TAIL-END DEHULLING OF CANOLA MEAL:
CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF DEHULLED MEAL FOR BROILER CHICKENS AND WEANED PIGS

By

Gustavo Adolfo Mejicanos

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ABSTRACT

Experiments were conducted to determine the optimal conditions for tail-end dehulling of canola meal (CM) and the production of high-protein, high-energy and low-fiber CM. The use of sieves from 250-600µm resulted in the production of dehulled fractions 1 and 2 from three different types of CM. On average, and in comparison with their parent meals, the dehulled fractions 1 and 2 contained less dietary fiber (19.4 and 22.9 vs. 27.5%) and more protein (44.5 and 43.1 vs. 40.1%), respectively. Growth performance experiments were conducted with broiler chickens and weaned piglets fed diets containing dehulled CM fractions. In the broiler chicken trial, no significant differences for feed intake, BWG and feed efficiency were observed, indicating that CM and its low-fiber fractions could replace SBM in the broiler pre-starter diets at a lower cost. In the swine experiment, a beneficial effect of dehulling on final body weight and feed efficiency was observed.

DEDICATION

I dedicate this work to my parents, Eduardo Mejicanos and Rosa Amalia de Mejicanos, to my wife Marian Mejicanos, to Reyna Leticia and our daughters María del Rosario, María Renée and María Alejandra, and to my siblings, Hugo Eduardo, Luis Alberto, Edgar Leonel, Marco Antonio and their appreciated families.

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FOREWORD

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LIST OF ABBREVIATIONS

AA	Amino Acids
ADF	Acid detergent fibre
ADFI	Average daily feed intake
ADG	Average daily gain
AID	Apparent ileal digestibility
Ala	Alanine
AME	Apparent Metabolizable Energy
AMEn	nitrogen-corrected AME
Arg	Arginine
Asp	Aspartic acid
ATTD	Apparent total tract digestibility
BW	Body weight
°C	Celsius degrees
Ca	Calcium
CAID	Coefficient of apparent ileal digestibility

CIGI	Canadian International Grain Institute
CM	Canola meal
CP	Crude protein
Cys	Cysteine
DE	Digestible energy
DM	Dry matter
G	Gram
GE	Gross Energy
G:F	Gain to feed ratio
GLS	Glucosinolates
Glu	Glutamic acid
Gly	Glycine
His	Histidine
Iso	Isoleucine
K	Potassium
Kcal	Kilocalorie
Kg	Kilogram

Leu	Leucine
Lys	Lysine
Mg	Magnesium
Met	Methionine
ME	Metabolizable energy
N	Nitrogen
Na	Sodium
NDF	Neutral detergent fibre
NE	Net energy
NRC	National Research Council
NSP	Non-starch polysaccharide
Phe	Phenylalanine
P	Phosphorus
PA	Phytic acid

PPSE	Pre-press solvent extraction (extracted)
Pro	Proline
SBM	Soybean meal
Ser	Serine
SD	Standard deviation
SEM	Standard error of the mean
SID	Standardized ileal digestibility
STTD	Standardized total tract digestible
Thr	Threonine
Trp	Tryptophan
Val	Valine

GENERAL INTRODUCTION

Canola is used to produce oil for human consumption and meal that is used as protein source for animal feeding (Canola Council of Canada, 2009). Canola oil and meal are mainly exported to USA for its proximity and easy trade, but other markets of canola include Mexico, China, the European Union and Japan (USDA, 2012). The meal obtained from the crushing of canola seeds is the second largest protein supplement after soybean meal (SBM). In 2013, the global rapeseed/canola meal production was 71.0 million metric tonnes, while SBM production was 284.1 million metric tonnes (USDA-FAS, 2014). When compared to SBM, several factors limit the use of CM in monogastric animal’s nutrition, including higher content of dietary fiber, lower metabolizable energy, lower and less consistent amino acid digestibility and less than optimal electrolyte balance due to high sulfur and low potassium contents (Khajali and Slominski, 2012).

The use of co-products such as CM is an alternative to offset the rising cost of livestock production, which currently exceeds 72% of the total cost of swine production (Zijlstra and Beltranena, 2013). To maximize the benefit of co-products, it is important to understand their nutritional characteristics and also, develop technologies aimed to improve their utilization in a cost effective way (Jha et al., 2013). In addition, the presence of anti-nutritional factors needs to be considered to minimize their effects. In this regards, studies have demonstrated that increased use of co-products with high fiber content can reduce the average daily feed intake (ADFI), average daily gain (ADG), and carcass weight and quality, as evidenced by lower dressing percentage and increased viscera weight (Nyachoti et al., 2000; Jha et al., 2013). That highlights the importance of minimizing the content of fiber in diets for monogastric animals to improve the acceptability of CM in the marketplace. In this regard, several approaches have been undertaken. Among them, the development of low-fiber, yellow-seeded canola or the use of feed enzymes to enhance nutrient utilization by monogastric animals have been proposed. Another promising route in reducing fiber content is removal of the hull prior to oil extraction (Simbaya et al., 1992; Slominski, 1997). It would appear evident that seed dehulling could also improve nutrient utilization (Khajali and Slominski, 2012). When evaluating meals from the front-end dehulling process (Simbaya et al., 1992), a significant increase in protein content of the dehulled vs. standard meal (47.2 vs. 40.8%) and a substantial reduction in the content of two major components of dietary fiber: nonstarch polysaccharides (14.7 vs. 18.1%) and lignin with associated polyphenols (4.3 vs. 7.7%) was observed . At the present time, seed dehulling or front-end dehulling has not been used on the commercial scale due to high costs involved. In addition, losses of oil during the front-end dehulling and excessive fineness of the meal and thus difficulties with percolation of the miscella through the cake appear critical (Khajali and Slominski, 2012).

Given the limitations of the front-end dehulling, this study was undertaken to investigate a tail-end dehulling process through sieving. This study also investigated the effect of the parent meals and their dehulled fractions on growth performance of broiler chickens fed corn/SBM-based pre-starter and starter diets. A second study was conducted to evaluate the effect of canola meal and their dehulled fractions on growth performance of weaned piglets fed corn/SBM based pre-starter and starter diets. The diets for both experiments were balanced for crude protein, amino acids, and energy such that all the diets had the same nutritive content and, as a result, their effect on growth performance would be solely due to differences in fiber content

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The name of canola is a contraction of Canada and “ola” that refers to “**o**il **l**ow **a**cid” (Canola Council of Canada, 2011). Its name was trademarked in 1978 by the Western Canadian Oilseed Crushers Association, but it was officially recognized in 1980 when the Canola Council of Canada was officially established (Canola: A new oilseed from Canada, 1981). The name was used to differentiate canola from the high-glucosinolate, high-erucic acid rapeseed. The name canola refers to “Seeds of the genus *Brassica* (*Brassica napus*, *Brassica rapa* or *Brassica juncea*) from which the oil shall contain less than 2% erucic acid in its fatty acid profile and the solid component shall contain less than 30 micromoles of any one or any mixture of 3-butenyl glucosinolate, 4-pentenyl glucosinolate, 2-hydroxy-3 butenyl glucosinolate, and 2-hydroxy-4-pentenyl glucosinolate per gram of air-dry, oil-free solid" (Canola Council of Canada, 2011).

Canola has become the second largest oil crop and its meal is now second after soybean meal (SBM). Canola oil and meal are mainly exported to the USA for its proximity and easy trade, but other markets of canola include Mexico, China, the European Union and Japan (USDA, 2012).

2.2 HISTORICAL PERSPECTIVE

It has been indicated that rapeseed was cultivated in India 2,000 years B.C. (Canola Varieties, 2011) and ancient Indian Sanskrit writing specifically mentions its use for cooking and illumination. It was introduced into China and Japan 2,000 years ago and to Europe in the 13th century. The development of steam power resulted in better industrial acceptance of rapeseed. It was introduced to Canada between 1936 and early 1940s as a method of diversifying crop production, especially for the Prairie Provinces (Bell, 1984; Oilseed Rape, 2007; Classen et al., 2004).). The fuel shortage caused by World War II led to the increased production of rapeseed. However, with the switch to diesel engines, and also the ban of the use of rapeseed for human consumption by the USA in 1956, the demand for rapeseed declined (USDA, 2012).

Low-erucic acid canola was developed in Canada by Dr. Baldour R. Stefansson of the University of Manitoba, who has been referred to as “The father of canola” because of his contribution to the development of low-erucic acid type. In early 1960s, he surveyed over 4,000 lines of rapeseed from all over the world and identified low-erucic acid lines which were then used in the breeding programs at the University of Manitoba and also by Dr. Keith Downey at the Agriculture Canada Research Station in Saskatoon. In 1968, the first low-erucic acid cultivars Tanka, Target and Turret were released and produced in Canada (Stefansson et al., 1961; Bell, 1984). The next step was to reduce the glucosinolates in the meal while increasing the yields of oil and protein (Downey and Craig, 1964). By 1974, Dr. Stefansson released the first double zero rapeseed cv. Tower

(Bell, 1984). Three types of rapeseed/canola varieties with different characteristics are currently grown in Western Canada: *Brassica napus*, *Brassica campestris* or *rapa* and high-erucic acid, low-glucosinolate *Brassica napus* (McVetty et al., 2012; MASK, 2014).

The importance of research and development in the case of canola (1960-1975) has been documented by Nagy and Furtan (1978), who using the Marshallian concepts of social welfare and costs as basis to estimate the gains made through rapeseed breeding found that canola research represents an internal rate of return of 101%, that is higher than the value estimated for research and development of hybrid corn in USA (35-40%) (Griliches, 1958), cotton in Brazil (89%)(Ayer and Shuh,1972), wheat in Mexico (75%) (Ardito-Barletta, 1971) and rice in Japan (75%) (Akino and Hayami, 1974). Reports from the Canola Council of Canada (2014) estimate that canola contributes 19.3 billion a year to the Canadian economy. Canola is used to produce high quality oil for human consumption and meal that is used as protein source for animal feeds (Canola Council, 2009).

2.3 THE SIZE OF CANOLA INDUSTRY IN CANADA

The production of rapeseed (*Brassica napus L.*) for human consumption in Canada was initiated in 1955 and the production increased from 35,000 tonnes/year in 1955 to a record high of 136,000 tonnes in 1956 (Canola: A new oilseed from Canada, 1981). By 1964 the production was about 250,000 tonnes of seed (Downey and Craig, 1964), and by 1966, rapeseed was the fourth largest of Canada’s field crops. Between 1968 and 1971, canola acreage and production increased five-fold (Canola: A new oilseed from Canada, 1981).

The replacement of traditional rapeseed with canola began with the release of the first double low variety of rapeseed in 1974. By 1976, canola began to dominate and by 1980 most of the rapeseed produced in Canada was of canola type. On January 1, 1985 low-erucic acid rapeseed varieties with low glucosinolate content were recognized as safe and received a GRAS status by the USA FDA, which opened the doors to the USA market (USDA, 2012). The acreage seeded began to increase and went from 6,875,000 acres in 1985 to 10,310,000 acres in 1993. By 2007, the acreage reached 15,771,000 acres and was reported an all times high of 22,021,000 acres by 2012 (Statistics Canada, 2014b).

Canola seed crush has also been in a steady increase in Canada and by 1985 it reached 1,298,619 tonnes, which represents an increase of one million from that crushed in 1972 (i.e., 299,583 tonnes). By 1993, the total of canola seed crushed set a record of 2,039,447 tonnes. As early as in 1998, the crush of 3 million tonnes of seed was achieved with a total of 3,380,731 tonnes. Ten years later, in 2008, the total seed crush was 4,217,716 tonnes and by 2012 it reached 7,130,571 tonnes. The total of canola meal produced increased from 174,009 tonnes in 1972 to a record high of 4,115,327 tonnes produced in 2012 (Statistics Canada. 2014).

Current projections of the Canola Council of Canada are to achieve 26 million metric tonnes by 2025 by increasing yields to 52 bushels/acre while maintaining the same acreage (Canola Council of Canada, 2014).

2.4 CHEMICAL AND NUTRITIVE COMPOSITION OF CANOLA MEAL

Earlier studies with different types of canola demonstrated that black and yellow seeds differ significantly in the chemical and nutritive composition, particularly in the contents of oil, protein and fiber (Slominski et al., 2012). As can be seen from Table 2.1, CP content of three different types of canola differed significantly, with *B. napus* "yellow" showing the highest protein content of 49.8 %, followed by 47.4% in *B. juncea* and 43.8% in *B. napus* "black" (DM basis). The oil extraction process of the seeds would also affect the crude protein content with oil-expelled CM containing 35.2%, while pre-press solvent extracted meal 37.5% of CP (as-fed basis) (National Research Council, 2012). Other factors that affect the protein content of CM are the environmental conditions during the growing season. Tipples (1988) found that over the 10 years, from 1978 to 1987, the CP content of CM ranged from 36 to 41%.

A high negative relationship between protein and dietary fiber content of meals derived from "black" and "yellow" *B. napus* canola has been documented (Slominski et al., 2012). Canola meal has lower levels of CP when compared to SBM, but contains more methionine and cysteine, but less lysine. Therefore, both meals complement each other when used in rations for livestock and poultry (Khajali and Slominski, 2012).

Dehulling has proven to increase the protein and amino acid contents of dehulled meals. Kratch et al. (1999) observed that following dehulling the CP content of canola meal increased from 39.6 to 42.4 % (DM basis). It was also found that the amounts of AA per kg of meal increased following dehulling by 11%, with lysine increasing by about 5% and methionine and cysteine by 26%.

The energy content can also differ between the samples of CM. In this context, the type of processing would have a profound effect on oil content with expelled CM containing the highest amounts of residual oil of 9.7%, compared to 3.2% for the pre-press solvent extracted meal (National Research Council, 2012). The oil content of the meal from the pre-press solvent extraction process would also be affected by the amount of gums added back to the meal following oil refining. As indicated by Bell (1993), gums may contain about 50% of canola oil and such oil is expected to increase the ME values of the meal.

Table 2.1. Chemical composition of meals derived from black- or yellow-seeded *B. napus* canola and canola quality *B. juncea* (% DM)[1]

Component	*B. napus* “black”	*B. napus* “yellow”	*B. juncea* “yellow”
Crude protein	43.8^{c}	49.8^{a}	47.4^{b}
Fat	1.8^{a}	1.6^{b}	1.7^{b}
Ash	7.3^{a}	7.0^{b}	7.2^{a}
Carbohydrates			
Monosaccharides[2]	0.2^{b}	0.3^{a}	0.3^{a}
Sucrose	8.8^{c}	10.2^{a}	9.2^{b}
Oligosaccharides[3]	3.1^{b}	2.5^{c}	3.6^{a}
Raffinose	0.6^{a}	0.5^{b}	0.6^{a}
Stachyose	2.6^{b}	2.0^{c}	3.0^{a}
Starch	0.4^{ab}	0.4^{a}	0.3^{b}
Dietary fiber	30.1^{a}	24.1^{c}	25.8^{b}
Phosphorus (P)	1.3^{a}	1.24^{b}	1.23^{b}
Phytate P	0.78	0.80	0.78
Non-phytate P	0.52^{a}	0.44^{b}	0.45^{b}
Glucosinolates, µmol/g[4]	27.1^{a}	17.1^{b}	17.2^{b}

[1]Adapted from Slominski et al. (2012); [2]Includes glucose and fructose; [3]Includes raffinose and stachyose; [4]Includes gluconapin, glucobrassicanapin, progoitrin, gluconapoleiferin, gluconasturtin, glucobrassicin, and 4-hydroxyglucobrassicin; ^{abc}Means within a row with no common superscripts differ significantly ($P<0.05$).

Theodoridou and Yu (2013) evaluated the effect of processing conditions on the nutritive value of canola meal and found significant differences between CM from *B. napus* “black” and *B. napus* “yellow” for the basic nutrients, except ash. The differences between “yellow” and “black” canola included NDF, ADF, CP, and condensed tannins. Yellow-seeded CM showed higher values for CP, total digestible CP, and lower fiber content (Bell, 1993).

As illustrated in Table 2.1, the carbohydrate content of different types of canola was significant with monosaccharides being higher in yellow-seeded *B. napus* and *B. juncea* by 0.3% point. Sucrose content for *B. napus* “yellow” was also higher, and averaged 10.2%, while the mean values for *B. juncea* and *B. napus* “black” were 9.2 and 8.8%, respectively. In the case of oligosaccharides, *B. juncea* showed the highest level of 3.6% compared to 2.5 and 3.1% found in *B. napus* “yellow” and conventional *B. napus* canola, respectively. Starch was also higher in *B. napus* “yellow” and *B. napus*” black”. In the case of expelled meal which contains, an average, 10.0% of ether extract, the energy values reported for GE, DE, ME and NE averaged 4,873, 3,779, 3,540 and 2,351 kcal/kg, respectively. For pre-press solvent extracted CM, which contains less ether extract (3.2% on average), the values for GE, DE, ME and NE average 4,332, 3,273, 3,013 and 1,890 kcal/kg, respectively (National Research Council, 2012).

2.5 FACTORS AFFECTING THE NUTRITIVE VALUE OF CANOLA MEAL

The meal obtained from the crushing of canola seeds is the second largest protein meal supplement after SBM (USDA. 2012). There are several factors that limit the use of canola meal, especially in monogastric animal nutrition. When compared with SBM, canola meal contains higher contents of dietary fiber, glucosinolates, sinapine, phytic acid, tannins, lower metabolizable energy, with less consistent amino acid digestibility and less than optimum electrolyte balance due to high sulfur and low potassium contents (Khajali and Slominski. 2012).

2.5.1 Dietary Fiber

Canola seeds are relatively small, but contain high amounts of oil (i.e., 44%). Therefore, the resulting meal following oil extraction contains relatively high amount of fiber. Crude fiber, acid detergent fiber, neutral detergent fiber and total dietary fiber values for CM are higher than those for SBM. As illustrated in Table 2.1, there are differences in total fiber content between the three main canola types with *B. napus* “black” showing the highest amounts, followed by “yellow” *B. juncea* and the lowest values for yellow-seeded *B. napus* (Khajali and Slominski, 2012). High fiber content of CM limits the inclusion rates of CM. However, Sanjayan et al. (2014) found that the values of nutrient digestibility of *B. napus* “black” and “yellow” *B. juncea* were similar showing similar apparent ileal digestibility of CP and AA for both canola meals. It was also found that the standardized ileal digestibility for Lys and Thr in *B. napus* “black” and *B. juncea* "yellow" were higher than those observed in the earlier studies, which is consistent with the fact that when compared with the old types of canola, the selection for better cultivars also included the selection for lower fiber content, which, in turn, could result in improved digestibility of amino acids.

2.5.2 Glucosinolates

To qualify for the canola status, the meal must contain less than 30 micromoles of any one or any mixture of 3-butenyl, 4-pentenyl, 2-hydroxy-3 butenyl, and 2-hydroxy-4-pentenyl glucosinolate per gram of air-dry, oil-free solid (Canola Council of Canada, 2011). However, new and improved canola cultivars would have glucosinolates at a much lower level. In a survey from 11 crushing plants across Canada, the level of glucosinolates was reported to average 3.9 µmol/g (Rogiewicz et al. 2012). Reports from France showed that the level of glucosinolates in double-zero rapeseed from 9 crushing plants averaged 10 µmol/g (Labalette et al., 2011).

Slominski and Simbaya (1999) found that broiler chickens fed diets containing *B. juncea* meal showed significant reduction in body weight gain, which could be explained by the fact that it contained high contents of aliphatic glucosinolates in the meal. Levels of glucosinolates in "yellow" *B. juncea* were almost 2 times higher than those found in "black" *B. napus*. According to Sanjayan et al. (2014), *B. juncea* meal contained 15.1 µmol/g of glucosinolates while *B. napus* 8.5 µmol/g. Landero et al. (2013) found the level of glucosinolates in "yellow" *B. juncea* of 10.8 µmol/g decreased ADG as levels of inclusion of CM in the diet increased, which indicates that piglets are very sensitive to glucosinolates present in *B. juncea* canola. Minkowski (2002) found significant differences in the glucosinolate content of the hull and embryo fractions with the values for polish rapeseeds averaging 21.3 µmol/g for the embryo, and 6.0 µmol/g for the hull fraction. These results are consistent with research by Bell (1993), who reported levels of glucosinolates of 20.6 µmol/g for the embryo and 4.7 µmol/g for the hulls with the levels of glucosinolates in the whole seed averaging 18.2 µmol/g. Landero et al. (2013) indicated that the reduced growth performance of weaned pigs is the result of high sensitivity of young pigs to glucosinolates of *B. juncea* meal, especially gluconapin which is the most abundant and responsible for growth depression in weaned pigs.

2.5.3 Sinapine

Sinapine is a choline ester of sinapic acid. It is present in canola meal at approximately 1% and has been associated with the production of fishy taint in brown-shelled eggs (Fendwick and Curtis, 1980). The taint is limited to hens of Rhode Island Red breed and linked to a genetic defect in this specific breed (Khajali and Slominski, 2012). The White Leghorns used for egg production in Canada have been reported not to be affected. Research in Germany is underway to reduce the levels of sinapine in rapeseed/canola by developing low-sinapine varieties with yellow-seeded and low-fiber characteristics (Norddeutsche Pflanzenzucht H. G. Lembke KG, 2010)

2.5.4 Phytic Acid

Phytic acid is the storage form of phosphorus in grains and seeds. Although its role in animal nutrition is not completely understood, it is considered an anti-nutritional factor (Khajali and Slominski, 2012). It is present in canola meal at levels of 4-6% and reduces its nutritional value by binding to multivalent cations like Zn, Ca, and Fe and thus reduce their bioavailability (Al-Asheh and Duvnjak, 1994). Phytase enzyme hydrolyzes phytic acid and eliminates the metal chelating properties of phytate and improves phosphorus utilization. Seeds and grains contain endogenous phytase. As well, the reduction in phytic acid content can be achieved by various enzymatic methods. Many microorganisms can produce phytase, including *Aspergillus ficuum, Penifora licei, Escherichia coli, Pichia pastoris*, and others (Nair and Dunvhjak, 1991; Al-Asheh and Duvnjak, 1994; Ikebudu et al., 2000; Khajali and Slominski, 2012). Woyengo and Nyachoti (2013) concluded that phytic acid can affect animal performance by reducing nutrient digestibility through binding to nutrients, the digestive enzymes or both which, in turn, would result in increased endogenous loses of amino acids.

2.5.5 Tannins

Tannins in canola are found mainly in hulls and dark-colored hulls contain more tannins than yellow hulls (Durkee, 1971). Insoluble tannins (i.e., proanthocyanidins) are predominant in canola and responsible for the dark color of the seeds. It has been demonstrated that adding soluble tannins to broiler diets resulted in growth depression

(Mansoori and Acamovic, 2007). However, tannins present in canola are basically water-insoluble and are located in the hulls and thus may have minimal effect on the nutritive value of canola (Khajali and Slominski, 2012). Environmental growing conditions can affect the content of tannins (Naczk et al., 1998). Research on the effect of tannins on growth performance and intestinal ecosystem in weaned pigs has demonstrated some improvement in feed efficiency, which indicates that tannins may have beneficial effects, not just anti-nutritional effects (Biagi et al., 2010)

2.5.6 Metabolizable Energy:

One of the factors that affect the use of CM in diet formulation is the low metabolizable energy (ME) content than SBM (i.e., 3013 kcal/kg for solvent-extracted CM vs. 3,294 for solvent-extracted 48%CP SBM) (National Research Council, 2012). Processing practices in the crushing plants can affect the level of energy in CM. Crushing plants add gums back to the meal, but the amount may be different in each plant. A survey conducted on the samples from 11 crushing plants across Canada demonstrated that fat content may range from 1.4 to 4.3% (10% moisture basis) (Rogiewicz et al., 2012). Another factor that can affect energy utilization is dietary fiber level which may influence the digesta passage rate. As demonstrated in a study by Walugembe et al. (2014), high amounts of fiber in the diet resulted in reduction of ADG in broiler chickens but not in laying hens.

2.5.7 Amino Acid Digestibility

Canola meal contains well balanced AA profile. When compared to SBM, it contains less lysine, but more sulfur amino acids, which make both CM and SBM a good combination in monogastric animal diets (Khajali and Slominski, 2012). However, CM contains less arginine than SBM and the digestibility of amino acids of CM is lower than that of SBM (Ajinomoto Animal Nutrition. 2013; Khajali and Slominski, 2012). It has been reported that the AA digestibility values range from 82.2 to 85.9% with the average for total AA of 84.2 % (Slominski et al., 1999). Such values are higher than those from other reports indicating the range from 73.1 to 96.7% with the average value of 80.1% (Zuprizal et al., 1991).

2.5.8 Dietary Electrolyte Balance

In the case of broiler production, optimal dietary electrolyte balance is important in order to maximize performance (Saedi and Khajali, 2010). There are some factors that affect this balance. Canola meal contains less potassium than SBM, therefore the dietary electrolyte balance in CM is much lower than that in SBM (Khajali and Slominski, 2012). In addition, CM contains approximately 1.14% of sulphur compared with 0.44% in SBM. Increased levels of dietary sulphur can result in reduced bird performance, although the addition of calcium to the diet can alleviate this problem (Summers, 1995). Selection of canola towards further reduction in glucosinolate content would also reduce the sulfur content of the meal and thus would improve the dietary electrolyte balance (Khajali and Slominski, 2012).

2.6 CANOLA MEAL AS FEED INGREDIENT FOR SWINE

In recent years, high prices of grains have had a direct impact on livestock production cost, as feed cost is currently exceeding 72% of the total cost of swine production (Zijlstra and Beltranena, 2013). For this reason, alternatives to improve the efficiency of swine production should be considered. Among those alternatives, the development of technologies to improve the utilization of co-products such as canola meal (CM), distillers dried grains with solubles (DDGS), and others have become of interest as cost-effective alternatives to soybean meal (SBM) or cereal grains. Additionally, co-products offer opportunities in the diversification of the feed matrix by using local feed ingredients for the formulation of swine diets to reduce feed cost (Jha et al., 2013).

The use of co-products offers some challenges, and as is the case for CM, the presence of anti-nutritive factors may limit its more extensive use. A study performed by Jha et al. (2013) demonstrated that increasing the use of co-products with high fiber content can reduce the average daily feed intake (ADFI), average daily gain (ADG), and carcass weight and quality, as evidenced by lower dressing percentage and increased viscera weight (Nyachoti et al., 2000; Jha et al., 2013). Therefore, it is very important to have sufficient supply of energy and nutrients to optimize pig production. To achieve this, accurate information on the nutritive value of feed ingredients to meet nutrient requirements of pigs with the right amounts of dietary energy and other nutrients present in the feedstuffs is the most cost effective way (Kil et al., 2013). Nyachoti et al. (2004) has indicated that the levels of nutrient intake are directly related to voluntary feed intake (VFI), and VFI is influenced by factors like environmental conditions, animal status and feed and feeding conditions, and that pigs tend to consume feed until their energy requirements are fulfilled.

When compared to SBM, several factors limit the use of CM in monogastric animal nutrition, including higher content of dietary fiber, lower metabolizable energy, lower and less consistent amino acid (AA) digestibility and less than optimal electrolyte balance due to high sulfur and low potassium contents (Khajali and Slominski, 2012).

One way to improve the utilization of CM has been the development of low-fiber, yellow-seeded *B. napus* canola. Slominski et al. (1999) found that this type of canola compares favorably with the conventional *B. napus* “black” canola with regard to protein and fiber contents. It has also been demonstrated that “yellow” *B. napus* has a higher available energy content than the “black” *B. napus* (Jia et al., 2012). Following a study on yellow-seeded and low-glucosinolate cultivars of rapeseed, Evrard (2004) concluded that such genetic improvements would allow for increased use of CM in animal feeding, which in the case of swine in Europe, is reported to have inclusion levels between 4 and 15% for fattening pigs.

In a study with weaned pigs, Sanjayan et al. (2013) demonstrated that the digestibility of meal derived from yellow-seeded *B. napus* canola was inferior to those of the conventional *B. napus* and *B. juncea* canola. In the same study, it was also found that the amino acid content of *B. napus* yellow meal was below the values reported by others, which highlights the importance of proper processing of the meal. Newkirk and Classen (2002) demonstrated that prior to desolventizing/toasting, processing has no effect on apparent ileal digestibility of AA, except for cysteine and serine. However, they found that meal desolventization/toasting significantly decreases protein and amino acids digestibilities, especially lysine. Such detrimental effects are caused by Maillard reaction which would lead to the formation of aldose products of amino acids which are not effectively utilized. Sanjayan et al. (2014) found that in swine the values of nutrient digestibility for *B. napus* “black” and *B. juncea* were similar, which is consistent with other studies indicating similar apparent ileal digestibility of crude protein and amino acids for both canola meals (Woyengo et al., 2010; Trindade-Neto et al., 2012). It was also found that standardized ileal digestibility of Lys and Thr in the conventional *B. napus* and *B. juncea* meals were higher than those reported earlier (AmiPig, 2000), which is consistent with the fact that when compared with the conventional canola, the selection for yellow-seeded canola would result in lower fiber content which, in turn, may improve the digestibility of AA.

When formulating diets based on net energy and standard ileal digestibility of AA, it was demonstrated that canola meal from *B. napus* and *B. juncea* can be included in the weaned pig diets at up to 25% without adverse effect on the growth performance (Sanjayan et al., 2014). In a study with *B. juncea*, Landero et al. (2013) found a linear reduction in nutrient digestibility coefficients with increased inclusion of CM, and attributed this to increased fibre content of the diets, which although being lower than the conventional *B. napus* “black”, was still higher than that of SBM. Among other factors, sensitivity of young pigs to the glucosinolate gluconapin that is most abundant in *B. juncea* CM was also indicated.

Quiniou et al. (2012) studied the effects of feeding 10% of low-glucosinolate rapeseed meal (*B. napus*) during gestation and lactation, over three reproductive cycles, on the performance of hyper prolific sows and their litters and found no differences when compared to diets containing no rapeseed meal. In their study sows farrowed 43.6 and 43.8 piglets over three reproductive cycles, respectively. Piglet weight at birth or weaning survival and litter weight gain were not affected by dietary inclusion of canola meal. Plasma thyroxin levels of sows and piglets indicated that thyroid function was not altered by inclusion of canola of less than 2 µmol/g of glucosinolates. This indicates that it is safe to feed gestation and lactation hyperprolific sows diets containing 10% of canola meal over three parities without affecting sow longevity, and reproductive and litter performance.

2.7 CANOLA MEAL AS FEED INGREDIENT FOR POULTRY

Canola meal has lower digestibility of crude protein (CP) and essential AA compared to soybean meal. Apparent ileal digestibility coefficients of CP for broilers, layers and roosters have been reported to be between 0.74 and 0.76% while those of AA between 0.79 and 0.80% (Huang et al., 2006). The same study illustrated that values for SBM were much higher with layers showing apparent ileal digestibility of CP of 0.89% and broilers and roosters of 0.85 and 0.84% respectively. The average apparent ileal digestibility coefficient for 15 AA was reported to be 0.90 for layers and 0.87 for both broilers and roosters (Huang et al., 2006). Such differences need to be taken into consideration in feed formulation and differences between feed ingredients should be balanced using AA digestibility rather than the total amino acid contents.

The level of inclusion of CM for layers has been at a maximum of 10%, although more recent studies support the levels of up to 17% (Canola Council of Canada, 2009). A limitation for the use of CM has been observed in the case of Rhode Island Red hen which has been reported to produce fishy taint in brown-shelled eggs (Fenwick and Curtis, 1980; Khajali and Slominski, 2012). Glucosinolates can also have an impact on growth performance of laying hens and broiler chickens. Levels of glucosinolates of 10 µmol/g of meal can be translated into diets for laying hens containing 15 to 20% of CM and 1.5 µmol per g of feed has been indicated as a "no-effect" level for poultry (Slominski and Simbaya, 1999; Labalette et al., 2011). The amount of fiber in the diet can also affect growth performance of broilers. It has been found that high amounts of fiber in poultry diets may result in reduced ADG in broiler chickens but not in laying hens (Walugembe et al., 2014).

Digestibility of nutrients such as phosphorus, carbohydrates and protein can be maximized with the use of exogenous enzymes, and the addition of phytase is a common practice, as phytase eliminates the metal chelating capacity of phytic acid thus increasing growth performance and phosphorus utilization (Al-Asheh and Duvnjak, 1994; Ikebudu et al., 2000). The efficiency of phytase supplementation may be enhanced with the use of

NSP-degrading enzymes which, in addition, can increase nutrient utilization in poultry by reducing viscosity and nutrient encapsulation (Slominski, 2011).

2.8 DEHULLING OF CANOLA

According to studies conducted in INRA, France more than 70% of rapeseed fiber is present in the hulls. Consequently, the removal of the hulls would improve the quality of the meal (Carre, 2009). Several seed dehulling processes have been developed. Reichert et al. (1986) developed a tangential abrasive dehuller device (TADD) consisting of an abrasive disk rotating horizontally, and a stationary lid with several grain cups over the rotating disk. The abrasive disk set to 80 degrees was found to be optimal for canola dehulling. Such a process, however, may require pre-conditioning of the seed to maximize the percentage of hull removal (Thakor et al., 1995). The French Institute for Oilseeds owns a patent for a dehuller that works based on a centrifugal propeller to separate the embryo and the hull fractions (Technical Feed Information, 2013). Dehulling can be done using an abrasive dehuller which requires conditioning of the canola seeds, and the dehulling index is variable depending on the time of moistening and heating, which makes the commercial application unpractical (Ikebudu et al., 2000). Other methods for dehulling (i.e., rolling) have been described but have not been shown to be very efficient.

Clark et al. (2001) assessed tail-end dehulling of CM for use in broiler diets and found that fecal and ileal energy utilization was improved. Dehulling resulted in an increase of faecal AME_n by 21% with the wide range of values reflecting inconsistency in the dehulling process. The method used in the dehulling of canola involved the addition of moisture up to 16%, milling and sieving trough a 70 mesh screen in order to obtain 2 fractions, one being partially dehulled CM with high protein and reduced fiber contents and the other, a coarse fraction, with partly elevated fibre and protein contents.

Another method of tail-end dehulling is “Air classification” which utilizes the difference in particle size/density (kg/m^3) between hulls and embryo (Thakor et al., 1995). Vibro-separation for meal classification has also been used in Alberta, Canada. Reducing the particle size by grinding of solvent-extracted *B. juncea* meal was effective in reducing the NDF content from 22.7% for fractions over 850 microns to 11.8% for fractions under 425 microns (Beltranena and Zijlstra, 2011).

3.0 MANUSCRIPT 1

Chemical composition and nutritive value of dehulled canola meal for broiler chickens

3.1 Abstract

The present study was conducted to explore the potential for the production of high-energy, high-protein and low-fiber canola meal to be used in high-nutrient density pre-starter diets for broiler chickens. Three pre-press solvent extracted canola meals (CM) from conventional "black" and yellow-seeded *B. napus* canola, and canola-quality *B. juncea* mustard were subjected to sieving technology. The use of sieves from 250 to 600 µm resulted in the production of dehulled low-fiber fractions 1 and 2. When compared with the parent meals, the content of total dietary fiber of fractions 1 and 2 decreased from 30.0 to 21.4 and 26.7% for conventional CM, from 27.0 to 21.6 and 23.4% for *B. napus* "yellow", and from 25.5 to 15.3 and 18.7% for *B. juncea* meal. Likewise, crude protein increased from 36.8 to 42.0 and 39.6% for conventional CM, from 41.0 to 43.6 and 43.0% for "yellow" CM, and from 42.3 to 47.9 and 46.8% for *B. juncea* meal. One-day-old male Ross 308 broiler chicks were randomly assigned to 10 dietary treatments of 8 replicate cages of 5 birds each to evaluate the effect of three parent CM and their respective dehulled fractions 1 and 2 at 15% of a diet on growth performance from 1 to 10 d of age. A corn/SBM-based diet served as a control. All diets were formulated based on the determined nutrient composition data and were balanced for energy, CP and amino acids. There were no significant differences among treatments for feed intake, body

weight gain and feed efficiency indicating that CM and its low-fiber fractions could effectively replace SBM in the broiler pre-starter diets. The benefits from using the dehulled meals could also be reflected in the cost of feed production which for diets containing the dehulled meals averaged \$0.60 per 1 kg of live chicken weight compared to \$0.65 for the corn/SBM-based diet. It could be concluded that canola fiber has minimal effect on nutrient utilization as evidenced by similar growth performance of young broiler chickens fed diets containing CM of different fiber content.

3.2 Introduction

Canola has become one of the most important crops in Canada, with the acreage and production increasing constantly with record high 22 million acres planted in 2012 and 20.2 million acres planted in 2014 (Statistics Canada, 2014). Reports from the Canola Council of Canada (2014) estimate that canola contributes \$19.3 billion a year to the Canadian economy.

Canola is used to produce high quality oil for human consumption and meal that is used as protein source for animal feeding. The meal obtained from the crushing of canola seeds is the second largest protein supplement after soybean meal (SBM). In 2013, the global rapeseed/canola meal production was 71.0 million metric tonnes, while SBM production was 284.1 million metric tonnes (USDA-FAS, 2014). When compared to SBM, several factors limit the use of CM in monogastric animal nutrition, including higher content of dietary fiber, lower metabolizable energy, lower and less consistent amino acid digestibility and less than optimal electrolyte balance due to high sulfur and low potassium contents (Khajali and Slominski, 2012).

Studies with broiler chickens to determine the nutritive value of canola meal derived from new and improved low-fiber, yellow-seeded canola have been conducted. Slominski et al. (1999) found that meal from yellow-seeded *B. napus* canola compared favorably with those of canola-quality *B. juncea* mustard and the conventional *B. napus* “black” with regard to protein and fibre contents. It has also been demonstrated that yellow-seeded *B. napus* would contain significantly more metabolizable energy than the conventional *B. napus* canola (Jia et al., 2012). In some studies, chickens fed diets containing *B. juncea* meal showed significant reduction in body weight gain (BWG), which can be explained by the high content of aliphatic glucosinolates in the meal (Slominski et al., 1999). The results of this study contradict with those found by Sanjayan et al. (2014), who demonstrated that the digestibility of meal derived from yellow-seeded *B. napus* canola and fed to weaned pigs was inferior to those of the conventional *B. napus* and *B. juncea* canola. In the same study, it was also found that the amino acid content of *B. napus* yellow meal was below the values reported by other authors, which highlights the importance of proper processing of the meal. Newkirk and Classen (2002) demonstrated that prior to desolventizing/toasting; processing has no effect on apparent ileal digestibility of amino acids, except for cysteine and serine. However, they found that meal desolventization/ toasting significantly decreases protein and amino acids digestibilities, especially lysine. Such detrimental effects are caused by Maillard reaction which would lead to the formation of aldose products of amino acids which are not effectively utilized.

Sanjayan et al. (2014) found that in swine the values of nutrient digestibility for *B. napus* “black” and *B. juncea* were similar, which is consistent with other studies indicating similar apparent ileal digestibility of crude protein and amino acids for both canola meals (Woyengo et al., 2010; Trindade-Neto et al., 2012). It was also found that standardized ileal digestibility of Lys and Thr in the conventional *B. napus* and *B. juncea* meals were higher than those reported earlier (Ajinomoto Animal Nutrition, 2013; AmiPig, 2000), which is consistent with the fact that when compared with the conventional canola, the selection for yellow-seeded canola would result in lower fiber content which, in turn, may affect the digestibility of amino acids.

The development of low-fiber, yellow-seeded canola and the application of enzymes are means to improve the nutritive value of CM. Another promising route in reducing fiber content is removal of the hull prior to oil extraction. When evaluating the meals from the dehulling process (Simbaya et al., 1992), a significant increase in protein content of the dehulled vs. standard meal (47.2 vs. 40.8%) and a substantial reduction in the content of two major components of dietary fiber: nonstarch polysaccharides (14.7 vs. 18.1%) and lignin with associated polyphenols (4.3 vs. 7.7%) was observed. It would appear evident that seed dehulling could also improve nutrient utilization (Khajali and Slominski, 2012). Several dehulling technologies have been developed, although some processes may require pre-conditioning of the seed (i.e., tempering, moistening, steaming, infrared treatment, etc.) to maximize the effectiveness of the dehulling process (Thakor et al, 1995; Mustafa et al., 1996; Ikebudu et al., 2000).

At the present time, seed dehulling or front-end dehulling has not been used on the commercial scale due to high costs involved. In addition, losses of oil during the front-end dehulling and excessive fineness of the meal and thus difficulties with percolation of the miscella through the cake appear critical (Khajali and Slominski, 2012). For these reasons, the present study was undertaken to investigate a tail-end dehulling process of meal sieving. This study also investigated the effect of the parent meals and their dehulled fractions on growth performance of broiler chickens fed corn/SBM-based pre-starter and starter diets. The experimental diets were balanced for crude protein, amino acids, energy and macro elements so all the diets had the same nutritive content and, as a result, their effect on growth performance would be solely due to differences in fiber content.

Therefore, the objectives of the current study were:

1. To investigate the potential for tail-end dehulling of canola meal, and
2. To investigate the effect of feeding parent meals from the conventional *B. napus* “black” and yellow-seeded *B. napus* canola, and canola-quality *B. juncea* mustard and their respective dehulled meals on growth performance of broiler chickens fed corn/SBM-based diets.

3.3 Materials and Methods

3.3.1 Material

Meal samples of conventional *B. napus* “black” canola and canola-quality *B. juncea* mustard were obtained from the Bunge Altona, MB, Canada processing plant and were produced using the conventional pre-press solvent extraction process. Seeds of yellow-seeded *B. napus* canola were provided by Agriculture and Agri-Food Canada Research Centre, Saskatoon, SK, Canada and were crushed at the POS Pilot Plant in Saskatoon, SK, Canada, using the same pre-press solvent extraction process.

3.3.2 Development of tail-end dehulling technology

A series of experiments was conducted to determine the optimal conditions for tail-end dehulling of canola meal. Sieve sizes ranging from 152μm to 1.18mm were evaluated. Additional grinding of the conventional meal followed by sieving was also investigated. A serious consideration was given to maximize the yield of dehulled fractions when using different sieve sizes. The effectiveness of the dehulling process was also investigated using meals from different crushing plants. As a result, the most effective set of sieves was chosen for the production of dehulled meals. As illustrated in Table 3.1 and Fig. 3.1., the most promising and distinctive fractions of dehulled meal were produced using the sieves within the range of 250-600 μm. The same set of sieves was also effective in the production of dehulled *B. juncea* meal (Table 3.2.; Fig. 3.2).

Table 3.1. Yield and neutral detergent fiber (NDF) and crude protein (CP) contents of *B. napus* canola meal fractions produced by sieving (%)

Sieve size	Particle size	Yield	NDF	CP
	Parent meal		23.6	36.9
< 250 µm	Fine 1	11.4	14.8	41.7
250 - 355 µm	Fine 2	9.8	19.3	39.6
355 – 600 µm	Medium	21.7	27.1	35.4
> 600 µm	Coarse	57.2	24.6	36.1

Fig. 3.1. *B. napus* canola meal fractions produced by sieving

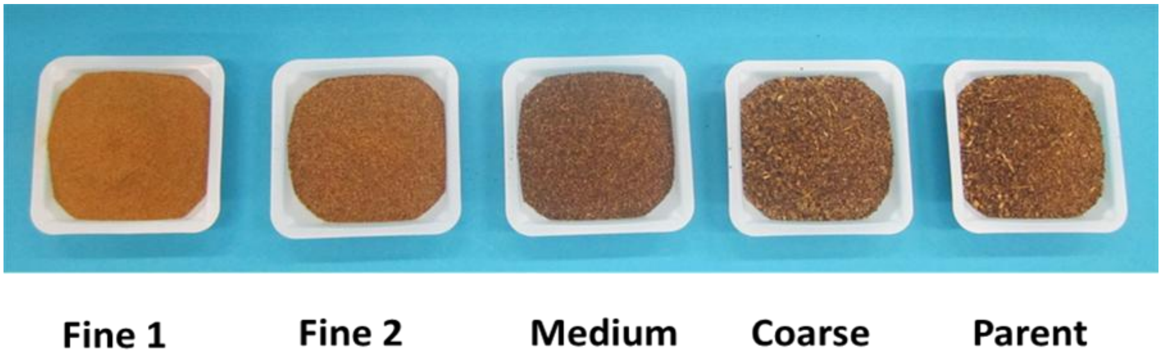
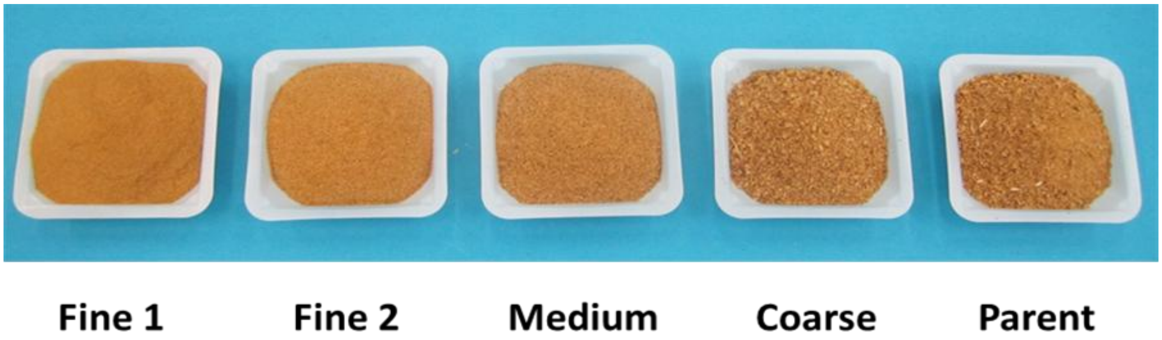


Table 3.2. Yield and neutral detergent fiber (NDF) and crude protein (CP) contents of *B. juncea* canola meal fractions produced by sieving (%)

Sieve size	Particle size	Yield	NDF	CP
	Parent meal		15.9	41.1
< 250 µm	Fine 1	11.4	8.7	46.7
250 - 355 µm	Fine 2	11.1	10.9	45.1
355 – 600 µm	Medium	22.0	16.8	39.9
> 600 µm	Coarse	55.4	16.2	39.9

Fig. 3.2. *B. juncea* canola meal fractions produced by sieving



3.3.3 Analytical procedures

In preparation for chemical analyses, samples were ground using a Foss Sample preparation Cyclotec™ 1093 mill (Foss Allé l, DK-3400 Hilleroed, Denmark). Meals were subject to crude protein (Nx6.25) analysis using a nitrogen analyzer, model TruSpec N (Leco Corp., St. Joseph, MI, USA). Standard AOAC (2005) procedures were used for dry matter (930.15), fat (2003.06), total phosphorus (965.17), and ash determination (942.05) (AOAC, 2005). Phytate phosphorus was determined using the procedure described by Haug and Lantzsch (1983). Samples for amino acid (AA) analysis were prepared according to the AOAC procedures 994.12, alternatives 3 and 1 (sulfur AA), and then determined using an amino acid analyzer (S4300, Sykam GmbH, Eresing, Germany). Starch was analyzed using the Megazyme Total Starch Kit (Megazyme International Ireland Ltd., Co. Wicklow, Ireland). Sucrose and glucosinolates were determined by gas-liquid chromatography as described by Slominski et al. (1994), and Slominski and Campbell (1987), respectively.

Dietary fiber was determined by a combination of neutral detergent fiber (NDF) and detergent-soluble non-starch polysaccharide (NSP) measurements and was calculated as the sum of NDF and detergent soluble NSP (Slominski et al., 1994). Neutral detergent fiber was determined using an Ankom fiber analyzer (Ankom Technology, Macedon, NY, USA) and AOAC procedure 2002.04 (AOAC, 2005). Total NSP were determined by gas-liquid chromatography (component neutral sugars) using an SP-2340 column and Varian CP3380 gas chromatograph (Varian Inc., Palo Alto, CA, USA) and colorimetry (uronic acids) using a Biochrom Ultrospec 50 (Biochrom Ltd., Cambridge, UK) and the procedure described by Englyst and Cummings (Englyst and Cummings 1984; 1988) with some modifications (Slominski and Campbell, 1990). The content of NSP was measured in both the meals and the NDF residues. Neutral detergent soluble NSP was calculated as total sample NSP minus NSP present in the NDF residue, and total dietary fiber was determined by summation of NDF and NDF-soluble NSP. The contents of crude protein (Nx6.25) and ash in NDF residue were also measured. The value for lignin and associated polyphenols was calculated by difference [NDF - (NSP + protein + ash)] (Slominski et al., 1994).

3.3.4 Animals and Housing

A total of 400 one-day-old male Ross-308 broiler chicks were purchased from a local commercial hatchery. Eighty pens were randomly assigned to 10 dietary treatments of 8 replicates/cages of 5 birds per cage. Feed consumption and body weight were determined using pen as an experimental unit. Feed and water was provided *at libitum*. Mortality was recorded daily, and the measurements of growth performance were adjusted accordingly.

The experimental protocol used in the present study was reviewed and approved by the Animal Care Committee of the University of Manitoba. Animals were cared for according to the guidelines of the Canadian Council on Animal Care (CCAC, 2009).

3.3.5 Diets

Birds were randomly assigned to 10 experimental diets for the pre-starter period from 1 to 10 d of age. The pre-starter diets consisted of a SBM/corn-based diet, and diets containing 3 different canola meals, *B. napus* conventional “black” meal, *B. napus* “yellow” meal, and canola-quality ***B.** juncea* meal and their corresponding dehulled fractions 1 and 2. The experiment was carried out over the starter phase with the starter diets consisting of a SBM/corn-based positive control diet and three diets containing only the parent *B. napus* “back”, *B. napus* “yellow” and *B. juncea* meals. The three different parent meals were assigned to the pens fed their corresponding parent meals and dehulled fractions 1 and 2 in the pre-starter phase of the experiment. Chickens were fed the starter diet from 11 to 20 d of age.

The chemical composition of canola meals and their dehulled fractions is presented in Tables 3.3 and 3.4. Several sources, including the Nutrient Requirements for Poultry, ninth edition, National Research Council, (1994), Breeder recommendations (Aviagen, 2007) and the feed industry expert opinions were used to determine the adequate nutrient balance (Tables 3.5 and 3.6).

The criteria to formulate the pre-starter diets were as follows: CP 23%, ME 2975 kcal/kg, Ca 1.05%, available P 0.50%, Met 0.50%, Lys 1.40%, Thr 0.90%, and Arg 1.45%. The criteria to formulate the starter diets were: CP 21%, ME 3050 kcal/kg, Ca 1.00%, available P 0.45%, Met 0.50%, Lys 1.20 %, Thr 0.72 %, and Arg 1.20%. The values for lysine and other amino acids used in the formulation of the pre-starter diets exceeded the NRC recommendations. The composition and calculated nutrient content of pre-starter and starter diets are shown in Tables 3.7 and 3.8.

Table 3.3. Chemical composition of conventional *B. napus* “black” canola meal, *B. napus* “yellow” meal and canola-type *B. juncea* “yellow” mustard meal, and their corresponding dehulled fractions 1 and 2 produced by sieving (%, as-is basis).

Component	*B. napus* “black”			*B. napus* “yellow”			*B. juncea* “yellow”		
	Parent meal	Dehulled fractions		Parent meal	Dehulled fractions		Parent meal	Dehulled fractions	
		1	2		1	2		1	2
DM	91.3	92.5	91.9	92.0	94.7	93.3	90.7	91.4	91.1
Crude protein (Nx6.25)	36.9	41.7	39.6	41.0	43.6	43.0	42.3	47.9	46.8
Fat	3.8	5.2	4.6	3.7	2.4	3.2	3.4	4.0	3.6
Ash	7.1	8.9	7.6	7.9	7.1	6.8	6.6	7.4	7.0
Sucrose	6.3	6.6	6.7	8.4	9.1	9.4	7.6	7.7	8.1
Dietary fiber fractions									
Acid detergent fiber	17.0	9.6	14.0	12.0	7.9	9.4	9.7	5.3	6.4
Neutral detergent fiber	23.6	14.8	19.0	16.4	13.4	14.1	15.9	8.7	10.9
Total dietary fiber	30.1	21.4	26.8	27.1	21.6	23.4	25.5	15.3	18.7
Non-starch polysaccharides	17.0	14.9	17.3	21.1	17.0	18.4	19.4	12.1	14.9
Lignin and polyphenols	10.3	4.8	7.3	2.7	1.7	2.1	4.0	2.3	2.6
Glycoprotein	2.8	1.7	2.2	3.2	2.9	2.9	2.1	0.9	1.2
Phosphorus (P)	0.95	1.27	1.13	1.25	1.28	1.27	1.04	1.19	1.12
Phytate P	0.56	0.66	0.62	0.80	0.87	0.92	0.58	0.64	0.66
Non-phytate P	0.39	0.61	0.51	0.44	0.41	0.35	0.46	0.55	0.55
Calcium	0.67	0.64	0.64	0.55	0.46	0.48	0.76	0.62	0.62
Glucosinolates (µmol/g)[1]	9.2	9.6	9.6	13.5	14.1	14.2	12.2	13.5	13.6

[1] Includes gluconapin, glucobrassicanapin, progoitrin, gluconapoleiferin, glucobrassicin, and 4-hydroxyglucobrassicin.

Table 3.4. Amino acid composition of conventional *B. napus* “black” canola meal, *B. napus* “yellow” meal and canola-type *B. juncea* “yellow” mustard meal, and their corresponding dehulled fractions 1 and 2 produced by sieving (%, as-is basis).

Amino acid	*B. napus* “black”			*B. napus* “yellow”			*B. juncea* “yellow”		
	Parent meal	Dehulled fractions		Parent meal	Dehulled fractions		Parent meal	Dehulled fractions	
		1	2		1	2		1	2
Alanine	1.49	1.76	1.63	1.56	1.89	1.80	1.72	2.05	1.94
Arginine	2.28	2.77	2.50	2.08	2.63	2.49	2.85	3.60	3.30
Aspartate	2.62	3.01	2.82	2.30	2.89	2.75	3.34	3.87	3.70
Cysteine	0.80	0.92	0.89	0.91	0.94	0.91	0.70	0.85	0.79
Glutamine	6.60	7.81	7.24	5.91	7.44	7.09	7.26	8.49	8.10
Glycine	1.85	2.19	2.02	1.45	1.85	1.75	2.16	2.56	2.40
Histidine	1.18	1.37	1.27	1.10	1.35	1.31	1.31	1.51	1.42
Isoleucine	1.21	1.46	1.34	1.06	1.34	1.24	1.21	1.81	1.63
Leucine	2.43	2.92	2.68	2.31	2.86	2.69	2.76	3.52	3.27
Lysine	2.02	2.26	2.17	1.91	2.34	2.23	1.95	2.29	2.20
Methionine	0.68	0.81	0.76	0.63	0.71	0.65	0.66	0.83	0.74
Phenylalanine	1.40	1.69	1.54	1.31	1.61	1.53	1.53	1.98	1.83
Proline	2.54	2.89	2.69	2.44	2.85	2.74	2.77	2.93	2.81
Serine	1.69	1.93	1.81	1.63	1.99	1.92	1.94	2.18	2.10
Threonine	1.62	1.85	1.74	1.33	1.66	1.58	1.82	2.14	2.03
Tyrosine	0.93	1.11	1.03	0.84	1.06	0.99	1.05	1.34	1.24
Valine	1.66	1.95	1.81	1.54	1.90	1.77	1.62	2.35	2.12

Table 3.5. Nutrient requirements of pre-starter diets for broiler chickens

Item	NRC (1994) 0-21 d of age	Breeder[1] and Industry recommendations 0-10 d of age
Crude protein (%)	23.0	23.0
ME (kcal/kg)	3200	2975
Ca (%)	1.00	1.05
Available P (%)	0.45	0.50
Methionine (%)	0.50	0.50
Lysine (%)	1.10	1.40
Threonine (%)	0.80	0.90
Arginine (%)	1.25	1.45

[1] Aviagen (2007)

Table 3.6. Nutrient requirements of starter diets for broiler chickens

Item	NRC (1994) 0-21 d of age	Breeder[1] and Industry recommendations 11-21 days of age
Crude protein (%)	23.0	21.0
ME (kcal/kg)	3200	3050
Ca (%)	1.00	1.05
Available P (%)	0.45	0.45
Methionine (%)	0.50	0.50
Lysine (%)	1.10	1.20
Threonine (%)	0.80	0.72
Arginine (%)	1.25	1.20

[1] Aviagen (2007)

Table 3.7. Composition and calculated nutrient contents of pre-starter diets (%, as-fed basis)

Ingredient	Control corn/SBM	*B. napus* “black”			*B. napus* “yellow”			*B. juncea* “yellow”		
		Parent meal	Dehulled fractions		Parent meal	Dehulled fractions		Parent meal	Dehulled fractions	
			1	2		1	2		1	2
Corn	60.65	54.11	56.70	55.54	56.31	57.33	57.10	56.09	59.44	58.88
SBM	28.99	18.51	16.35	17.30	16.44	15.55	15.72	16.81	13.90	14.40
Fish meal	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Canola meal	-	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Canola oil	0.90	3.20	2.79	2.98	2.86	2.75	2.76	2.87	2.37	2.44
Calcium carbonate	1.11	1.01	1.11	1.06	1.06	1.07	1.08	1.00	1.08	1.08
Di-calcium phosphate	1.24	1.10	0.96	1.04	1.11	1.18	1.14	1.09	1.05	1.03
Vitamin premix[1]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mineral premix[2]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-Lysine	0.22	0.22	0.25	0.24	0.31	0.26	0.27	0.29	0.32	0.32
Threonine	0.01	-	-	-	0.05	0.01	0.02	-	-	-
DL-Methionine	0.08	0.05	0.04	0.04	0.06	0.05	0.11	0.06	0.04	0.05
Internal marker Cr_2O_3	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Calculated composition										
CP, %	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
ME, kcal/kg	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975
Ca, %	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Available P, %	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Methionine + cysteine, %	0.81	0.87	0.88	0.88	0.87	0.87	0.87	0.85	0.86	0.85
Methionine, %	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Cysteine, %	0.34	0.38	0.39	0.39	0.39	0.39	0.39	0.36	0.37	0.36
Lysine, %	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Threonine, %	0.90	0.92	0.93	0.93	0.90	0.90	0.90	0.93	0.94	0.93
Arginine, %	1.45	1.29	1.27	1.28	1.24	1.27	1.26	1.28	1.25	1.25
Analyzed composition										
Crude protein, %	24.0	24.4	25.0	24.5	24.4	24.0	23.6	24.2	24.2	24.2

[1] Supplied per kg of diet: Vitamin A, 8255 IU; Vitamin D3, 3000 IU; Vitamin E, 30 IU; Vitamin K, 2.0 mg; Riboflavin, 6.0 mg; Niacin, 24.5 mg; Folic acid, 4.0 mg; Biotin, 250 µg; Vitamin B12, 13 µg, Choline, 1081 mg.

[2] Supplied per kg of diet: Mn, 70 mg; Cu, 10 mg; Fe, 80 mg; Zn, 80 mg; Se, 0.3 mg; I, 0.5 mg, Na, 1.7 g.

Table 3.8. Composition and calculated nutrient contents of starter diets (%, as-fed basis)

Ingredient	Control	*B. napus* “black”	*B. napus* “yellow”	B. juncea “yellow”
	Corn/SBM	Parent meal	Parent meal	Parent meal
Corn	60.70	54.14	56.34	56.13
SBM	31.30	20.81	18.18	19.11
Canola meal		15.00	15.00	15.00
Canola oil	2.69	5.00	4.65	4.66
Calcium carbonate	1.41	1.28	1.36	1.29
Di-calcium phosphate	1.75	1.64	1.61	1.60
Vitamin premix[1]	1.00	1.00	1.00	1.00
Mineral premix[2]	0.5	0.5	0.5	0.5
L-Lysine	0.20	0.21	0.30	0.38
Threonine	0	0	0	0
DL-Methionine	0.15	0.12	0.14	0.13
Internal marker Cr_2O_3	0.30	0.30	0.30	0.30
Calculated nutrient composition				
CP, %	21.00	21.00	21.00	21.00
ME, kcal/kg	3050	3050	3050	3050
Ca, %	1.00	1.00	1.00	1.00
Available P, %	0.45	0.45	0.45	0.45
Methionine + Cysteine, %	0.77	0.82	0.84	0.80
Methionine, %	0.50	0.50	0.50	0.50
Cysteine, %	0.36	0.34	0.35	0.32
Lysine, %	1.20	1.20	1.20	1.20
Threonine, %	0.78	1.02	0.74	0.82
Arginine, %	1.30	1.20	1.10	1.20
Analyzed composition				
Crude protein, %	21.1	21.7	21.7	22.8

[1] Supplied per kg of diet: Vitamin A, 8255 IU; Vitamin D3, 3000 IU; Vitamin E, 30 IU; Vitamin K, 2.0 mg; Riboflavin, 6.0 mg; Niacin, 24.5 mg; Folic acid, 4.0 mg; Biotin, 250 µg; Vitamin B12, 13 µg, Choline, 1081 mg.

[2] Supplied per kg of diet: Mn, 70 mg; Cu, 10 mg; Fe, 80 mg; Zn, 80 mg; Se, 0.3 mg; I, 0.5 mg, Na, 1.7 g.

3.3.6 Statistical Analysis

The study was set up as a completely randomized design, and data were evaluated by the GLM procedure of the SAS (SAS version 9.2). Means were separated by Tukey's honesty significance difference. All statements of significance are based on $P \leq 0.05$. The feed cost of producing 1 kg of live body weight was also estimated and subject to statistical analysis.

3.4 Results and Discussion

Preliminary studies were effective in establishing the optimum sieve sizes for fraction separation and tail-end dehulling. The use of sieves from 250 to 600 µm resulted in the production of low-fiber fractions 1 and 2 and was effective for all three types of CM used in the study.

The chemical composition of the dehulled meals used in the broiler chicken experiment is presented in Tables 3.3 and 3.4. As illustrated in Table 3.3, dehulling resulted in the production of two distinctive fractions 1 and 2 containing higher amounts of protein and lower amounts of fiber than their parent meals. When compared with the parent meals, the content of total dietary fiber of fractions 1 and 2 decreased from 30.0 to 21.4 and 26.7% for *B. napus* "black" canola, from 27.0 to 21.6 and 23.4% for *B. napus* "yellow" canola, and from 25.5 to 15.3 and 18.7% for *B. juncea* meal, respectively. Likewise, crude protein increased from 36.8 to 42.0 and 39.6% for *B. napus* "black" canola, from 41.0 to 43.6 and 43.0% for *B. napus* "yellow" canola, and from 42.3 to 47.9 and 46.8%

for *B. juncea* meal. Both total P and non-phytate P increased in the dehulled fractions of *B. napus* “black” and *B. juncea* meals, but not in *B. napus* “yellow” meal.

Amino acids contents of the dehulled fractions 1 and 2 were also higher than their corresponding parent meals (Table 3.4). As an example, methionine increased from 0.68 to 0.81 and 0.76% for *B. napus* “black” fractions 1 and 2, from 0.63 to 0.71 and 0.65% for *B. napus* “yellow” fractions 1 and 2, and from 0.66 to 0.83 and 0.74% for *B. juncea* fraction 1 and 2, respectively. Lysine also increased from 2.02 to 2.26 and 2.17% for “black” *B. napus* fractions 1 and 2, from 1.91 to 2.34 and 2.23% for *B. napus* “yellow” fractions 1 and 2, and from 1.95 to 2.29 and 2.20% for *B. juncea* fractions 1 and 2, respectively.

Other components of CM were also affected by dehuling. This was the case for lignin and polyphenols which when compared to the parent meal decreased from 10.3 to 4.8 and 7.3% for *B. napus* “black” fractions 1 and 2; from 4.0 to 2.3 and 2.6% for yellow-seeded *B. juncea* fractions 1 and 2, and from 2.7 to 1.7 and 2.1% for yellow-seeded *B. napus* fractions 1 and 2, respectively.

The levels of sucrose in the dehulled fractions 1 and 2 from all three meals also increased which along with some increases in the fat content of the dehulled fractions observed for *B. napus* “black” and *B. juncea* canola could contribute to the higher available energy contents. Higher levels of sucrose in the dehulled fractions could also improve their palatability which along with the reduced levels of tannins should improve the overall acceptability of the dehulled meals by monogastric animals. As well, the sieving technology only slightly enriched glucosinolates content in the dehulled fractions.

The results of the current study indicate that sieving can be an effective tool in producing the dehulled canola meal with increased nutritive content and reduced level of anti-nutritional factors, including tannins. The results of the present study are consistent with the dehulling experiments conducted by Kracht et al. (2004) who studied the nutritional value of rapeseed meal produced by front-end dehulling of the seeds and found that the nutritive value of dehulled meal can be improved significantly by removing the hull fraction. They reported that dehulling yielded a significant decrease in crude fiber content by 40%, ADF by 35%, and NDF by 28%, which was followed by an increase in protein and sugars contents by 7 and 14% points, respectively.

The results of the current study are also consistent with findings of Safari et al. (2011) who studied the effect of sieving on chemical composition of rapeseed/canola using 5 sieves with openings ranging from 1.19 mm to 0.42 mm and found that as the sieve size decreased, crude fiber, ADF, and NDF contents decreased while total phosphorus and protein increased. In a somewhat similar study, Beltranena and Zijlstra (2011) studied the effect of sieving on the quality of dehulled *B. juncea* meal when using sieves from 425 to 850 µm. When compared with the parent meal, the contents of crude protein and NDF increased from 40.5 to 47.0% and decreased from 22.8 to 11.8% in the dehulled meal, respectively. In a more recent study, Zhou et al. (2013) used the air classification technology for a production of two dehulled fractions “light” and “heavy” with the former one showing higher protein and lower fiber contents similar to those observed for the dehulled fraction 2 produced in the current study. The effectiveness of the dehulling process observed in the present study was also more pronounced than that reported by Mustafa et al. (1996) who found NDF values decreasing from 26.7 to only 24.6% and protein increasing from 37.7 to only 40.2% for the parent meal and the low-fiber fraction, respectively.

The growth performance of broiler chickens fed pre-starter diets is shown in Table 3.9. No statistically significant differences in feed intake, body weight gain, and feed conversion ratio were observed. All canola meal containing diets had similar effect on feed intake regardless of the differences in fibre content of each diet, which is consistent with the findings of Walugembe et al. (2014) who when evaluating the effects of high fiber ingredients on growth performance of broiler and layer chicks demonstrated no effect of dietary fiber on feed intake.

Table 3.9. Growth performance of broiler chickens fed pre-starter diets from 1 to 10 d of age.

Diet	Feed intake g/bird	BWG g/bird	FCR g feed/g gain
Control (corn/SBM)	352.3	285.2	1.24
B. napus conventional “black”			
Parent meal	348.6	293.1	1.19
Dehulled meal, fraction 1	331.3	279.7	1.19
Dehulled meal, fraction 2	335.0	299.4	1.16
B. napus “yellow”			
Parent meal	336.5	278.3	1.17
Dehulled meal, fraction 1	336.3	277.6	1.21
Dehulled meal, fraction 2	348.3	289.0	1.21
B. juncea “yellow”			
Parent meal	326.3	273.2	1.20
Dehulled meal, fraction 1	339.7	288.0	1.18
Dehulled meal, fraction 2	338.1	282.1	1.20
SEM[1]	7.95	7.05	0.019
P value	0.410	0.346	0.288

[1] Standard error of the mean

All treatments showed similar body weight gain, indicating that canola meal and its dehulled fractions would have similar effect as that of the SBM-based control diet. Our results are consistent with the studies by Slominski and Simbaya (1999) who when evaluating the nutritive value of meals derived from yellow-seeded canola found no significant difference in body weight gain of broiler chickens fed canola meal containing diets of different fiber content. Although the inclusion level of canola meals in the current study was 15%, Walugembe et al. (2014) demonstrated that higher dietary levels of canola meal and thus higher fiber content could result in a significant decrease in weight gain of broiler chickens.

Overall, it was demonstrated that chicken performance was equal regardless of the type and the dehulled fraction of CM used, and that fiber content would have minimal effect on growth performance thus indicating that poultry can efficiently utilize diets containing higher amounts of canola fiber right from the early stages of growth. This could be due to the fact that canola fiber is for the most part water-insoluble and thus would have minimal effect on nutrient digestion and absorption.

Statistically significant differences, however, were observed for feed cost per kg of live chicken weight produced (Table 3.10) with the control corn/SBM-based showing the highest cost of $0.65 with diets containing the dehulled fraction 2 of *B. napus* and fraction 1 of *B. juncea* showing the lowest cost of $0.60. The rest of the diets were in the range of $0.62 to $0.63 per kg of live chicken weight.

Table 3.10. Feed cost analysis of pre-starter diets

Diet	Feed price $/tonne	Feed cost $/kg of live chicken weight
Control (corn/SBM)	528.29	0.65[a]
B. napus conventional "black"		
Parent meal	526.69	0.63[ab]
Dehulled meal, fraction 1	516.82	0.61[ab]
Dehulled meal, fraction 2	521.23	0.60[b]
B. napus "yellow"		
Parent meal	522.09	0.61[ab]
Dehulled meal, fraction 1	516.37	0.63[ab]
Dehulled meal, fraction 2	519.82	0.63[ab]
B. juncea "yellow"		
Parent meal	521.37	0.62[ab]
Dehulled meal, fraction 1	508.79	0.60[b]
Dehulled meal, fraction 2	511.07	0.61[ab]
SEM[1]		0.010
P value		0.030

[1] Standard error of the mean
[ab] Means with different superscripts differ significantly (P<0.05)

The current study was conducted in the winter of 2013 when the prices of the ingredients used to formulate the diets were relatively high as a result of the volatility that has characterized prices of grains and feedstuffs in recent years. The prices of feed ingredients were the only factor taken into consideration when determining the feed cost, and following the guidance from experts in Agricultural Economics the price for all of the canola fractions were set at the same level, regardless of the protein content.

In the starter phase of the experiment, no statistically significant effects of parent canola meals on feed intake, body weight gain, and feed conversion ratio were observed (Table

3.11). Only a trend in feed cost (P=0.107) was observed with the values ranging from $0.67 per kg of live chicken weight for the control corn/SBM diet to $64 per kg of live chicken weight for the diets containing dehulled fractions of canola meal (Table 3.12).

Table 3.11. Growth performance of broiler chickens fed starter diets from 11 to 20 d of age.

Diet	Feed Intake g/bird	BWG g/bird	FCR g feed/g gain
Control (corn/SBM)	866.7	628.4	1.38
B. napus conventional "black"			
Parent meal	857.7	638.6	1.34
Dehulled meal, fraction 1	839.8	639.0	1.32
Dehulled meal, fraction 2	890.7	651.2	1.37
B. napus "yellow"			
Parent meal	868.0	633.3	1.37
Dehulled meal, fraction 1	851.9	615.8	1.38
Dehulled meal, fraction 2	842.3	614.1	1.37
B. juncea "yellow"			
Parent meal	840.3	628.0	1.34
Dehulled meal, fraction 1	847.9	636.8	1.33
Dehulled meal, fraction 2	839.1	617.3	1.36
SEM[1]	17.95	13.96	0.018
P value	0.577	0.703	0.206

[1] Standard error of the mean

Table 3.12. Feed cost analysis of starter diets.

Diet	Feed price $/tonne	Feed cost $/kg of live chicken weight
Control (corn/SBM)	485.34	0.67
B. napus conventional “black”		
Parent meal	484.48	0.65
Dehulled meal, fraction 1	484.48	0.64
Dehulled meal, fraction 2	484.48	0.66
B. napus l “yellow”		
Parent meal	478.84	0.66
Dehulled meal, fraction 1	478.84	0.66
Dehulled meal, fraction 2	478.84	0.66
B. juncea “yellow”		
Parent meal	478.91	0.64
Dehulled meal, fraction 1	478.91	0.64
Dehulled meal, fraction 2	478.91	0.65
SEM[1]		0.0086
P value		0.1072

[1] Standard error of the mean

3.5 Conclusions

The present study demonstrated that the chemical and nutritive composition of canola meal could be improved by tail-end dehulling and the production of low-fiber, high-energy and high-protein meals. It is believed that high nutrient density of dehulled meals would allow for a significant replacement of SBM in the pre-starter broiler chicken diets since the use of 15% of dehulled meal resulted in equal growth performance of broiler chickens to that of corn/SBM-based diets. It could also be concluded that canola fiber has minimal effect on nutrient utilization as evidenced by similar growth performance of young broiler chickens fed diets containing canola meals of different fiber content. The benefit from using dehulled canola meals could be reflected in the cost of feed production which for the pre-starter diets containing low-fiber fractions averaged $0.60 per 1 kg of live chicken weight compared to $0.65 for the SBM-based diet.

4.0 MANUSCRIPT 2

Growth performance of weaned pigs fed diets containing conventional and dehulled meals of *B. napus* and *B. juncea* canola

4.1 Abstract

An experiment was conducted to investigate the effect of feeding diets containing high-nutrient density dehulled canola meal (CM) on growth performance of weaned pigs. The conventional *B. napus* “black” canola and canola-quality “yellow” *B. juncea* mustard were used to produce the dehulled fractions 1 and 2. A comprehensive chemical composition of the parent meals and their corresponding dehulled fractions is presented in Manuscript 1 of this thesis. A total of 168 weaned pigs were assigned in a randomized complete block design to 7 dietary treatments with 8 replicate pens of 3 pigs each to evaluate the effect of parent meals and their respective dehulled fractions at 15% of diet on growth performance from 1 to 14 d of age (Phase I) and from 15 to 28 d of age (Phase II). A corn/soybean meal-based diet served as the control. Diets were formulated to meet or exceed NRC 2012 nutrient specification for growing pigs, and were offered *ad libitum*. The experiment had factorial elements such that two types of CM and 3 levels of dehulling, i.e., parent meals and their respective dehulled fractions 1 and 2 were used. Data were analyzed using the Proc-Mix procedure of SAS. Contrasts were applied and demonstrated a significant effect of dehulling on final BW (P=0.01) with the dehulled fractions 2 showing increased final BW compared to the parent meals, dehulled fractions 1, and that of the corn/SBM-based control diet. Dehulling had an effect on ADG in Phase

II (P=0.025) and over the entire trial (P=0.044). When compared with the parent meals, the dehulled fractions 2 showed an increase in ADG by 47.2 g/d for Phase II, and by 31.5 g/d for the entire trial. The type of CM used in the study had an effect on ADG, and as was the case for Phase II and the entire trials, *B. napus* meal increased ADG values compared to *B. juncea* and the corn/SBM-based control diet. Higher amounts of total glucosinolates in *B. juncea* meal, with their further increase in the dehulled fractions 1 and 2, could have an effect on growth performance, especially with regard to feed efficiency which showed statistically significant differences for Phase I, Phase II and the entire trial, with the dehulled fractions of *B. napus* canola showing an increase in G:F ratio when compared to *B. juncea*. Canola type x dehulling effect was observed for feed efficiency in Phase I diets containing dehulled fraction 1 of *B. napus* but not *B. juncea*. When compared to the control SBM-based diet, a consistent improvement for *B. napus* fraction 2 in final BW, ADG in Phase II and the entire trial and feed efficiency in Phase II and the entire trial were observed. It would appear evident that dehulling of canola meal would allow for a significant replacement of SBM in Phase I and Phase II diets for growing pigs with the potential for increased growth performance without affecting voluntary feed intake. The use of *B. napus* dehulled meal at the inclusion level of 15% could result in increased final BW, better ADG and better feed efficiency.

4.2 Introduction

In recent years, high prices of grains have had a direct impact on livestock production cost, as feed cost is exceeding 72% of the total cost of swine production (Zijlstra and Beltranena, 2013). For this reason, alternatives to improve the efficiency of swine production should be considered. Among those alternatives, the development of technologies to improve the utilization of co-products such as canola meal (CM), distillers dried grains with solubles (DDGS), and others have become of interest as cost-effective alternatives to soybean meal (SBM) or cereal grains. Additionally, co-products offer opportunities in the diversification of the feed matrix by using local feed ingredients for the formulation of swine diets to reduce feed cost (Jha et al., 2013).

The use of co-products offers some challenges, and as is the case for CM, the presence of anti-nutritive factors may limit its more extensive use. A study performed by Jha et al. (2013) demonstrated that increasing the use of co-products with high fiber content can reduce the average daily feed intake (ADFI), average daily gain (ADG), and carcass weight and quality, as evidenced by lower dressing percentage and increased viscera weight (Nyachoti et al., 2000; Jha et al., 2013). When compared to SBM, CM contains higher amounts of dietary fiber, glucosinolates, sinapine, phytic acid, tannins, and lower metabolizable energy contents with less consistent AA digestibility and less than optimum electrolyte balance due to high sulfur and low potassium contents (Khajali and Slominski, 2012). One way to improve the utilization of CM has been the development of low-fiber, yellow-seeded *B. napus* canola. Simbaya (1996) found that this type of canola compares favorably with the conventional *B. napus* “black” canola with regard to protein and fiber contents. It has also been demonstrated that "yellow" *B. napus* has higher available energy content for poultry than the "black" *B. napus* (Jia et al., 2012). Following a study on yellow-seeded and low-glucosinolate cultivars of canola, Evrard (2004) concluded that such genetic improvements would allow for increased use of CM in animal nutrition.

Among other factors precluding higher inclusion levels of CM in diets for poultry and swine is high level of phytic acid. It is well known that phytic acid can affect animal performance by reducing nutrient digestibility through binding to nutrients, the digestive enzymes or both which, in turn, would result in increased endogenous loses of amino acids (AA) (Woyengo and Nyachoti, 2013). The negative impact of phytic acid can be minimized by the addition of phytase to improve phosphorus availability and to reduce the anti-nutritional effects of phytic acid. The use of other exogenous enzymes has been shown to have a positive effect on fiber utilization in swine (Kerr, 2013). Omegbenigun et al. (2004) demonstrated that the use of multienzyme preparations would improve growth performance of weaned pigs by improving ileal and fecal digestibility of DM, energy, CP, starch, phytate and dietary fiber components.

Dehulling of canola has been indicated as a means to improve the nutritive value of CM by reducing fiber content and increasing protein and energy contents (Simbaya et al., 1992; Kratch et al, 1999; Zhou et al, 2013). When evaluating the meals from the front-end dehulling process (Simbaya et al., 1992), a significant increase in protein content of the dehulled meal and a reduction in the content of two major components of dietary fiber: nonstarch polysaccharides and lignin with associated polyphenols was observed. Kratch et al. (1999) demonstrated that following front-end dehulling, the feeding value of rapeseed/canola meal would improve as documented by improved AA digestibility and energy utilization. In addition to reduction in dietary fiber content, dehulling may increase the glucosinolate content of the meal (Bell and Shires, 1982) due to the fact that glucosinolates are concentrated in the embryo of canola seed (Bell, 1993). Recent surveys of eleven Canadian canola crushing plants revealed the levels of glucosinolates to average 4.3, 5.2 and 5.1 µmol/g (10% moisture basis) for the three consecutive years 2011, 2012 and 2013, respectively (Rogiewicz et al., 2012; Adewole et al., 2014). Considering 2.0 µmol of glucosinolates per gram of the diet as the maximum level of glucosinolates in piglet diets (Bell, 1993), higher inclusion rates of CM than the traditional 4-6% could be considered.

The present study was conducted to evaluate the effect of CM and their dehulled fractions on growth performance of weaned piglets fed pre-starter and starter diets. The experimental diets were balanced to meet or exceed nutrient requirements as recommended by NRC (2012) recommendations. All diets had the same nutritive content and, as a result, their effect on growth performance would be solely due to differences in fiber content. Two types of canola *B. napus* “black” and canola-quality *B. juncea* mustard meals and their dehulled fractions were used in the study.

4.3 Materials and Methods

4.3.1 Material

Meal samples of conventional *B. napus* “black” canola and canola-quality *B. juncea* mustard were obtained from the Bunge Altona, MB, Canada processing plant and were produced using the conventional pre-press solvent extraction process. The dehulled CM fractions were produced at the Canadian International Grains Institute, Winnipeg, Manitoba, Canada using a Plansifter, Model MPAR-8HK, Bühler AG, CH-9240, Uzwil, Switzerland. The parent meals and their dehulled fractions were the same as those used in the broiler chicken study reported in Manuscript 1 of this thesis.

4.3.2 Analytical procedures

The procedures used for chemical characterization of CM and their dehulled fractions were the same as those described in Manuscript 1 of this thesis.

4.3.3 Animals and housing

A total of 168 pigs (Yorkshire-Landrace x Duroc) with initial body weight (BW) of 6.86 ±0.83 kg (mean ± SD) and weaned at 21 ±1 days of age, were acquired from Glenlea Swine Research Unit, University of Manitoba. Three pigs per pen were randomly allocated to 4 rooms based on their initial BW and sex. Barrows had average BW of 6.86 ±0.13 kg (mean ±SD). Gilts had average BW of 6.85 ±0.26 kg (mean ±SD). Pens with plastic-covered expanded metal floors were used (space allowed was 0.6 m^2 per pig) and were equipped with nipple bowl drinkers and metal feed troughs. Room temperature was initially set at 29 ±1°C and was gradually decreased by 1°C/week. A 16 hour light (0600-2200h), and 8 hour dark cycle was provided. Pigs had unlimited access to feed and water throughout the 4-wk study. Body weight and feed disappearance were monitored weekly. The experimental protocol used in the present study was reviewed and approved by the Animal Care Committee of the University of Manitoba. Animals were cared for according to the Guidelines of the Canadian Council on Animal Care (CCAC, 2009).

4.3.4 Diets

Pigs were randomly assigned to seven dietary treatments. The experimental diets consisted of a control corn/SBM-based diet and diets containing two different canola meals and their respective dehulled fractions 1 and 2. The chemical composition of CM and their dehulled fractions produced by sieving is shown in Tables 4.1, 4.2, and 4.3. Diets were formulated to meet or exceed NRC (2012) nutrient specification for growing pigs. Pre-starter (Phase I) and starter (Phase II) diets were formulated. The composition and calculated nutrient content of experimental diets is shown in Tables 4.4 and 4.5.

Table 4.1. Chemical composition of conventional *B. napus* "black" canola meal and canola-type *B. juncea* "yellow" mustard meal, and their corresponding dehulled fractions 1 and 2 produced by sieving (%, as-is basis)

Component	*B. napus* "black"			*B. juncea* "yellow"		
	Parent meal	Dehulled fractions		Parent meal	Dehulled fractions	
		1	2		1	2
DM	91.3	92.5	91.9	90.7	91.4	91.1
Crude protein (Nx6.25)	36.9	41.7	39.6	42.3	47.9	46.8
Fat	3.8	5.2	4.6	3.4	4.0	3.6
Ash	7.1	8.9	7.6	6.6	7.4	7.0
Sucrose	6.3	6.6	6.7	7.6	7.7	8.1
Dietary fiber fractions						
Acid detergent fiber	17.0	9.6	14.0	9.7	5.3	6.4
Neutral detergent fiber	23.6	14.8	19.0	15.9	8.7	10.9
Total dietary fiber	30.1	21.4	26.8	25.5	15.3	18.7
Non-starch polysaccharides	17.0	14.9	17.3	19.4	12.1	14.9
Lignin and polyphenols	10.3	4.8	7.3	4.0	2.3	2.6
Glycoprotein	2.8	1.7	2.2	2.1	0.9	1.2
Phosphorus (P)	0.95	1.27	1.13	1.04	1.19	1.12
Phytate P	0.56	0.66	0.62	0.58	0.64	0.66
Non-phytate P	0.39	0.61	0.51	0.46	0.55	0.55
Calcium	0.67	0.64	0.64	0.76	0.62	0.62
Glucosinolates (µmol/g)[1]	9.2	9.6	9.6	12.2	13.5	13.6

[1] Includes gluconapin, glucobrassicanapin, progoitrin, gluconapoleiferin, glucobrassicin, and 4-hydroxyglucobrassicin.

Table 4.2. Glucosinolates content of *B. napus* "black" and *B. juncea* "yellow" meals and their respective dehulled fractions 1 and 2 (µmol/g, as-is basis)

Glucosinolate	*B. napus* "black"			*B. juncea* "yellow"		
	Parent Meal	Dehulled fractions		Parent Meal	Dehulled fractions	
		1	2		1	2
Gluconapin	2.1	2.6	2.3	10.1	11.2	11.2
Glucobrassicanapin	0.3	0.3	0.3	0.8	0.9	1.0
Progoitrin	5.1	5.7	5.3	0.8	0.9	1.0
Gluconapoleiferin	0.2	-	0.3	-	-	-
Glucobrassicin	0.4	0.3	0.4	0.1	0.1	0.1
4-Hydroxyglucobrassicin	1.2	0.8	1.1	0.3	0.3	0.4
Total glucosinolates	9.2	9.6	9.6	12.2	13.5	13.6

Table 4.3. Amino acid composition of conventional *B. napus* "black" canola meal and canola-type *B. juncea* "yellow" mustard meal, and their corresponding dehulled fractions 1 and 2 produced by sieving (%, as-is basis).

Amino acid	*B. napus* "black"			*B. juncea* "yellow"		
	Parent meal	Dehulled fractions		Parent meal	Dehulled fractions	
		1	2		1	2
Alanine	1.49	1.76	1.63	1.72	2.05	1.94
Arginine	2.28	2.77	2.50	2.85	3.60	3.30
Aspartate	2.62	3.01	2.82	3.34	3.87	3.70
Cystine	0.80	0.92	0.89	0.70	0.85	0.79
Glutamine	6.60	7.81	7.24	7.26	8.49	8.10
Glycine	1.85	2.19	2.02	2.16	2.56	2.40
Histidine	1.18	1.37	1.27	1.31	1.51	1.42
Isoleucine	1.21	1.46	1.34	1.21	1.81	1.63
Leucine	2.43	2.92	2.68	2.76	3.52	3.27
Lysine	2.02	2.26	2.17	1.95	2.29	2.20
Methionine	0.68	0.81	0.76	0.66	0.83	0.74
Phenylalanine	1.40	1.69	1.54	1.53	1.98	1.83
Proline	2.54	2.89	2.69	2.77	2.93	2.81
Serine	1.69	1.93	1.81	1.94	2.18	2.10
Threonine	1.62	1.85	1.74	1.82	2.14	2.03
Tyrosine	0.93	1.11	1.03	1.05	1.34	1.24
Valine	1.66	1.95	1.81	1.62	2.35	2.12

Table 4.4. Composition and calculated nutrient contents of Phase 1 diets (%, as-fed basis)

Ingredient	Control corn/ SBM	*B. napus* "black" Parent meal	*B. napus* "black" Dehulled fractions 1	*B. napus* "black" Dehulled fractions 2	*B. juncea* "yellow" Parent meal	*B. juncea* "yellow" Dehulled fractions 1	*B. juncea* "yellow" Dehulled fractions 2
Corn	32.95	30.75	31.80	31.22	32.24	33.28	32.91
Wheat	20.00	20.00	20.00	20.00	20.00	20.00	20.00
SBM	15.00	-	-	-	-	-	-
Fish meal	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Canola meal	-	15.00	15.00	15.00	15.00	15.00	15.00
Dried whey	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Porcine plasma	4.00	6.49	5.42	6.02	4.77	3.66	4.05
Canola oil	-	-	-	-	-	-	-
Calcium carbonate	0.96	0.88	0.99	0.95	0.88	0.97	0.97
Di-calcium phosphate	0.35	0.25	0.08	0.16	0.21	0.13	0.13
L-Lysine	0.40	0.37	0.44	0.39	0.55	0.61	0.59
DL- Methionine	0.20	0.15	0.14	0.14	0.20	0.18	0.19
Threonine	0.14	0.11	0.13	0.12	0.15	0.16	0.16
L-Tryptophan	-	-	-	-	-	0.01	-
Vitamin premix[1]	0.50	0.5	0.5	0.5	0.50	0.50	0.50
Mineral premix[2]	0.50	0.5	0.5	0.5	0.50	0.50	0.50
Calculated nutrient composition							
Crude protein, %	22.00	22.00	22.00	22.0	22.00	22.00	22.00
Net energy, kcal/kg	2478	2451	2460	2458	2500	2511	2510
Calcium, %	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Available P, %	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Methionine + cysteine (SID, %)	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Methionine (SID, %)	0.52	0.49	0.49	0.49	0.52	0.51	0.52
Cysteine (SID, %)	0.30	0.33	0.33	0.33	0.30	0.30	0.30
Lysine (SID, %))	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Threonine (SID, %)	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Tryptophan (SID, %)	0.29	0.28	0.27	0.27	0.26	0.26	0.25
Analyzed composition							
Crude protein, %	21.6	22.2	22.9	23.3	22.8	23.5	23.5

[1] Supplied per kg of diet: Vitamin A, 8250 IU; Vitamin D3, 825 IU; Vitamin E, 40 IU; Vitamin K, 4.0 mg; Thiamin (B1): 2.0 mg; Riboflavin, 10.0 mg; Pantothenate: 15 mg; Choline, 500 mg Niacin, 22.5 mg; Vitamin B6 4.5mg; Vitamin B12: 25 µg ; Biotin, 200 µg; Folic Acid, 2.0 mg..

[2] Supplied per kg of diet: Cu, 150 mg; Zn, 150 mg; Fe, 100 mg; Mn, 50 mg; I, 0.4 mg; Se, 0.3 mg.

Table 4.5. Composition and calculated nutrient contents of Phase 2 diets (%, as-fed basis)

Ingredient	Control corn/ SBM	*B. napus* “black”			*B. juncea* “yellow”		
		Parent meal	Dehulled fractions		Parent meal	Dehulled fractions	
			1	2		1	2
Corn	46.33	40.46	43.00	41.74	45.88	48.46	47.70
Wheat	20.00	20.00	20.00	20.00	20.00	20.00	20.00
SBM	26.25	15.59	13.72	14.73	12.35	10.43	11.07
Canola meal	-	15.00	15.00	15.00	15.00	15.00	15.00
Canola oil	2.98	4.66	4.02	4.26	2.32	1.64	1.76
Calcium carbonate	1.14	1.02	1.11	1.06	1.00	1.10	1.10
Di-calcium phosphate	1.25	1.15	1.02	1.09	1.16	1.11	1.10
L-Lysine	0.65	0.74	0.76	0.75	0.85	0.86	0.85
DL- Methionine	0.19	0.16	0.15	0.15	0.20	0.17	0.19
Threonine	0.21	0.22	0.22	0.22	0.24	0.23	0.23
L-Tryptophan	-	-	-	-	-	-	-
Mineral premix[1]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Vitamin premix[2]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Calculated nutrient composition							
Crude protein, %	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Net energy, kcal/kg	2448	2448	2448	2448	2448	2448	2448
Calcium, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Available P, %	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Methionine + cysteine (SID, %)	0.74	0.74	0.74	0.74	0.74	0.74	0.74
Methionine (SID, %)	0.45	0.44	0.44	0.43	0.46	0.45	0.46
Cysteine (SID, %)	0.28	0.30	0.31	0.31	0.28	0.29	0.28
Lysine (SID, %)	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Threonine (SID, %)	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Tryptophan (SID, %)	0.29	0.26	0.26	0.26	0.25	0.25	0.25
Analyzed composition							
Crude protein, %,	21.4	20.7	20.8	21.2	20.0	19.5	21.3

[1] Supplied per kg of diet: Vitamin A, 1560 IU; Vitamin D3, 180 IU; Vitamin E, 13.2 IU; Vitamin K, 0.6 mg; Thiamin (B1): 1.2 mg; Riboflavin, 3.0 mg; Pantothenate: 6.6 mg; Choline, 360 mg Niacin, 12.0 mg; Vitamin B6 1.2 mg; Vitamin B12: 12.0 µg ; Biotin, 200 µg; Folic Acid, 0.36 mg..

[2] Supplied per kg of diet: Cu, 4.8 mg; Zn, 72.0 mg; Fe, 72.0 mg; Mn, 2.4 mg; I, 0.168 mg; Se, 0.18 mg.

4.3.5 Statistical Analysis

The study was conducted as randomized complete block design with 7 treatments and 8 replicates per treatments. Data were analyzed using the Mixed Procedure of SAS software release 9.4. The treatments consisted of the control corn/SBM as well as the factorial combination of two canola meals *B. napus* ”black” and *B. juncea* “yellow” and their corresponding dehulled fractions 1 and 2. Treatments were randomly assigned to 4 rooms with 14 pens per room, for a total of 56 pens. The pen of 3 pigs served as an experimental unit. Random effects of sex, room, sex-treatment interaction and block-treatment-sex interaction were considered. Factorial effects were as follows: CM main effect, dehulling main effect, canola and dehulling effect. To determine the significance for factorial effects contrasts were applied and t-test for main effect was used. The factor was considered significant when $P<0.05$. Dunnett-Hsu for mean separation was used to compare canola treatments to the control corn/SBM diet. Two levels of significance were considered, $P\leq0.05$ and $P\leq 0.10$.

4.4.0 Results and Discussion

4.4.1 Quality characteristics of dehulled canola meals

The chemical composition of *B. napus* and *B. juncea* dehulled meals is shown Table 4.1. When compared with the parent meals, the content of total dietary fiber of fractions 1 and 2 decreased from 30.0 to 21.4 and 26.7% for *B. napus* “black” canola, and from 25.5 to 15.3 and 18.7% for *B. juncea* meal, respectively. Likewise, crude protein increased from 36.8 to 42.0 and 39.6% for *B. napus* “black” canola, and from 42.3 to 47.9 and 46.8% for *B. juncea* meal.

Our results are consistent with those found by Beltranena and Zijlstra (2011), who reported improvements in quality of *B. juncea* meal when using sieves from 425 to 850 µm with the CP values for the dehulled fractions ranging from 40.5% to 47.0% and the NDF contents from 22.8 to 11.8%. When using sieves from 250 to 600 µm, they reported the CP values of 41.5% to 47.7% and NDF values of 22.3 to 11.4%. In another study, Zhou et al. (2013) used air-classification and two types of CM and produced 2 fractions with protein levels of 39.2% for the "light" fraction and 41.9% for the "heavy" fraction, compared to 37.3% for the parent *B. napus* "black" meal.

The glucosinolate content of the meals is shown in Table 4.2. According to their structure, glucosinolates can be divided into aliphatic glucosinolates, including sinigrin, gluconapin, glucobrassicanapin and progoitrin, and indole glucosinolates, including glucobrassicin and hydroxyl-glucobrassicin. In different *Brassica* species the composition of glucosinolates is different. The major glucosinolates of *B. napus* rapeseed are gluconapin, progoitrin, and 4-hydroxyglucobrassicin while gluconapin is a predominant glucosinolate of *B. juncea* (Slominski et al., 2012). As illustrated in Table 4.2, sieving technology slightly enriched glucosinolates content in the dehulled fractions, more so in those from *B. juncea* than from *B. napus* canola.

As was the case with increased protein content of dehulled meals, the AA contents of the dehulled fractions 1 and 2 were also higher than those of their corresponding parent meals (Table 4.3). A comprehensive discussion about the chemical composition and nutritive value of dehulled canola meal is included in manuscript 1 of the present thesis.

4.4.2 Animal performance

The effect of *B. napus* canola and canola-quality *B. juncea* mustard meals and their respective dehulled fractions 1 and 2 on growth performance of young pigs is summarized in Table 4.6. The results didn't show an effect of gender on growth performance. Type of diet did not have an effect on ADFI, indicating that pigs readily consumed Phase I and Phase II diets containing 15% of *B. napus* canola and canola-quality *B. juncea* mustard meals and their dehulled fractions 1 and 2. When contrasts were applied to final BW data, a dehulling effect was noted (P=0.01) with dehulled fractions 2 showing increased final BW compared to the parent meals and dehulled fractions 1. Additionally, diets containing *B. napus* "black" canola outperformed diets containing *B. juncea* "yellow" for final BW (P=0.039).

When Dunnett-Hsu mean separation was applied, the results showed that piglets fed diets containing *B. napus* dehulled fraction 2 increased their final BW compared to all other canola treatments, and to that of the corn/SBM-based control diet. These data are in contrast with those of Zhou et al. (2013) who did not observe any significant improvement in final BW of piglets fed *B. napus "*black" or *B. juncea* "yellow" parent meals and their dehulled "light" or "heavy" fractions. As well, no effect of diets containing *B. napus "*black" or *B. juncea* meals at different inclusion rates on growth performance of pigs was noted in the study by Sanjayan et al. (2014).

Table 4.6. The effect of *B. napus* canola and canola-quality *B. juncea* mustard meals and their respective dehulled fractions 1 and 2 on growth performance of young pigs

Item	ADG			ADFI			G:F			Final BW
	g/day/pig			g/day/pig			g gain/g feed			kg
	Phase I	Phase II	Overall	Phase I	Phase II	Overall	Phase I	Phase II	Overall	
Diet										
Control (SBM)	371.0	348.4	359.4	467.5	737.4	619.4	0.80	0.47	0.58	16.86
B. napus, conventional										
Parent meal	345.9	409.6*	377.3	428.6	742.9	595.7	0.80	0.55*	0.63	17.39
Dehulled meal, fraction 1	376.7	421.7**	399.3	421.2	731.9	587.9	0.89**	0.58**	0.68**	17.81
Dehulled meal, fraction 2	366.4	468.6**	416.8**	425.8	774.5	608.5	0.87	0.61**	0.69**	18.53**
B. juncea meal										
Parent meal	362.8	373.8	368.3	424.8	730.6	587.1	0.86	0.51	0.63	17.29
Dehulled meal, fraction 1	341.7	378.9	359.9	433.5	731.1	583.2	0.79	0.51	0.62	16.93
Dehulled meal, fraction 2	376.4	407.3*	391.7	481.2	749.5	625.9	0.78	0.54	0.62	17.90*
Pooled SEM	15.40	19.91	14.48	19.41	16.03	18.37	0.018	0.021	0.014	0.310
Least squares means for main effects										
Canola type effect										
B. napus meal	363.0	433.4	398.0	425.2	749.6	597.4	0.85	0.58	0.67	17.9
B. juncea meal	360.2	387.0	373.4	446.2	737.1	598.8	0.81	0.52	0.62	17.4
Pooled SEM	8.42	12.22	8.68	11.1	12.42	12.71	0.009	0.011	0.007	0.22
Dehulling effect										
Parent meal (as-is)	354.3	391.5^{b}	372.9^{b}	426.7	736.77	591.4	0.83	0.53	0.63	17.3b
Dehulled meal, fraction 1	359.2	400.6^{b}	379.8^{ab}	427.4	731.3	585.5	0.84	0.55	0.65	17.4b
Dehulled meal, fraction 2	371.4	438.7^{a}	404.4^{a}	453.5	762.0	617.2	0.823	0.57	0.65	18.2a
Pooled SEM	10.61	14.016	10.04	13.68	13.46	14.38	0.012	0.014	0.0269	0.26
Factors and significance[1]										
Diet	0.510	0.002	0.027	0.180	0.400	0.400	0.009	0.005	0.002	0.007
Canola type effect	0.828	0.004	0.026	0.188	0.348	0.933	0.019	0.003	0.002	0.039
Dehulling effect	0.514	0.025	0.044	0.287	0.147	0.165	0.620	0.140	0.221	0.010
Canola type x dehulling	0.198	0.730	0.500	0.267	0.699	0.659	0.003	0.790	0.097	0.400

[1] Based on the MIXED analysis using contrast to derive main effects and interactions from the seven treatments

**Values differ significantly ($P \leq 0.05$) from control using Dunnett-Hsu mean separation

*Values differ significantly ($P > 0.05$ & ≤ 0.10) from control using Dunnett-Hsu mean separation

[ab] Main effect means sharing a common letter within a factor are not significantly different using a t-test $P<0.05$

Dehulling had a significant effect on ADG for Phase II (P=0.025) and the entire trial (P=0.044). When comparing parent meals with their dehulled fractions 2, the dehulled meals showed an increase in ADG by 47.2 g/d/pig for Phase II diets, and by 31.5 g/d/pig over the entire trial. The type of CM used in the study had an effect on ADG, and as was the case for Phase II (P=0.004) and the entire trial (P=0.026) *B. napus* "black" increased ADG values compared to *B. juncea* "yellow" and the corn/SBM-based control diet.

The results of the current study are consistent with those of Landero et al., (2013) who demonstrated that feeding increased levels of *B. juncea* meal to young pigs resulted in decreased growth performance when compared to a SBM-based diet. Such an effect could be due to differences in the glucosinolate contents and profile. As illustrated in Table 4.2, higher amounts of total glucosinolates in *B. juncea* meals, with further increased amounts in the dehulled fractions 1 and 2, could have an effect on growth performance, especially with regard to feed efficiency which showed statistically significant differences for Phase I (P=0.019), Phase II (P=0.003) and the entire trial (P=0.002) with *B. napus* "black" canola showing an increase in G:F ratio when compared to *B. juncea* meal.

The results of the current study did not show any canola type x dehulling effect for most of the growth performance parameters measured except for feed efficiency with Phase I diets containing fraction 1 showing an effect on gain to feed ratio when using *B. napus* "black" but not *B. juncea* "yellow" (Table 4.7).

Table 4.7. The effect of canola meal and their dehulled fractions on feed efficiency in Phase 1 of the experiment

Diet	G:F g gain/g feed
B. napus, conventional "black"	
Parent meal	0.80^{ab}
Dehulled meal, fraction 1	0.89^{a}
Dehulled meal, fraction 2	0.86^{ab}
B. juncea meal, "yellow"	
Parent meal	0.86^{ab}
Dehulled meal, fraction 1	0.79^{b}
Dehulled meal, fraction 2	0.78^{b}
SEM	0.018
P value	0.003

^{ab}Means with no common superscript differ significantly ($P<0.05$)

Dehulled *B. juncea* fractions 1 and 2 tended to decrease feed efficiency which could be attributed to the higher levels of glucosinolates in the dehulled fractions of *B. juncea*, and more specifically the glucosinolate gluconapin (Table 4.2). This is consistent with the results by Landero et al. (2013) who found that feeding piglets with increased levels of *B. juncea* meal (i.e., from 60 to 240 g/kg) resulted in decrease growth performance. This effect was attributed to the sensitivity of pigs to the glucosinolate gluconapin that is common for *B. juncea* meal. This concept is also supported by the data by Zhou et al. (2013) who found that feeding *B. juncea* lowered the ADFI compared with *B. napus*.

When diets containing parent CM and their dehulled fractions were compared to the control SBM-based diet using Dunnett-Hsu mean separation test, a consistent improvement for *B. napus* fraction 2 in final BW, ADG in Phase II and the entire trial and feed efficiency in Phase II ($P\leq 0.05$) and the entire trial were observed. Overall, the growth performance of pigs fed the dehulled fractions or their parent meals outperformed the control corn/SBM-based.

4.5 Conclusions

In conclusion, the results of this study indicate that dehulling of canola meal could allow for a significant replacement of SBM in Phase I and Phase II diets for growing pigs with the potential for increased growth performance without affecting voluntary feed intake. The use of *B. napus* “black” dehulled meal at the inclusion level of 15% could result in increased final BW and feed efficiency. It would also appear evident that the use of conventional CM in combination with SBM could be beneficial and result in better ADG than when using SBM alone.

5.0 GENERAL DISCUSSION

The first objective of the current study was to investigate the potential for tail-end dehulling of canola meal. To achieve our goal a series of preliminary experiments was conducted to determine the optimal conditions for tail-end dehulling of canola meal. As a result, the most promising and distinctive fractions of dehulled meal were produced using the sieves within the range of 250-600 µm. Such sieves were effective for the production of low-fiber fractions 1 and 2 from all three types of CM used in the study. When compared with the parent meals, the content of total dietary fiber of fractions 1 and 2 decreased from 30.0 to 21.4 and 26.7% for *B. napus* "black" canola, from 27.0 to 21.6 and 23.4% for *B. napus* "yellow" canola, and from 25.5 to 15.3 and 18.7% for *B. juncea* meal, respectively. Likewise, crude protein increased from 36.8 to 42.0 and 39.6% for *B. napus* "black" canola, from 41.0 to 43.6 and 43.0% for *B. napus* "yellow" canola, and from 42.3 to 47.9 and 46.8% for *B. juncea* meal. Both total P and non-phytate P increased in the dehulled fractions of *B. napus* "black" and *B. juncea* meals, but not in *B. napus* "yellow" meal.

Amino acids contents of the dehulled fractions 1 and 2 were also higher than their corresponding parent meals. Such increases are important elements to consider when formulating diets for poultry and swine. Methionine increased from 0.68 to 0.81 and 0.76% for *B. napus* "black" fractions 1 and 2, from 0.63 to 0.71 and 0.65% for *B. napus* "yellow" fractions 1 and 2, and from 0.66 to 0.83 and 0.74% for *B. juncea* fraction 1 and 2, respectively. Lysine also increased from 2.02 to 2.26 and 2.17% for *B. napus* "black" fractions 1 and 2, from 1.91 to 2.34 and 2.23% for *B. napus* "yellow" fractions 1 and 2, and from 1.95 to 2.29 and 2.20% for *B. juncea* fractions 1 and 2, respectively. As well, arginine increased from 2.28 in the parent meal, to 2.77 and 2.50% for *B. napus* “black” fractions 1 and 2, from 2.08 to 2.63 and 2.49% for *B. napus* “yellow” fractions 1 and 2, and from 2.85 to 3.6 and 3.30% for *B. juncea* fractions 1 and 2, respectively.

The increases in amino acids contents of the dehulled fractions would allow for higher inclusion levels of CM in poultry and swine diets. However, further research is needed to investigate the digestibility of amino acids, and the effect of anti-nutritional factors, due to the fact that sieving technology could slightly enrich glucosinolate content in the dehulled fractions, while decreased lignin and polyphenols (i.e., tannins). The increased levels of sucrose in the dehulled fractions 1 and 2 from all three meals along with some increases in the fat content of the dehulled fractions in *B. napus* “black” and *B. juncea* canola could contribute to the higher available energy contents. Higher levels of sucrose and lower levels of tannins observed in the dehulled fractions could also improve palatability and the overall acceptability of the dehulled meals in monogastric animals. The results of the current study indicate that sieving can be an effective tool in producing the dehulled canola meal with increased nutritive content and reduced level of anti-nutritional factors, including tannins.

The second objective was to investigate the effect of feeding parent meals from the conventional *B. napus* “black” and yellow-seeded *B. napus* canola, and canola-quality *B. juncea* mustard and their respective dehulled meals on growth performance of broiler chickens fed corn/SBM-based diets. The broiler chicken experiment showed no statistically significant differences in feed intake, body weight gain, and feed conversion ratio. All canola meal containing diets had similar effect on feed intake regardless of the differences in fibre content of each diet. This is consistent with the findings of Walugembe et al. (2013) who evaluated the effects of high fiber ingredients on growth performance of broilers and layers and found no effect of dietary fiber on feed intake. Similar body weight gain observed in the current experiment indicates that canola meal and its dehulled fractions would have similar effect as that of the SBM-based control.

Slominski and Simbaya (1999) evaluated the nutritive value of meals derived from yellow-seeded canola and found no significant difference in body weight gain of broiler chickens fed canola meal containing diets of different fiber content. The present experiment did not evaluate different levels of fiber as such, however, the inclusion level of canola meals in the study was 15%, and differences in fiber content between the parent meals and their dehulled fractions were quite distinct. Walugembe et al. (2014) found that higher dietary levels of canola meal and thus higher fiber content could result in a significant decrease in weight gain of broiler chickens. The present experiment demonstrated that fiber content would have minimal effect on growth performance indicating that poultry can efficiently utilize diets containing higher amounts of canola fiber since early stages of growth. This could be due to the fact that canola fiber is for the most part water-insoluble and thus would have minimal effect on nutrient digestion and absorption.

Cost analysis was performed and statistically significant differences were observed for feed cost per kg of live chicken weight produce. The control corn/SBM-based showed the highest cost of $0.65 per kg of live chicken weight produced, while diets containing the dehulled fraction 2 of *B. napus* and fraction 1 of *B. juncea* showed the lowest cost of

$0.60. It was demonstrated that chicken performance was equal regardless of the type and the dehulled fraction of CM used.

The effect of canola meal from *B. napus* “black” and canola-quality *B. juncea* mustard and their dehulled fractions on growth performance of weaned piglets fed pre-starter and starter diets was also investigated. For the swine experiment, the type of diet did not have an effect on ADFI, indicating that pigs readily consumed Phase I and Phase II diets containing 15% of *B. napus* canola and canola-quality *B. juncea* mustard meals and their respective dehulled fractions 1 and 2. However, when applying contrasts the final BW data showed dehulling effect (P= 0.01). Dehulled fractions 2 increased final BW compared to the parent meals and dehulled fractions 1. Furthermore, diets containing *B. napus* “black” canola outperformed diets containing *B. juncea* “yellow” for final BW (P=0.039).

Improved performance of weaned piglets fed diets containing low fiber, high protein fractions is in contrast with findings by Zhou et al. (2013) who did not observe any significant improvement in final BW of piglets fed *B. napus* “black” or *B. juncea* “yellow” parent meals and their dehulled “light” or “heavy” fractions. Besides, no effect of diets containing *B. napus* “black” or *B. juncea* meals at different inclusion rates on growth performance of pigs was noted in the study by Sanjayan et al. (2014). Although in the broiler experiment dehulling had no effect on ADG, the swine data indicated that dehulling had an effect on ADG for Phase II (P=0.025) and the entire trial (P=0.044). When comparing parent meals with their dehulled fractions 2, the dehulled meals showed an increase in ADG by 47.2 g/day/piglet for Phase II diets, and by 31.5 g/day/piglet for the entire trial. Such increase in ADG could be translated into faster time to reach market weight with the corresponding savings on feed and all related expenses. The type of CM used in the study had an effect on ADG and *B. napus* "black" increased ADG values compared to *B. juncea* "yellow" and the corn/SBM-based control diet for Phase II and the entire trials. Such results are consistent with the findings of Landero et al., (2013) who demonstrated that feeding increased levels of *B. juncea* meal to young pigs resulted in decreased growth performance compared to a SBM-based diet. Such an effect could be due to differences in the glucosinolate amounts and their profile. In contrast to the broiler experiment, that did not showed statistical significance for feed efficiency, the swine experiment showed statistically significant differences for Phase I, Phase II and the entire trial, with the dehulled fractions of *B. napus* "black" canola showing an increase in G:F ratio when compared to *B. juncea* meal. The results showed canola x dehulling effect for feed efficiency with Phase I diets containing fraction 1 showing an effect on gain to feed ratio when using *B. napus* "black" but not *B. juncea* "yellow". Dehulled *B. juncea* fractions 1 and 2 tended to decrease feed efficiency which could be attributed to the higher levels of glucosinolates in the dehulled fractions of *B. juncea*, and more specifically the glucosinolate gluconapin

When diets containing parent canola meals and their fractions were compared to the control SBM-based diet, a consistent improvement for *B. napus* fraction 2 in final BW, ADG in Phase II and the entire trial and feed efficiency in Phase II and the entire trial were observed. Overall, the growth performance of pigs fed the dehulled fractions or their parent meals outperformed the control corn/SBM-based diet.

6.0 SUMMARY AND CONCLUSIONS

The present study demonstrated that the chemical and nutritive composition of CM could be improved by tail-end dehulling and the production of low-fiber, high-energy and high-protein meals.

High nutrient density of dehulled meals would allow for a significant replacement of SBM in the pre-starter broiler chicken diets. Results also indicate that dehulling of canola meal would allow for a significant replacement of SBM in the pre-starter and starter diets for growing pigs

Canola fiber has minimal effect on nutrient utilization of young broiler chickens fed diets containing canola meals of different fiber content. In growing pigs, the dehulling had an effect on final BW but not that of ADFI, indicating a potential for increased growth performance without affecting voluntary feed intake. The use of *B. napus* “black” dehulled meal at the inclusion level of 15% could result in increased final BW and feed efficiency. The benefit of dehulling can be observed in the cost of feed production which for the pre-starter broiler diets containing low-fiber fractions averaged $0.60 per 1 kg of live chicken weight compared to $0.65 for the SBM-based diet. In the case of swine diets, the benefit could be reflected on increased ADG when pigs are fed dehulled fractions of CM, and their market weight has the potential to be achieved in a shorter period of time. It would also appear evident that the use of conventional CM in combination with SBM could be beneficial and result in better ADG than when using SBM alone.

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