of six dietary treatments in a completely randomized design. The control diet was based on corn and soybean meal and contained 15% canola meal. The experimental diets contained 3, 6, 9, 12 or 15% canola protein concentrate added at the expense of canola meal. There were five birds per pen and six replicate pens per treatment. Feed and water were available *ad libitum* throughout the 21-day experiment. Chromic oxide (0.35%) was added to all diets as a digestibility marker and was fed throughout the experimental period. The digestibility of dry matter, energy and phosphorus increased linearly ($p<0.01$) with increasing levels of canola protein concentrate. Although nutrient digestibility was higher for birds fed diets containing canola protein concentrate, these improvements did not translate into improvements in broiler performance. Weight gain was unaffected ($p = 0.24$) by level of canola protein concentrate. Feed intake was significantly increased ($p<0.01$) with the result that feed conversion tended to be poorer ($p = 0.07$) for birds fed diets containing canola protein concentrate. Mortality was also unaffected ($p = 0.56$) by dietary treatment. (**Key Words :** Broilers, Poultry, Canola Protein Concentrate, Performance, Digestibility)

INTRODUCTION

Soybean meal is one of the most widely utilized protein supplements incorporated into poultry rations and it is generally a consistent, high quality product (Waldroup, 2002; Britzman, 2006). However, as transportation costs for feed increases, poultry producers will have to maximize the use of locally produced feedstuffs. Therefore, it is important that alternative sources of supplementary protein be developed.

Canola is the name given to varieties of rapeseed that are low in glucosinolates and erucic acid (Bell, 1993). Canola meal, which results from the solvent extraction of the oil from the canola seed, is a commonly used and economically effective feed ingredient in commercial broiler diets (Newkirk, 2009). However, canola meal contains antinutritional factors that may lower broiler performance. The major antinutritional factors include fiber, oligosaccharides, phenolic compounds, glucosinolates and phytic acid (Bell, 1993; Thiessen et al., 2004).

There have been numerous attempts to improve the nutritional value of canola meal through the implementation of various processing techniques. Examples include solvent washing (McCurdy and March, 1992), micronization (Thacker, 1998), tail-end dehulling (Clark et al., 2001) and toasting (Newkirk and Classen, 2002; Thacker and Newkirk, 2004). The nutritional value of canola meal may also be improved by fractionating and then concentrating the protein component of the meal resulting in the production of a canola protein concentrate (Tzeng et al., 1990; Yoshie-Stark et al., 2006). A proprietary process has been developed at the University of Saskatchewan to produce a new canola protein concentrate (Maenz, 2002; Classen et al., 2004). In the process, the canola protein is extracted and fully denatured to render the protein insoluble. Soluble anti-nutritional factors such as glucosinolates and phenolics (sinapine and tannins) are washed from the protein. The resulting product is low in non-starch polysaccharides and phytic acid. This canola protein concentrate has been successfully incorporated into diets fed to tilapia (Borgenson et al., 2006) and rainbow trout (Thiessen et al., 2004; Drew et al., 2007) However, the nutritive value of

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this newly developed ingredient has not been extensively tested with poultry. Therefore, the following trial was conducted to determine the effects of including canola protein concentrate in diets fed to broiler chickens on nutrient digestibility and broiler performance.

MATERIALS AND METHODS

Production of canola protein concentrate

The canola protein concentrate used in the present experiment was obtained from Can Pro Ingredients (Arborfield, Saskatchewan). The canola protein concentrate was produced by a proprietary process developed at the University of Saskatchewan and patented under US Patent 6800308 (Maenz et al., 2004). The procedure involves a two-step extraction and dephytinization process. Briefly, crushed and defatted canola seed is mixed with water preheated to 50°C in a ribbon mixer. The extract is then passed through a Continuous Flow Belt Press (Frontier Technology Incorporated, Allegan, MI) which compresses the material between two polypropylene monofilament belts. Passage through the flow belt press separates the material into a liquid extract and a residual press cake. The liquid extract is then passed through a mechanical de-pulper equipped with 150-micron openings. The de-pulping procedure serves to remove most of the hull fragments from the extract.

The de-pulped extract from three passes through the belt press was placed in a 100 L steam kettle and the flow of steam to the kettle was adjusted until the temperature of the extract was increased to 50°C. Phytase (Natuphos 5000, BASF, Ludwigshafen, Germany) was added to the mixture to provide 1,500 FTU per kg of original starting material. The extract was maintained at 50°C with constant stirring for 60 min to affect dephytinization of the extract. The extract was centrifuged at 5,000×g for 2 min in a swinging bucket centrifuge. The supernatant was poured off and collected. The solid pellets from the centrifuge were re-suspended in an equal volume of water and centrifuged again at 5,000×g for 2 min to wash off residual soluble material associated with the pellets.

The supernatants obtained from the centrifugation step were pooled and placed in a 100 L steam kettle. The steam to the kettle was adjusted such that the temperature of the extract reached 95°C and this temperature was maintained for 5 min. Then, cold water was passed through the jacket of the steam kettle for 20 min. A protein precipitate or curd is typically formed on top of the extract during this heating and subsequent cooling procedure. The contents of the steam kettle were then poured through a 200 micron nylon mesh (Nitex^{TM}, Great Western Manufacturing Company, Leavenworth, KS). The curd was collected in the mesh while the liquid passes through the mesh and was collected in a tub.

The curd was subsequently wrapped in mesh and placed in a cheese mold. The mold was placed in a cheese press and compacted for 10 min at compressions of 34, 69, 138 and 207 kPa followed by a final 20 min of compression at 276 kPa. All of the liquid expelled during the compression of the mold was combined. The liquid was passed then through a 10,000 molecular weight cut off ultra-filtration membrane. Water was added to the retentate and the filtration process was repeated.

A total of six rounds of ultra-filtration were conducted to concentrate the protein in the retentate. Finally, the combined permeate from ultra-filtration was passed through a nanofiltration membrane. A chemical analysis of the canola protein concentrate as well as the other major ingredients used in this experiment is shown in Table 1.

Broiler performance trial

The experimental protocol used for the following experiment was approved by the University of Saskatchewan Animal Care and Use Committee. The birds were housed and managed according to the Canadian Council on Animal Care Guidelines (1993).

A total of 180, day-old, male broiler chicks (Ross-308 line; Lilydale Hatchery, Wynyard, Saskatchewan) weighing an average of 52.8±0.6 g were randomly assigned to one of six dietary treatments in a completely randomized design. The control diet was based on corn and soybean meal and contained 15% canola meal. The experimental diets contained 3, 6, 9, 12 or 15% canola protein concentrate added at the expense of canola meal (Table 2). The experimental diets were formulated to supply 3,100 kcal/kg ME, 1.25% lysine, 0.90% threonine, as well as 0.92% methionine and cystine. DL-methionine was added to ensure that all diets provided a similar level of all essential amino acids. Canola oil and dicalcium phosphate were added to the diets containing canola meal to compensate for its lower energy and available phosphorus content relative to canola protein concentrate. All diets were supplemented with sufficient vitamins and minerals to meet or exceed the levels recommended by the National Research Council (NRC, 1994) for starter birds. The experiment diets were provided in mash form (3 mm screen).

This experiment was conducted in an environmentally controlled broiler facility located on the campus of the University of Saskatchewan (Saskatoon, Saskatchewan). The chicks were housed in raised-floor battery cages (83.8 cm×45.7 cm×25.4 cm; Jamesway Manufacturing Co., Ft. Atkinson, WI, USA) with mesh grate floors located above excreta collection trays. There were five birds per pen and six replicate pens per treatment. Feed and water were available *ad libitum* throughout the 21-day experiment.

Table 1. Chemical and amino acid analysis of main ingredients used to determine the nutritive value of canola protein concentrate for broiler chickens

	Corn	Soybean meal	Canola meal	Canola protein concentrate
Chemical composition (% as fed)				
Moisture	10.88	8.15	8.21	6.50
Crude protein	8.11	46.19	35.19	54.37
Ash	1.47	6.58	6.91	8.73
Ether extract	2.63	1.41	3.80	3.02
Neutral detergent fiber	9.60	8.45	25.84	28.34
Calcium	0.04	0.31	0.65	0.70
Total phosphorus	0.28	0.74	0.92	1.43
Phytate phosphorus	0.22	0.47	0.59	0.00
Non phytate phosphorus	0.06	0.27	0.33	1.43
Essential amino acids (% as fed)				
Arginine	0.24	3.01	1.94	3.03
Histidine	0.19	1.23	0.96	1.41
Isoleucine	0.26	1.99	1.32	2.31
Leucine	0.94	3.45	2.42	4.22
Lysine	0.27	2.97	2.11	2.87
Methionine and cystine	0.34	1.38	1.65	2.08
Phenylalanine	0.35	2.19	1.26	2.26
Threonine	0.29	1.78	1.54	2.37
Valine	0.45	2.31	1.85	3.14

[1] All data are the results of a chemical analysis conducted in duplicate.

Table 2. Ingredient composition of diets used to determine the effects of graded levels of canola protein concentrate on the performance of broiler chicks (0-21 days)

	Level of canola protein concentrate (%)					
	0	3	6	9	12	15
Corn	43.67	45.83	47.98	50.14	52.31	54.42
Soybean meal	30.70	29.07	27.45	25.83	24.20	22.60
Canola protein concentrate	0.00	3.00	6.00	9.00	12.00	15.00
Canola meal	15.00	12.00	9.00	6.00	3.00	0.00
Canola oil	6.39	5.89	5.40	4.90	4.40	3.90
Vitamin-mineral premix[1]	0.50	0.50	0.50	0.50	0.50	0.50
Dicalcium phosphate	1.63	1.54	1.45	1.36	1.27	1.19
Limestone	1.04	1.10	1.16	1.22	1.28	1.35
Salt	0.50	0.5	0.50	0.50	0.50	0.50
Superzyme enzyme[2]	0.05	0.05	0.05	0.05	0.05	0.05
Choline chloride	0.08	0.08	0.08	0.08	0.08	0.08
Chromic oxide	0.35	0.35	0.35	0.35	0.35	0.35
Methionine	0.09	0.09	0.08	0.07	0.06	0.06

[1] Supplied per kilogram of diet: 11,000 IU vitamin A, 2,200 IU vitamin D_3, 30 IU vitamin E (dl-α-topheryl acetate), 2.0 mg menadione, 1.5 mg thiamine, 6.0 mg riboflavin, 60 mg niacin, 4 mg pyridoxine, 0.02 mg vitamin B_{12}, 10.0 mg pantothenic acid, 6.0 mg folic acid, 0.15 mg biotin, 0.625 mg ethoxyquin, 500 mg $CaCO_3$, 80 mg Fe, 80 mg Zn, 80 mg Mn, 10 mg Cu, 0.8 mg I, 0.3 mg Se.

[2] Canadian Bio-Systems, Calgary, Alberta.

Broilers were weighed at the start (day 1) and end of the experiment (day 21) as well as at weekly intervals. Weighed amounts of feed were added as required with a single weigh back at the conclusion of the experiment to allow for the calculation of feed consumption and feed conversion on a pen basis. The battery brooder was maintained at a temperature of 35°C for the first week with the temperature gradually reduced to 29°C by the end of second week. Incandescent lighting (10 lux) was provided continuously throughout the experiment.

Digestibility trial

Chromic oxide (0.35%) was added to all diets as a digestibility marker and was fed throughout the experimental period. During the final two days of the experiment (morning and afternoon), clean excreta (free from feathers and feed) were collected from plastic liners placed in the excreta collection trays underneath each pen of birds. The excreta samples from the four collections were pooled and then frozen for storage. Prior to analysis, the samples were dried in a forced air oven at 55°C for 72 h, followed by fine grinding (0.5 mm screen) using a centrifugal mill (Retzsch ZM 100, Retzsch GmbH, Haan Germany). The digestibility coefficients for dry matter and gross energy as well as nitrogen retention were determined using the equations for the indicator method described by Schneider and Flatt (1975).

Coefficients for total tract apparent digestibility (TTAD) were calculated using the indicator method based on the following equation:

$$TTAD = 1-[(Cr_{diet}/Cr_{out})\times(Nut_{out}/Nut_{diet})]$$

where Cr_{diet} was the initial chromic oxide concentration in the diet; Nut_{diet} was the dietary concentration of the nutrient or dietary component being assessed and Cr_{out} and Nut_{out} were the concentrations of chromic oxide and the nutrient/dietary component in the excreta.

Chemical analysis

Samples of the ingredients, experimental diets and excreta were analyzed according to the methods of the Association of Official Analytical Chemists (AOAC, 2007). Analyses were conducted for moisture (AOAC method 930.15), crude protein (AOAC method 984.13), ash (AOAC method 942.05), neutral detergent fiber (AOAC method 2002.04) and ether extract (AOAC method 920.39). An adiabatic oxygen bomb calorimeter (Parr; Moline, Illinois) was used to determine gross energy. Chromic oxide was determined by the method of Fenton and Fenton (1979).

Calcium and phosphorus were determined using the nitric-perchloric acid digestion method of Zasoski and Burau (1977) with calcium determined on a Atomic Absorption Spectrophotometer (Perkin-Elmer Model 4000; Waltham, MA) using AOAC method 968.08 while total phosphorus was determined colorimetrically (Pharmacia LKB Ultrospec III, GE Healthcare, Little Chalfont, UK) using a molybdovanadate reagent (AOAC method 965.17). Phytate was determined following the procedures of Newkirk and Classen (1998). The concentration of phytate bound phosphorus in each ingredient was calculated as 28.2% of phytate (Tran and Sauvant, 2004) and non-phytate phosphorus was calculated as the difference between the concentration of total phosphorus and phytate bound phosphorus.

The amino acid content of the diets and ingredients were determined by High Performance Liquid Chromatography (Hitachi L-8800 Amino Acid Analyzer, Tokyo, Japan). All samples were hydrolyzed for 24 h at 110°C with 6 M HCl prior to analysis. Sulphur-containing amino acids were analyzed after cold formic acid oxidation for 16 h before acid hydrolysis.

Statistical analysis

All data were analysed as an one-way ANOVA using the General Linear Models procedure of the Statistical Analysis System Institute (1999). Treatment means were also tested for linear, quadratic and cubic effects of graded levels of canola protein concentrate. Differences were considered to be significant when $p<0.05$.

RESULTS AND DISCUSSION

The chemical analyses (Table 1) of the corn, soybean meal and canola meal used in the present experiment are within the range of those previously reported for these ingredients in standard industry sources such as Feedstuffs (Dale and Batal, 2007), the Novus Raw Material Compendium (Novus, 1994) as well as the National Research Council's Feed Composition Tables (NRC, 1994).

For canola protein concentrate to be included in broiler rations, it will likely have to compete with canola meal which is recommended to be limited to less than 20% of diets fed to broilers (Newkirk, 2009). Therefore, a comparison of the chemical composition of canola protein concentrate with canola meal seems warranted. As the name implies, the process used to produce canola protein concentrate increases the protein content of the final product (Table 1). The crude protein content of the canola protein concentrate was 35% higher than canola meal (54.37 vs. 35.19%. The levels of all nine essential amino acids measured were also higher in canola protein concentrate than canola meal. Of particular importance are the levels of lysine, threonine and the sulphur containing amino acids which were 26.5, 35.0 and 20.7% higher in canola protein concentrate than canola meal. As a result of

the higher content of these amino acids in canola protein concentrate, less canola protein concentrate would have to be used when formulating diets that meet the amino acid requirements of poultry than if the diet was formulated using canola meal.

The neutral detergent fiber content of the canola protein concentrate was higher than canola meal (28.34 vs. 25.84%). This finding was somewhat surprising as the de-pulping step in the production process for canola protein concentrate is designed to remove most of the hull fragments from the extract. This finding is not an artefact as the neutral detergent fiber content of the diets containing canola protein concentrate also had a higher neutral detergent fiber content than diets based on canola meal. Therefore, some fine tuning of the process used to produce canola protein concentrate may be necessary as an increase in fiber levels will detract from the nutritional value of the product.

Since glucosinolates, phytates and phenolics have significantly lower molecular weights than rapeseed proteins, the use of ultrafiltration in the process used to produce canola protein concentrate should provide a means of separating these undesirable components from the canola protein in an aqueous solution (Tzeng et al., 1990). We have previously determined the total glucosinolate content of a canola meal obtained from a similar source as that used in the present study and reported a value of 8.78 μmol/g of total glucosinolates for canola meal (Thacker and Petri, 2009). This is similar to the 7.2 μmol/g reported as typical for canola meal by the Canola Council of Canada (Newkirk, 2009). According to the manufacturer, canola protein concentrate contains only 2.59 μmol/g of glucosinolates (Can Pro Ingredients Limited, 2010) indicating that that the process used to produce canola protein concentrate reduces its glucosinolate content. The principal glucosinolates found in canola meal are 3-butenyl glucosinolate, 2-hydroxyl-3-butenyl glucosinolate and 4-hydroxyl-3-methylindoyl glucosinolate (Blair et al., 1986; Thacker and Newkirk, 2004; Thacker and Petri, 2009). The principle glucosinolates found in canola protein concentrate appear to be the same as those found in canola meal (Can Pro Ingredients Limited, 2010).

The total phosphorus content of canola protein concentrate was 35.7% higher than canola meal (1.43 vs. 0.92%). The process used to dephytinize the phosphorus in canola protein concentrate was highly successful as no phytate phosphorus was detectable in this product. As a result, the non phytate phosphorus content of canola protein concentrate was 76.9% higher than canola meal (1.43 vs. 0.33%). This change would be expected to increase the available phosphorus content of canola protein concentrate relative to canola meal.

The chemical analysis conducted on the broiler rations confirmed that the diets met the specifications called for in the diet formulation (Table 3). All diets contained

Table 3. Chemical and amino acid analysis of diets used to determine the effects of graded levels of canola protein concentrate on the performance of broiler chicks (0-21 days)

	Level of canola protein concentrate (%)					
	0	3	6	9	12	15
Chemical composition (% as fed)						
Moisture	9.53	9.25	9.69	9.24	9.71	9.91
Ash	6.36	6.27	6.88	7.66	6.70	6.00
Crude protein	23.92	23.91	24.17	25.29	24.15	24.68
Ether extract	7.96	8.44	7.97	8.27	6.34	6.37
Neutral detergent fibre	17.58	19.64	19.21	20.44	18.98	19.09
Calcium	0.97	0.98	0.99	1.05	1.03	0.95
Phosphorus	0.76	0.80	0.81	0.84	0.75	0.72
Essential amino acids (% as fed)						
Arginine	1.25	1.21	1.26	1.39	1.24	1.17
Histidine	0.56	0.55	0.58	0.61	0.57	0.56
Isoleucine	0.88	0.89	0.92	0.99	0.92	0.89
Leucine	1.78	1.78	1.85	1.95	1.87	1.85
Lysine	1.24	1.24	1.25	1.30	1.20	1.17
Methionine+cystine	0.96	0.92	0.88	0.94	0.83	0.85
Phenylalanine	1.03	1.02	1.05	1.11	1.04	1.07
Threonine	0.86	0.88	0.91	0.99	0.91	0.88
Valine	1.04	1.05	1.11	1.18	1.11	1.08

[1] All data are the results of a chemical analysis conducted in duplicate.

Table 4. The effects of graded levels of canola protein concentrate on nutrient digestibility and nitrogen retention of diets fed to broiler chickens

	Level of canola protein concentrate (%)							p values		
	0	3	6	9	12	15	SEM[1]	Linear	Quadratic	Cubic
Dry matter (%)	66.88[ab]	65.70[b]	67.12[ab]	69.23[ab]	70.08[a]	70.02[a]	0.90	<0.01	0.69	0.06
Energy (%)	71.14[ab]	70.06[b]	71.28[ab]	73.97[a]	73.40[ab]	73.27[ab]	0.85	<0.01	0.76	0.05
Calcium (%)	60.74	59.57	62.11	53.11	65.63	55.89	2.24	0.43	0.88	0.32
Phosphorus (%)	47.37[a]	49.84[ab]	51.98[ab]	51.51[ab]	54.44[b]	51.23[ab]	1.54	0.01	0.09	0.60
Nitrogen retention (%)	62.29	58.67	62.00	61.79	62.92	64.21	1.40	0.07	0.23	0.32

[1] Standard error of the mean.

approximately the same crude protein content. The neutral detergent fibre content of the diets increased as the inclusion level of canola protein concentrate increased, reflecting the higher level of this fraction in the test ingredient. The ether extract content declined with increasing canola protein concentrate reflecting the fact that less canola oil was used when formulating the diets containing canola protein concentrate to compensate for its perceived higher energy content.

The amino acid analysis (Table 3) of the diets confirmed that the diets met the requirements for 0 to 3 week old broilers (NRC, 1994). However, it should not be forgotten that higher levels of supplemental methionine were required in order to meet amino acid requirements using canola meal than were required when the diet was formulated with canola protein concentrate.

The effect of including canola protein concentrate in broiler diets on the digestibility of various nutrients is shown in Table 4. The digestibility of dry matter and energy increased linearly ($p<0.01$) with increasing levels of canola protein concentrate. Typically, when improvements in nutrient digestibility are observed, they are usually associated with a decrease in the fiber content of the diet (Janssen and Carre, 1985; Pettersson and Razdar, 1993; Jorgensen et al., 1996; Carrie, 2004). Dietary fiber reduces nutrient digestibility due to its physiochemical properties, leading to a more rapid rate of passage which limits the amount of time available for nutrient breakdown (Burkett et al., 1972). However, a decrease in dietary fiber cannot be the explanation for the improvement in nutrient digestibility in the present trial as neutral detergent fiber levels increased as the amount of canola protein concentrate in the diet increased (Table 3).

Phosphorus digestibility was linearly increased ($p = 0.01$) as the level of canola protein concentrate in the diet increased (Table 4). This is likely a reflection of the fact that the process used to produce canola protein concentrate dramatically reduced its phytate phosphorus content (Table 1). Poultry are relatively inefficient in utilizing phytate phosphorus because they do not produce significant quantities of the digestive enzyme phytase that is required to hydrolyze the phytate molecule (Sebastian et al., 1998). The poor digestibility of phytate phosphorus means that inorganic sources of phosphorus (i.e. dicalcium phosphate) must be used in diet formulation in order to meet the bird's nutritional requirements. The improvements in phosphorus digestibility observed when diets containing canola protein concentrate are fed may allow lower levels of dicalcium phosphate to be included in the diet, thereby decreasing the cost of poultry production.

Although nutrient digestibility was higher for birds fed diets containing canola protein concentrate, these improvements did not translate into improvements in broiler performance (Table 5). Weight gain was unaffected by level of canola protein concentrate ($p = 0.24$). Feed intake was significantly increased ($p<0.01$) with the result that feed conversion tended to be poorer for birds fed diets containing canola protein concentrate ($p = 0.07$). Mortality was unaffected by dietary treatment ($p = 0.56$).

To the author's knowledge, this study is the first to report on the nutritional value of canola protein concentrate fed to broiler chickens. Our results indicate that although

Table 5. Performance of broiler chickens fed graded levels of canola protein concentrate (0-21 days)

	Level of canola protein concentrate (%)							p values		
	0	3	6	9	12	15	SEM[1]	Linear	Quadratic	Cubic
Weight gain (g)	819	854	841	849	855	868	25.5	0.24	0.87	0.56
Feed intake (g)	1,192	1,211	1,268	1,294	1,307	1,306	29.9	<0.01	0.32	0.62
Feed conversion	1.46	1.42	1.51	1.53	1.54	1.51	0.04	0.07	0.39	0.22
Mortality (%)	3.33	3.33	3.33	0.00	0.00	3.33	2.72	0.56	0.51	0.32

[1] Standard error of the mean.

the digestibility of dry matter, gross energy and phosphorus were higher for birds fed canola protein concentrate compared with canola meal, these improvements did not translate into improvements in broiler performance.

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REFERENCES

Association of Analytical Chemists (AOAC). 2007. Official Methods of Analysis, 18th edn, AOAC, Washington, DC.

Bell, J. M. 1993. Factors affecting the nutritional value of canola meal: A review. Can. J. Anim. Sci. 73:679-697.

Blair, R., R. Misir, J. M. Bell and D. R. Clandinin. 1986. The chemical composition and nutritional value for chickens of meal from recent cultivars of canola. Can. J. Anim. Sci. 66:821-825.

Borgeson, T. L., V. J. Racz, D. C. Wilkie, L. J. White and M. D. Drew. 2006. Effect of replacing fishmeal and oil with simple or complex mixtures of vegetable ingredients in diets fed to Nile tilapia (*Oreochromis niloticus*). Aquacult. Nutr. 12:141-149.

Britzman, D. G. 2006. Soybean meal. An excellent protein source for poultry feeds. American Soybean Association Technical Bulletin. http://edu.docin.com/product-6754393.html

Burkett, D. P., A. R. Walker and N. S. Painter. 1972. Effect of dietary fibre on stools and transit times and its role in the causation of disease. Lancet 2:1408-1412.

Canadian Council on Animal Care. 1993. Guide to the care and use of experimental animals. Vol 1. 2nd ed. Canadian Council on Animal Care, Ottawa, ON.

Can Pro Ingredients Limited, 2010. Canola Protein Concentrate. Fact sheet available at http://www.canproingredients.ca/products/canola_protein_concentrate.php. Last accessed Nov 8, 2010.

Carré, B. 2004. Causes for variation in digestibility of starch among feedstuffs. World's Poult. Sci. J. 60:76-88.

Clark, W. D., H. L. Classen and R. W. Newkirk. 2001. Assessment of tail-end dehulled canola meal for use in broiler diets. Can. J. Anim. Sci. 81:379-386.

Classen, H. L., R. W. Newkirk and D. D. Manez. 2004. Effects of conventional and novel processing on the feed value of canola meal for poultry. Feedinfo News Service, Scientific Reviews. 12/02/2004.

Dale, N. and A. Batal. 2007. Ingredient analysis table: 2007 Edition. Feedstuffs Reference Issue and Buying Guide, Feedstuffs 78:16-23.

Drew, M. D., A. E. Ogunkoya, D. M. Janz and A. G. Van Kessel. 2007. Dietary influence of replacing fish meal and oil with canola protein concentrate and vegetable oils on growth performance, fatty acid composition and organochlorine residues in rainbow trout (*Oncorhynchus mykiss*). Aquaculture 267:260-268.

Fenton, T. W. and M. Fenton. 1979. An improved procedure for the determination of chromic oxide in feed and faeces. Can. J. Anim. Sci. 59:631-634.

Janssen, W. M. M. A. and B. Carre. 1985. Influence of fibre on digestibility of poultry feeds. Pages 71-88 in Recent Advances in Animal Nutrition (Ed. W. Haresign and D. J. A. Cole). Butterworths, London, UK.

Jorgensen, H., X. Zhao, K. E. B. Knudsen and B. O. Eggum. 1996. The influence of dietary fibre source and level on the development of the gastrointestinal tract, digestibility and energy metabolism in broiler chickens. Br. J. Nutr. 75:379-395.

Maenz, D. D. 2002. Fractionization of oil-extruded canola into high-valued products. Feedinfo News Service: Scientific Reviews 20/10/2002

Maenz, D. D., R. W. Newkirk, H. L. Classen and R. T. Tyler. 2004. Fractionation and processing of oilseed meal. US Patent # 6800308. United States Patent and Trademark Office, Alexandria, VA.

McCurdy, S. M. and B. E. March. 1992. Processing of canola meal for incorporation in trout and salmon diets. J. Am. Oil Chem. Soc. 69:213-220.

National Research Council (NRC). 1994. Nutrient requirements of poultry. 9th Revised Edition. National Academy Press, Washington, DC, p. 155.

Newkirk, R. W. and H. L. Classen. 1998. *In vitro* hydrolysis of phytate in canola meal with purified and crude sources of phytase. Anim. Feed Sci. Technol. 72:315-327.

Newkirk, R. W. and H. L. Classen. 2002. The effects of toasting canola meal on body weight, feed conversion efficiency and mortality in broiler chickens. Poult. Sci. 81:815-825.

Newkirk, R. 2009. Canola meal feed industry Guide 4th Edition, Canola Council of Canada, Winnipeg, Manitoba 47 pp.

Novus. 1994. Raw material compendium: A Compilation of Worldwide Data Sources. 2nd Edition. Novus International Inc., Brussels, Belgium, p. 541.

Pettersson, D. and A. Razdan. 1993. Effects of increasing levels of sugar-beet pulp in broiler chicken diets on nutrient digestion and serum lipids. Br. J. Nutr. 70:127-137.

Schneider, B. H. and W. P. Flatt. 1975. The evaluation of feeds through digestibility experiments. University of Georgia Press, Athens, Georgia p. 423.

Sebastian, S., S. P. Touchburn and E. R. Chavez. 1998. Implications of phytic acid and supplemental microbial phytase in poultry nutrition. A review. Worlds Poult. Sci. J. 54:26-47.

Statistical Analysis System Institute. 1999. SAS/STAT Users Guide, Version 6, 4th Edition. SAS Institute Inc., Cary, NC.

Thacker, P. A. 1998. Effect of micronization of full-fat canola seed on performance and carcass characteristics of growing-finishing pigs. Anim. Feed Sci. Technol. 71:89-93.

Thacker, P. A. and R. W. Newkirk. 2004. Performance of growing-finishing pigs fed barley-based diets containing toasted or non-toasted canola meal. Can. J. Anim. Sci. 85:53-59.

Thacker, P. A. and P. Petri. 2009. Nutrient digestibility and performance of broiler chickens fed regular or green biodiesel press cakes produced using a micro-scale production process. J. Sci. Food Agric. 89:1307-1313.

Thiessen, D. L., D. D. Maenz, R. W. Newkirk, H. L. Classen and M. D. Drew. 2004. Replacement of fishmeal by canola protein concentrate in diets fed to rainbow trout (*Oncorhynchus mykiss*). Aquacult. Nutr. 10:379-388.

Tran, G. and D. Sauvant. 2004. Chemical data and nutritional value. Pages 17-24. In Tables of Composition and Nutritional Value of Feed Materials: Pigs, Poultry, Cattle, Sheep, Goats, Rabbits, Horses, Fish (Ed. D. Sauvant, J. M. Perez and G. Tran). Institut National de la Recherche Agronomique, Association Francaise de Zootechnie, Paris, France.

Tzeng, Y. M., L. L. Diosady and L. J. Rubin. 1990. Production of canola protein materials by alkaline extraction, precipitation, and membrane processing. J. Food Sci. 55:1147-1156.

Waldrop, P. W. 2002. Soybean meal in poultry nutrition. Soybean meal infosource. Published by Soybean Growers for the Feed Industry. Available at http://www.soymeal.org/pdf/Infomay2002.pdf

Yoshie-Stark, Y., Y. Wada, M. Schott and A. Wasche. 2006. Functional and bioactive properties of rapeseed protein concentrates and sensory analysis of food application with rapeseed protein concentrates. LWT-Food Sci. Tech. 39:503-512.

Zasoski, R. J. and R. G. Burau. 1977. A rapid nitric-perchloric acid digestion method for multi-element tissue analysis. Commun. Soil Sci. Plant Anal. 8:425-436.