EVALUATION OF CANOLA MEAL DERIVED FROM B*rassica juncea* AND *Brassica napus* AS AN ENERGY SOURCE FOR CATTLE

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ABSTRACT

Two trials were carried out to evaluate the effect of inclusion level of canola meal derived from *Brassica* (*B.*) *napus* and *B. juncea* on cattle performance and nutrient utilization. Trial 1 consisted of backgrounding (54 d) and finishing (153 d) phases. The control diet for the backgounding (BK) phase consisted of 39% barley silage, 30.4% barley grain, 22.8% brome grass hay and 7.8% supplement (DM). Treatments consisted of *B. napus* or *B. juncea* at 15 or 30% (DM) inclusion, replacing barley grain. The finishing control diet consisted of 88.3% barley grain, 4.4% barley silage and 7.3% supplement (DM). Treatments consisted of *B. napus* or *B. juncea* at 10 or 20% (DM) inclusion, replacing barley grain. During BK, dry matter intake (DMI), average daily gain (ADG), gain: feed (G:F) increased linearly ($P < 0.01$) as the level of inclusion of *B. juncea* meal increased. Cattle fed *B. napus* meal showed a quadratic response ($P = 0.05$) in DMI and linear increase ($P = 0.02$) in ADG with increasing inclusion. During finishing, DMI increased linearly ($P = 0.05$) for cattle fed *B. juncea* meal while a quadratic response ($P = 0.02$) was seen with *B. napus* meal. Feed efficiency and NEg content of the diet ($P \leq 0.02$) decreased linearly with increasing inclusion of both meals. Trial 2 evaluated dietary rumen fermentation and total tract digestibility characteristics in a 5 x 5 Latin Square Design. Diets were similar to finishing phase of Trial 1. There was no effect of treatment on rumen pH, however a linear increase in acetate ($P \leq 0.01$), ammonia ($P < 0.01$) and decrease ($P < 0.01$) in propionate was seen with both meal types. Crude protein and acid detergent fiber digestibility increased ($P = 0.03$) linearly with increasing inclusion of *B. juncea* meal. The results indicate that canola meal derived from *B. napus* and *B. juncea* is not suitable as a supplemental energy source replacing for barley grain in finishing diets but canola meal from *B. juncea* can be fed at levels up to 30% of the DM in backgrounding diets if priced appropriately.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
ADG	Average daily gain
Ammonia –N	Ammonia nitrogen
B. juncea	*Brassica juncea*
B. napus	*Brassica napus*
BW	Body weight
CP	Crude protein
d	day
DM	Dry matter
DMI	Dry matter intake
Feed efficiency	kg gain:kg feed
h	hour
HCW	Hot carcass weight
mL	milliliters
N	Nitrogen
NDF	Neutral detergent fiber
NEm	Net energy maintenance
NEg	Net energy gain

P	Probability
SARA	Subacute ruminal acidosis
SAS	Statistical analysis system
SD	Standard deviation
VFA	Volatile fatty acid
wt	Weight
%	Percentage

1.0 GENERAL INTRODUCTION

Increasing demand and price for cereal grains due to expansion of biofuel industry in North America has resulted in a greater reliance on high protein by-products as an energy source for cattle. Recent expansion of canola crushing industry in western Canada has resulted in an increasing availability of canola meal as a feed source for cattle. *Brassica napus* is the major canola crop in Canada. However, there is increasing popularity and acreage of *B. juncea* canola, a species developed from *B. juncea* mustard with oil and meal quality equivalent to that of other canola varieties (Gan et al. 2008). Meal derived from *B. juncea* has a higher protein and lower fiber content and hence is expected to be higher in energy relative to conventional *B. napus* meal. As a result, the energy value of *B. juncea* meal for feedlot cattle needs to be assessed.

Canola meal has been traditionally used as a protein supplement for beef and dairy cattle (Zinn 1993; Brito and Broderick 2007). However, very limited data is available on the use of canola meal as an energy source for feedlot cattle. Petit et al. (1994) reported an increase in ADG in feedlot steers when timothy silage was supplemented with canola meal relative to unsupplemented animals. Yang et al. (2013) reported an increase in DMI, ADG and G:F of steers when canola meal replaced barley at 10% inclusion in a backgrounding diet. In a companion feedlot experiment, He et al. (2013) used canola meal derived from *B. napus* and *B. juncea* at 15 and 30% in replace of barley, to evaluate the feedlot performance of individually fed steers. The results of the trial showed that substituting barley with either canola meal did not affect the ADG of cattle during backgrounding or finishing. However, overall DMI was higher and G:F lower for cattle fed both canola meals at 30% relative to the control diet fed cattle. It was concluded that 30% is too high a level of inclusion of canola meal in feedlot diets.

Substituting canola meal for barley in feedlot finishing diet reduces the starch content of the diet. Lower starch content is expected to reduce the incidence of sub-acute ruminal acidosis (SARA) in cattle fed finishing diets. At the same time, the change in proportion of starch and protein by the addition of canola meal is expected to alter the proportion and concentrations of volatile fatty acids (VFA) in the rumen. Koenig et al. (2012) reported a numerical increase in acetate and butyrate concentration and a numerical decrease in propionate concentration in steers supplemented with 7.2% canola meal relative to unsupplemented cattle. There is no published data available on the effect of substitution of barley with canola meal derived from *B. napus* and *B. juncea* at two levels of inclusion with respect to rumen fermentation and total tract digestibility characteristics of nutrients in a barley-based finishing diet.

The objectives of the literature review are to provide an insight into the nutrient composition and energy value of canola meal varieties with respect to feedlot performance, carcass characteristics and rumen and total tract digestibility parameters.

2.0 LITERATURE REVIEW

2.1 Development of Canola

Present day canola is a result of adopting selective plant breeding techniques to develop oil seeds from rape seed with less than 2% erucic acid in the oil and less than 30 micromoles of glucosinolates per gram of solid fraction of the seed (Bell 1993). The term canola to represent Canadian double low (i.e. low in both erucic acid and glucosinolates) varieties of rapeseed was adopted in 1979 (Bell 1984). Double low *Brassica* (*B.*) *napus* was licensed in Canada in1974 (Bell 1984). *Brassica juncea* has been traditionally grown as a mustard crop in Canada. Canola quality *B. juncea* with quality of seed oil and meal equivalent to that of other canola varieties is relatively new and was developed by Agriculture and Agri-Food Canada and the Saskatchewan Wheat Pool and made available for growers in 2002 (McInnis 2004). There is increasing popularity for *B. juncea* owing to its greater oil and protein and lower fiber content in the seed and yellow meal color (Rahman and McVetty 2011) and high drought tolerance and disease resistance (Johnson et al. 2010). As a result, canola meal derived from *B. juncea* with higher crude protein and lower fiber content than canola meal derived from *B. napus* may become increasingly available (He et al. 2013).

2.1.1 Canola Processing

Most of the canola crushing plants in Canada use the pre-press solvent extraction method for separating oil. This involves seed cleaning, pre-conditioning and flaking, cooking, pressing and solvent extraction followed by desolventizing and toasting for canola meal production. After cleaning, the seed is flaked to rupture the cell wall. The flakes are then cooked at a temperature of 80 - 90°C for 15 – 20 minutes. The cooked canola flakes are then pressed using a screw press or expeller. Pressing removes 50 – 60% of oil from the seed, followed by solvent extraction with

hexane which removes most of the remaining oil. After solvent extraction, less than 1% oil remains in the meal. Desolventization and toasting removes the hexane and brings the moisture content of the meal to about 12%. Other processing methods include double pressing and cold pressing with the resultant meal having a higher percent of oil (10 - 14%) than solvent extracted meal (Canola council of Canada).

Most of the canola crushing plants in Canada have similar processing conditions and hence the resultant canola meal does not vary a great deal from plant to plant. However, any variation in processing will affect meal quality. Addition of gums and soap stocks from oil refining to canola meal increases the oil and thereby the energy content of the meal. High cooking temperatures can adversely affect protein quality as high temperatures during desolventizing and toasting stages can denature the protein, and decrease the available lysine content in the meal (Canola Council of Canada).

The hull fraction in *B. napus* comprises approximately 16% of seed weight and 30% of meal weight (Bell 1984). The hull consists mostly of fiber and this fraction remains in the meal after oil extraction. Air classification (Bayley and Hill 1975), front-end (Bell 1993b) and tail-end (McCurdy and Fedec 1995) dehulling are some of the methods used to remove the hull from the meal (Mustafa et al. 1996). However, dehulling is not commercially viable owing to small seed size and higher oil loss in the hull as well as difficulty in separating the hull from the cotyledon (Ikebudu et al. 2000). Studies with dehulled canola meal failed to provide improvements in pig and poultry performance (Bell and Shires 1982; Bell 1993b). Both front and tail end dehulling are associated with major drawbacks such as reduced efficiency, higher residual oil in the meal and as the fiber content of meal is not significantly reduced, these procedures are not used commercially (Dave Hickling 2007).

2.1.2 Canola Meal Nutrient Composition

Relative to canola seed, pre-press solvent extraction of oil results in removal of fat (3.8 vs. 48.8 ± 0.92%) and concentration of crude protein (40.9 vs. 20.4 ± 0.85%), phosphorus (1.2 vs. 0.03 ± 0.001%) and NDF (22.7 vs. 17.9 ± 2.5%) in the meal (Assadi et al. 2011). Several factors affect nutrient variability among and within canola meal types, including the type of seed and the environment the plant is grown (i.e. climate, soil and geographic location) (Bell 1993; Simbaya et al. 1995). Yellow seeded *Brassica* genotypes have thinner and translucent seed coat with a comparatively larger embryo and consequently higher oil and protein content in the seed relative to black/brown seeded *Brassica* genotypes (Rahman and McVetty 2011). Slominski and Campbell (1990) reported that the meal derived from yellow seeded canola contained more non starch polysaccharide, cellulose and neutral detergent fiber and only half the lignin of *B. napus* meal.

The hull from *B. juncea* generally contains one third less fiber, more protein and oil than the brown seed (*B. napus*) hull (Stringam et al. 1974). Bell and Shires (1982) also reported that the composition of *B. napus* hull is different from that of *B. juncea*. The ADF and NDF content of *B. napus* hull were 59.9 and 71.2% of oil free hull on DM basis, respectively (Bell and Shires 1982). Corresponding values for the *B. juncea* hull were 51.7 and 66.3% (Bell 1993). Consequently, dehulling of canola improves the ME of the resultant meal (Bell 1993).

2.1.2.1 Fat

Pre-press solvent extraction leaves canola meal with less than 1% fat. Fat content of the final product after desolventizing - toasting can be modified based on whether gum from oil refining is added to the meal or not. Gum contains up to 50% oil, addition of which at 1 -2 % level enhances the overall fat content of the meal (Bell 1993). Average fat content of canola meal

derived from *B. napus* ranged from 3.6 to 4.1% (Bell 1993; Bell and Jeffers 1976) and that of *B. juncea* from 1.2 to 2.8% (Bell et al. 1998; He et al. 2013). In a study conducted by Bell and Keith (1991) to assess the variability in the nutrient composition of canola meal across Canada, canola meal samples were collected from seven different crushing plants. The fat percentage in the meal ranged from 2.3% with no added gum to 4.8% with added gum. The gross energy of canola meal is greatly influenced by the amount of fat contained in the meal (Bell and Keith 1991).

2.1.2.2 Crude Protein

Canola meal is used as a protein supplement in the livestock industry owing to its high protein content and well-balanced amino acid profile (Mustafa et al. 2010). The crude protein content of canola meal ranged from 38 to 43.5% when samples from seven different canola crushing plants were analyzed (Bell and Keith 1991). Meal derived from yellow seeded *B. juncea* contains more protein than the brown seeded *B. napus* meal (Rahman and McVetty 2011; He et al. 2013). Processing conditions significantly affect the protein quality of canola meal. Too high a temperature for too long during desolventizing – toasting stage of processing damages the crude protein by decreasing lysine availability and over all protein digestibility (Canola council of Canada).

Canola meal has been shown to be a good source of rumen degradable protein (RDP) (McAllister et al. 1993). Kendall et al. (1991) showed that the effective rumen degradability of canola meal ranged from 44.3 to 59.0% at a rumen turnover rate of 0.05% h^{-1} when canola meal samples from five different processing plants in western Canada were incubated *in situ* in steers. Since canola meal protein is relatively rapidly degraded in the rumen (Hill 1991; Kendall et al. 1991; McAllister et al. 1993; Gozho et al. 2009), it is considered a poor source of rumen

undegraded protein (Deacon et al. 1988; Khorasani et al. 1989). Heating canola meal at 125ºC for 10 minutes reduced the rumen degradability of canola meal protein from 58 to 30% (Mckinnon et al. 1991). A key point in ruminant protein nutrition is to provide adequate RDP that is sufficient to meet the nitrogen (N) requirements of the rumen microbial population and optimize microbial crude protein synthesis while providing ruminally undegradable protein in quantities sufficient to balance the absorbed AA profile (NRC 2001). Boila and Ingalls (1992) reported that levels of several essential amino acids were enriched in rumen undegraded canola meal protein and that canola meal provided adequate degradable protein levels that met the N requirements of the rumen microbial population when fed at appropriate levels.

2.1.2.3 Fiber

The hull portion of canola seed comprises 16% of the seed and 30% of meal weight (Bell 1984). It is largely fiber and most of it remains in the meal after oil extraction (Bell 1993). Yellow seeded *B. juncea* contains less hull in the seed and consequently less fiber in the meal. Bell (1991) evaluated the ADF and NDF content of canola meal obtained from seven different crushing plants in western Canada. The values ranged from 18.1 – 21.3% and 22.9 – 24.6%, respectively (Mean 19.1 ± 0.24% and 23.5 ± 0.16 respectively). Slominski et al. (1994) found that the neutral detergent fiber content of yellow seeded canola meal (18.6 ± 1.6%) was lower than that of brown seeded canola meal (25.7 ± 1.0%). The hull portion of yellow meal contains higher non starch polysaccharide (21.5 ± 0.6 vs. 17.8 ± 0.2%), less lignin (3.2 ± 1.0 vs. 8.0 ± 1.1%) and hence lower total dietary fiber (27.3 ± 1.6 vs. 30.2 ± 0.9%) than brown canola meal (Slominski et al. 1994). Fiber components other than non-starch polysaccharides including cell wall protein (2.2 vs. 4.4%), ash (0.8 vs. 1.9%) and lignin (4.1 vs. 9.1%) were also lower in *B. juncea* meal (Simbaya et al. 1995).

2.1.2.4 Minerals

Canola meal is a good source of most of essential major and minor minerals. (Clandinin1986). Canola meal from seven different crushing plants in Western Canada had a calcium concentration ranging from 0.57 – 0.82% with a mean of 0.7 ± 0.01% and phosphorus levels from 1.08 – 1.25% with a mean of 1.13 ± 0.01% (Bell and Keith 1991). Bell et al. (1984) reported 0.57% calcium and 1.33% phosphorus in canola meal samples and the values for Bell and Keith (1987) ranged from 0.69 – 0.73% for calcium and 1.12 – 1.14% for phosphorus. Environmental factors and soil mineral content both affect the mineral composition of canola meal (Bell and Keith 1991).

Bell et al. (1999) examined the genetic and environmental effect on mineral status of canola seed grown at different locations over a period of four years. Calcium, phosphorus, copper and zinc levels were not affected by the year of cultivation, but the location had a significant effect with low soil pH assumed to have reduced the uptake of certain minerals like calcium, phosphorus, copper and manganese. Mean calcium values were 0.63 ± 0.01% for *B. napus* and 0.57 ± 0.02% for *B. juncea* meal and the respective phosphorus levels were 1.03 ± 0.02% and 1.14 ± 0.03%. Yellow seeded *B. juncea* meal contained higher copper and zinc levels (8.1 ± 0.3 mg kg^{-1} and 51.1 ± 1.5 mg kg^{-1}) than *B. napus* meal (5.0 ± 0.3mg $^{-1}$ and 40.6 ± 1.1 mg kg^{-1} respectively). Iron and manganese levels were affected by year and location and were higher for *B. napus* meal (201 ± 26 mg kg^{-1} and 58 ± 1.2 mg kg^{-1}) than *B. juncea* meal (158 ± 7 mg kg^{-1} and 48 ± 1.4 mg kg^{-1} respectively).

Bell and Shires (1982) reported that the ash content of *B. napus* hull was higher than that of the embryo and nearly one third of ash in the hull was calcium whereas phosphorus was more

concentrated in the embryo. Bell and Shires (1982) also reported that dehulling would decrease the calcium content of the meal by 30 to 50% and increase phosphorus by 30 to 40%. Ravindran et al. (1995) reported that canola meal contains large amounts of phytate phosphorus. Ruminants can utilize phosphorus from phytate phosphorus better than non-ruminants (McGillivray (1974); NRC 2000). Phytic acid also binds with other minerals like calcium, magnesium, zinc and copper to form insoluble complexes (Thompson 1990).

2.2 Energy Value of Canola Meal in Feedlot Diets

Canola meal is conventionally used as a protein supplement, but its energy content is equally important in feed formulation (Bell 1993). The mean gross energy value of canola meal samples collected from seven canola crushing plants in western Canada was 20.4 ± 0.07 MJ kg^{-1} (Bell and Keith 1991). The major factors affecting the energy value of canola meal include the fat, protein and fiber content. These determinants of energy content are dependent on the canola variety and the type of processing involved. For example, the percentage of fat is determined by the processing method and the proportion of gum added back to the meal (Bell 1993). Canola press cake, produced by cold pressing of canola contains higher levels of oil than solvent extracted canola meal (McKinnon and Walker 2009).

McKinnon et al. (1993) reported that ADG of steers fed a low energy diet linearly increased with increasing inclusion of canola meal elevated the CP content of the diet from 11 to 19%. It was concluded that increased protein levels in the diet improved the energy balance of the steers. Digestible energy content (Mcal kg^{-1} DM) of a high energy feedlot diet supplemented with 20% (DM) canola meal was numerically higher relative to an unsupplmented basal diet (Zinn 1993). Yang et al. (2012) reported a numerical increase in NEg (Mcal kg^{-1} DM) content of

canola meal supplemented (10%; DM) backgrounding diet relative to an unsupplemented control diet.

However, since the hull portion of canola seed constitutes up to 30% of the meal, and the hull is comprised mostly of fiber, much of the energy content of the meal depends on the digestibility of the hull fiber fraction. He et al. (2013) reported that the fiber digestibility of canola meal is lower than that of other high protein by-products like soybean meal or wheat DDGS and hence the use of canola meal as an energy source in feedlot diets is limited. Bell (1993) reported that yellow seeded canola hull had higher CP (22.9 vs. 17.1%), lower NDF (66.3 vs. 79.6%), ADF (51.7 vs. 67%) and lignin (14.8 vs. 18.5%) and hence higher digestibility relative to brown seeded canola hull. The seed coat of *B. napus* also contains a high level of tannin which significantly affects the digestibility of the meal by affecting protein hydrolysis whereas the *B. juncea* meal contains less tannin and fiber and hence possess superior digestibility (Rahman and McVetty 2011).

2.2.1 Canola Meal Compared to Canola Seed and Presscake

Canola seed has been used as a protein as well as a fat source for feedlot diets (Leupp et al. 2006). Canola seed contains about 20% protein and 40% fat (Khorasani et al. 1991). Unless processed, because of the fibrous hull, canola seed is relatively resistant to ruminal and intestinal digestion (Khorasani et al. 1992; Hussein et at. 1995). However, the inclusion of processed canola seed in dairy cattle diets could be limited due to the negative effect of unsaturated fat on ruminal digestion (Khorasani et al. 1991). Rule et al. (1994) reported a numerical decrease in DMI by steers fed a corn-based finishing diet supplemented with extruded or ground canola meal containing 8.6 and 7.8% dietary fat (DM), respectively. Palmquist and Jenkins (1980) reported

that supplemental fat levels of more than 6% (DM) could decrease fiber digestion. Bulls fed ground canola supplemented corn-based diet had lower ADG relative to those supplemented with canola meal at similar dry matter intake (DMI) (Rule et al. 1994). Apparent total tract digestibility of OM, ADF and NDF was lower in steers supplemented with canola seed treated with alkaline hydrogen peroxide and untreated crushed canola seed as compared to those supplemented with canola meal (Hussein et at. 1995).

Canola cold presscake is produced by cold pressing of canola for oil extraction without the use of heat and solvent (McKinnon and Walker 2009). It contains less protein (36.3 vs. 41.7%) and higher fat (12.3 vs. 4.5%) than regular canola meal. McKinnon and Walker (2009) reported no significant difference in the NEg (1.02 vs. 1.04 Mcal kg^{-1}), ADG (1.32 vs. 1.35 kg) or feed efficiency (0.14 vs. 0.15) when steers were fed either canola meal or canola press cake in a backgrounding diets. Similarly, He et al. (2013) also reported minimal effect of canola meal type on DMI or ADG of feedlot steers supplemented with canola meal vs. canola press cake.

2.2.2 Performance of Cattle Fed Canola Meal in Barley-based Diets

Williams et al. (2008) reported that feeding steers a dry rolled barley-based diet containing 6% canola meal (DM) during backgrounding resulted in similar ADG (1.23 vs. 1.29 kg) and an increased DM intake (8.25 vs. 8.02 kg d^{-1}) relative to cattle fed processed barley/canola meal pellet. There was a significant increase in ADG (2.0 vs. 1.8 kg) and DM intake (12.5 vs. 11 kg d^{-1}) for cattle fed diet containing 5% canola meal (DM) relative to cattle fed the processed barley/canola meal pellet during finishing. Yang et al. (2013) reported a significant increase in DMI, ADG and feed efficiency of steers fed a canola meal supplemented (10%; DM) backgrounding diet relative to cattle fed an unsupplemented control diet. Steers fed a low energy diet had a linear increase in ADG upon supplementation with increasing levels of canola meal

(McKinnon et al. 1993). However, He et al. (2013) reported that steers fed canola meal at 30% (DM) had a higher DMI and lower feed efficiency during finishing relative to steers supplemented with 15% (DM) canola meal.

In a study evaluating the effect of protein source on rumen microbial protein synthesis, Koenig et al. (2004) reported an increase in microbial protein supply to the small intestine with canola meal supplementation relative to cattle fed an unsupplemented barley-based control diet. There was also a numerical increase in DMI and total tract organic matter digestibility with the inclusion of canola meal. Zinn (1993) reported a significant increase in total tract CP digestibility in steers supplemented with 20% (DM) canola meal in a high energy barley-based diet relative to steers fed an unsupplemented diet. Similarly, Gozho et al. (2009) reported an increase in total tract OM, NDF and ADF digestibility in steers supplemented with canola meal (8.8%; DM) relative to rumen undegraded protein canola meal and canola oil combination supplemented steers.

2.2.2.1 Impact of Processing of Barley and Inclusion of Canola Meal on Feedlot Performance

Processing barley by dry and temper rolling results in rupture of the fibrous hull portion which helps the microbial enzymes to act on the internal structures (Koenig and Beauchemin 2011). The objective of processing is to ensure maximum carbohydrate digestibility of the grain at a desirable rate (Koenig et al. 2003). Williams et al. (2008) reported that dry rolled barley was superior to pelleted barley with respect to DMI during backgrounding and ADG and DMI during finishing. Koenig et al. (2003) reported that a diet containing steam rolled barley with a processing index of 81 showed a tendency for increased ruminal nitrogen digestibility and

ammonia concentration relative to a diet having steam rolled barley with a PI of 61. Similarly, Zinn (1993) reported that the total tract digestibility of OM, ADF, starch and CP was lower for feedlot steers fed a finishing diet containing dry rolled barley relative to steers fed steam rolled barley. However Mathison et al. (1997) reported that there is no effect of dry rolling vs. steam rolling of barley with respect to ADG and feed efficiency in feedlot steers fed a finishing diet. Similarly carcass characteristics were also not influenced by the method of barley processing. It was concluded that there was no advantage for steam rolling of barley for growing and finishing cattle in Western Canada.

Beauchemin et al. (2001) reported that extensive processing of barley resulted in bloat and rumen acidosis. There was a tendency for quadratic decrease for the duration for rumen pH > 6.2 with increasing processing index (Beauchemin et al. 2001). Koenig et al. (2003) also found that cattle fed a steam rolled barley-based diet with a processing index of 86, containing 20% barley silage had the least duration of ruminal pH < 5.8 (h d^{-1}) relative to cattle fed diet containing barley with a processing index of 61 and 5% barley silage. Supplementation of canola meal in a barley-based diet resulted in a higher mean ruminal pH and lowest time for pH <5.8 (h d^{-1}) relative to supplementation with urea or blood meal (Koenig et al. 2004).

The optimum processing index for temper rolled barley for the feedlot diets is 75% or lower at which the ruminal microbial protein synthesis and total tract nitrogen digestibility tended to be higher (Beauchemin et al. 2001). Mathison et al. (1997) reported that optimum processing index for dry rolled barley can be higher than that of temper rolled barley as the weight per unit volume of processed barley is lower for temper rolled relative to dry rolled.

2.2.2.2 Performance of Feedlot Cattle Fed Canola Meal in Combination with Other Cereal Grains

Barley is traditionally used in feedlot diets in western Canada. In recent years, when drought conditions increased the barley prices, corn was imported as a replacement (Gibb and McAllister 2004). Corn contains less protein and degradable intake protein, but more starch than barley (NRC 1996). When a corn-based diet was supplemented with either canola meal or urea as protein sources, steers had similar DM intake and ADG as with a barley-based diet and higher DM intake and ADG than unsupplemented corn-based diets. Also carcass characteristics like hot carcass weight, dressing percentage and rib-eye area were similar among barley and supplemented corn-based diets (Koenig and Beauchemin 2005). Bulls supplemented with 10.1% canola meal in a corn-based finishing diet had higher gains than bulls supplemented with ground canola seed at similar DM intake (Rule et al. 1994).

2.2.2.3 Energetics of Protein Feeding

Protein is the most expensive nutrient on a weight basis. Supplementing protein above the minimum requirement however has been shown to increase the performance of growing and finishing feedlot cattle, with the response depending on the level and source of protein (McKinnon et al. 1993; Huntington et al. 2001; Gleghorn et al. 2004). Balancing rumen degradable (RDP) and undegradable intake protein (UIP) improves animal performance and reduces nitrogen excretion (Wagner et al. 2010). With a high grain diet, rumen microbes require increased DIP for maximum microbial protein synthesis (Broderick 2003; Gleghorn et al. 2004). Fluharty and Loerch (1995) reported that high protein diets are beneficial to newly received feedlot steers during the initial stages when DM intake is low. Even though ammonia nitrogen is

the major nitrogen source for most of the rumen microbes, some species require non ammonia nitrogen like amino acids and peptides for efficient and rapid growth (Allison 1982). Amylolytic bacteria, which degrade nonstructural carbohydrates, grow rapidly in the rumen and use ammonia, peptides and amino acids as the nitrogen source compared to cellulolytic bacteria which grow slow and use ammonia nitrogen as their primary nitrogen source (Russell et al. 1992). McKinnon et al. (1993) reported that increased inclusion of canola meal in a low energy diet increased the energy status of the total mixed ration. Rumen fermentation of excess dietary amino acids could result in their deamination and the production of volatile fatty acids. For example, the carbon skeletons of branched-chain amino acids result in the production of branched-chain fatty acids, which are important for the growth of fiber-digesting bacteria (NRC 1985). Systemic oxidative deamination, transamination and subsequent oxidation of amino acids in the tricarboxylic acid cycle also yields energy (McKinnon et al. 1993). Response to protein supplementation varies with the stage of growth. Increasing the crude protein level in a corn-based finishing diet linearly increased the ADG and feed efficiency of steers during the first 56 days of feeding whereas from day 84 through to slaughter, there was a quadratic response in the performance of animals with increased protein supplementation (Gleghorn et al. 2004).

2.2.2.4 Significance of Protein Supplementation and Energy Content of Feed

Scales et al. (1974) reported no improvement in ADG of grazing calves to supplemental energy (corn grain) when protein intake was limiting. High energy diets require increased supply of RDP as there is an increased demand by rumen microbes for nitrogen for use in microbial protein synthesis, which thereby increases the supply of metabolizable protein to the small intestine (Broderick 2003). Rumen degradable protein increases the rumen ammonia concentration and

branched-chain volatile fatty acids, which enhances the cellulolytic bacteria resulting in increased NDF and ADF digestibility (Broderick 2003). Rius et al. (2010) reported that the post absorptive nitrogen efficiency of lactating dairy cattle was higher with a high energy, high protein diet relative to a low energy high protein diet. McKinnon et al. (1993) reported a linear increase in ADG of steers fed a low energy diet supplemented with increasing inclusion of canola meal. Cattle fed a high energy diet had similar ADG across treatments. McKinnon et al. (1993) concluded that the energy status of the total mixed ration was improved by protein supplementation.

2.2.2.5 Implants and Protein Supplementation

Implantation of beef cattle with growth promoters is a common management practice in North America (Lopez-Campos et al. 2012). Implantation of steers with a combination of trenbolone acetate (TBA) and estradiol results in 15 – 20% improved feed efficiency relative to non-implanted animals (Bartle et al. 1992). It also results in increased ADG and carcass protein accretion (Johnson et al. 1996). Herschler et al. (1995) reported that daily gains of steers with implants containing estradiol and TBA in 1: 10 ratio was higher than that with implants containing estradiol and TBA in 1:5 ratio when fed a corn-based finishing diet. DiCostanzo (1996) reported that steers given a high potency TBA-based implant had higher DM intake, ADG and feed efficiency than non-implanted steers. DiCostanzo (1996) also reported that with increasing dietary CP concentration, DMI and ADG of steers with TBA implants increased relative to non-implanted steers. Implantation with β-adrenergic agonists results in lean tissue deposition by redirecting nutrients away from fat to protein deposition. Both hormonal implants and β-adrenergic agonists increase protein deposition even though the mechanism of action is different (Lopez-Campos et al. 2012)

2.3 Carcass Characteristics Associated with Feeding of Canola Meal

Backgrounded yearlings fed increasing levels of protein at lower dietary energy levels responded with a linear increase in ADG and carcass gain, as crude protein content of the diet increased from 11 to 19%. It was concluded that excess dietary crude protein contributed to the energy status of the animal when the protein was provided as canola meal (McKinnon et al. 1993). Supplementing canola meal as a protein source to yearling beef cattle resulted in a numerical increase in marbling scores and quality grades relative to cattle fed a urea-canola meal protein supplement in a barley-potato processing residue-based finishing diet. The *longissimus* muscle area in steers fed the canola meal supplement was numerically larger than that of cattle supplemented with urea (Hinman 1999). Rolled barley supplemented with 5% canola meal resulted in increased intramuscular fat content in feedlot steers relative to cattle fed barley/canola meal pellet. This was attributed to a decrease in DM intake by cattle fed the pelleted barley/canola meal likely due to sub-acute rumen acidosis leading to poor gains (Williams et al. 2008).

2.3.1 Meat Quality from Steers Fed Canola Meal

From a human health perspective, it is desirable to have mono and polyunsaturated fatty acids and favorable conjugated linoleic acid isomers in intramuscular fat (Mir et al. 2003; He et al. 2013). He et al. (2013) also reported that the level of polyunsaturated fatty acids (PUFA) in diaphragm was higher in feedlot steers supplemented with canola meal at 30% relative to 15% inclusion. It was also reported that the percentage of conjugated linoleic acid (CLA) and vaccenic acid (VA) and total n-3 fatty acids in diaphragm also increased with 30 vs. 15% inclusion of canola meal. Fatty acid composition of the pectoral muscle in steers fed canola meal

had higher C18:1 than those fed ground canola or extruded soybean meal and higher C18:2 and C18:3 and C20:4 than soybean meal supplemented steers (Rule et al. 1994). Wood et al. (1999) reported that rumen biohydrogenation of dietary unsaturated fatty acids results in more saturated than unsaturated muscle fat in ruminants. However, as evidenced by the results of Rule et al. (1994) and He et al. (2013) ruminant tissue fatty acid composition can be manipulated by feeding unsaturated fat sources such as canola seed or pressed canola meal.

2.4 Impact of Canola Meal on Rumen Fermentation

2.4.1 Volatile Fatty Acid Production

A characteristic feature of ruminant carbohydrate metabolism is anaerobic fermentation in the rumen by bacteria. The resultant products are volatile fatty acids (VFAs) and energy (ATP). Major VFAs produced in the rumen are acetate, propionate and butyrate, but other products also include isobutyrate, valerate, isovalerate, caproate and isocaproate. The relative proportions of these VFAs vary based on the nature of the substrate and the composition of rumen microbial flora (Sutton 1968). High forage diets result in an increased proportion of acetate whereas high concentrate diets increase propionate (Sutton et al. 2003).

Addition of canola meal at 7.2% (DM basis) as a protein supplement in a barley-based diet resulted in a numerical increase in acetate concentration relative to blood meal and increased butyrate concentration compared to unsupplemented control diets (Koenig et al. 2004). Beauchemin et al. (2001) found a tendency for molar concentration of propionate to be higher and butyrate lower when the processing index of temper rolled barley was decreased from 82 to 75 when steers were fed a feedlot finishing diet supplemented with canola meal at 1.5% (DM basis).

2.4.2 Rumen Ammonia Production

A key point in ruminant protein nutrition is to provide adequate rumen degradable protein (RDP) that is sufficient to meet the N requirements of the rumen microbial population and to optimize microbial crude protein synthesis, while providing sufficient quantity of ruminally undegradable protein to optimize the absorbed AA profile (NRC 2001). Ruminal bacteria derive nitrogen for microbial protein synthesis from ammonia, peptides and amino acids, of which ammonia is the predominant source for cellulolytic bacteria (Leng and Nolan 1984). However, peptides and amino acids are the preferred source of nitrogen for microbes that ferment nonstructural carbohydrates in barley-based finishing diets (Russel et al. 1983; Koenig et al. 2004). Increasing availability of amino acids and peptides derived from rumen degradable intake protein fraction of supplemental protein results in increased microbial protein synthesis and amino acid fermentation for energy (Argyle and Baldwin 1989).

Extensive rumen degradation of rolled barley results in a higher ammonia requirement in order to optimize rumen microbial growth and fermentation (Odle and Schaefer 1987; Koenig et al. 2004). Optimum rumen ammonia concentration for maximum microbial growth and rumen fermentation is more than 5 mg dL^{-1} (Hume et al. 1970; Mehrez et al. 1977). Gozho et al. (2009) reported a rumen ammonia concentration of 9.4 mg dL^{-1} when heifers were supplemented with 9.3% canola meal in a barley-based diet. Supplementation of timothy silage with 15% canola meal resulted in a rumen ammonia concentration of 12.2mg dL^{-1} relative to 10.2 mg dL^{-1} with unsupplemented diet (Petit and Veira 1994).

2.5 Ruminal Acidosis

Acidosis is a metabolic disturbance to the normal functioning of the rumen, typically caused by the ingestion of large quantities of readily fermentable carbohydrates (Nagaraja and Titgemeyer 2007). Acidosis is characterized by a rapid decrease in rumen pH and depending on the severity of the drop in rumen pH and the nature of short chain fatty acids (SCFA) that accumulate in the rumen, it can be classified as acute (ARA) or sub-acute rumen acidosis (SARA). Acute rumen acidosis is associated with a drastic reduction in rumen pH to values of ≤ 5.2 for extended periods of time with accumulation of lactic acid in the rumen. Sub-acute rumen acidosis is associated with accumulation of SCFA in the rumen and the pH is generally in the range of 5.2 - 5.6. Beauchemin and Penner (2009) reported that in SARA, there will be repeated bouts of low pH with the animal recovering after each bout. Beauchemin and Penner (2009) also reported that during subsequent bouts of SARA, the rumen pH may not recover fully with the animal becoming increasingly susceptible to SARA. With high grain feeding during finishing stages, cattle are at risk of developing acute or sub-acute ruminal acidosis particularly with poorly formulated diets or poorly managed feedlots.

Increased availability of readily fermentable substrates like starch and sugar enhances the proliferation and fermentation activity of rumen microbes resulting in increased production of SCFA. As long as the absorption of SCFA keeps up with production, normal rumen pH (5.6 - 6.5) and SCFA concentration (80 - 170 mM) are maintained (Nagaraja and Titgemeyer 2007). With rapid degradation of excess fermentable carbohydrates and the development of low rumen pH, populations of *Streptococcus bovis* in the rumen can exponentially increase, resulting in a shift from a mixed volatile fatty acid to a homolactic fermentation (Russell and Hino 1985; Finlayson 1986; Nagaraja and Titgemeyer 2007). Lactate accumulates in the rumen due to slow

absorption resulting in the downward spiral of pH. Damage to the rumen epithelium due to low pH, hyperosmolality, production of endotoxins and histamines all lead to impaired rumen function and SCFA absorption (Nagaraja and Titgemeyer 2007).

Passive lipophilic diffusion of undissociated SCFA, bicarbonate dependent exchange of dissociated SCFA and bicarbonate independent uptake are the major routes of SCFA absorption (Aschenbach et al. 2011). With a pKa of 4.8, SCFA uptake increases by lipophilic diffusion as the pH drops, as more and more VFAs become protonated and undissociated (Nagaraja and Titgemeyer 2007). However, as the pH drops, lactate production increases. Having a pKa of 3.9, lactate is ten times stronger than the other major SCFAs and is more dissociated than VFAs at the same pH (Nagaraja and Titgemeyer 2007). Lactate is absorbed slowly from the rumen and hence, a rapid rate of production is not necessary for lactate to accumulate in the rumen at concentrations ≥ 5 mMol L^{-1}, the threshold for the development of acute rumen acidosis (Nocek, 1997; Aschenbach et al. 2011)

2.6 Digestibility of Canola Meal

The ADF, NDF and OM digestibility in the total tract of heifers fed 8.8% canola meal in a barley-based diet was higher than that of heifers supplemented with a combination of canola meal and canola oil (Gozho et al. 2009). Ruminal organic matter, ADF and feed nitrogen digestibilities of a feedlot diet supplemented with 20% canola meal (DM) was 63.8, 23.7 and 67.9%, respectively. Respective total tract digestibilities were 78.6, 38.9 and 79.2%. Total tract nitrogen digestibility was significantly higher ($P < 0.01$) for canola meal supplemented diet relative to unsupplemented basal diet (Zinn 1993). Total tract DM and OM digestibility of canola

meal (40% CP) was found to be 82 and 87% respectively, and had a digestible energy value of 4.12 Mcal kg^{-1} (Zinn 1993).

2.7 Nitrogen Balance

2.7.1 Nitrogen Utilization in Ruminants

The crude protein requirement of growing cattle encompasses the essential amino acid requirement of the animal as well as the requirement of rumen microbes for protein synthesis. The fraction of intake protein that is degraded in the rumen (degradable intake protein; DIP) along with the non-protein nitrogen in the feed is extensively broken down to peptides, amino acids and ammonia, which are utilized by the rumen microbes for the microbial protein synthesis (Tamminga 1979). Cellulolytic bacteria require ammonia nitrogen as the primary N source for amino acid synthesis (Owen and Bergen 1983). However, nonstructural carbohydrate-degrading bacteria can utilize peptides and amino acids as well (Russell et al. 1992). Microbial protein synthesis is generally sufficient to supply 50 – 100% of the metabolizable protein requirement of beef cattle depending on the UIP content of the diet (NRC 2000). However, microbial crude protein synthesis may not meet the essential amino acid requirements of high producing ruminants like lactating dairy cattle (Huber and Kung 1981). Metabolizable protein (MP) is the true protein absorbed by the intestine which includes the microbial crude protein and the undegraded intake protein (UIP) (NRC 2000). The intestinal digestibility of bacterial crude protein and undegraded intake protein is considered to be 80% (NRC 2000).

2.7.1.1 Urea Nitrogen Metabolism

Extensive ruminal degradation of dietary protein, nonprotein nitrogen and endogenous urea results in the production of ammonia which is utilized by the rumen microbes for the synthesis of

microbial protein. Absorption of ammonia across the rumen wall is based on pH as well as concentration gradient (Hogan 1961). The absorbed ammonia is converted to urea by the liver and is excreted in the urine and a portion recycled back to the rumen via saliva, diffusion (Houpt and Houpt 1968) and facilitated transport (Stewart and Smith 2005) across the rumen. The quantity of urea nitrogen recycled to the rumen is negatively related to the rumen ammonia concentration and positively to plasma urea concentration (Owens and Bergen 1983). Recycling of urea nitrogen to the rumen is a unique characteristic of ruminants to salvage nitrogen (Kennedy and Milligan 1980). The urea recycled to the rumen from the blood is hydrolyzed to ammonia by bacteria which attach to the rumen wall and produce urease (Cheng and Costerton 1980). This ammonia can be used by the ruminal microbes for protein synthesis. High grain diets significantly affect the amount of rumen ammonia nitrogen assimilated to microbial protein (Firkins et al. 2007). Ruminants fed high-concentrate diets are expected to have a higher potential for nitrogen recycling owing to a rapid rate of fermentation of carbohydrates in these diets relative to ruminants fed high forage diets (Cole 1999).

2.7.2 Nitrogen Retention

Nitrogen retention is an indicator of protein deposition for productive purposes such as milk, meat and wool as well as for other tissues such as skin and mucosal tissue (Owens and Bergen 1983). As the crude protein content of the diet increases, daily intake of dietary nitrogen increases, with a linear increase in fecal and urinary urea nitrogen excretion and typically a nonsignificant numerical increase in nitrogen retention (Vasconcelos et al. 2009). Average nitrogen retention by feedlot cattle is less than 20% (Bierman et al. 1996). Spanghero and Kowalski (1997) reported that about 20g nitrogen is needed for 1 kg of lean tissue deposition. Growing ruminants can deposit lean tissue even when in negative energy status at the expense of

body fat as long as the amino acid supply is not limiting (Chowdhury et al. 1997; Pittroff et al. 2006). There is continuous turnover of body protein even if the animal is in negative energy status. Rate of protein accretion varies depending up on the stage of growth, rate of growth and breed (Byers 1982).

2.8 Environmental Impact of Feeding Canola Meal on Nitrogen and Phosphorus Excretion

2.8.1 Nitrogen Excretion

The two major nutrients concerned with excretion through feces and urine and with environmental impact are nitrogen and phosphorus with their potential to escape to surface water and soil causing water pollution (Vasconcelos et al. 2009). Both nitrogen and phosphorus are important contaminants of surface water through runoff (Vasconcelos et al. 2007). Nitrogen escapes to the atmosphere by volatilization (Zehnder and DiCostanzo 1997). Erickson et al. (1998) found that 50 – 70% of nitrogen from feces volatilizes from a feedlot pen after excretion. Solubility of ammonia in water and leaching of nitrate N poses a threat if the runoff from a feedlot reaches surface water (Zehnder and DiCostanzo 1997). The major nitrogenous compound in urine is urea which accounts for up to 97% of urinary nitrogen (McCrory and Hobbs 2001). Urea is hydrolyzed by bacterial urease to ammonia. Volatilization of nitrogen reduces the fertilizer value of manure, as N: P ratio drops to 1:1 in dry compared to 5:1 in fresh manure (Cole, 1999). Vasconcelos et al. (2006) found that a lower N: P ratio could lead to phosphorus build up in crop lands. High protein by-products like DDGS and canola meal increases dietary CP content when used as an energy source. Nitrogen intake, absorption and retention as well as

fecal and urinary nitrogen excretion increased as dietary CP concentration increased when lambs were fed a 90% concentrate diet (Cole 1999).

2.8.2 Phosphorus Excretion

Phosphorus is an important nutrient with a potential to cause water pollution if it reaches surface water through runoff (Vasconcelos et al. 2007). As phosphorus does not volatilize from the pen surface (Klopfenstein and Erickson 2002) it accumulates in the soil when manure is applied to soil as fertilizer if it is not offset by plant uptake. Leaching and runoff of P to surface water results in eutrophication which leads to undesirable algal growth, reduced oxygen in water and severe reduction in water quality (Morse 1995). Average phosphorus content of canola meal is 1.13% (DM basis) (Bell and Keith 1991) which is higher than that of soybean meal (0.67%; Batal et al. 2010) and wheat and corn DDGS (0.97 and 0.89%, respectively; Walter et al. 2010). Feeding by-products of ethanol production aggravates issues of phosphorus overfeeding as nutrients get concentrated in the meal after extraction of ethanol (Klopfestein 2002). Similarly, canola meal also contains higher phosphorus content relative to canola seed. Phosphorus excretion is significantly related to phosphorus intake. Walter et al. (2012) reported that with increasing dietary CP due to supplementation with both wheat and corn DDGS, there was a linear increase in phosphorus intake along with increased fecal and urinary phosphorus excretion. Increased phosphorus intake did not affect phosphorus digestibility when steers were fed brewers grits-based diets containing phosphorus levels above the NRC requirement (Geisert et al. 2010). The salivary recirculation of phosphorus is an important endogenous source for ruminants. Phosphorus requirements of growing feedlot steers weighing 270-600 kg are not clearly defined (Klopfenstein et al. 2002). Recent research has shown that the NRC recommendation for phosphorus is over-estimated and most feedlot cattle consume phosphorus

in excess of requirements (Satter et al. 2002). Similarly, Van Horn et al. (1996) reported that most dairy farmers overfeed phosphorus relative to NRC (1989) recommendations.

A successful feedlot waste management system depends on reducing excess dietary nutrients (Zehnder and DiCostanzo 1997). Feeding minerals in quantities which match the animal's requirement will greatly reduce excess mineral excretion in feedlots, ensuring environmental stability and minimizing feeding cost (Zehnder and DiCostanzo 1997). Starnes et al. (1984) and Spears (1990) reported that apparent absorption and retention of minerals like magnesium and phosphorus was increased by ionophore supplementation in steers. Van Horn et al. (1996) found that balancing rumen degradable (RDP) and undegradable (UIP) protein reduced nitrogen excretion by 15% in dairy cattle compared to NRC (1989) recommended CP standards. Substitution of barley with high protein by-products like DDGS and canola meal as an energy source has to be accompanied by nutrient management strategies to minimize feeding cost and nutrient loss and to improve environmental stability.

2.9 Summary

Canola is an important Canadian cash crop with over 7 million acres seeded annually. The high level of production has resulted in a significant expansion of the canola crushing industry. It is estimated that canola meal production in Canada will exceed 4million tonnes annually (COPA monthly, August 2013). As a result, canola meal has become an easily available and economically viable source of protein and energy for the livestock feed industry (Gozho et al. 2009).

Considerable information exists on the use of canola meal as a protein supplement for dairy cattle and to a limited extent for beef cattle (Hill 1991). Petit et al. (1994) reported that

when finishing steers were supplemented with canola meal, they had increased daily weight gain, reduced days on feed and similar carcass characteristics when compared with steers fed only timothy silage. They concluded canola meal was a good source of protein for beef cattle. The dry matter and organic matter digestibility of canola meal (40% CP) was reported to be 82 and 87%, respectively (Zinn 1993). Petit et al. (1994) reported that supplementation of canola meal in the diet of steers increased nitrogen digestibility and digestible energy value of timothy silage, but decreased the ADF digestibility when compared with un-supplemented timothy silage. These authors also reported that feeding canola meal at the rate of 15% increased the dry matter digestibility and the digestible energy value of the diet when compared with 7.5% inclusion.

Limited data exist on the potential to use canola meal as an energy and protein supplement in backgrounding and finishing diets for beef cattle. In a study investigating the protein requirement of large frame steers, McKinnon et al. (1993) fed diets formulated to 11.17 or 11.88 MJ ME kg^{-1} DM with crude protein levels ranging from 11 to 19%. Canola meal was used to vary crude protein levels. The results showed that weaned calves and backgrounded yearlings fed the lower energy diets exhibited a linear increase in ADG as dietary CP concentration increased. The response to canola meal supplementation was attributed to improved energy balance as a result of excess crude protein intake being directed to energy metabolism.

There is increasing popularity for *B. juncea* owing to its drought tolerance and disease resistance (Johnson et al. 2010). This has resulted in increased availability of canola meal derived from *B. juncea* (He et al. 2013). Further evaluation of *B. juncea* meal as an energy source for cattle is particularly relevant as the meal is higher in protein and lower in lignin and fiber content relative to canola meal derived from the common *B. napus*.

Typical canola meal derived from *B. napus* has 36 - 38% protein and 20% acid detergent fiber and 25% neutral detergent fiber (Bell et al. 1993 and 1998; Newkirk et al. 1997). In *B. juncea*, protein content can increase to > 40% while acid and neutral detergent fiber levels can drop to 12 - 13% and 19 - 21%, respectively (Newkirk et al. 1997). Based on chemical differences, the meal derived from yellow seed canola could be more digestible owing to its low lignin and polyphenol content (Rahman and Mcvetty 2001). Very limited published comparisons of these two canola meal types exist with respect to beef cattle performance. In a recent companion study to the proposed research, He et al. (2013) compared the performance of individually fed steers fed canola meal derived from both *B. napus* and *B. juncea* at 15 and 30% of the diet DM. The study showed that feed intake was increased at the 30% inclusion level and that gain: feed was superior for the cattle fed the 15% inclusion level. No effect of canola meal type was observed.

The hypothesis of the research conducted in this thesis was that increasing inclusion of canola meal derived from *B. juncea* but not *B. napus* as a replacement for barley in feedlot backgrounding and finishing diets will result in superior performance and more efficient gains of feedlot cattle by the mitigation of low rumen pH and improved total tract digestibility of nutrients.

The objectives of the research carried out were to evaluate the effect of graded levels of inclusion of canola meal derived from *B. juncea* and *B. napus* as a replacement for barley on performance and total digestibility and rumen fermentation characteristics of growing/finishing cattle.

3.0 EVALUATION OF CANOLA MEAL DERIVED FROM *Brassica (B.) juncea* AND *B. napus* AS AN ENERGY SOURCE FOR FEEDLOT STEERS

3.1 Introduction

With increasing global demand for cereal grains, the cattle industry is more reliant on by-product feeds in order to meet both the energy and protein needs of cattle. An example is the wide spread use of distillers dried grains with solubles (i.e. DDGS) which are a co-product of ethanol production. These co-products are widely used as a source of both energy and protein in cattle diets across North America (Klopfenstein 1996; Beliveau and McKinnon 2008; Walter et al. 2010). Recent expansion of Western Canada's canola crushing industry has resulted in canola meal becoming increasingly available as a feed source for cattle. Traditionally canola meal has been used as a protein source for ruminants but increasing supply and competitive pricing could result in increasing use as an energy supplement. Newer varieties of canola such as the yellow seeded *Brassica* (*B.*) *juncea* yield canola meal with a higher protein and less acid and neutral detergent fiber content than canola meal derived from conventional *B. napus*. As a result, the energy value of *B. juncea* canola meal is likely to be higher than that of meal derived from *B. napus*.

There has not been a great deal of research on the use of canola meal as an energy source for cattle. McKinnon et al. (1993) reported a linear increase in ADG of backgrounded yearlings when canola meal content increased from 0 to 30% in a low energy (11.17 MJ kg^{-1} DM) total mixed ration. It was concluded that the energy balance of the diet was improved by protein supplementation. Williams et al. (2008) reported a greater ADG and fewer days on feed for

steers fed a dry rolled barley-based diet supplemented with canola meal relative to those fed a processed barley/canola pellet. This response was attributed to subacute ruminal acidosis and associated lower DMI with the feeding of the processed barley/canola pellet. Several studies with by-products of the ethanol industry (i.e. wheat and corn DDGS) which are also high in protein have reported improvements in feedlot performance when fed as an energy source. For example, in a feedlot backgrounding study using wheat DDGS in which 50 and 100% of the barley content in the control diet was replaced by wheat DDGS, McKinnon and Walker (2008) reported an increase in ADG and feed efficiency in cattle fed wheat DDGS relative to cattle fed the control diet. Similarly, during finishing, when steers were fed graded levels of corn DDGS, there was a quadratic improvement in feed efficiency (Walter et al. 2010). In a companion study to the present feedlot trial, He et al. (2013) fed canola meal derived from *B. napus* and *B. juncea* at 15 and 30% (DM) inclusion to steers in replace of barley, during the backgrounding and finishing stages. The results showed that there was no difference in ADG during backgrounding and finishing, whereas dry matter intake was higher and gain:feed lower for cattle fed both canola meal varieties at 30% inclusion. Their conclusion was that 30% is too high a level of inclusion of canola meal as an energy supplement in feedlot diets.

There is a need to evaluate the energy value of these two varieties of canola meal at graded levels of inclusion in a typical group fed feedlot scenario in order to further refine inclusion levels with respect to optimizing feedlot performance and carcass characteristics. The objectives of this trial were to evaluate the effect of level of inclusion of canola meal derived from *B. juncea* and *B. napus* as a replacement for barley as an energy source with respect to performance of backgrounding and finishing cattle.

3.2 Materials and Methods

3.2.1 Housing and Experimental Design

3.2.1.1 Housing

A total of 300 crossbred steers (~292 kg) were purchased and shipped to the Beef Cattle Research and Teaching Unit (BCRTU) of the University of Saskatchewan. Upon arrival, they were ear tagged and administered Bimectin™ pour-on (Bimeda-MTC Animal Health Inc., Cambridge, Ontario, Canada) for internal and external parasites, Somnu-Star Ph™ (Novartis Animal Health Canada Inc. Mississauga, Ontario, Canada) for *Pasteurella haemolytica* and *Histophilus somni*, Starvac 4 Plus™ (Novartis Animal Health Canada Inc. Mississauga, Ontario, Canada) for Infectious Bovine Rhinotracheitis, Bovine Viral Diarrhea (Type 1 and 2), Para Influenza type 3 and Bovine Respiratory Syncytial Virus and Covexin plus™ (Intervet Canada Corp., Kirkland, QC, Canada) for Clostridial diseases. Steers with a temperature greater than 39°C on arrival were treated with long acting Liquamycin LA-200 (Pfizer Animal Health, Pfizer Canada Inc., Kirkland, QC, Canada). All steers were implanted upon arrival with Ralgro™ (Intervet Inc., Kirkland, QC, Canada) and were reimplanted with Revalor XS™ (Intervet Canada Corp., Kirkland, QC, Canada) 2 months later. From arrival, to the start of the trial, the steers were fed an adaptation diet consisting of 35.2% barley silage, 28.5% grass hay and 36.3% fortified grain screening pellets (DM basis). All the steers used for the study were cared for as per the guidelines of the Canadian Council on Animal Care (CCAC, 1993).

3.2.1.2 Experimental Design

Steers were weighed on two consecutive days at the beginning of the trial and the average used as the start of test weight. The experiment was designed as a completely randomized design. The

steers were stratified by weight and distributed evenly to one of the 25 outdoor pens for similar average initial weight across the pens with 12 head per pen. Pen was considered as the experimental unit. Each pen was randomly assigned to one of five dietary treatments. The targeted end point of the trial was 645 kg live weight (unshrunk basis), at which time the steers were sent as a group for slaughter to Cargill Foods, High River, AB.

3.2.2 Treatments and Dietary Composition

The trial started one month after the arrival of steers in order to minimize experimental variation due to diseases by transportation and mixing of steers. The trial was divided in to two phases (Backgrounding and finishing). The backgrounding phase lasted 54 days at which point the cattle weighed ~400 kg. The finishing phase lasted for 153 days with the cattle slaughtered at an average live weight of 645 kg (unshrunk). During each phase, two varieties of canola meal, derived from *B. napus* (brown hull color, high fiber and low crude protein) and *B. juncea* (yellow hulled, low fiber, high crude protein) were evaluated at two levels of inclusion. During the backgrounding period, the control diet consisted of 39% barley silage, 22.8% brome hay, 30.4% barley grain and 7.8% vitamin-mineral supplement (DM) and was formulated to 12.2% CP and 1.48 and 0.89 Mcal kg^{-1} DM of NEm and NEg, respectively in order to target 1.3 kg d^{-1} daily gain (Table 3.1). In all four backgrounding diets, canola meal derived from *B. napus* and *B. juncea* replaced barley grain at 15 and 30% of the diet (DM), resulting in the 15% canola meal replacing 50% of the barley and the 30% canola meal replacing all of barley in the diet.

The control diet during finishing consisted of 88.3% barley grain, 4.4% barley silage; and 7.3% vitamin-mineral supplement (DM) and was formulated to 12.1% CP and 1.85 and 1.22 Mcal kg^{-1} DM of NEm and NEg, respectively (Table 3.2). The four treatment diets consisted of replacing barley grain with *B. napus* and *B. juncea* meals at 10 and 20% of the diet (DM).

Table 3.1. Composition of backgrounding control and 15 and 30% *Brassica (B.) napus* and *B. juncea* meal diets for the first 54 days of the trial

	Treatment				
		B. napus		*B. juncea*	
	Control	15%	30%	15%	30%
Diet composition (% DM basis)					
Barley silage	39.0	39.1	39.2	39.1	39.1
Brome hay	22.8	22.9	22.9	22.8	22.8
Barley grain	30.4	15.2	0.0	15.2	0.0
Supplement	7.8	7.8	7.8	7.8	7.8
B. napus meal	0.0	15.0	30.1	0.0	0.0
B. juncea meal	0.0	0.0	0.0	15.1	30.3
Supplement composition (% DM basis)					
Ground barley	75.7	75.7	75.7	75.7	75.7
Limestone	12.9	12.9	12.9	12.9	12.9
Urea	4.4	4.4	4.4	4.4	4.4
Salt	4.2	4.2	4.2	4.2	4.2
Monocalcium phosphate	1.1	1.1	1.1	1.1	1.1
Canola oil	1.0	1.0	1.0	1.0	1.0
Rumensin	0.2	0.2	0.2	0.2	0.2
Trace mineral mix[z]	0.4	0.4	0.4	0.4	0.4
Vitamin mix[y]	0.1	0.1	0.1	0.1	0.1
Formulated diet composition (% DM basis)					
Dry matter	58.1	58.0	57.9	58.1	58.1
Crude protein	12.2	16.6	21.1	17.6	23.0
Calcium	0.72	0.84	0.95	0.84	0.95
Phosphorus	0.33	0.44	0.57	0.45	0.57
NEm of diet (Mcal kg^{-1})	1.48	1.45	1.42	1.47	1.46
NEg of diet (Mcal kg^{-1})	0.89	0.87	0.84	0.88	0.87

[z]Contains 545 mg Zn, 482 mg Mn, 184 mg Cu, 17 mg I, 5 mg Co, 1 mg Se kg^{-1} supplement

[y]Contains 40000 IU vitamin A, 10000 IU vitamin D3, 500 IU vitamin E kg^{-1} supplement

Table 3.2. Composition of finishing control and 10 and 20% *Brassica (B.) napus* and *B. juncea* meal diets fed from day 55 through the end of trial

	Treatment				
		B. napus		*B. juncea*	
	Control	10%	20%	10%	20%
Diet composition (% DM basis)					
Barley silage	4.4	4.7	4.7	4.7	4.7
Barley grain	88.3	77.8	67.9	77.8	67.8
Supplement	7.3	7.1	7.1	7.0	7.1
B. napus meal	0.0	10.4	20.3	0.0	0.0
B. juncea meal	0.0	0.0	0.0	10.5	20.4
Supplement composition (% DM basis)					
Ground barley	44.2	48.2	48.2	48.2	48.2
Prairie pride pellets	25.0	25.0	25.0	25.0	25.0
Limestone	20.5	20.5	20.5	20.5	20.5
Salt	4.2	4.2	4.2	4.2	4.2
Urea	4.0	0.0	0.0	0.0	0.0
Canola oil	1.5	1.5	1.5	1.5	1.5
Trace mineral mix[z]	0.3	0.3	0.3	0.3	0.3
Rumensin	0.2	0.2	0.2	0.2	0.2
Vitamin mix[y]	0.2	0.2	0.2	0.2	0.2
Formulated composition (% DM basis)					
Dry matter	84.6	84.1	83.9	84.1	84.0
Crude protein	12.1	14.3	17.2	14.9	18.5
Calcium	0.62	0.68	0.75	0.68	0.76
Phosphorus	0.41	0.44	0.52	0.49	0.52
NEm of diet (Mcal kg^{-1})	1.85	1.83	1.82	1.85	1.84
NEg of diet (Mcal kg^{-1})	1.22	1.20	1.19	1.21	1.21

[z]Contains 543.6 mg Zn, 498 mg Mn, 16.6 mg I, 4.84 mg Co, 1.35 mg Se kg^{-1} supplement

[y]Contains 30000 IU vitamin A, 5000 IU vitamin D3, 500 IU vitamin E kg^{-1} supplement

The inclusion levels of both *B. napus* and *B. juncea* meals for the finishing trial were based on the results of the finishing study by He et al. (2013) who reported that 30% inclusion of canola meal resulted in higher DMI and lower feed efficiency relative to inclusion at 15%. The concentrate levels in the finishing diets (barley grain in the control diet and barley grain and canola meal in the treatment diets) averaged 88.2 ± 0.04% DM. Calcium to phosphorus ratios were formulated to range from 1.5:1 to 2:1. Monensin sodium was incorporated in the supplement pellet and formulated to provide 33 ppm (DM). The NEm and NEg content of both backrgounding and finishing diets were calculated based on animal performance as per Zinn and Shen (1998).

Steers fed both canola meals at 30% (DM) were transitioned to the final backgrounding diet by a two-step adaptation process in which the steers were fed 50% of the allocated canola meal for first 3 days followed by the final diet for the remaining backgrounding period. During finishing phase, there was a seven step adaptation period which lasted for 21 days during which the diet composition changed every three days in such a way that the barley silage and hay content of the diet was gradually decreased and the barley grain content increased to the levels of the final finishing diet. Canola meal content was adjusted to final finishing levels in the first step of diet adaptation process.

The barley silage (AC Rosser) was grown at the University of Saskatchewan. Samples of barley silage were taken weekly during the entire trial with DM content determined and used to adjust diets to a constant DM content. Barley grain (dry rolled to a processing index of 78), brome grass hay and the vitamin-mineral pellets were purchased from commercial sources. Ingredient samples were taken every two weeks, DM determined and a representative sub-sample served for chemical analysis. The two varieties of canola meal were sourced by the

Canola Council of Canada from Bunge Canada, Altona, MB. The *B. juncea* meal was sourced from a separate crush from the same plant which utilized only seeds derived from *B. juncea*.

Feed was provided once daily as a total mixed ration (TMR) with an aim to have no more than a 5% refusal. Pelleted supplements for the control and the treatment diets (sourced from Co-Op Feeds, Saskatoon, SK) included minerals, vitamins and ionophore (monensin sodium). Bunk samples of TMR were taken bi-weekly from each pen on a treatment basis and DM determined. All samples of feed and total mixed rations were composited on a monthly basis for analysis.

3.2.3 Data Collection

Feed delivered to each pen was recorded daily. Bunks were read each morning and the daily feed allotted was based on the residual feed in the bunk and the amount fed the previous day. Every two weeks prior to weighing of animals, bunks were cleaned and the orts weighed and sub-sampled to determine DM content. Body weights were taken before the morning feeding every four weeks during backgrounding and every two weeks during finishing. Performance parameters recorded included average daily weight gain, dry matter intake, gain:feed and days on feed.

3.2.4 Chemical Analysis

The forage and the bunk samples were dried in a forced air oven at 55º C for 72 h. After drying, the forage samples were ground using a hammer mill through a 1 mm screen (Christy & Norris 8” Lab mill, Christy Turner Ltd. Chelmsford, UK). The concentrate samples were ground using a Retsch ZM 100 grinder (Haan, Germany) through a 1 mm screen. Total mixed ration samples were analyzed in duplicate according to the Association of Official Analytical Chemists (2000) for DM by drying at 135º C (AOAC method 930. 15), ash (AOAC method 942.05), CP using the

Kjeldahl method (AOAC method 984. 13), NDF treated with amylase and with the addition of sodium sulphite (Ankom technology Method 6, Ankom Technology, Macedon, NY), ADF (Ankom technology Method 5, Ankom Technology, Macedon, NY) and ether extract (AOAC method 920. 39). Calcium and phosphorus were analyzed using the dry ashing procedure (AOAC methods 927. 02 and 965. 17, respectively). Calcium was determined using an atomic absorption spectrophotometer (ice 3000 series, Thermo scientific, Waltham, Massachusetts, USA) equipped with a Cetac ASX 260 auto sampler (Cetac technologies, Omaha, Nebraska, USA). Phosphorus levels were determined at 410 nm on a Helios delta spectrometer (Thermo Fischer Scientific, Waltham, Massachusetts, USA).

Both varieties of canola meal, barley, barley silage and hay samples were analyzed by Cumberland Valley Analytical Services (CVAS, Hagerstown, MD) according to the Association of Official Analytical Chemists (2000). Samples were analyzed for DM by drying at 135º C (AOAC method 930. 15), CP (AOAC method 990. 03) using a Leco FP 528 Nitrogen Combustion Analyzer (Leco, St Joseph, MI), ADF (AOAC method 973. 18), NDF by the method of Van Soest et al. (1991) with the addition of amylase and sodium sulfite, ash (AOAC method 942. 05) and fat using a tecator extraction unit (AOAC method 2003. 05).

3.2.5 Statistical Analysis

Data was analyzed as a completely randomized design, with pen as the experimental unit and treatment as the fixed effect using the mixed model procedure of SAS (version 9.3; SAS Institute, Inc. Cary, NC). Denominator degrees of freedom were determined using the Kenward-Roger option which uses the Satterthwaite adjustment. End of backgrounding body weight was used as a covariate in the analysis of finishing performance. Polynomial contrasts were used to determine the linear and quadratic effects of inclusion level of *B. napus* and *B. juncea* meals in

the diet. Significance was declared at $P < 0.05$. Yield and quality grade data were analyzed using the GLIMMIX macro (SAS, version 9.3; SAS Institute, Inc. Cary, NC) with a binomial error structure and logit data transformation.

3.3 Results and Discussion

The *B. napus* meal used in the trial had lower CP, NEm and NEg and higher ether extract, ADF and NDF content (DM) than *B. juncea* meal (Table 3.3). The *B. napus* meal values for CP, ADF, NDF, EE, calcium and phosphorus were similar to those reported by Bell (1993). The crude protein content of the *B. juncea* meal was in the range reported by Montoya et al. (2009) and Newkirk et al. (1997). The ADF and NDF values of *B. juncea* were comparable to those of Newkirk et al. (1997). The EE content of the *B. juncea* meal was higher than the values reported by Montoya et al. (2009) and Newkirk et al. (1997).

3.3.1 Backgrounding Phase

Substituting barley with 15 and 30% *B. napus* meal resulted in a linear increase ($P < 0.05$) in dietary CP, EE, ADF, NDF, and phosphorus and a trend ($P = 0.06$) for a linear increase in calcium levels in the total mixed ration whereas increasing levels of *B. juncea* meal resulted in a quadratic response in CP ($P = 0.04$) and a linear increase in calcium and phosphorus levels ($P \leq 0.04$) in the diet (Table 3.4). For example, the CP content increased from 12% in the control diet to 16.1 and 20.1% in 15 and 30% *B. napus* meal diets, respectively. Similarly, compared to the control diet, the CP content increased to 17.2 and 21.3% in the 15 and 30% *B. juncea* meal diets respectively. The CP content of *B. napus* (40.9%) and *B. juncea* meals (47.1%) were higher than that of barley (11.4%; Table 3.3). In the present feedlot trial, both *B. napus* and *B. juncea* meals were used as an alternative energy source to barley grain for growing beef cattle. Since these by-products were more concentrated in CP after oil extraction, inclusion of these meals as a

Table 3.3. Composition of feed ingredients used for the feedlot trial

				Canola meal[z]	
	Barley silage	Barley	Brome hay	*B. napus*	*B. juncea*
Chemical composition (% DM basis)[y]					
Crude protein	12.3	11.4	10.3	40.9	47.1
Ether extract	2.7	1.9	1.6	3.8	2.7
Acid detergent fiber	33.2	8.2	44.4	17.3	9.5
Neutral detergent fiber	48.8	18.6	64.9	22.7	14.8
Calcium	0.42	0.05	0.68	0.79	0.80
Phosphorus	0.37	0.42	0.10	1.2	1.2
NEm (Mcal kg^{-1})	1.41	1.94	1.10	1.76	1.87
NEg (Mcal kg^{-1})	0.81	1.28	0.53	1.12	1.23

[z]*B = Brassica*

[y]Analyzed at Cumberland Valley Analytical Services, Inc., Maugansville, MD

Table 3.4. Analysis of control and 15 and 30% *Brassica (B.) napus* and *B. juncea* meal backgrounding diets for the first 54 days of the trial (n = 2)

	Treatment					*P*-value contrast[z]			
		B. napus		*B. juncea*		*B. napus*		*B. juncea*	
	Control	15%	30%	15%	30%	L	Q	L	Q
Diet analysis (% DM basis ± SE)[y]									
Crude protein	12.0 ± 0.09	16.1 ± 0.2	20.1 ± 0.81	17.2 ± 0.27	21.3 ± 0.01	< 0.01	0.91	< 0.01	0.04
Ether extract	2.2 ± 0.09	2.4 ± 0.04	2.7 ± 0.20	2.1 ± 0.03	2.1 ± 0.06	0.01	0.64	0.10	0.66
Acid detergent fiber	24.7 ± 1.77	26.0 ± 0.07	29.4 ± 1.51	25.4 ± 1.46	26.9 ± 0.37	0.02	0.44	0.30	0.48
Neutral detergent fiber	39.2 ± 3.20	40.9 ± 1.74	45.0 ± 1.77	39.6 ± 1.78	43.3 ± 0.41	0.05	0.59	0.12	0.43
Calcium	0.70 ± 0.04	0.77 ± 0.10	0.84 ± 0.05	0.71 ± 0.05	0.93 ± 0.03	0.06	1.00	0.02	0.06
Phosphorus	0.33 ± 0.01	0.43 ± 0.02	0.52 ± 0.01	0.35 ± 0.01	0.49 ± 0.08	< 0.01	0.29	0.04	0.22

[z]L = Linear; Q = Quadratic

[y]Values shown with standard error

replacement for barley was reflected in the higher CP and NDF content of the respective total mixed rations. Similar to CP, the ADF content of *B. napus* meal diets increased from 24.7% in the control diet to 26 and 29.4% (DM) and that of the *B. juncea* meal diets increased to 25.4 and 26.9% (DM) in the 15 and 30% diets, respectively. The NDF content of the diets showed similar increases as the level of each meal increased to 15 and 30%, respectively. As expected, ADF and NDF values for *B. juncea* meal diets were lower than *B. napus* meal diets, while CP levels were higher. Ratios of calcium to phosphorus ranged from 1.6: 1 to 2.1: 1 across all treatments.

Cattle fed *B. napus* meal diets exhibited a quadratic response in DMI ($P = 0.05$) while cattle fed *B. juncea* meal diets exhibited a linear increase ($P < 0.01$) as meal inclusion level increased (Table 3.5). These results contrast with those of He et al. (2013) who observed no effect of inclusion of canola meal on DMI during backgrounding. While the results of the present study differ from He et al. (2013), it should be pointed out that the increase seen in the present study is relatively small (i.e. 8.3 kg d^{-1} for cattle fed control diet vs. 9.0 kg d^{-1} for cattle fed 30% *B. napus* or *B. juncea* meal diets). The difference between the two studies may have been due to the fact that in the present study cattle were group fed while in the work of He et al. (2013) they were individually fed. It has been shown that competition increases feed intake (Kidwell et al. 1954; Albright 1993). Other reasons for an increase in DMI could be a potential decrease in energy content of the diet as cattle increase DMI in order to maintain energy intake, or an increase in NDF content of the total mixed ration resulting in energy dilution and a compensatory increase in DMI (Galyean and Defoor 2002).

Similar to DMI, cattle fed *B. napus* meal diets showed a quadratic response ($P = 0.03$) while cattle fed *B. juncea* meal diets had a linear increase ($P < 0.01$) in DMI as a percent of body weight with increasing inclusion. Average daily gain increased linearly with increasing inclusion

Table 3.5. Effect of feeding control and 15 and 30% *Brassica (B.) napus* and *B. juncea* meal diets on performance of backgrounding cattle (Days 1-54; n = 5)

	Dietary Treatment						*P*-value contrast[z]			
		B. napus		*B. juncea*			*B. napus*		*B. juncea*	
	Control	15%	30%	15%	30%	SEM	L	Q	L	Q
Start of trial weight (kg)[y]	310	311	311	311	311	0.3				
Day 54 weight (kg)[y]	384	397	397	395	400	2.6	0.02	0.13	< 0.01	0.29
Dry matter intake (kg d^{-1})	8.3	9.0	9.0	8.7	9.0	0.10	< 0.01	0.05	< 0.01	0.33
Average daily gain (kg d^{-1})	1.36	1.59	1.59	1.56	1.65	0.049	0.02	0.14	< 0.01	0.32
Intake as % of BW	2.15	2.26	2.28	2.21	2.24	0.017	< 0.01	0.03	< 0.01	0.51
Gain:Feed	0.166	0.178	0.176	0.178	0.186	0.0041	0.11	0.29	< 0.01	0.37
NEm of diet (Mcal kg^{-1})[x]	1.69	1.73	1.73	1.75	1.77	0.022	0.32	0.45	0.02	0.41
NEg of diet (Mcal kg^{-1})[x]	1.07	1.11	1.10	1.13	1.14	0.019	0.31	0.38	0.03	0.41

[z]L = Linear; Q = Quadratic

[y]Start of trial and day 54 weights are reported on a 4% shrunk basis

[x]Calculated as per Zinn and Shen (1998)

of both *B. napus* ($P = 0.02$) and *B. juncea* meal ($P < 0.01$). As with DMI, He et al. (2013) did not observe any effect of inclusion level of canola meal on ADG of backgrounding cattle. The increase in ADG of cattle fed both *B. napus* and *B. juncea* meal in the present study is a reflection of the increased DMI of cattle fed these diets.

Feed efficiency or gain to feed ratio (G:F) during backgrounding increased linearly ($P < 0.01$) as the level of inclusion of *B. juncea* meal increased in the diet. However, there was no improvement ($P = 0.11$) for cattle fed *B. napus* meal. He et al. (2013) did not observe any influence of inclusion level of either canola meal type on feed efficiency during backgrounding. The lack of improvement in G:F of cattle fed *B. napus* meal indicates that the increased DMI with increasing inclusion of the meal did not translate in to a substantial improvement in daily gain. The linear increase in feed efficiency by cattle fed *B. juncea* meal in the present trial is a result of disproportionate increases in DMI and ADG as inclusion level increased and a potential increase in the energy content of the diet. It also indicates that replacing 15 or 30% barley grain (DM) with *B. juncea* meal in growing diets for cattle does not have any adverse effect on performance.

The NEm and NEg content of the total mixed ration as predicted from animal performance increased linearly ($P = 0.03$) as the level of *B. juncea* but not *B. napus* increased in the diet. The results for NEg for cattle fed *B. juncea* meal indicate that inclusion of *B. juncea* meal has in fact improved the energy status of the total mixed ration. Since all the treatment diets were formulated to meet or exceed the NRC requirement for CP, it could be concluded that excess dietary amino acids in *B. juncea* meal contributed to the energy balance of the diet. Rumen fermentation of branched chain amino acids in dietary protein could result in production of branched chain volatile fatty acids. Fiber-digesting bacteria require branched-chain volatile

fatty acids for growth (NRC 1985) and their availability may have resulted in an improvement in fiber digestion. Also, systemic oxidative deamination; and transamination and subsequent oxidation of amino acids by tricarboxylic acid cycle yield energy which is available to the animal. This increased energy content in part contributed to a linear increase in ADG and feed efficiency during backgrounding. Similar results were also reported by McKinnon et al. (1993) who reported a linear increase in ADG when steers were fed a low energy diet and supplemented with increasing levels of CP by inclusion of canola meal in a finishing diet.

Body weight measurements on day 54 showed a linear increase in body weight of cattle at the end of backgrounding phase for those fed both *B. napus* ($P = 0.02$) and *B. juncea* meal ($P < 0.01$). The body weight increase is explained by a quadratic response in DMI and associated linear increase in ADG by cattle fed *B. napus* meal. The linear increase in body weight at the end of backgrounding reflects the linear increase in DMI and NEg of cattle fed *B. juncea* meal which was also reflected by increases in ADG and feed efficiency.

3.3.2 Finishing Phase

Substituting barley with *B. napus* meal at 10 and 20% inclusion resulted in a linear increase ($P \leq 0.02$) in CP, EE, NDF, calcium and phosphorus and a quadratic response ($P = 0.03$) in ADF levels in the total mixed rations, whereas *B. juncea* meal resulted in a linear increase ($P \leq 0.02$) in CP, EE, ADF, calcium and phosphorus levels with increasing inclusion (Table 3.6). For example, CP content of *B. napus* meal diets increased to 14.1 and 16.8% respectively, as the level of canola meal inclusion increased to 10 and 20% relative to 12.1% CP in the control diet. Similarly, CP content of total mixed ration increased to 15 and 18% in the 10 and 20% *B. juncea* meal diets, respectively relative to the control diet. The ADF content increased from 7.7% in the control diet to 9.7 and 10.8% in 10 and 20% % *B. napus* meal diets and 8.8 and 9.4% in

Table 3.6. Analysis of control and 10 and 20% *Brassica (B.) napus* and *B. juncea* meal finishing diets fed from day 55 through the end of trial (n = 4)

	Treatment					*P*-value contrast[z]			
		B. napus		*B. juncea*		*B. napus*		*B. juncea*	
	Control	10%	20%	10%	20%	L	Q	L	Q
Diet analysis (% DM basis ± SE)[y]									
Crude protein	12.1 ± 0.38	14.1 ± 0.45	16.8 ± 0.32	15.0 ± 0.92	18.0 ± 0.81	< 0.01	0.17	< 0.01	0.96
Ether extract	2.5 ± 0.13	2.8 ± 0.09	3.1 ± 0.30	2.6 ± 0.10	2.8 ± 0.21	< 0.01	0.98	0.02	0.46
Acid detergent fiber	7.7 ± 0.38	9.7 ± 0.30	10.8 ± 0.16	8.8 ± 0.39	9.4 ± 0.67	< 0.01	0.03	< 0.01	0.40
Neutral detergent fiber	19.6 ± 1.03	20.8 ± 0.82	21.7 ± 0.76	19.9 ± 0.18	20.2 ± 0.78	< 0.01	0.83	0.26	0.96
Calcium	0.66 ± 0.06	0.77 ± 0.12	0.79 ± 0.07	0.78 ± 0.09	0.81 ± 0.04	0.02	0.38	0.03	0.42
Phosphorus	0.37 ± 0.01	0.44 ± 0.01	0.50 ± 0.01	0.44 ± 0.01	0.51 ± 0.01	< 0.01	0.85	< 0.01	0.30

[z]L = Linear; Q = Quadratic

[y]Values shown with standard error.

B. juncea meal diets, respectively. Neutral detergent fiber content showed a similar increase with increasing inclusion of *B. napus* but not *B. juncea* meal. As expected, the ADF and NDF values for *B. juncea* meal diets were lower than *B. napus* meal diets while CP values were higher. Ratio of calcium to phosphorus ranged from 1.6: 1 to 1.8:1 across all treatments.

Due to the response of cattle fed *B. napus* and *B. juncea* meal during backgrounding and the subsequent increase in live weight, finishing performance was first analyzed using end of backgrounding live weight as a covariate. Since the results revealed that the end of backgrounding body weight had no influence on finishing performance, the data set was re-analyzed without including this parameter as covariate. Cattle fed *B. napus* meal diet showed a quadratic response ($P = 0.02$) whereas cattle fed *B. juncea* meal showed a linear increase ($P = 0.05$) in DMI with increasing inclusion (Table 3.7). When DMI was expressed as a percent of body weight, cattle fed *B. napus* meal showed a linear increase ($P < 0.01$) whereas cattle fed *B. juncea* meal showed a tendency ($P = 0.06$) for a linear increase. A lower energy content and higher NDF content of the finishing diet could result in a compensatory increase in DMI in order to maintain energy intake. (Galyean and Defoor 2002). He et al. (2013) also reported an increase in DMI by finishing steers fed 30% *B. napus* and *B. juncea* meal as a replacement for barley grain relative to those fed 15% during finishing. An increase in DMI in cattle fed finishing diets was also reported in other trials when high protein by-products (i.e. wheat DDGS) were substituted for barley (Gibb et al. 2008; Walter et al. 2010).

Table 3.7. Effect of replacing barley with 10 and 20% *Brassica (B.) napus* and *B. juncea* meals on performance of finishing cattle (n = 5)

	Dietary Treatment						*P*-value contrast[z]			
		B. napus		*B. juncea*			*B. napus*		*B. juncea*	
	Control	10%	20%	10%	20%	SEM	L	Q	L	Q
Start of trial weight (kg)[y]	384	397	397	395	400	2.6				
End of trial weight (kg)[y]	630	648	634	640	642	4.9	0.61	0.02	0.14	0.49
Dry matter intake (kg d^{-1})	10.8	11.4	11.2	11.2	11.2	0.13	0.04	0.02	0.05	0.42
Average daily gain (kg d^{-1})	1.61	1.64	1.55	1.60	1.58	0.029	0.18	0.08	0.85	0.54
Intake as % of BW	1.71	1.75	1.77	1.74	1.75	0.012	< 0.01	0.14	0.06	0.60
Gain:Feed	0.149	0.145	0.138	0.144	0.141	0.0018	< 0.01	0.69	< 0.01	0.55
NEm of diet (Mcal kg^{-1})[x]	1.87	1.85	1.80	1.84	1.82	0.013	< 0.01	0.38	0.03	0.69
NEg of diet (Mcal kg^{-1})[x]	1.23	1.21	1.17	1.20	1.19	0.012	< 0.01	0.49	0.02	0.67

[z]L = Linear; Q = Quadratic

[y]Start and end of trial weights are reported on a 4% shrunk basis

[x]Calculated as per Zinn and Shen (1998)

Cattle fed *B. napus*, but not *B. juncea* meal showed a tendency ($P = 0.08$) for a quadratic response to ADG. He et al. (2013) also reported minimal effect of inclusion of canola meal (*B. napus* or *B. juncea*) at levels of 15 or 30% on ADG during the finishing period.

For both meals (*B. napus* and *B. juncea*) there was a linear decrease in G:F. This was a result of an increase in DMI with no change in ADG. He et al. (2013) also reported poorer feed efficiency for cattle fed 30% canola meal during finishing relative to those fed 15% canola meal or the control diet. Similar to the results of the present study, Gibb et al. (2008) reported a linear increase in DMI associated with no effect on ADG resulting in a linear decrease in G:F with increasing inclusion of wheat DDGS.

The decrease in G:F observed when canola meal and other high protein by-product feeds replaced barley in finishing diets indicate that these high protein by-product feeds have a lower energy content than barley grain. For both canola meals used in the present study, this was affirmed when one looks at the net energy content of the TMR calculated from animal performance. With increasing inclusion of both *B. napus* and *B. juncea* meal, there was a linear decrease in NEm ($P \leq 0.03$) and NEg ($P \leq 0.02$) content of the respective diets. The linear decrease in net energy content of both *B. napus* and *B. juncea* meal diets was reflected in increased DMI, similar or decreased ADG and poorer feed efficiency.

End trial weight of cattle fed *B. napus* meal showed a quadratic response ($P = 0.02$) with increasing inclusion. This response in part reflects the quadratic response in DMI and ADG of *B. napus* meal fed cattle and also the fact that these cattle started finishing at a slightly higher start of trial weight relative to controls due to higher gains during backgrounding.

3.3.3 Carcass Quality

Cattle fed *B. napus* meal showed a quadratic response ($P < 0.02$) in hot carcass weight as the level of inclusion increased in the diet (Table 3.8). The quadratic response in hot carcass weight is a reflection of the quadratic response ($P = 0.02$) in live weight of these cattle fed *B. napus* meal. He et al. (2013) observed no effect of level of inclusion of canola meal on hot carcass weight or rib eye area. Minimal effect on carcass characteristics by the substitution of barley grain with high protein by-products (i.e. wheat/corn DDGS) as an energy source was also reported by Beliveau and McKinnon (2008) and Walter et al. (2010).

Similar to hot carcass weight, cattle fed *B. napus* meal showed a quadratic response ($P = 0.03$) in dressing percentage with increasing inclusion. Hot carcass weight and dressing percentage were higher than that reported by Amat et al. (2012) for cattle fed to a similar slaughter weight using corn or wheat DDGS as a replacement for barley grain. There was a trend for a linear decrease ($P = 0.06$) in Canada AAA carcass and a quadratic response ($P = 0.02$) in Canada AA carcass with increasing inclusion of *B. napus* meal. Cattle fed *B. juncea* meal showed a trend ($P = 0.10$) for a linear increase in Canada AA carcass with increasing inclusion. There was no effect on rib eye area, back fat thickness and yield grade as the level of inclusion of both *B. napus* and *B. juncea* meal increased in the diet. The results of the present study are similar to a number of trials involving high protein by-product feeds in that there has been a minimal effect of replacing barley grain with high protein by-product feeds on carcass quality (Gibb et al. 2008; Walter et al. 2010; He et al. 2013).

Table 3.8. Effect of feeding control and 10 and 20% *Brassica (B.) napus* and *B. juncea* meal diets on carcass quality of feedlot steers (n = 5)

	Dietary Treatment						*P*-value contrast[z]			
		B. napus		*B. juncea*			*B. napus*		*B. juncea*	
	Control	10%	20%	10%	20%	SEM[y]	L	Q	L	Q
Shrunk shipping weight (kg)	630	648	634	640	642	4.9	0.61	0.02	0.14	0.49
Hot carcass (kg)	378	390	377	385	384	2.9	0.86	< 0.01	0.18	0.28
Dressing percentage	59.7	60.3	59.5	60.1	59.8	0.26	0.56	0.03	0.78	0.41
Rib eye area (cm^2)	92.3	94.2	91.6	94.2	92.2	0.18	0.61	0.21	0.89	0.48
Fat thickness (cm)	0.94	1.02	0.89	1.09	1.04	0.02	0.57	0.17	0.22	0.11
Yield grade[xw]										
CBGA 1	61.2	56.1	61.1	49.1	44.5	0.28	0.66	0.93	0.19	1.00
CBGA 2	32.7	35.1	35.2	41.8	44.4	0.28	0.59	0.62	0.16	0.54
CBGA 3	6.1	8.8	3.7	9.1	11.1	0.54	0.68	0.24	0.38	0.87
Quality grade[xw]										
CBGA AAA	57.1	33.3	35.2	41.8	46.3	0.28	0.06	0.26	0.62	0.52
CBGA AA	40.8	63.1	61.1	54.6	51.9	0.28	0.02	0.02	0.10	0.13
CBGA A	2.1	1.8	3.7	0.0	1.8	0.94	0.51	0.71	1.00	0.34
CBGA B	0.0	1.8	0.0	3.6	0.0	0.86	1.00	0.18	1.00	0.18

[z]L = Linear; Q = Quadratic

[y]SEM = pooled standard error of the mean

[x]Percent of total

[w]According to Canadian Beef grading Agency (CBGA)

3.3.4 Conclusion

The results of this trial indicate that the response of steers to substitution of barley with canola meal derived from both *B. napus* and *B. juncea* as an energy source depends on the canola meal variety, level of inclusion and the stage of growth. Cattle fed *B. juncea* meal during backgrounding at levels up to 30% inclusion had superior growth and feed efficiency owing to an increase in DMI and NEg of the total mixed ration with increasing inclusion. This could be attributed to the linear increase in CP and lower fiber content of the total mixed ration which contributes to the energy status relative to *B. napus* supplemented diet. Steers fed *B. napus* meal during backgrounding showed no improvement in G:F or NEg as a result of increasing canola meal in the diet. The higher fiber content of *B. napus* meal could possibly moderate the effect of higher CP, resulting in high DMI and less efficient backgrounding performance. In order not to compromise feed efficiency, inclusion of *B. napus* meal should be limited to 15% in backgrounding diets.

Performance of finishing cattle fed both *B. napus* and *B. juncea* meal was adversely affected by a linear decrease in NEg with increasing inclusion, indicating that the energy value of both the canola meal varieties is inferior to that of barley when substituted at 10 and 20% DM in a high energy finishing diet. Dry matter intake of cattle fed both meals increased in order to compensate for the lower energy content of the diet resulting in less efficient gains. However, most of the carcass characteristics were unaffected by the level of inclusion of either meal. These results indicate that during finishing no performance benefit was observed by replacing barley with either meal type.

4.0 EVALUATION OF CANOLA MEAL DERIVED FROM *Brassica (B.) napus* AND *B. juncea* ON RUMEN FERMENTATION AND TOTAL TRACT DIGESTIBILITY CHARACTERISTICS OF FEEDLOT HEIFERS

4.1 Introduction

Rapid expansion of biofuel industry has resulted in an increasing demand and price for cereal grains. As a result, there is an increasing use of high protein by-product feeds as an energy source for cattle (He et al. 2013). With the rapid expansion of canola crushing industry in western Canada, there is increasing availability of canola meal which makes it an easily available and economically viable source of protein and energy for cattle. Newer varieties of canola like the yellow seeded *B. juncea* yield meal with high protein and low fiber content and potentially are higher in digestible energy content. Increasing popularity and acreage for this canola variety in the drier regions of western Canada makes the canola meal derived from *B. juncea* a potential substitute for barley in feedlot diets (May et al. 2010; He et al. 2013). As a result, the energy value of *B. juncea* meal for feedlot cattle needs to be assessed. Replacing barley with canola meal reduces the starch content of finishing diets. This is expected to reduce the incidence of sub-acute (SARA) and acute ruminal acidosis (ARA) in feedlot cattle. Also varying the proportion of starch and protein by the addition of canola meal, the quantity and proportion of volatile fatty acids (VFA) produced in rumen is likely to be different than that of conventional barley grain fed cattle. For example, supplementing a barley-based diet with 7.2% canola meal resulted in a numerical increase in acetate and butyrate and a decrease in propionate concentration in the rumen relative to un-supplemented cattle (Koenig et al. 2004).

There is no published data available on the effect of inclusion of canola meal derived from *B. napus* and *B. juncea* with respect to rumen fermentation and total tract digestibility characteristics of barley-based diets. With increased availability of canola meal from the canola processing industry and development of newer varieties of canola (*B. juncea*) which produce meals with higher protein and lower fiber, the energy value of these by-products needs to be assessed with respect to finishing feedlot cattle. The objectives of the present study were to evaluate the effect of level of inclusion of canola meal derived from *B. juncea* and *B. napus* as a replacement for barley with respect to rumen fermentation, total tract digestibility characteristics and digestible energy content of canola meal supplemented diet when fed at varying inclusion rates in finishing diets of growing heifers.

4.2 Materials and Methods

4.2.1 Animal and Housing

Five yearling Hereford Gelbvieh cross heifers (387 ± 6.5 kg, mean ± SD) were purchased from a commercial source and housed at the University of Saskatchewan Metabolism Unit in individual indoor pens with a floor space of $9m^2$. Each pen was equipped with a self-feeder, automatic water bowl and rubber floor mat. Three days after arrival, all five heifers were spayed and fitted with soft rubber rumen cannulas (10 cm diameter; Barr Diamond, Parma, ID). All heifers were cared for as per the guidelines of the Canadian Council on Animal Care (CCAC 1993).

4.2.2 Experimental Design

The trial started 2 months after the arrival and cannulation of heifers. The experiment was designed as a 5x5 Latin square. Before the start of trial, there was a 14 day, 8 step diet transition, with diet changes occurring on alternate days. During this period, the control diet fed to heifers

was transitioned from an all forage diet to the final dietary composition of 89% barley grain, 3.7% barley silage and 7.3% vitamin-mineral supplement (DM). The four treatment diets included substituting barley grain with canola meal derived from either *B. napus* or *B. juncea* at 10 and 20% of total mixed ration (DM; Table 4.1). Substitution of 10% *B. napus* or *B. juncea* meal was achieved in first step of the transition, while for the 20% canola meal treatments; the final inclusion rate was achieved in the second transition step.

The trial lasted 160 days with five periods and 32 days per period. The first 12 days of each period were used for diet adaptation; voluntary intake was measured from days 13 to 18. On day 19, rumen fluid was collected every 2 h over a 24 h period. Days 21 to 24 were used for measurement of rumen pH using in-dwelling pH probes. From day 24 to the end of each period, cattle were fed at 95% of voluntary intake to assure consumption of all feed. On day 26, urinary catheters were inserted and total urine and fecal collections were carried out on days 27 to 32.

4.2.3 Treatments and Dietary Composition

All heifers were fed *ad libitum* hay from arrival until the beginning of the trial period. The diets were similar in composition to the finishing diets used for the feedlot trial in chapter 3. All five diets were formulated to meet or exceed the NRC (2000) requirement for CP. Trace minerals and fat soluble vitamins were included in the vitamin-mineral pellet. Calcium: phosphorus ratio was formulated to range from 1.5:1 to 2:1, monensin sodium was provided at 33 mg kg^{-1} (DM) and was incorporated in the mineral-vitamin pellet.

All feed ingredients were hand mixed and fed in two equal proportions at 0800 and 1600 h throughout the trial period. All heifers were fed *ad libitum* until day 23 of each period so that 0.5 – 0.75 kg of orts remained in the bunk the next day. Before morning feeding, the bunks were

Table 4.1. Composition of finishing control and 10 and 20% *Brassica (B.) napus* and *B. juncea* meal diets for the metabolism trial

	Treatment				
		B. napus		*B. juncea*	
	Control	10%	20%	10%	20%
Diet composition (% DM basis)					
Barley silage	3.7	4.0	4.0	4.0	4.0
Barley grain	89.0	78.0	67.8	78.0	67.7
Supplement	7.3	7.1	7.1	7.1	7.1
B. napus meal	0.0	10.9	21.1	0.0	0.0
B. juncea meal	0.0	0.0	0.0	10.9	21.2
Supplement composition (% DM basis)					
Ground barley	44.2	48.2	48.2	48.2	48.2
Prairie pride pellets	25.0	25.0	25.0	25.0	25.0
Limestone	20.5	20.5	20.5	20.5	20.5
Salt	4.2	4.2	4.2	4.2	4.2
Urea	4.0	0.0	0.0	0.0	0.0
Canola oil	1.5	1.5	1.5	1.5	1.5
Trace mineral mix[z]	0.25	0.25	0.25	0.25	0.25
Rumensin	0.2	0.2	0.2	0.2	0.2
Vitamin mix[y]	0.15	0.15	0.15	0.15	0.15
Formulated composition (% DM basis)					
Dry matter	83.9	83.8	83.9	83.8	84.1
Crude protein	13.1	15.3	18.1	16.0	19.6
Calcium	0.69	0.79	0.87	0.80	0.88
Phosphorus	0.40	0.49	0.57	0.49	0.57
NEm of diet (Mcal kg^{-1})[x]	1.86	1.84	1.82	1.85	1.84
NEg of diet (Mcal kg^{-1})[x]	1.22	1.21	1.19	1.22	1.21

[z]Contains 543.6 mg Zn, 498 mg Mn, 16.6 mg I, 4.84 mg Co, 1.35 mg Se kg^{-1} supplement

[y]Contains 30000 IU vitamin A, 5000 IU vitamin D3, 500 IU vitamin E kg^{-1} supplement

[x]Calculated as per Zinn and Shen (1998)

cleaned, orts weighed and sub-sampled during the voluntary intake period for determination of DM content and during total collection for chemical analysis. All heifers were weighed at the beginning and end of voluntary intake period (day 13 and 18) in order to calculate DM intake as a percentage of body weight.

Barley grain was purchased from commercial sources, stored and dry rolled at the Beef Cattle Research and Teaching Unit of the University of Saskatchewan before transporting to the Livestock Research Facility. Barley samples were taken every two weeks, DM determined and stored for chemical analysis. Barley silage (AC Rosser) was grown and ensiled at the University of Saskatchewan. Silage samples were taken weekly to determine the DM content for making necessary adjustments in DM content of the complete diet.

Brassica napus and *B. juncea* meals as well as the mineral-vitamin pellets for the control and treatment groups were the same as that for the feedlot trial. Samples of both varieties of canola meal and pellets were taken every two weeks, DM determined and stored for later analysis.

4.2.4 Rumen Fermentation

4.2.4.1 Rumen Fluid Collection

Rumen fluid was collected every 2 h on day 19 of each period starting at 0800 h. During each collection, approximately 250 ml of rumen fluid from four different regions of the rumen (ventral, anterior, posterior and rumen mat) was collected and strained through two layers of cheese cloth and solids discarded. Using a model 265A portable pH meter (Orion Research Inc., Beverly, MA), the pH was measured immediately in duplicate and recorded. In addition, three 10 ml samples of rumen fluid were collected in three 15 ml centrifuge tubes (Fisher Scientific,

Waltham, MA), one containing 2 ml of 25% metaphosphoric acid for VFA analysis, a second containing 2 ml of 1% sulphuric acid for ammonia analysis and the third without preservative for measurement of osmolality. After sampling, the tubes were stored at -20°C for later analysis.

4.2.4.2 In-dwelling Rumen pH Measurement

On day 21 of each period, all five heifers were fitted with in-dwelling rumen pH system consisting of probes coupled to data loggers for the continuous measurement of ruminal pH (Dascor, Escondido, CA) as described by Penner et al. (2006). Standardization of probes was done using standard buffers (pH 4 and 7). The system measured rumen pH every minute for 72 hours starting at 0800 h on day 21. On day 24, at 0800 h the pH probes were removed from rumen, washed and the data downloaded.

The pH data was then averaged for each minute on a daily basis and the mean, minimum and maximum pH determined. The duration and area under pH threshold 5.8, 5.5 and 5.2 were also calculated to determine the severity and extent of pH depression. Ruminal acidosis was characterized as mild (pH < 5.8), moderate (pH < 5.5) and severe (pH < 5.2) with thresholds ranging between 5.5 and 5.8 for SARA and 5.0 and 5.2 for ARA (Nocek 1997; Penner et al. 2007).

4.2.4.3 Volatile Fatty Acid Analysis

Tubes containing the rumen fluid samples were thawed overnight at 4°C. The contents were then mixed thoroughly before being centrifuged at 10,000 rpm for 10 min at 4°C using a Beckman Centrifuge (Model Avanti J -E; Palo Alto, CA). After centrifugation, 1.5 ml of supernatant was pipetted into duplicate microcentrifuge tubes (VWR™ 1.5 ml microcentrifuge tube with snap cap, Radnor, PA) and centrifuged again at 12,000 rpm for 10 min at 4°C using a microcentrifuge

(Beckman Coulter ™, Brea, CA). Following this step, 1 ml of the supernatant in a GC vial (Agilent Technologies™, Santa Clara, CA) was mixed with 0.2 ml of internal standard (isocaproic acid). The internal standard was prepared by mixing 20 ml of 25% metaphosphoric acid with 300µL of isocaproic acid and made up to a volume of 100 ml with double distilled water. Prepared samples in GC vials were loaded into the autosampler of a Agilent 6890 series Gas chromatography system (Agilent Technologies™, Santa Clara, CA) equipped with an Agilent 7683 series 5 µL injector, Zebron ZB-FFAP high performance GC capillary column (30 m x 320 µm x 0.25µm, Phenomenex, Torrance, CA) and an Agilent split focus liner (Agilent Technologies™, Santa Clara, CA). A mixed standard, containing known amounts of acetic, propionic, butyric, isobutyric, valeric, isovaleric, caproic and isocaproic acids were used to construct a calibration curve for analysis of unknown samples. The concentration of each VFA was measured by comparing their peak areas with that of the internal standard, isocaproic acid. Samples were prepared daily and kept at 4°C until the initiation of the daily run to prevent volatilization.

4.2.4.4 Rumen Ammonia and Osmolality

Rumen fluid samples for determining ammonia concentration were thawed overnight at 4°C. Contents of each tube were thoroughly mixed and then centrifuged at 12,000 rpm at 4°C for 10 min in a Beckman Centrifuge (Model Avanti J -E; Palo Alto, CA). The supernatant was used to determine the concentration of ammonia by colorimetric method using the phenol-hypochlorite procedure outlined by Broderick and Kang (1980).

Non-acidified rumen fluid samples for determination of rumen osmolality were thawed overnight at 4°C and then centrifuged at 10,000 rpm for 10 min at 4°C using a Beckman Centrifuge. After centrifugation, 1.5 ml of supernatant was pipetted into a microcentrifuge tube

and centrifuged again at 12,000 rpm for 10 minutes at 4°C using a microcentrifuge. Following this, duplicate 250 µL samples of the supernatant were used to measure the osmolality directly using an osmometer (Model 3250, Advanced Instruments Inc., Norwood, MA). Three reference solutions of 100, 290 and 500 mOsmol/kg (Advanced instruments Inc., Norwood, MA) were used at the beginning of each run to calibrate the osmometer.

4.2.5 Total Tract Collection

Total tract collection of feces and urine was carried out starting at 0800 h on day 27 through 0800 h on day 32 for each period. Twelve h prior to the commencement of total tract collection, heifers were fitted with indwelling bladder catheters (Bardex Foley Catheter, C. R. Bard Inc., Covington, GA). The heifers were tethered to the pen but were provided with adequate space to stand, eat, drink and lie down. The urinary catheters were attached to Nalgene plastic tubes which were connected to 20L Nalgene plastic containers containing 150 ml of concentrated HCl to prevent the volatilization of urinary ammonia. Each day at 0800 h starting on day 28, total volume of urine was weighed. A sample (10% of daily output for each heifer) was taken and stored in 10L plastic containers and kept in a freezer at -20°C. Each day during total collection, daily urine samples were added to the plastic container to have a representative sample for the period per animal. At the end of each total collection period, the composite urine sample in the 10L container was thawed, mixed and a 500 ml sub-sample for each animal was stored at -20°C for analysis of nitrogen and phosphorus.

Total tract collection of feces was carried out by observing pens every 2 h from 0600 to 2200 h. If present, manure was scraped from the floor and stored in Rubbermaid^{TM} plastic containers with lids. From 2200 to 0600 h, the pens were checked every 4 h. Every day at 0800 h starting on day 28, total daily output of feces was weighed and sampled into pre-weighed

aluminium trays at 6% of daily output. Fecal samples from each period were dried in a forced air oven at 55º C for 120 h.

4.2.6 Chemical Analysis

Samples of barley, mineral-vitamin pellets, *B. napus* and *B. juncea* meals and orts were dried in a forced air oven at 55º C for 48 h whereas barley silage samples were dried for 72 h. Forage samples, orts and fecal samples were ground using a hammer mill through a 1 mm screen (Christy & Norris 8" Lab mill, Christy Turner Ltd. Chelmsford, UK). Concentrate samples were ground through a 1 mm screen using a Retsch ZM 100 grinder (Haan, Germany). All silage, concentrate, orts and fecal samples were sent to Cumberland Valley Analytical Services (CVAS, Hagerstown, MD) for analysis according to the Association of Official Analytical Chemists (2000). Samples were analyzed for DM by drying at 135º C (AOAC method 930. 15), CP (AOAC method 990. 03) using a Leco FP 528 Nitrogen Combustion Analyzer (Leco, St Joseph, MI), ADF (AOAC method 973. 18), and ash (AOAC method 942. 05). Fat content of fecal samples were determined by acid ether extraction (AOAC method 2003.05). The method of Van Soest et al. (1991) with the addition of amylase and sodium sulfite was used to analyze NDF content. Calcium and phosphorus were analyzed using the dry-ashing procedure (AOAC methods 927. 02 and 965. 17, respectively).

Gross energy of forages, concentrates, orts and fecal samples were determined using Parr 1281bomb calorimeter (Parr Instrument Company, Moline, IL). Ether extract of feed ingredients and ort samples were determined by AOAC method 920. 39. Urinary nitrogen was determined using Kjeldahl method (AOAC method 984. 13).

4.2.7 Statistical Analysis

Rumen fermentation data including in-dwelling rumen pH measurements, total tract digestibility parameters, and nitrogen balance data were analyzed as a Latin Square Design using Mixed Model Procedure of SAS (Version 9.3; SAS Institute, Inc. Cary, N. C.) with heifer considered as a random effect and treatment and period as fixed effects. Rumen VFA proportion and concentration, ammonia, osmolality and spot pH data were analyzed as repeated measures with the fixed effect of time (day) and treatment x time (day) interaction included in the model. Denominator degrees of freedom were determined using the Kenward-Roger option which uses the Satterthwaite adjustment. Polynomial contrasts were used to determine the linear and quadratic effects of inclusion level of *B. napus* and *B. juncea* meal in the diet. Significance was declared at $P < 0.05$.

4.3 Results and Discussion

The metabolism trial utilized the same *B. napus* and *B. juncea* meals and vitamin-mineral supplements for the treatment and control groups as the feedlot trial (Trial 1). Barley silage used for metabolism trial had higher CP (13.1 vs. 12.3%), lower ADF (30.7 vs. 33.2%) and NDF (46.7 vs. 48.8%) than that used for trial 1 (Table 4.2). Similarly, barley grain used for metabolism trial had higher CP (12.4 vs. 11.4%) and lower ADF (7.9 vs. 8.2%) and NDF (18.2 vs. 18.6%) content than that used for the feedlot trial.

Higher protein content of barley silage and barley grain resulted in an increase in CP content of the control diet when compared to that of the feedlot finishing diet (13.1 ± 0.87 vs.12.1 ± 0.38%, Mean ± SD, % DM basis). Similarly the CP values of the treatment diets were also proportionately higher than those of the feedlot finishing trial. Ether extract, ADF, NDF,

Table 4.2. Composition of ingredients used in the metabolism trial

	Barley silage	Barley	Supplement		Canola meal[z]	
	(n = 5)	(n = 5)	Control	Treatment	*B. napus*	*B. juncea*
Chemical composition (% DM basis)[y]						
Crude protein	13.1 ± 0.42	12.4 ± 0.98	21.1	10.1	40.0	46.7
Ether extract	2.9 ± 0.11	1.9 ± 0.2	3.0	3.7	4.1	2.8
Acid detergent fiber	30.7 ± 0.55	7.9 ± 0.72	5.2	6.0	19.5	11.6
Neutral detergent fiber	46.7 ± 1.28	18.2 ± 1.48	11.9	14.7	25.5	17.4
Calcium	0.47 ± 0.14	0.05 ± 0.04	8.5	9.3	0.73	0.80
Phosphorus	0.42 ± 0.12	0.4 ± 0.05	0.41	0.51	1.15	1.19

[z]*B. = Brassica*

[y]Analyzed at Cumberland Valley Analytical Services, Inc., Maugansville, MD

calcium and phosphorus values of finishing diets were comparable between the two trials. As with the feedlot trial, substituting barley with *B. napus* meal at 10 and 20% inclusion resulted in a linear increase ($P < 0.05$) in CP, Ether extract, ADF, NDF, calcium and phosphorus levels in the total mixed rations, with *B. juncea* meal resulting in similar increase except for NDF concentration (Table 4.3). For example, CP content increased from 13.1% in the control diet to 15.3 and 18.1% respectively, in the 10 and 20% *B. napus* meal diets. Similarly, inclusion of *B. juncea* meal in the total mixed ration at 10 and 20% levels increased the CP content to 16 and 19.6%, respectively. Ether extract content increased from 2% in the control diet to 2.3 and 2.6% in *B. napus* and 2.2 and 2.3% in *B. juncea* meal diets, respectively. As expected, NDF and ADF values for *B. juncea* meal diets were lower than *B. napus* meal diets while CP values were numerically higher.

4.3.1 Rumen pH (In-dwelling and Spot)

Cattle fed *B. juncea* meal showed a trend ($P = 0.08$) for a quadratic response in mean rumen pH (Table 4.4). However, spot sample rumen pH measurements showed a linear increase in mean daily rumen pH with increase in inclusion of both *B. napus* ($P = 0.05$) and *B. juncea* meal ($P < 0.01$) in the diets. This variation in pH values between spot sampling and indwelling system could be attributed to the fact that for spot sampling, rumen fluid was collected from 4 different regions of rumen whereas the indwelling system measures rumen pH in the ventral ruminal sac. Since rumen pH varies in different regions of rumen (Duffield et al. 2004), extensive pH gradient exists within rumen (Aschenbach et al. 2011). The duration (min d^{-1}) and area (pH*min) under pH threshold 5.8 (mild acidosis) and 5.5 (moderate acidosis) and 5.2 (Severe acidosis) (Penner et al. 2007) were not significantly affected ($P > 0.05$) by the inclusion of either *B. napus* or *B. juncea* meal in the diet.

Table 4.3. Analysis of control and 10 and 20% *Brassica (B.) napus* and *B. juncea* meal diets used for the metabolism trial (n = 5)

	Treatment					*P*-value contrast[z]			
		B. napus		*B. juncea*		*B. napus*		*B. juncea*	
	Control	10%	20%	10%	20%	L	Q	L	Q
Diet analysis (% DM basis ± SE)[y]									
Crude protein	13.1 ± 0.87	15.3 ± 0.76	18.1 ± 0.67	16.0 ± 0.76	19.6 ± 0.67	< 0.01	0.47	< 0.01	0.49
Ether extract	2.0 ± 0.18	2.3 ± 0.15	2.6 ± 0.14	2.2 ± 0.15	2.3 ± 0.14	< 0.01	0.72	0.03	0.76
Acid detergent fiber	8.6 ± 0.61	9.9 ± 0.54	11.1 ± 0.46	9.1 ± 0.51	9.5 ± 0.46	< 0.01	0.74	0.02	0.87
Neutral detergent fiber	18.8 ± 1.25	19.9 ± 1.09	20.6 ± 0.94	19.0 ± 1.1	18.9 ± 0.95	0.02	0.81	0.84	0.81
Calcium	0.69 ± 0.03	0.79 ± 0.04	0.87 ± 0.02	0.80 ± 0.03	0.88 ± 0.02	< 0.01	0.37	< 0.01	0.18
Phosphorus	0.40 ± 0.04	0.49 ±0.04	0.57 ± 0.03	0.49 ± 0.04	0.57 ± 0.03	< 0.01	0.76	< 0.01	0.83
Gross energy (Mcal kg^{-1})	4.09 ± 0.09	4.13 ± 0.08	4.17 ± 0.07	4.13 ± 0.08	4.17 ± 0.07	0.14	0.93	0.15	0.98

[z]L = Linear; Q = Quadratic

[y]Values shown with standard error.

Table 4.4. Rumen pH measurements of cattle fed with *Brassica (B.) napus* and *B. juncea* meal at 10 and 20% inclusion (n = 5)

	Treatment						*P*-value contrast[z]			
		B. napus		*B. juncea*			*B. napus*		*B. juncea*	
	Control	10%	20%	10%	20%	SEM[y]	L	Q	L	Q
Mean Daily rumen pH										
In-dwelling pH	5.72	5.83	5.60	5.84	5.69	0.068	0.37	0.14	0.70	0.08
Spot sample pH[x]	5.49	5.68	5.66	5.66	5.72	0.102	0.05	0.17	< 0.01	0.50
Rumen pH parameter 5.8 or lower										
Total duration (min d^{-1})	876	765	983	764	855	72.5	0.48	0.21	0.82	0.23
pH area (pH*min)	301.6	245.1	443.8	243.5	371.3	62.84	0.24	0.21	0.48	0.28
Rumen pH parameter 5.5 or lower										
Total duration (min d^{-1})	466	358	660	333	562	98.7	0.29	0.19	0.52	0.16
pH area (pH*min)	98.9	79.5	190.7	76.7	156.9	39.72	0.22	0.30	0.39	0.38
Rumen pH parameter 5.2 or lower										
Total duration (min d^{-1})	127	105	317	113	250	75.9	0.19	0.34	0.33	0.50
pH area (pH*min)	16.2	15.9	51.2	19.6	39.0	13.39	0.15	0.40	0.33	0.70

[z]L = Linear; Q = Quadratic

[y]SEM=Pooled standard error of mean

[x]This variable was significant for time of collection (hour) ($P < 0.01$)

The lack of increase in rumen pH by the substitution of barley with canola meal was surprising. Feeding high grain diets as well as rapid fermentation of dietary carbohydrates result in production of organic acids in the rumen which readily dissociate to reduce rumen pH (Nagaraja and Titgemeyer 2007; Allen 1997; Aschenbach et al. 2011). Replacing a source of starch (barley) with a non-starch, high protein and high fiber meal reduces the proportion of starch in the total mixed ration and should reduce the rate of fermentation and acid production (Beauchemin and Penner, 2009). Starch content of barley ranges from 51 – 64% (Holtekjolen et al. 2006), of which 80 – 90% gets digested in the rumen (Nocek and Tamminga 1991; Khorasani et al. 2000). Starch content of *B. napus* meal used for this research was 1.6% and that of *B. juncea* meal was 2.6% (DM). Hence, substitution of barley with either of the canola meals was expected to reduce the rate and extent of drop in the rumen pH that is inherent to barley-based diets. Also, fermentation of protein results in release of ammonia. Haaland et al. (1982) reported that higher rumen ammonia concentration results in higher rumen pH and higher rumen buffering capacity. Since canola meal is a source of ruminally degradable protein, it should provide ammonia bases which could readily bind with protons, leading to an elevation in rumen pH (Wang and Fung 1996; Owens et al. 1998; Aschenbach et al. 2011). Eventhough ammonia levels in the rumen were higher for heifers fed canola meal diets relative to the control diet fed heifers in the present trial, no such beneficial effect of substitution of barley with canola meal was observed. The proportion of barley in the total mixed ration was 68 and 78%, for cattle supplemented with either variety of canola meal at 10 and 20% respectively. This level is still higher than the proposed limit of 35 – 40% diet DM of non-structural carbohydrate to prevent ruminal acidosis as proposed by Hoover and Miller (1995). Also, Koenig et al. (2004) reported a numerical decrease in mean rumen pH and an increase in time that pH was less than 5.8 for a diet

supplemented with canola meal at 7.2% (DM) relative to a barley-based control diet. Similar results were also reported by other researchers using high protein by-products (i.e. DDGS) as a substitution for barley in finishing diets (Beliveau and McKinnon 2009; Li et al. 2011; Walter et al. 2012). Beliveau and McKinnon (2009) concluded that low physically effective NDF (peNDF) content of the DDGS could be the reason for the inability to mitigate low rumen pH even when barley was replaced by a low starch-high protein supplement. Increase in the peNDF content of the diet increases the chewing time, and thereby salivary salivary secretion, which has an important role in buffering ruminal pH through the production of sodium bicarbonate (Owens 1998). Beauchemin et al. (2003) also reported that adequate physically effective NDF was necessary for normal ruminal function and salivary production. Even though particle size of barley or canola meal used for this trial was not measured, a review of literature indicates that only 14% of dry rolled barley passed through 1.18 mm sieve (Yang et al. 2013) whereas 74% of canola meal passed through a sieve of similar pore size (Safari et al. 2011). A reduction in particle size of the TMR supplemented with canola meal in the present trial could potentially eliminate the beneficial effect of lowering the proportion of starch in the diet on rumen pH.

Aldrich et al. (1993) reported that there was a significant reduction in rumen pH when cattle were fed high rumen available protein diets. These authors reported that the time lag of 6 – 10 h from feeding to the onset of minimum rumen pH and the associated rumen dilution and out flow eliminated the potential beneficial effects of rumen degraded protein sources on preventing a drop in rumen pH. Warner (1981) reported that an increased feed intake is associated with an increased rumen outflow of liquid and particulate matter. The rumen outflow of protein supplements greatly affects the extent of rumen degradation. In the present trial, cattle fed *B. napus* meal had a linear increase (P = 0.03) in DMI as inclusion level increased. Dry matter

intake while numerically higher for cattle fed *B. juncea* was not affected ($P > 0.1$) by inclusion level. The higher DMI by cattle fed the canola meal treatments, particularly *B. napus* meal could result in an increased rumen outflow resulting in escape of a larger proportion of canola meal from rumen degradation. This process could also contribute to inefficient buffering by the products of protein degradation in the rumen.

4.3.2 Rumen Fermentation (VFA, Osmolality and NH3-N)

Cattle fed both *B. napus* and *B. juncea* meal showed a linear increase ($P \leq 0.01$) in acetate concentration with increasing inclusion in the diet (Table 4.5). In contrast, there was a linear reduction ($P < 0.01$) in propionate concentration with increasing inclusion of both *B. napus* and *B. juncea* meals. Similar changes in molar concentrations of VFAs were also reported by other researchers using high protein by-products (i.e. DDGS) in feedlot heifers fed a finishing diet (Beliveau and McKinnon 2009; Walter et al. 2012). Substituting barley with both *B. napus* and *B. juncea* meal resulted in a linear increase ($P < 0.01$) in A:P ratio. Aldrich et al. (1993) and Koenig et al. (2003) reported that a diet high in rumen available nonstructural carbohydrates as in high grain feeding results in increased concentration of propionate and a lowered acetate to propionate (A:P) ratio. Canola meal derived from both *B. napus* and *B. juncea* contains higher ADF and NDF levels relative to barley. Substitution of barley with canola meal resulted in an increase in ADF and NDF content in both total mixed rations. Sutton et al. (2003) reported that a high forage diet results in increased acetate concentration. Similarly, Friggens et al. (1998) reported that feeds with a higher NDF content resulted in a higher proportion of acetate relative to propionate. Thus, the increasing inclusion of canola meal derived from both *B. napus* and *B. juncea* resulted in graded reduction in nonstructural carbohydrate and an increase in NDF

Table 4.5. Rumen fluid characteristics of cattle fed *Brassica (B.) napus* and *B. juncea* meals at inclusion levels of 10 and 20% in the diet (n = 5)

	Treatment						*P*-value contrast[z]			
		B. napus		*B. juncea*			*B. napus*		*B. juncea*	
	Control	10%	20%	10%	20%	SEM[y]	L	Q	L	Q
VFA *(mmol L⁻¹)*[x]										
Acetate	47.1	52.4	51.9	50.4	53.1	4.32	0.01	0.06	< 0.01	0.57
Propionate	46.7	39.6	36.5	40.4	38.6	4.29	< 0.01	0.35	< 0.01	0.17
Butyrate	12.0	9.1	13.7	10.6	9.7	2.18	0.13	< 0.01	0.06	0.98
Isobutyrate	0.6	0.7	0.8	0.7	0.7	0.04	< 0.01	0.30	< 0.01	0.04
Valerate	2.3	2.5	2.0	2.5	2.1	0.48	0.06	0.03	0.27	0.08
Isovalerate	1.9	1.8	2.5	1.1	1.3	0.63	0.03	0.22	0.02	0.03
Total VFA *(mmol L ⁻¹)*	110.5	106.0	107.3	105.7	105.5	5.85	0.48	0.47	0.35	0.63
A:P Ratio[w]	1.07	1.45	1.57	1.31	1.51	0.196	< 0.01	0.09	< 0.01	0.45
Osmolality *(mOsm L⁻¹)*	361.8	360.3	366.0	357.7	360.9	8.46	0.54	0.54	0.89	0.58
NH3-N *(mg dL ⁻¹)*	3.5	6.5	11.4	5.9	11.2	1.27	< 0.01	0.10	< 0.01	0.02

[z]L = Linear; Q = Quadratic

[y]SEM=Pooled standard error of mean

[x]P-value for time was significant (*P*=0.01) for all tested variables except isovalerate (*P* = 0.31); P-value for treatment*time was not significantly different for any variable

[w]A:P Ratio = Acetate(A, mmol):Propionate(P, mmol) ratio

content leading to an increase in acetate, a decrease in propionate and subsequently an increase in A:P ratio.

Cattle fed *B. napus* meal showed a quadratic response ($P < 0.01$) while those fed *B. juncea* meal tended to exhibit a linear decrease ($P = 0.06$) in butyrate concentration with increasing inclusion levels. Isobutyrate concentration linearly increased ($P < 0.01$) with *B. napus* and responded quadratically ($P = 0.04$) with *B. juncea* meal as the level of inclusion increased in the diet. Branched chain volatile fatty acids (BCVFA) such as isobutyrate and isovalerate are produced from the rumen degradation of true protein and also by microbial protein decomposition (Miura et al. 1980; Yang 2002). Most of the fiber-digesting bacteria utilize BCVFA as a source of carbon skeleton for the synthesis of branched chain amino acids (Allison et al. 1962). Cattle fed both *B. napus* and *B. juncea* meal showed a quadratic response in valerate concentration ($P = 0.03$ and 0.08 respectively) with increasing inclusion of canola meal in the diet. There was a linear increase in isovalerate concentration ($P = 0.03$) in cattle fed *B. napus* meal and a quadratic response ($P = 0.03$) in cattle fed *B. juncea* meal. There was no effect of inclusion level of either canola meal on total VFA concentration in the rumen. Total rumen VFA concentration averaged 107 ± 2.1 $mmol\ L^{-1}$ across all treatments.

Rumen osmolality averaged 361.3 ± 3 mOsmol L^{-1} across all treatments with no effect of treatment. This was well within the normal ruminal osmolality range of 200 – 500 mOsmol kg^{-1} as reported by Mackie and Therion 1984. Since VFA production contributes significantly to osmolality (Carter and Grovum 1990b) and as the total VFA was not influenced by treatment in the present trial, a lack of effect of treatment on osmolality was not unexpected.

There was a diurnal pattern for most of the rumen fermentation parameters. This time effect on rumen fermentation is well documented (Carter and Grovum 1990; Nagaraja and Titgemeyer 2007; Aschenbach et al. 2011). The effect of time on VFA, ammonia and osmolality post feeding is illustrated in Figures 2, 3 and 4 (Appendix). The time effect was significant ($P < 0.01$) for all the rumen fermentation parameters except for isovalerate ($P = 0.31$). The treatment x time interaction was not significant ($P > 0.10$) for any of the measured rumen fermentation parameters.

Rumen ammonia concentration of cattle fed *B. juncea* meal responded quadratically ($P = 0.02$) with inclusion level whereas there was a linear increase ($P < 0.01$) in cattle fed *B. napus* meal. Higher rumen ammonia concentration associated with canola meal diets is directly linked to the higher protein content and rumen degradability of canola meal. Protein content of 10 and 20% *B. napus* (15 and 18%) and *B. juncea* (16 and 20%, respectively) meal diets was higher than that of the control diet (13%) (DM). Rumen degradability of canola meal is high (Kendall et al. 1991) so an increasing concentration of canola meal in the diet is associated with an increased rumen degradation of protein and results in an increase in rumen ammonia concentration. Several studies using high protein by-products (i.e. DDGS) as a replacement for barley have shown a similar increase in ammonia concentration with increasing dietary inclusion (Beliveau and McKinnon 2009; Walter et al. 2010).

4.3.3 Digestibility

Increasing the level of *B. napus* but not *B. juncea* meal linearly increased DMI ($P = 0.03$; Table 4.6). This contrasts somewhat with the feedlot trial where cattle fed *B. napus* meal responded quadratically while cattle fed *B. juncea* meal had a linear increase in DMI. The difference in DMI between the feedlot and the present trial could be due to the fact that

Table 4.6. Effect of feeding *Brassica (B.) napus* and *B. juncea* meals at 10 and 20% inclusion in the finishing diets on apparent nutrient digestibility coefficients of heifers (n = 5)

	Treatment						*P*-value contrast[z]		
		B. napus		*B. juncea*			*B. napus*		*B. juncea*	
	Control	10%	20%	10%	20%	SEM[y]	L	Q	L	Q
Dry Matter Intake (kg d^{-1})	8.5	10.1	10.2	9.8	9.0	0.53	0.03	0.22	0.60	0.19
Dry Matter Intake (% BW)	1.59	1.85	1.87	1.79	1.66	0.085	0.21	0.52	0.77	0.41
Apparent nutrient digestibility coefficient (% DM basis)										
Dry matter	80.1	78.2	78.5	79.8	79.9	0.47	0.08	0.27	0.61	0.62
Organic matter	82.0	80.4	80.9	81.8	82.3	0.43	0.17	0.26	0.99	0.53
Crude protein	78.3	77.9	79.0	79.3	81.9	0.83	0.67	0.61	0.03	0.54
Ether extract	50.2	54.0	57.1	53.8	54.9	1.58	0.10	0.98	0.37	0.62
Neutral detergent fiber	43.5	42.6	45.8	44.8	48.3	1.81	0.43	0.41	0.11	0.64
Acid detergent fiber	35.4	34.1	36.8	37.7	43.7	2.03	0.70	0.52	0.03	0.53
Gross energy	79.7	77.9	78.7	79.6	80.3	0.46	0.29	0.23	0.80	0.60
Digestible energy *(Mcal kg^{-1})*	3.26	3.22	3.28	3.28	3.34	0.021	0.96	0.52	0.42	0.71
Digestible energy intake *(Mcal d^{-1})*	27.8	32.5	33.3	32.2	29.9	1.72	0.03	0.35	0.49	0.19

[z]L = Linear; Q = Quadratic

[y]SEM = Pooled standard error of mean

in the feedlot trial, steers were group fed and in the present trial, heifers were individually fed with no competition.

As the level of *B. napus* meal in the diet increased, there was a trend for a linear decrease (P = 0.08) in DM digestibility but not OM digestibility (P = 0.17). There was no such response for cattle fed *B. juncea* meal. Petit and Veira (1994) reported an increase in DM digestibility in steers fed silage, supplemented with canola meal at 15 versus 7.5% inclusion. Organic matter digestibility of both 20% *B. napus* (80.9%) and *B. juncea* (82.3%) meal diets was higher than that reported by Zinn (1993) who found a total tract OM digestibility of 78.6% in cattle fed a barley-based finishing diet supplemented with 20% canola meal. Gozho et al. (2009) reported a total tract OM digestibility of 76.3% in cattle fed a barley-based finishing diet supplemented with 8.8% canola meal which is lower than the OM digestibility of both the 10% *B. napus* and *B. juncea* meal diets in the present trial.

There was a linear increase in CP digestibility (P = 0.03) in cattle fed increasing levels of *B. juncea* meal. No effect was observed with inclusion of *B. napus* meal. Zinn (1993) reported a similar crude protein digestibility (79%) in Holstein steers fed a 20% (DM) canola meal supplemented feedlot diet that was similar to that of the present trial (79 ± 1.5%). A similar response in CP digestibility was also reported in studies using DDGS in finishing diets of feedlot heifers (Li et al. 2011; Walter et al. 2012). Increased total tract CP digestibility associated with *B. juncea* meal diets could be attributed to the high rumen degradable protein content and a higher protein digestibility of the meal (Bell 1993). Crude fat digestibility in cattle fed *B. napus* meal showed a tendency (P = 0.10) for a linear increase with increasing inclusion. It should be pointed out however that the fat content of all diets were relatively low (range 2.0 to 2.6%; DM).

There was no effect of inclusion ($P > 0.10$) of either canola meal variety on NDF digestibility. However, there was a numerical increase in NDF digestibility of the diet as the level of inclusion of *B. juncea* meal increased. Neutral detergent fiber digestibility of canola meal diets in the present study was similar to that reported by Koenig et al. (2004) who reported an NDF digestibility of 42.7% in heifers fed a finishing diet supplemented with 7.2% canola meal . Cattle fed *B. juncea*, but not *B. napus* meal showed a linear increase ($P = 0.03$) in ADF digestibility as the level of inclusion increased. Zinn (1993) reported an ADF digestibility of 39% in cattle fed a finishing diet supplemented with canola, a value within the range of this trial. Griswold et al. (1996) reported an increase in ADF digestibility associated with an increase in RDP *in vitro*. Increased ADF and NDF digestion in cattle supplemented with *B. juncea* meal could be due to improved rumen fermentation and increased supply of RDP which stimulates growth of cellulolytic bacteria.

There was no effect of inclusion level of either canola meal on GE digestibility ($P > 0.10$) or on digestible energy content (Mcal kg^{-1}) of the diet ($P > 0.10$). There was, however a linear increase ($P = 0.03$) in total daily digestible energy intake as the inclusion level of *B. napus* meal increased. This was due primarily to the fact that DMI increased linearly with increasing inclusion of *B. napus* meal.

Digestible energy content of the diet supplemented with both *B. napus* and *B. juncea* meal was similar to that of the control diet (Table 4.6). This finding indicates that the diet supplemented with either meal provided similar digestible energy to cattle relative to heifers fed the control diet. Since the composition of the control and the canola meal supplemented diets are quite different, it is evident that the energy content of starch with the substitution barley was compensated by the increased content and digestibility of protein, ether extract and fiber of

canola meal (Tables 4.3 and 4.6). A higher proportion of rumen degradable protein in canola meal (Kendall et al. 1991; McAllister et al. 1993) increases the availability of peptides, amino acids and ammonia in the rumen. As growth of cellulolytic bacteria is enhanced by the increased availability of ammonia and bacteria that ferment nonstructural carbohydrate could utilize peptides and amino acids as well, an improved digestibility of diets supplemented with *B. juncea* meal could be attributed to an increase in substrates of protein degradation. At the same time, excess dietary amino acids could contribute to the energy balance as the carbon skeleton of branched chain amino acids could be utilized for the production of branched chain volatile fatty acids. Systemic oxidative deamination; and transamination and subsequent oxidation of amino acids via the tricarboxylic acid cycle also could contribute to the energy status of the animal.

The DE results somewhat contrasts with the feedlot NEg results where NEg decreased with increasing inclusion of both meals. This lack of response in DE content of the diet could be explained in part by the fact that both NEg and DE are different measures of energy and calculated by different methods. Net energy for gain was calculated from NEm described by Zinn et al. (2002). Net energy for maintenance was calculated based on feedlot performance data including body weight, ADG and DMI according to Zinn and Shen (1998). Digestible energy calculation is based in the gross energy content of the diet and its percentage digestibility. As both methods predict different measures of energy value of a diet, the different approach could possibly result in different response to effect of inclusion of both canola varieties. At the same time, steers were fed *ad libitum* and housed in outdoor pens during the feedlot trial whereas heifers were housed in indoor pens and feed intake was restricted to 95% of voluntary intake during total collection in the present trial.

4.3.4 Nitrogen and Phosphorus Excretion

Total nitrogen intake increased linearly ($P < 0.01$) as the level of inclusion of both *B. napus* and *B. juncea* meal increased (Table 4.7). Similarly, total nitrogen excretion also linearly increased with inclusion level of both *B. napus* ($P < 0.01$) and *B. juncea* ($P = 0.01$). Increased nitrogen intake and excretion associated increasing canola meal intake is directly correlated to increased CP content of the canola meal diets. Beliveau and McKinnon (2009) and Walter et al. (2012) reported similar increases in total nitrogen intake and excretion with increasing levels of wheat and/or corn DDGS in the diets.

Fecal nitrogen excretion also increased linearly ($P < 0.01$) with increasing levels of *B. napus* meal, but only a trend (P = 0.09) was seen with *B. juncea* meal. Similar to fecal nitrogen excretion, urinary nitrogen excretion also increased linearly ($P < 0.01$) with increasing levels of inclusion of both *B. napus* and *B. juncea* meal. This is a result of increased rumen ammonia concentration due to the high level of protein in canola meal. Excess ammonia is absorbed and converted to urea in the liver and the majority is excreted in the urine. Increased urinary nitrogen excretion was also facilitated reflected in an increase in urine output (Table 4.7). Cattle fed *B. juncea* meal showed a trend ($P = 0.07$) for a linear decrease in percent of total nitrogen excreted in feces and an increase in percent of total nitrogen excreted in urine. This indicates the greater digestibility of *B. juncea* meal protein in the rumen and total tract resulting in lower fecal loss.

Apparent nitrogen retention values ranged from 47.9 g d^{-1} for the control diet fed cattle to 79 g d^{-1} for the 20% *B. napus* meal fed cattle. There was a trend ($P = 0.09$) for a linear increase in apparent nitrogen retention (g d^{-1}) with increasing inclusion of *B. napus* meal. Similar response in nitrogen retention was reported by Walter et al. (2012) where high protein DDGS was fed as an energy supplement to cattle. However, the nitrogen retention values (g d^{-1}) in the

Table 4.7. Effect of feeding *Brassica (B.) napus* and *B. juncea* meals at 10 and 20% inclusion in the finishing diets on nitrogen (N) balance in heifers (n = 5)

	Treatment						*P*-value contrast[z]			
		B. napus		*B. juncea*			*B. napus*		*B. juncea*	
Item (%)	Control	10%	20%	10%	20%	SEM[y]	L	Q	L	Q
Fecal output, *(kg DM d⁻¹)*	1.7	2.2	2.2	2.1	1.8	0.13	0.02	0.16	0.49	0.21
Urine output, *(kg d⁻¹)*	7.4	8.7	12.5	8.8	10.3	1.17	< 0.01	0.41	0.11	1.00
Nitrogen (g d⁻¹)										
Total N intake	178.4	245.7	291.3	248.6	276.2	17.25	< 0.01	0.59	< 0.01	0.41
Total N excreted	130.5	193.1	212.4	195.9	222.2	20.40	< 0.01	0.26	0.01	0.48
Feces	38.3	54.5	61.0	51.3	50.8	3.80	< 0.01	0.33	0.09	0.27
% of total excreted	29.6	28.7	29.4	26.5	23.9	2.05	0.93	0.78	0.07	0.92
Urine	92.2	138.6	151.4	144.5	171.3	18.20	< 0.01	0.32	< 0.01	0.58
% of total excreted	70.4	71.3	70.6	73.5	76.1	2.05	0.93	0.78	0.07	0.92
Apparent total N retained	47.9	52.7	79.0	52.7	54.0	12.87	0.09	0.48	0.72	0.91
N retained as a % of intake	26.3	21.9	26.8	21.2	20.5	5.37	0.94	0.39	0.43	0.73

[z]L = Linear; Q = Quadratic

[y]SEM=Pooled standard error of mean

present trial are somewhat higher than what one would expect for the rate of muscle tissue accretion observed. Spanghero and Kowalski (1997) indicated that about 20 g nitrogen is required for 1 kg lean tissue deposition. With the average nitrogen retention of 57 ± 12 g d^{-1} in the present trial, the animals should gain about 3 kg d^{-1} which is unrealistic. One reason for the higher retention could be due to nitrogen loss during drying of fecal samples for analysis, which could lead to underestimation of fecal nitrogen. Nitrogen loss from urine samples was minimized by the addition of HCl in order to keep the urine pH below 3 for all periods. Other reasons for variation in nitrogen retention include gaseous nitrogen loss and also formation of nitrogenous compounds like nitrite and nitrate which are not detected by Kjeldahl analysis of urine and fecal samples (Spanghero and Kowalski 1997).

4.4 Conclusion

Results of this study indicate that both *B. napus* and *B. juncea* meal could successfully replace barley at 20% inclusion (DM) in finishing diets without compromising rumen fermentation and nutrient digestibility. Digestible energy content (Mcal kg^{-1}) of the diet supplemented with both the canola meals was similar to that of the control diet. Increased proportion and digestibility of CP, EE and fiber content of canola meal supplemented diet compensated for the energy content of starch in the barley which it replaced. However, there was no increase in rumen pH by the substitution of a part of the barley with either canola meal. Lower particle size of canola meal and a possible higher passage rate in cattle fed canola meal supplemented diets could have resulted in inefficient rumen buffering by the supplemented canola meal. Concentration of acetate increased and propionate decreased with increasing inclusion of both canola meals. Concentration of isobutyrate, ammonia and A:P ratio increased linearly ($P < 0.01$) with increasing inclusion of both *B. napus* and *B. juncea* meal in the diet. Total nitrogen intake and

excretion increased linearly ($P < 0.01$) with increasing inclusion of both *B. napus* and *B. juncea* meal. It could be concluded that canola meal derived from both *B. napus* and *B. juncea* provides similar digestible energy when substituted for barley with minimum effect on rumen pH and fermentation.

5.0 GENERAL DISCUSSION

The feedlot and the metabolism trials conducted in this thesis were designed to i) evaluate the effect of graded levels of inclusion of canola meal derived from *B. juncea* and *B. napus* as a replacement for barley as an energy source with respect to performance of backgrounding and finishing steers and ii) evaluate the rumen fermentation and total tract digestion characteristics of canola meal derived from *B. juncea* and *B. napus* at two levels of inclusion in finishing diets of feedlot heifers. Trial 1 was intended to evaluate the performance of steers supplemented with *B. napus* or *B. juncea* at 15 and 30% inclusion (DM) during backgrounding and 10 and 20% (DM) during finishing as a replacement for barley and to determine the level of inclusion of *B. juncea* meal for optimum energy content in backgrounding and finishing diets. Cattle fed *B. juncea* meal at 30% inclusion during backgrounding had superior DMI, ADG and G:F relative to unsupplemented steers. The improved feed efficiency could be attributed to the disproportionate increase in DMI and ADG as well as to the linear increase in NEg content of the diet with increasing levels of *B. juncea* meal. However, cattle fed *B. napus* meal during backgrounding had a quadratic response in DMI and ADG with non-significant improvement in G:F. The lack of improvement in feed efficiency could be attributed in part to the fact that there was no substantial improvement in ADG with increased DMI and also that NEg content of the diet did not improve with increasing inclusion. It was concluded that the level of inclusion of *B. juncea* meal could be up to 30% (DM) whereas *B. napus* meal should be limited to 15% (DM) during backgrounding in order not to affect the performance of feedlot cattle.

Dry matter intake increased linearly for cattle fed *B. juncea* meal and responded quadratically for cattle fed *B. napus* meal as the level in the finishing diet increased. He et al. (2013) in a companion study also reported that 30% inclusion of both *B. napus* and *B. juncea* meals resulted in increased DMI and lower G:F relative to inclusion at 15% during finishing. Results of these researchers contrast with that of Trial 2 where DMI linearly increased for cattle fed *B. napus* meal but no such response was observed for cattle fed *B. juncea* meal. The variation in DMI could be attributed to the fact that in Trial 1 the steers were group fed whereas in Trial 2 the heifers were individually fed. Kidwell et al. (1954) and Albright (1993) reported that competition increases DMI. This was supported by the fact that the average DMI across treatments in Trial 1 was 11.2 ± 0.21 whereas that in Trial 2 was 9.5 ± 0.74.

Feed efficiency of cattle fed both *B. napus* and *B. juncea* meal during finishing linearly decreased as the level of inclusion increased. This response was attributed to a linear decrease in NEg content of the canola meal diets as the level of meal was increased. This result somewhat contrasts with the results of DE content of the treatment diets in Trial 2 where there was no effect of inclusion of either canola meal on DE content of the diet. This lack of response in DE content of the treatment diets in Trial 2 could be attributed in part to the fact that both DE and NEg are different measures of energy and calculated by different methods. Net energy for gain was calculated from NEm as described by Zinn et al. (2002). Net energy for maintenance was calculated based on the feedlot performance including body weight, ADG and DMI according to Zinn and Shen (1998). On the other hand, DE content of the diets in Trial 2 was calculated based on the gross energy content of the diet and its digestibility. The two different modes of energy calculation may have resulted in different estimates and response of energy for the level of canola meal supplementation in Trial 1 and 2. Another reason could be the fact that in Trial 1 the

steers were housed in outdoor pens with *ad libitum* feeding whereas in Trial 2 the heifers were fed 95% of voluntary intake and housed indoors. The results indicate that canola meal derived from *B. napus* and *B. juncea* is not suitable as a supplemental energy source replacing for barley grain in high energy finishing diets.

Carcass characteristics such as rib eye area, backfat thickness and yield grade were not affected by the level of inclusion of either *B. napus* or*B. juncea* meal. The quadratic response in hot carcass weight of cattle fed *B. napus* meal is a reflection of this same response in live weight of these cattle. This response reflects the fact that the DMI of cattle fed *B. napus* meal responded quadratically and that these cattle started finishing at a slightly higher weight due to higher ADG during backgrounding. The results of the present study indicate that substituting barley grain with canola meal has minimum effect on carcass traits.

The final objective of the experiment was to evaluate the rumen fermentation and total tract digestion characteristics of canola meal derived from *B. juncea* and *B. napus* at two levels of inclusion in finishing diets of feedlot heifers. The lack of increase in rumen pH by the supplementation of either canola meal was surprising. A reduction in starch content of the diet by substituting barley (starch source) with canola meal (protein source) was expected to reduce the duration and area under pH for all measured thresholds. A low peNDF content of the canola meal supplemented diets as well as a potential increase in rumen out flow rate could eliminate the beneficial effects of lowered starch content of the total mixed ration. Further research in the area of feeding behavior, peNDF content of canola meal, and the rumen outflow rate with supplementation of canola meal could potentially explain the failure of canola meal to result in a higher ruminal pH.

Even though mean rumen pH remained below 6 across all treatments for most of the day (Figure 1; Appendix) the DMI or nutrient digestibility was not adversely affected. Ruminants are well equipped to adapt to varying rumen conditions. Russell (1998) in an in vitro study using rumen fluid inoculum found that the rumen bacteria from cows fed 90% concentrate produced as much VFA at pH 5.2 as at pH 6.5 but, the rumen bacteria from cows that fed an all forage diet were significantly inhibited at pH < 5.5. This clearly indicates that some of the rumen starch fermenting bacteria could be successfully adapted to lower rumen pH. Increased ADF and a numerical increase in NDF digestibility by cattle fed *B. juncea* meal indicate that fiber digestibility was not adversely affected by low rumen pH.

With increasing inclusion of both *B. napus* and *B. juncea* meal, molar concentration of acetate was increased and propionate decreased and as a result, the acetate: propionate ratio was increased. Isobutyrate concentration linearly increased with increasing inclusion of both *B. napus* and *B. juncea* meal. Similarly, isovalerate concentration linearly increased with increasing inclusion of *B. napus* meal. Increased molar concentrations of branched chain volatile fatty acids like isobutyrate and isovalerate are indicative of microbial degradation of protein in the rumen. Allison et al. (1962) found that either isobutyrate or isovalerate was essential for the growth of *Ruminococcus flavefaciens*, a cellulolytic rumen bacterium. It could be inferred that increased branched chain volatile fatty acids in the rumen could possibly enhance the growth of certain fibrolytic bacteria in the rumen which is reflected by the improved fiber digestibility by the cattle fed *B. juncea* meal diets. Since the VFA concentration was not significantly different among the treatments, the rumen fluid osmolality was not different and averaged 361.3 ± 3 mOsmol L^{-1} across all treatments.

Crude protein and ADF digestibility of cattle fed *B. juncea* meal linearly increased with increasing inclusion. Since the hull portion of *B. juncea* is thin and translucent, the fiber content of *B. juncea* meal is much less, and is more digestible than that of canola meal derived from *B. napus*. With increasing inclusion of both *B. napus* and *B. juncea* meal in the diet, total nitrogen intake and excretion increased. Linear increase in urinary nitrogen excretion with increasing inclusion of both *B. napus* and *B. juncea* meal indicate that a major portion of excess rumen ammonia was excreted as urea. The trend for a linear increase in percent of urinary nitrogen excretion and a decrease in fecal nitrogen excretion by cattle fed *B. juncea* meal indicate that *B. juncea* meal is more digestible in the total tract relative to *B. napus* meal. As a result, the digestible energy content (Mcal kg^{-1}) of *B. juncea* meal showed a numerical increase with increasing inclusion. On the other hand, the dry matter digestibility of canola meal derived from *B. napus* meal linearly decreased, indicating lower digestibility of nutrients in the meal. This was reflected in the numerical decrease in digestible energy content (Mcal kg^{-1}) of 10% *B. napus* meal. The increasing DMI of cattle fed *B. napus* meal could thus be justified as the heifers attempted to meet their energy requirement through increased feed intake.

Based on the results of the present research, it could be concluded that canola meal derived from *B. napus* and *B. juncea* could substitute barley up to 15 and 30% (DM) inclusion respectively in backgrounding rations as an energy source provided the relative economics of the two canola meal sources are comparable to barley. However during finishing no performance benefit was observed with replacing barley with either canola meal. Inclusion of both *B. juncea* and *B. napus* meal at 10 and 20% (DM) in finishing rations resulted in less efficient gains as the NEg content of the ration decreased with increasing inclusion. There was no effect of inclusion

of either canola meal on mitigation of low rumen pH associated with feeding of high grain rations.

Further research is needed in the area of omasal sampling during metabolism trial in order to measure the rumen out flow rate and ruminal and post ruminal nutrient digestion in order to better understand the reason for the lack of response in mitigation of low rumen pH by the substitution of barley with canola meal as observed in the present research.

6.0 GENERAL CONCLUSION

The hypothesis of the research in the present thesis was that graded levels of inclusion of canola meal derived from *B. juncea* as a replacement for barley will result in superior performance and more efficient gains of feedlot cattle. The results indicated that *B. juncea* meal up to 30% inclusion resulted in superior performance of cattle during backgrounding whereas finishing cattle fed up to 20% inclusion performed poorly (higher DMI and lower feed:gain) due to lower NEm and NEg content of the diet. Cattle fed canola meal derived from *B. napus* meal up to 30% inclusion during backgrounding had no significant improvement in feed efficiency and finishing cattle fed up to 20% inclusion had a linear decrease in NEm and NEg content of the diet. In order not to compromise feed efficiency, the level of inclusion of *B. napus* meal should be limited to 15% in backgrounding diets whereas no performance benefit was observed by either meal types during finishing. There was no beneficial effect of inclusion of canola meal on mitigation of low rumen pH associated with high grain feeding. However, there was increased CP and ADF digestibility with increasing inclusion of *B. juncea* meal. Total nitrogen intake and excretion increased with increasing inclusion of both *B. napus* and *B. juncea* meal. Further research is needed to measure the rumen out flow and ruminal and post ruminal digestion of canola meal in order to better understand the lack of beneficial effect in mitigation of ruminal acidosis by substituting barley with canola meal as observed in the present research.

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Appendix:

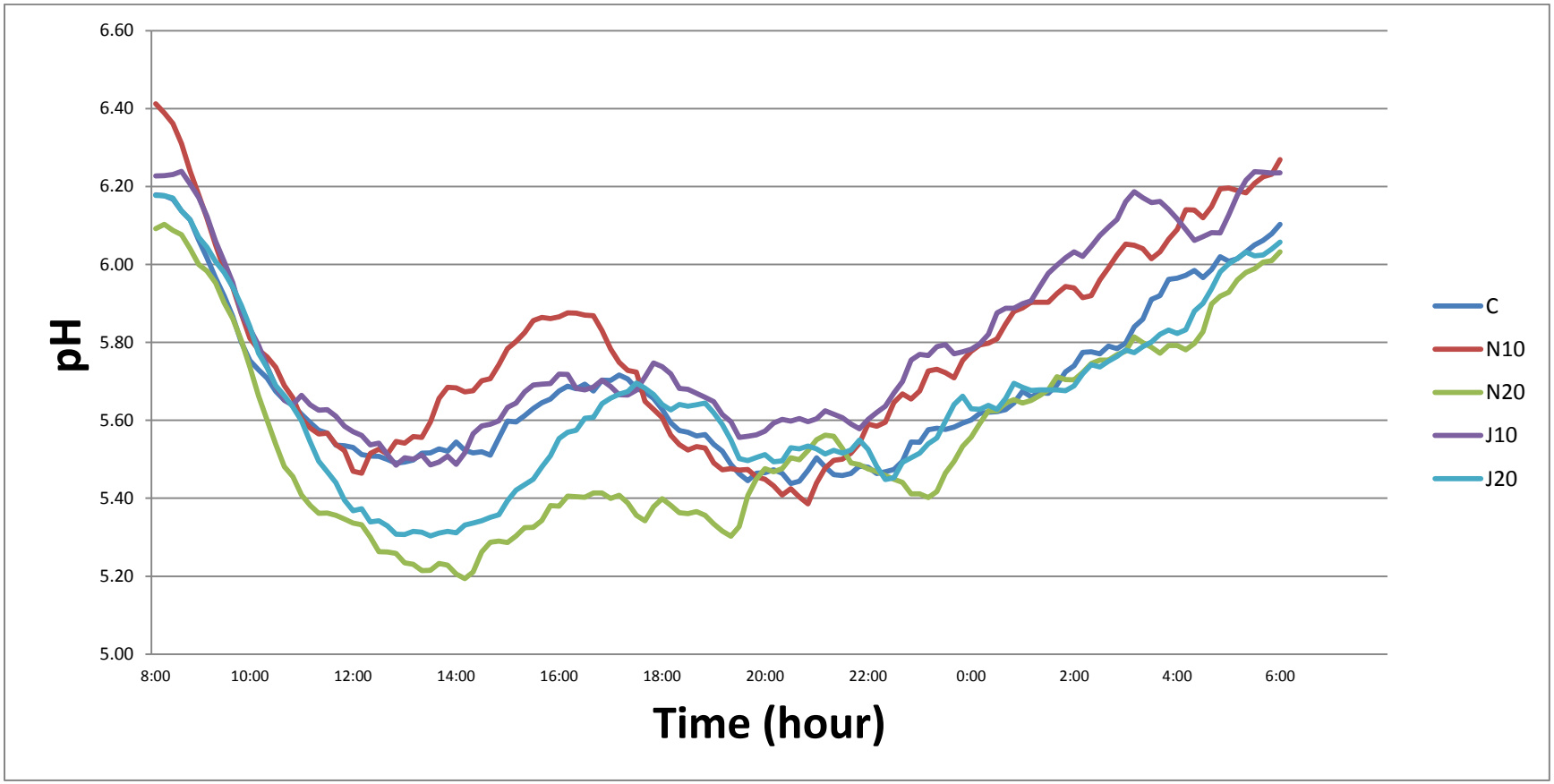

Figure 1. Effect of feeding canola meal derived from *B. napus* and *B. juncea* at 10 and 20% inclusion in the finishing diets of feedlot heifers on rumen pH using in-dwelling pH probes, averaged over 24 h feeding period.

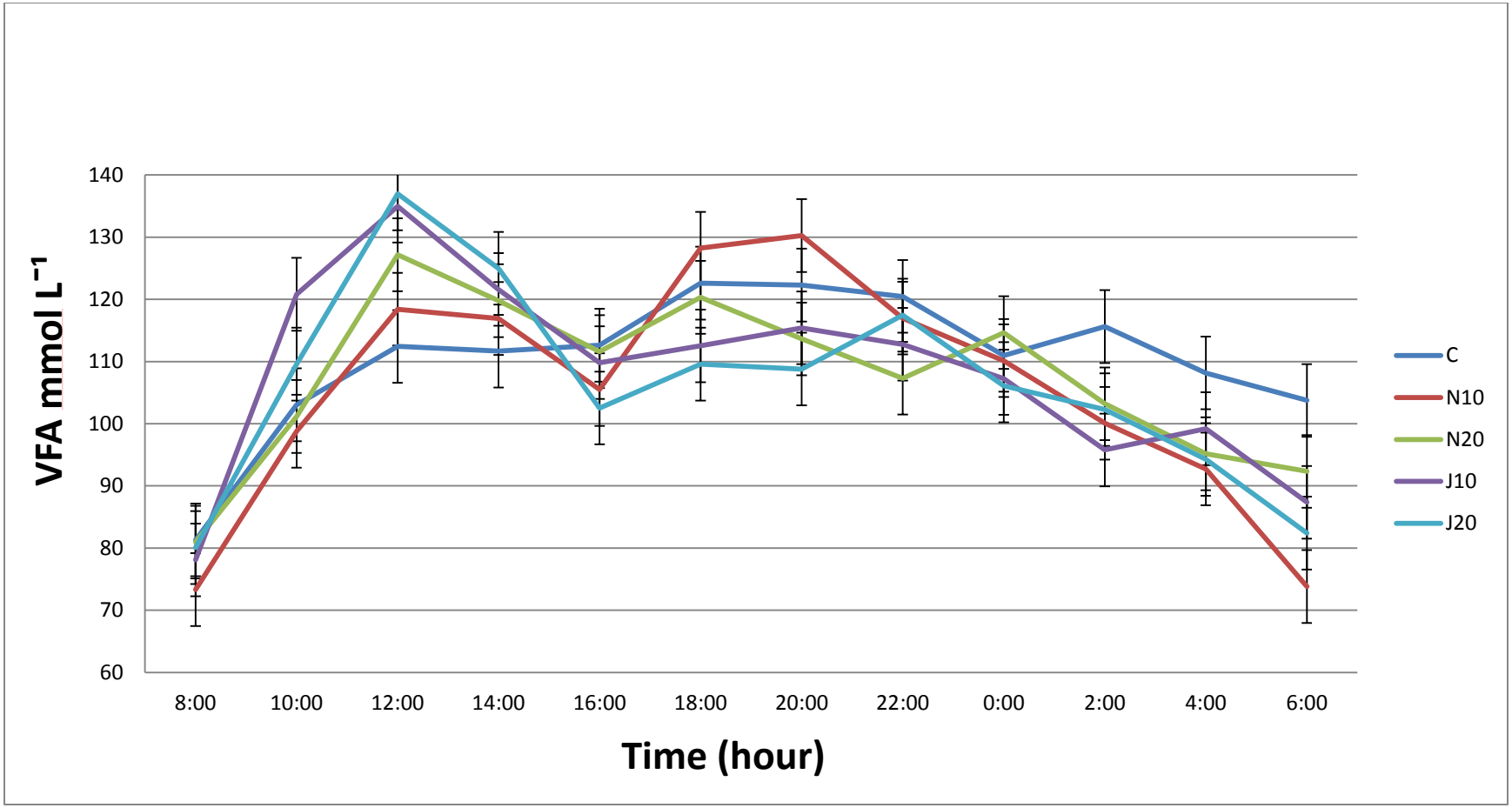

Figure 2. Effect of feeding canola meal derived from *B. napus* and *B. juncea* at 10 and 20% inclusion in the finishing diets of feedlot heifers on total volatile fatty acid concentration (mmol/L) over 24 h feed.

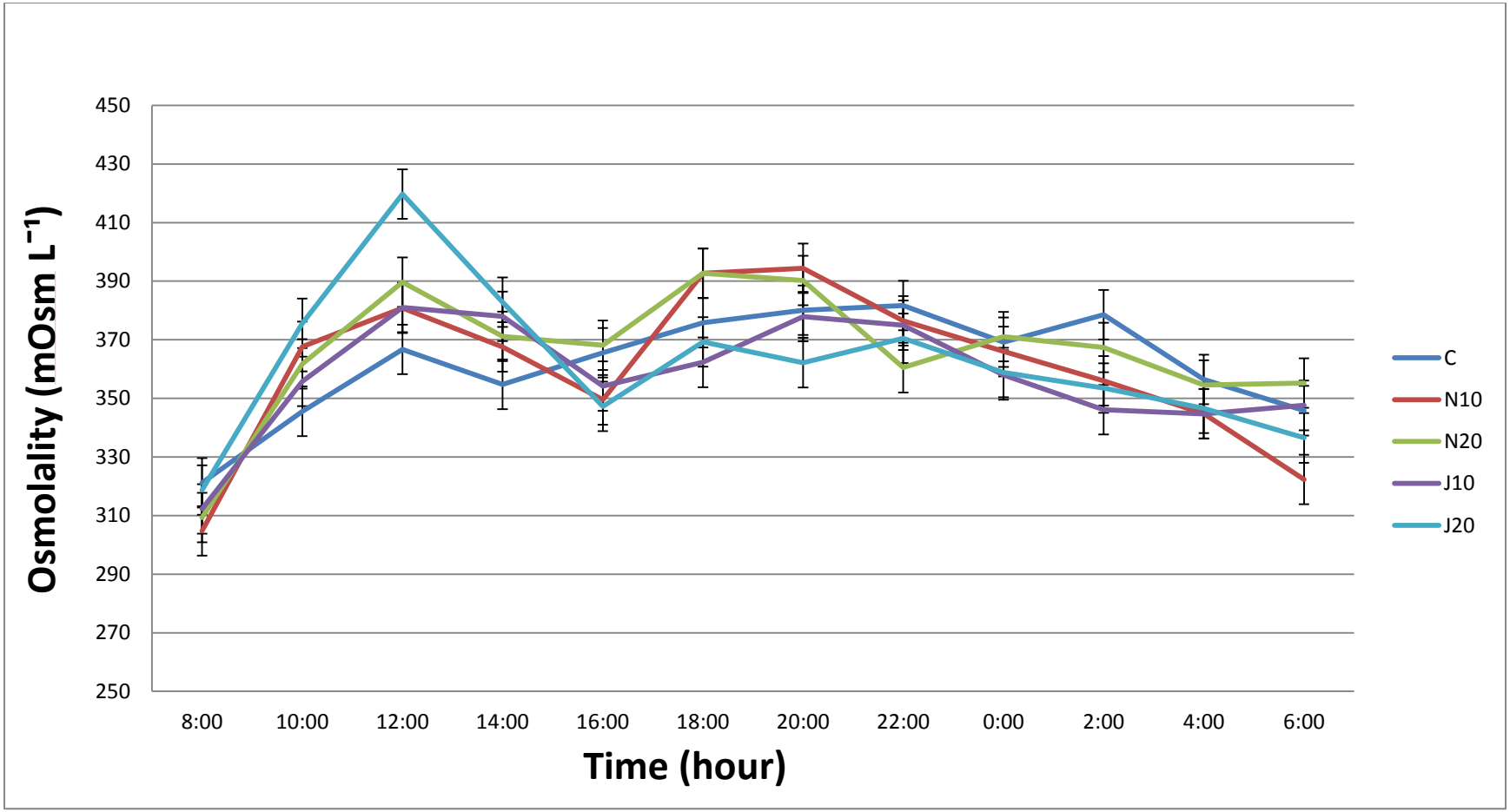

Figure 3. Effect of feeding canola meal derived from *B. napus* and *B. juncea* at 10 and 20% inclusion in the finishing diets of feedlot heifers on rumen osmolality over 24 h feeding period.

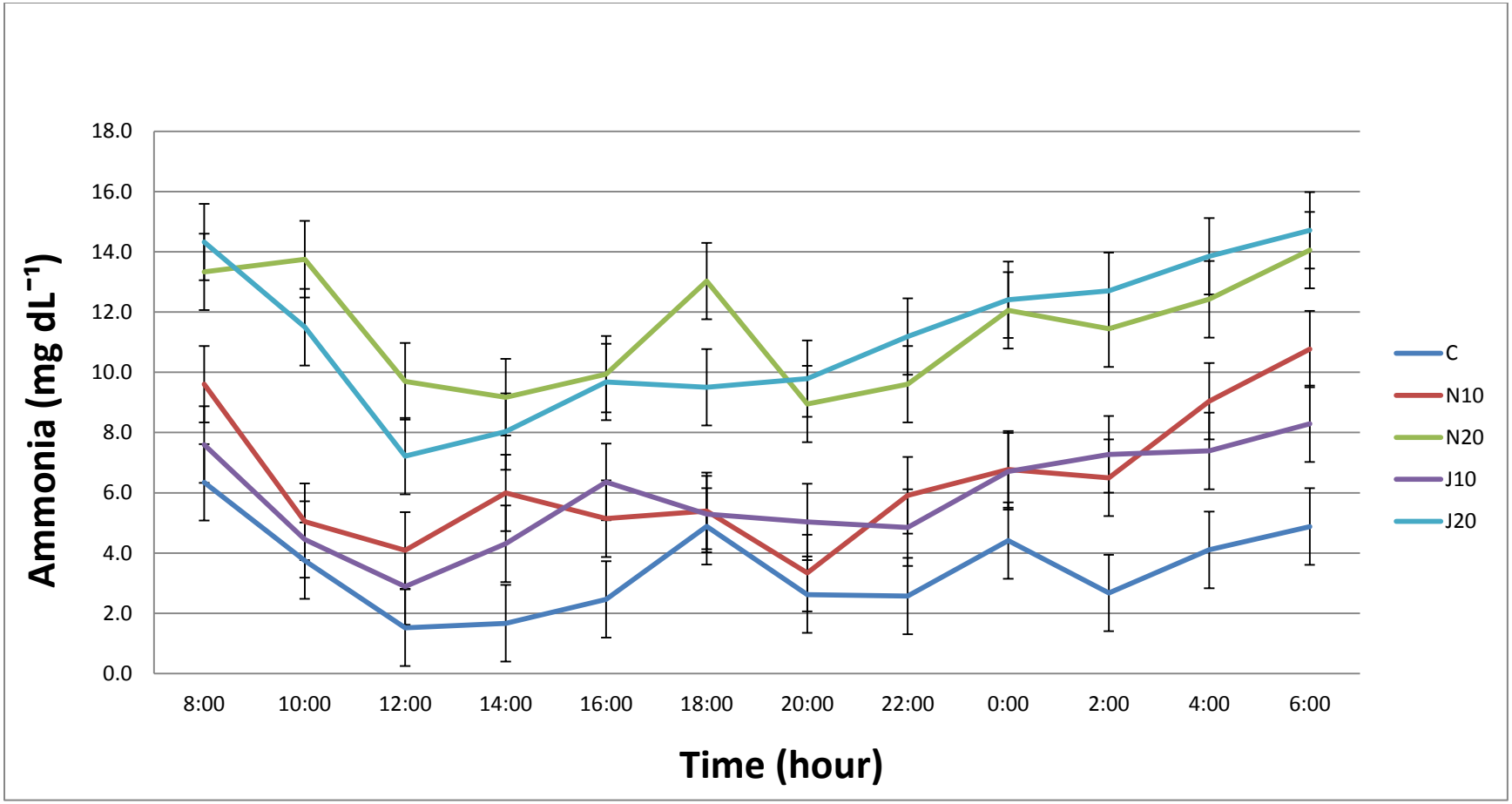

Figure 4. Effect of feeding canola meal derived from *B. napus* and *B. juncea* at 10 and 20% inclusion in the finishing diets of feedlot heifers on rumen ammonia nitrogen levels over 24 h feeding period.