Nutritional Evaluation and Processing of Canola Screenings for Ruminants

Final Report

Prepared for Saskatchewan Canola Development Commission

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Executive Summary:

The development of strong global markets and increasing market share has resulted in Canadian agriculture expanding its canola production and processing two fold on the prairies in the past decade. As a result, Canada's total crush has increased from an average of 1.3 million tonnes in the late 1980s to 2.6 million tonnes in the mid 1990s. These increases in grain production create opportunities for use of canola by-products, such as canola screenings, for the livestock industry. Canola screenings are the result of cleaning canola grain prior to crushing for oil extraction, to remove dockage and improve quality and consistency. Canola screenings produced from the crushing industry consist primarily of chaff, cereal grains and a variety of small and damaged canola and weed seeds.

Feed costs have a large impact on profitability of a commercial beef operation. The use of low cost by-product feeds can reduce cash input costs and reduce some of the risk in feeding management. Parallel to this, during periods of feed shortages, the cost of acquiring protein and energy feeds can rise substantially adding increased risk and cost of production. Use of by-product feeds to replace common commodities such as barley grain and silage can have a large impact on cost of production. However, studies investigating the use of by-products from the grain cleaning industry have been, for the most part, limited or shown the products to vary considerably in quality and consistency. As a result, products such as canola screenings have not been extensively used in backgrounding and feedlot rations due to minimal information on their energy, protein and fiber profiles and consistency.

The objectives of this study were to:

1) develop methodology and investigate the physical and chemical composition of canola screenings from western Canadian crushing plants.
2) study voluntary intake and nutrient digestibility of growing steers fed unprocessed and processed canola screenings and the effects of the fat content of canola screenings on these parameters.

3) determine the effects of feeding canola screenings in combination with barley grain on the rumen environment (ph, VFA and ammonia N levels) and on performance and carcass characteristics of feedlot steers.

4) Determine the effects of supplemental calcium on voluntary intake and nutrient digestibility of canola screenings containing greater than 12% fat.

In Trial one, canola dockage was collected and analyzed to establish a data base on canola dockage, the parent material from which canola screenings are generated. The variation in physical and chemical composition of dockage over the course of one year between and within different geographical locations was determined. The results of the work showed that canola dockage averaged 48% fines, 27% large particles and 25% aspirations. The coarse fraction (aspirations and large particles) of canola dockage contained lower levels of protein and ether extract and similar levels of fiber as canola fines indicating that a higher level of canola fines is desirable from the standpoint of the protein and energy content of the canola screening pellets.

The results from Trial 1 also show that both season of year and plant of origin will influence the chemical composition of canola dockage. Plant effects appear to be greater and likely reflect growing conditions specific to geographical location of each crushing plant. Although this study is not able to define local growing conditions or look at year effects, it is apparent that while season and plant of origin will influence quality, the magnitude of their effects are minimal. The most significant observation from this trial was that the nutrient content of canola screenings is primarily influenced by the inclusion level of canola fines which in turn appears to be related to the cleaning method employed by an individual crushing plant.

In trial 2, consumption and utilization of unprocessed canola screenings was similar to that of chopped alfalfa-brome hay / barley diets. Grinding and pelleting of canola screenings depressed dry matter intake but improved apparent digestibility of dry matter, crude protein and fatty acids. It is unclear whether improved nutrient utilization was a result of physical disruption of the seed coat of canola seeds in canola screenings or

due to the observed reduction in dry matter intake. Feeding dietary fat up to 10% (100 g kg^{-1} of dry matter) processed canola screenings did not result in the commonly negative associative effects on ruminal digestion and feed intake typically seen with this level of fat supplementation. Further research is required to elucidate the mechanism which allows a higher level of dietary fat to be fed to ruminants, and to determine the true impact of dietary fat inclusion level on microbial fermentation.

In trial 3, addition of barley grain to diets based on canola screenings resulted in shifts in ruminal fermentation towards lower ruminal pH, higher overall levels of VFA and lower acetate:propionate ratios. The current findings indicate that canola screenings used as a fiber source in finishing diets, while superior to barley grain, were marginal in providing a stable ruminal environment to buffer against fluctuations in rumen pH. The incidence of bloat increased, during the first 43 d of the feeding trial, when canola screenings exceeded 50% of the diet. Improvements in daily gain and feed efficiency occurred as barley replaced canola screenings suggesting that although canola screenings were readily fermented, barley grain was more digestible and yielded more fermentable energy than canola screenings. Nonetheless, cattle performed in a cost efficient manner with acceptable gains when fed 25 or 50% (250 or 500 g kg^{-1}) canola screenings in the diet, indicating that canola screenings may serve as a viable feed ingredient in high grain rations.

The last trial undertaken examined the potential of adding calcium to canola screening based diets in an effort to minimize the negative effects of fat on rumen fermentation and dry matter intake. The results showed that increasing the level of added calcium to high fat canola screening diets did not improve dry matter intake. Digestibility of acid detergent fiber and ether extract were not significantly affected by increasing the dietary calcium level.

Dry matter and organic matter digestibility showed a quadratic decrease with increasing dietary calcium level. Crude protein digestibility decreased in a cubic fashion as dietary calcium level increased. Energy digestibility and digestible energy content (Mcal/kg dry matter) showed a linear decrease with increasing calcium level in the diet. Similarly, neutral detergent fiber also showed a linear ($P<0.05$) decrease with increasing dietary calcium level. Based on these results, one would not consider the idea of using

calcium supplements to improve rumen function and nutrient digestibility of canola screening based diets. The results in fact show that supplemental calcium actually resulted in a negative effect on digestibility, possibly due to excess calcium levels in the rumen fluid.

Recommendations for feeding cattle that arise from this work include:

- Canola screenings are a viable alternative to conventional energy and protein sources for feeding cattle.
- Canola screenings are a byproduct feed that is characterized by high protein, fat and fiber levels.
- The nutritive value of canola screenings is directly related to the content of canola fines.
- Processing of canola screenings is required to achieve optimal digestion and can be accomplished by grinding and/or pelleting.
- Based on the results of this work, nutritionists and livestock producers should ensure that dietary fat levels do not exceed 10% when canola screenings are the primary source of supplemental fat.
- Supplemental calcium will not improve intake or digestibility problems when fat levels in excess of 10% are fed.
- Care should be paid to potential problems with bloat from high inclusion levels of canola screenings (i.e. 75 or 100 % of dry matter)
- The use of an ionophore is recommended when feeding canola screening based rations.
- As such this feed product is an excellent source of digestible energy and protein for backgrounding programs.
- In finishing diets the optimal level of inclusion was found to be 25% of the diet, however the results showed that they could be fed at levels up to 50% of the dry matter in finishing rations without adversely influencing cost of gain or performance.
- Actual inclusion rates in the diet will vary with the relative pricing of canola screenings to other energy and protein sources available to livestock producers

Introduction:

The production of canola seed in western Canada has increased substantially in the past 10 years. As a result, seed cleaning and processing has also increased producing larger quantities of canola by-products. The cattle feeding industry is driven by competitive production costs and feed efficiencies. The cost of feed is the single largest cost that a producer can control in beef production. Opportunities to decrease the cost of gain exist by feeding low cost feed commodities and improving feed efficiency.

Canola screenings are a by-product produced by the canola seed processing industry. Their composition consists of chaff, dust and cereal grains along with small and damaged canola and weed seeds. Limited studies on this by-product have estimated canola screenings to contain on average 19.6% crude protein, 22.5% fat and 28% acid detergent fiber. This profile becomes appealing when protein is the single most expensive nutrient unit for feedlot diets in western Canada.

Use of canola screenings in large feeding operations has been minimal. Reasons include limited information on nutritional profile, a perception that canola screening quality is variable making it difficult to feed cattle for time destined markets and that nutrients are of limited use because of the level of weed seeds. Few feeding experiments have been completed with canola screenings (Tait et al. 1986). Results have suggested that the feeding value of canola screenings were similar to mixed feed oats but high levels of fat restricted their usage due to possible negative adverse effects on palatability and nutrient digestion.

The ruminant animal has evolved with the ability to ingest and ferment large quantities of forages by way of a dynamic rumen microbial ecosystem. The rumen microflora digest and ferment fiber and protein. This process enables the host to utilize end products of fermentation for synthesis of protein, glucose and body fat. Although this system can capture energy and amino acids from most feedstuffs, fat or lipids are one source that is of limited use to rumen microflora. Supplemental fat has been shown to depress fiber digestion in the rumen and alter fermentation (Palmquist and Jenkins 1980). Numerous research experiments have attempted to identify possible causes and methods to minimize these disturbances. Scientists have summarized

these adverse effects as a combination of physical coating of fiber with fat, toxic effects of fat for microbial cells, reduction of cation availability in the rumen and defauntation of protozoa. As a result various products have been developed to minimize these interactions in the rumen. A generalized list would include calcium soaps of fat, extrusion of oilseeds, dried fats, encapsulation of fat in protein and hydrogenation. The most effective method of feeding higher levels of fat is via raw oilseeds which still contains the fat in the cellular structure of the seed.

Canola screenings can contain up to 10% canola and 17% weed seeds while canola fines have been reported to contain up to 66% canola seed (Darroch et al. 1990). Information on the use of canola screenings as a high fat feed is presently limited. Methods of processing to enhance the feeding value of whole seeds contained within canola screenings while still providing protection to the rumen microflora from added fat is also limited. Secondly, canola screenings contain high levels of protein and could serve as a protein/energy source for growing ruminants at a lower cost than traditional sources of protein and energy.

The objectives of this study were to :

1) develop methodology and investigate the physical and chemical composition of canola screenings from western Canadian crushing plants.
2) study voluntary intake and nutrient digestibility of growing steers fed unprocessed and processed canola screenings and the effects of the fat content of canola screenings on these parameters.
3) determine the effects of feeding canola screenings in combination with barley grain on the rumen environment on performance and carcass characteristics of feedlot steers.
4) Investigate, develop and evaluate processing technology that will result in a value-added feed product based on canola screenings for ruminant diets. Specifically, it is our intent to develop a high fat, high protein pellet suitable for feeding growing or lactating cattle.

Methodology

In order to achieve these objectives, four trials were under taken. These included:

Trial 1:

1. Nutrient and Chemical Makeup of Western Canadian Canola Screenings

Objectives:

1) to develop methodology that would allow for the physical separation and partitioning of canola dockage based on particle characteristics.
2) to determine the physical and chemical composition of canola dockage derived from three canola crushing plants over a twelve month period.
3) to utilize the chemical and physical composition parameters of canola dockage to estimate chemical composition of canola screenings derived from canola crushing plants.

Trial 2:

1. Effects of Pelleting on Nutrient Utilization of Canola Screenings

Objectives:

1) To determine the voluntary intake and nutrient digestibility of unprocessed and processed (ground and pelleted) canola screenings and to compare nutrient utilization of the canola screening products to that from processed (ground & pelleted) and unprocessed (chopped) alfalfa hay / barley grain.

2. Effects of Dietary Fat Level on Nutrient Utilization of Canola Screenings

Objectives:

1) To determine the effects of increasing levels of fat (7.1; 10.8; 13.9 & 17.6 % ether extract) in canola screenings diets on voluntary intake and nutrient digestibility/utilization of growing beef steers.

Trial 3:

1. The Effects of Canola Screening Inclusion Level on Rumen Fermentation Characteristics and performance and carcass characteristics of feedlot cattle.

Objectives:

1) To determine the effects of feeding canola screenings in combination with different levels of barley grain on:

    1) voluntary feed intake and rumen adaptation;
    2) nutrient utilization;
    3) rumen digestive parameters (pH, volatile fatty acid levels, osmolality, ammonia N); of growing/finishing cattle.

Trial 4:

1. Nutrient Value of High Fat Canola Screening Pellets with Increasing Levels of Added Calcium

Objectives:

1) To study the effects of feeding increasing levels of added calcium from ground limestone (0, 1, 1.5 and 2% added calcium)in pelleted high fat canola screenings on voluntary intake and nutrient digestibility of cattle.

The results of these four trials are presented separately in the following chapters. The executive summary attempts to draw the results together and to present recommendations to livestock producers who wish to incorporate canola screenings into their feeding operations.

Trial 1

Physical and Chemical Composition of Canola Dockage and Its Relationship to Canola Screenings

INTRODUCTION

Recent increased export demands for Canadian canola seed and oil has resulted in canola production in Canada nearly doubling in capacity in the last decade. As a result, annual tonnage of canola screenings, a by-product removed during the cleaning process, has also increased. Canola screenings originate from routine seed cleaning to remove unwanted dockage and improve seed quality and consistency. Dockage composition of canola has been shown to vary and consists primarily of off-grade canola seed, chaff, dust and volunteer cereal grains (Durnin 1980). The dockage content of canola is determined at the time it is graded for quality through standards established by the Canadian Grain Commission.

As the tonnage of canola screenings increases in western Canada, its use as a low cost feed commodity for the beef industry has become more inviting. However, recent research suggests that the feeding value of canola screenings may be limited due to reported inconsistencies in their composition (Tait et al. 1986). Beames et al. (1986) reports canola screenings to contain large variations in chaff, dust, cereal grains, canola and small weed seed content based on the origin of the product. These results are similar to those of other researchers who also indicate canola screenings to vary in their composition (Darroch et al. 1990; Keith and Bell 1983; Bell and Shires 1980). Darroch et al. (1990) suggests that variations in the composition of canola screenings can arise from differences in the type of cultivar grown, local growing conditions, harvesting practices and from differences in the type and operation of seed cleaning equipment.

Research investigating the extent of variation in the physical composition of canola screenings is limited (Beames et al. 1986). Additional information examining the physical make-up of canola screenings through the study of canola dockage may provide necessary information required to evaluate their feeding value for livestock. Similarly, no information exists on identifying the effect of canola screenings source and season on canola screenings

quality. Therefore, the objectives of this research were to develop methodology that would allow for the physical separation and partitioning of canola dockage based on particle characteristics, to determine the physical and chemical composition of canola dockage derived from three canola crushing plants over a twelve month period and to utilize the chemical and physical composition parameters of canola dockage to estimate chemical composition of canola screenings derived from canola crushing plants.

Materials and Methods

Development and Manufacture of Aspirator and Sieve Analysis System

Aspirator

The air classification system was designed and constructed in cooperation with the department of Agriculture and Bio-Resource Engineering at the University of Saskatchewan to characterize canola dockage and canola screenings fractions utilizing principles currently in place in canola crushing plants. A diagram of the air-aspirator is shown in Figure 1. The air aspirator was constructed with a 125 mm clear cast acrylic tube powered by a ¼ hp industrial squirrel cage blower fan (max. capacity: 5.238 m^3 min^{-1}). A 15 AMP Powerstat® variable auto-transformer was installed to regulate air flow rates by regulating the fan motor speed. This method was incorporated to ensure even air distribution within the column. Air velocity measurement was facilitated by a vanEE® (Saskatoon, SK) 125 mm flow measuring station equipped with a cross-sectional pitot tube (part No. 1605109) and an Omega manometer (model HHP-100A). Plastic tubes (210 mm long x 6.3 mm I.D. and 0.15 mm wall thickness) were installed equally between the blower fan and flow measuring station to ensure even air distribution. Air flow distribution and calibration of the air flow measuring station was completed using a velocity anamometer. Above the flow measuring station, the acrylic tube was split and a 152 mm air tight removable section manufactured. To this section or 'cup', a handle was manufactured to aid in its removal along with upper and lower matching face plates to maintain an air-tight seal. To the lower face plate, a 80 mesh screen was installed to serve as a base for the cup and hold samples in the air column. When the cup and sample is returned to the air column, an air stream is then allowed to pass freely through the screen suspending light weight particles based on the air velocity produced, allowing for varying degrees of particle

separation. As shown in Figure 1, an adjacent acrylic column of the same diameter was installed parallel to the suspension column and connected by a 180° elbow. Attached to this column was a light weight cotton bag fitted with a zipper. The bag allows all aspirated material to be reclaimed. Once a test run is completed, heavy particles remain in the cup while light particles are captured by the cotton bag. All fractions are then allowed to be reclaimed for weighing and classification.

Sieve system

A mechanical sieving method was designed to remove canola fines from the large particles, which remained in the cup of the air aspirator. The design of this method was undertaken by utilizing a range of round hole hand sieves (No. 5, 5.5, 6, 6.5, 7, 7.5) as recommended for canola seed grading in the 1995 Official Grain Grading Guide (Canadian Grain Commission). This method involved testing each sieve individually to examine its effectiveness to maximize the removal of canola fines materials while minimizing the loss of large particles. The examination consisted of weighing and visually inspecting each sample for purity.

Sample Collection

Canola Dockage

Graded canola dockage was obtained from three canola crushing plants. The dockage collection protocol was implemented from Dec. 1, 1995 to Nov. 30, 1996. In this study, the term "canola dockage" will refer to all materials removed from a mass of canola seed (500 g) by official grain grading personnel for the purpose to grade and establish a dockage content in a shipment of canola seed. Dockage samples were collected for two consecutive days in each week for the duration of the 52 week collection period. Samples were then composited by week, labeled and shipped to the University of Saskatchewan. The grading procedure used for dockage assessment in a lot of canola seed considered to be not commercially clean is outlined in the Official Grain Grading Guide (Canadian Grain Commission 1995).

Aspirations and Cleaner sieve

Samples from the cleaner sieve and air aspirator in each canola crushing plant were obtained by quality control personnel while crushing plants were in production. Collection of samples was completed each morning and afternoon for the duration of five days. Samples were then bagged and labeled by their source and sampling time and shipped to the University of Saskatchewan. Samples were collected to assess their content (by weight) of canola fines present in each fraction in the seed cleaning system. This information was necessary in order to accurately estimate the level of canola fines in canola screenings from the dockage collected from each plant. Sub-samples were also used as a method to test and calibrate the laboratory aspirator and sieve system.

Calibration of Experimental Aspirator and Cleaner Sieve System

Aspirator

Collected aspirator and cleaner sieve samples from each crushing plant were sub-sampled and subjected to a range of air velocities and test times to establish the duration and air velocity of the air aspirator. The calibration parameters were designed in a similar manner to industry standards where aspirators are set to maximize the removal of chaff and dust while minimizing the removal of canola fines. Through a range of testing times (30 sec. to 180 sec.) and air velocities (0.567 to 2.124 m^3 min^{-1}) samples were analyzed and visually inspected to achieve a combination setting that would allow for optimal separation of chaff and dust from large particles. An air velocity of 1.869 m^3 min^{-1} with a run time of 60 seconds was selected as the parameters which would maximize the removal of chaff and dust without removing large particles or canola fines.

Cleaner Sieve

The parameters for the cleaner sieve were set in a similar manner as the air aspirator. Calibration guidelines were set to identify a sieve size that would allow for maximal retention of large particles (grain, wild oats, stems, rocks) on the screen while minimizing the retention of canola fines. The testing times ranged from 10, 20 or 30 sieve revolutions (15, 30 or 45

seconds) with each sieve (No. 5, 5.5, 6, 6.5, 7, 7.5, Arrow Products, Winnipeg, MB). The most effective sieve size for this procedure was determined to be the No. 7 round hole sieve with a minimal separation time of 30 revolutions completed in 45 seconds.

Physical Analysis of Canola Dockage, Aspirator and Cleaner Sieve Samples

Samples of collected canola dockage were analyzed in triplicate, and aspirator and cleaner sieve samples in duplicate, using the experimental aspiration and sieve analysis system. Samples were first thoroughly mixed by hand in a large plastic tub and then transferred through a riffle divider (model H3985) to ensure sample mixing. A sub-sample was then randomly drawn from each side of the riffle divider using a 50 gram sample scoop and a 100 gm sample was weighed for analysis. The sample was then poured into the aspirator cup and inserted into the air column and aspirated at 1.869 m^3 min^{-1} for the duration of one minute. The aspirated material was then removed from the collection bag, weighed, labeled and classed as aspirations. The particles remaining in the cup were then passed over the No. 7 sieve for the duration of 30 revolutions. The fraction remaining on top of the sieve was weighed, labeled and classed as large particles while the material passing through the sieve was weighed, labeled and classed as canola fines.

Chemical Analysis

Prior to chemical analysis canola dockage fractions (aspirations, large particles and canola fines) were ground through a 1 mm screen using a Thomas-Wiley mill (Model 4, A. H. Thomas Co.). Data from the physical composition study suggested that aspirations and large particles are represented in approximately equal quantities in canola dockage. These two fractions were equally combined for analysis and labeled as the "coarse" fraction. The coarse fraction and canola fines, were analyzed for moisture, crude protein (Kjeldahl nitrogen x 6.25), acid detergent fiber (ADF), ash and ether extract (EE) according to the procedures of the Association of Official Analytical Chemists (AOAC 1990). Neutral detergent fiber (NDF) was determined using the method of Van Soest et al. (1991).

Statistical Analysis

Data were analyzed as a randomized complete block using each quarter (3 month period) as a block. The treatment structure was a 3 x 4 factorial arrangement with the main effects of plant and season and their interactions included in the model (Steel and Torrie 1980). Analysis was carried out using the General Linear Model of the Statistical Analysis Systems Institute, Inc. (SAS 1989). Means comparison was completed using a Student-Newman-Keuls test (Steel and Torrie 1980).

Results and Discussion

Physical Composition

No interactions between plant source and season were observed for physical composition. Therefore, only means for the main effects are presented (Table 1). Particle size distribution of all fractions was affected ($P<0.05$) by plant source Plant source. Plant A contained higher ($P < .05$) levels of canola fines than plants B and C. Level of large particle content in canola dockage was higher ($P < 0.05$) in plant B than plant C and was higher ($P < .05$) in plant C than plant A. As a result of higher large particle content, plant B exhibited lower ($P < .05$) levels of aspirated material than both plants A and C with higher ($P < .05$) levels in plant C than plant A. Aspirations were higher ($P < .05$) in quarter four than other times of the year. Similarly, large particle content was higher ($P < .05$) in the last half of the season (quarters three and four) than in previous seasons (quarters one and two). As a result, canola fines were present in higher ($P < .05$) quantities during quarters one and two and then significantly decreased ($P < .05$) in quarters three and four.

In a study on canola dockage in western Canada, Durnin (1983) reported variations of 32 to 48% for coarse particles, 36 to 44% for air blown materials and 16 to 24% for canola fines materials. These values are considerably higher for aspirations and large particles and lower than canola fines reported in the current study. The author concluded that considering the

range of particle distribution in dockage throughout the prairie provinces, the amounts of total dockage were similar across geographical location. The actual composition of canola dockage may arise from differences in the variety of seed grown, geographical growing conditions, method and timing of harvest practices and from differences in the type and operation of seed cleaning equipment. Bell (1993) suggests that variations in the composition of canola meal may occur as a result of differences in cultivars of seed and growing conditions.

Chemical composition

Ash and EE levels of coarse fraction were different ($P<0.05$) between the three crushing plants (Table 2). Coarse fraction from plant A had higher ($P<0.05$) crude protein (CP) and lower ($P<0.05$) ADF content than the other two plants. However, NDF level was similar in the three crushing plants (average 41.2%). Higher CP and EE levels in coarse fraction obtained from plant A may be a reflection of overall aspiration in plant A indicating higher concentrations of seed fragments in the coarse fraction. A source x season interaction ($P < .05$) was noted for CP (Figure 2). In plant A, CP increased and then decreased, while it steadily declined over time for plant B. A similar decline was noted for plant C however, it increased markedly in the fourth quarter. No effect of season was observed for NDF, EE and ash levels in the coarse fraction. Overall, differences in chemical composition of the coarse fractions between plants or over seasons were not of great magnitude.

Chemical composition of canola fines

Canola fines from plant C contained less ($P<0.05$) CP and more ($P<0.05$) EE than canola fines from plant A and B (Table 3). Crude protein values were not different for plant A or plant B while EE levels in Plant B were lower ($P < 0.05$) than those observed in Plant A. Neutral detergent fiber values were similar for plants B and C and were higher ($P < 0.05$) than Plant A. Ash content was not different between sources. Similarly, there were no observed seasonal differences in level of CP, NDF or EE in canola fines. However, ash levels were higher ($P < .05$) in the fourth quarter than at other times of the year. A source x season interaction was detected ($P < .05$) for ADF content (Figure 3). In Plant A and B, ADF level remained relatively constant throughout the coarse of the year while it increased in plant C

($P<0.05$) over time. Increases in ADF would in part explain the lower value for CP and higher level of NDF. The current observations would suggest that season may have an effect on the chemical composition of canola fines within a given source. However, while significant, these differences are minimal (Table 3).

Results from Table 2 and 3 showed that relative to canola fines, the coarse fraction contained on average 31.4% less CP, 18% more NDF, 7% more ADF, 70% less EE and 39% more ash. Differences in chemical composition between these two fractions is likely due to the fines fraction containing more small canola and weeds seeds and less dust and chaff than the coarse fraction (Bell and Shires 1980). The results also suggest that there is both seasonal and plant of origin effects on the chemical composition of canola dockage. Plant effects appear to be greater and likely reflect growing conditions specific to geographical location of each crushing plant at time of sample collection. Although this study is not able to define local growing conditions

or look at year effects, it is apparent that while season and plant of origin will influence quality, the results of this study show that these effects are minimal.

Physical characteristics of collected aspirator and cleaner sieve samples

The mean physical composition, range and standard deviations for collected samples of aspirations and cleaner sieves from crushing plants are presented in Table 4. Particle distribution for aspirator samples ranged from 80 to 90% for aspirations, 1.5 to 6.0% for large particles and 8 to 18% for canola fines. In contrast, cleaner sieve samples ranged from 9 to 33% for aspirated material, 61 to 82% for large particles and 5 to 9% for canola fines. The high percentage recovery for aspirations (80 to 90%) in the aspirator samples and high recovery of large particles (61 to 82%) in the cleaner sieve samples suggest that calibration of the aspirator and sieve analysis system developed for this project was effective in characterizing current cleaning systems within western Canadian canola crushing plants.

As noted previously in Table 1, the level of canola fines in canola dockage ranged from 44.4 to 57.2%. However when these results are compared with those shown in Table 4, it is interesting to note that only minimal amounts of canola fines were present in either the aspirator (8 to 18%) or cleaner sieve (5 to 9%) samples obtained from crushing plant cleaning systems.

Canola screenings which are commercially available to the livestock industry would contain both the aspirations and cleaner sieve fractions similar to ones collected for the experiment. It would appear from the current observations that removal of canola fines from canola seed may be minimized during the cleaning stage and remain with the seed to be crushed for oil. It is also important to note that canola fines appear in higher overall quantities in the aspirator samples than in cleaner sieve samples (Table 4), suggesting that the removal of canola fines during cleaning may in fact be due more so to the removal by air rather than by mechanical means. These observations would also be supported by the large variation noted in canola fines concentrations between crushing plant aspirator samples (7.8 to 17.8%) and minimal variation between cleaner sieve samples (4.9 to 8.9%). Although the data is limited, it is indicative that removal of canola fines may also be different amongst crushing plant cleaning systems and not directly related to the composition of the canola dockage. As shown in Table 4, fines in the aspirator samples were numerically higher in plants A and B than in plant C.

Estimation of Canola Screenings Composition

The primary purpose for collecting cleaner sieve and aspirator samples from each canola crushing plant was to determine the level of canola fines in each of these respective samples. With this knowledge and the knowledge of the relative physical and chemical composition of canola dockage, it was then possible to establish a tabular estimation of the nutrient composition of canola screenings for each crushing plant at various inclusion rates of canola fines, including the specific levels found in the aspirator and cleaner sieve samples for each plant. The point of origin was a canola screenings product with no canola fines present and to this base product, varying degrees of canola fines were then included to establish a nutritional range for screenings produced by a specific cleaning system (Table 5).

Inclusion levels of 8.5% canola fines for plant A, 13.4% for Plant B and 6.9% for plant C were derived from sum totals of mean values for canola fines from Table 4. These values were then adjusted to a 50:50 ratio of aspirations and cleaner sieve fractions. Increased levels of canola fines had minimal effects on NDF and ADF, numerically improved CP and EE contents while decreasing ash levels. The minimal effect on fiber suggests that the fiber level in canola screenings was similar across plants. These results indicate that observed variations in the

nutritional quality of canola screenings may in fact be due more to variations in the composition of the coarse fraction than in the canola fines. However, increased inclusion levels of canola fines can improve the nutritional quality by increasing the CP and EE content. These improvements are noted by increasing levels of protein and fat with minimal effects on fiber.. Interestingly, Plant B contained higher levels of canola fines than those found in Plants A and C, however, the EE content of canola screenings did not reflect these differences. Observed differences would be reflective of lower quality of canola fines found in plant B dockage.

Conclusions

The results from this study suggest that both season of year and plant of origin will influence the chemical composition of canola dockage. Plant effects appear to be greater and likely reflect growing conditions specific to geographical location of each crushing plant. Although this study is not able to define local growing conditions or look at year effects, it is apparent that while season and plant of origin will influence quality, the magnitude of their effects are minimal. Therefore the current observations indicate that the nutrient content of canola screenings may be primarily influenced by the inclusion level of canola fines which in turn appears to be related to the cleaning method employed by an individual crushing plant.

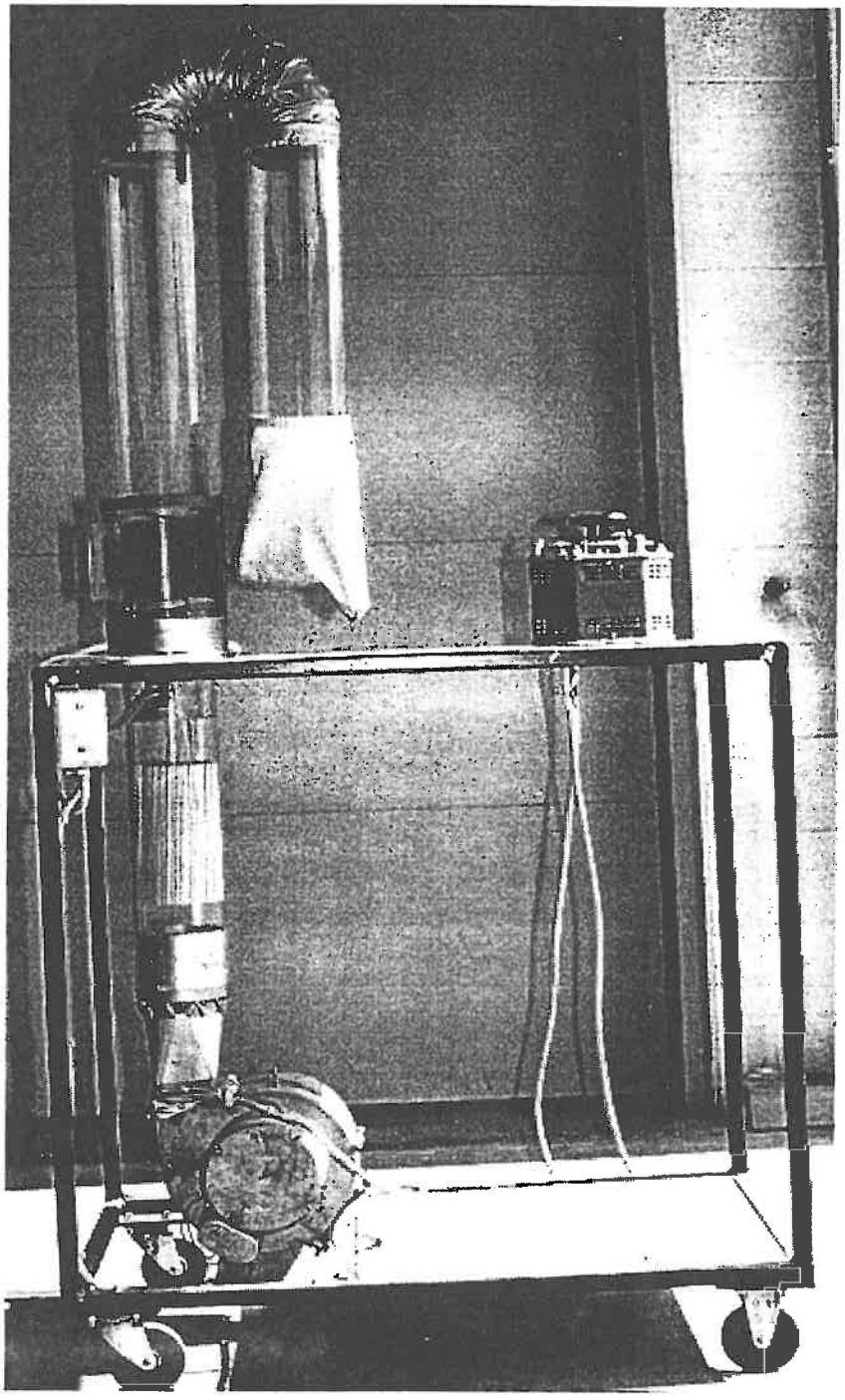

Figure 3. Air Aspirator

Table 1. Effect of plant source and season on the physical composition of canola dockage collected from canola crushing plants.

	% Fraction (As is)		
Parameter	Aspirations	Large particles	Fines
Plant A	23.6b	18.7c	57.2a
Plant B	22.4c	32.6a	44.9b
Plant C	26.9a	28.7b	44.4b
SEM	0.53	0.58	0.70
Quarter one	23.0b	24.3b	53.0a
Quarter two	23.9b	25.2b	51.1a
Quarter three	24.4b	27.1a	48.5b
Quarter four	26.0a	30.2a	43.5c
SEM	0.61	0.67	0.80

a-c Means in the same column for plant or quarter followed by different letters differ ($P < 0.05$).
SEM = Pooled standard error of the mean.

Table 2. Effect of plant source and season on nutrient composition of the coarse fraction of canola dockage collected from canola crushing plants.

	% Nutrient (DM basis)				
Parameter	Crude protein[Z]	Neutral detergent fiber	Acid detergent fiber	Ether extract	Ash
Plant A	15.0a	41.0	23.8b	8.3a	9.3a
Plant B	13.7b	40.3	24.5b	6.1c	8.5b
Plant C	14.0b	42.2	25.5a	6.9b	7.6c
SEM	0.10	1.00	0.27	0.13	0.14
Quarter one	14.4	40.1	24.2b	7.0	8.7
Quarter two	14.3	40.5	24.4b	7.1	8.6
Quarter three	14.2	42.9	24.3b	7.3	8.3
Quarter four	14.0	41.3	25.4a	7.0	8.3
SEM[Y]	0.11	1.08	0.32	0.16	0.16

[Y]SEM = Pooled standard error of the mean.

[Z]Interaction: Plant X Quarter ($P < 0.05$).

a-c Means in the same column for plant or quarter followed by different letters differ ($P < 0.05$).

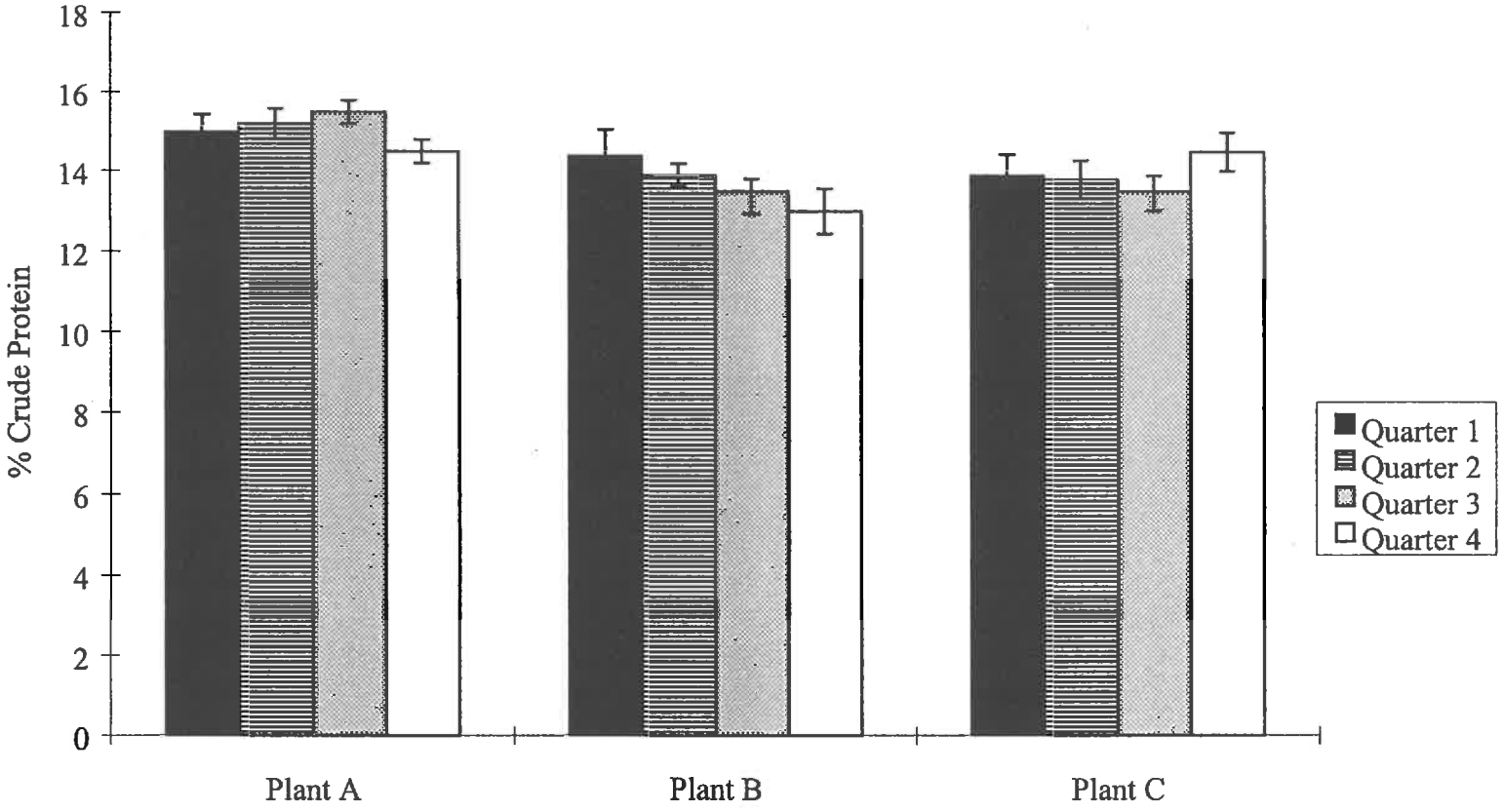

Figure 2. Plant x source interaction on crude protein content of coarse fraction of canola dockage

Table 3. Effect of plant source and season on nutrient composition of the fines fraction of canola dockage collected from canola crushing plants.

Parameter	% Nutrient (DM basis)				
	Crude protein	Neutral detergent fiber	Acid detergent fiber[Z]	Ether extract	Ash
Plant A	20.9a	33.6b	22.7b	23.3b	6.1
Plant B	21.0a	35.8a	22.4b	21.9c	6.1
Plant C	20.1b	35.3a	24.0a	24.9a	6.2
SEM[Y]	0.10	0.27	0.19	0.33	0.10
Quarter one	20.8	34.3	22.6b	23.1	6.1b
Quarter two	20.8	34.7	22.8ab	23.2	5.9b
Quarter three	20.6	35.3	23.2ab	23.5	6.0b
Quarter four	20.4	35.2	23.3a	23.5	6.5a
SEM[Y]	0.13	0.31	0.21	0.40	0.12

a-c Means in the same column for plant or quarter followed by different letters differ ($P < 0.05$)
SEM = Pooled standard error of the mean.
[Z]interaction Plant X Quarter ($P < 0.05$)

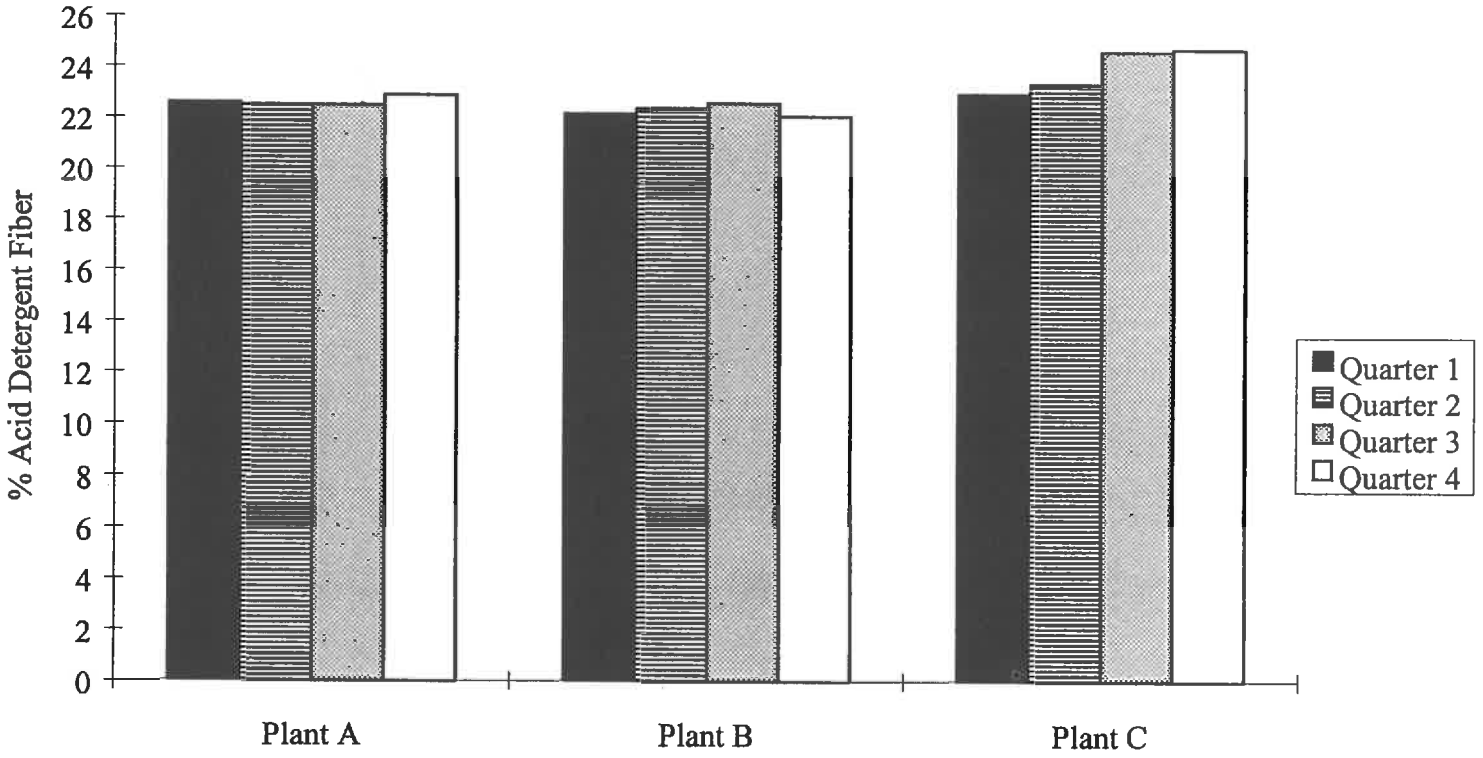

Figure 3. Source X season interaction on acid detergent level of the fines fraction of canola dockage.

Table 4. Analysis of physical composition of aspirator and cleaner sieve samples collected during the cleaning stage of canola seed from 3 western Canadian canola crushing plant.

		Collected Fraction					
		Aspirator			Cleaner Sieve		
		Plant			Plant		
		A N=5	B N=8	C N=6	A N=5	B N=8	C N=9
Aspirations	Mean	81.4	79.6	90.0	16.1	8.73	33.0
	Range	78.0 - 84.8	77.4 - 82.8	88.2 - 92.6	15.8 - 17.3	7.0 - 14.4	10.8 - 42.9
	SD[Z]	4.8	1.8	1.6	0.8	2.4	9.0
Large Seed	Mean	6.0	2.5	1.5	79.0	82.3	61.1
	Range	5.3 - 6.6	1.9 - 3.2	1.0 - 2.0	77.7 - 79.8	79.3 - 84.2	50.8 - 65.2
	SD	0.94	0.51	0.51	1.0	2.1	8.7
Fines	Mean	12.0	17.8	7.8	4.9	8.9	5.9
	Range	10.6 - 13.5	15.2 - 19.9	5.0 - 10.6	4.3 - 6.0	5.9 - 11.3	4.3 - 7.9
	SD	2.0	1.4	2.0	0.7	2.1	1.2

[Z]standard deviation of the mean

Table 5. Effect of inclusion rate of canola fines on nutritional profile of potential canola screenings produced from each canola Crushing plant.

Parameter	Item (DM Basis)		Level of Canola Fines Inclusion					
	Coarse Fraction	Fines Fraction	0%	5%	8.5%[Z]	10%	20%	25%
Plant A	%	%						
Crude Protein	15.0	20.9	15.0	15.3	15.5	15.6	16.2	16.5
Neutral Detergent Fiber	41.0	33.6	41.0	40.6	40.4	40.3	39.5	39.2
Acid Detergent Fiber	23.8	22.7	23.8	23.7	23.7	23.7	23.6	23.5
Ether Extract	8.3	23.3	8.3	9.1	9.6	9.8	11.3	12.1
Ash	9.3	6.1	9.3	9.1	9.0	9.0	8.7	8.5
	Coarse Fraction	Fines Fraction	0%	5%	10%	13.4%[Z]	15%	20%
Plant B	%	%						
Crude Protein	13.7	21.0	13.7	14.1	14.4	14.7	14.8	15.2
Neutral Detergent Fiber	40.3	35.8	40.3	40.1	39.9	39.7	39.6	39.4
Acid Detergent Fiber	24.5	22.4	24.5	24.4	24.3	24.2	24.2	24.1
Ether Extract	6.1	21.9	6.1	6.9	7.7	8.2	8.5	9.3
Ash	8.5	6.1	8.5	8.4	8.3	8.2	8.1	8.0
	Coarse Fraction	Fines Fraction	0%	5%	6.9%[Z]	10%	15%	20%
Plant C	%	%						
Crude Protein	14.0	20.1	14.0	14.3	14.4	14.6	14.9	15.2
Neutral Detergent Fiber	42.2	35.5	42.2	41.9	41.7	41.5	41.2	40.8
Acid Detergent Fiber	25.5	24.0	25.5	25.4	25.4	25.4	25.3	25.2
Ether Extract	6.9	24.9	6.9	7.8	8.1	8.7	9.6	10.5
Ash	7.6	6.2	7.6	7.5	7.5	7.5	7.4	7.3

[Z]Estimated level of canola fines based on the sum total measured in aspirator and cleaner sieve samples in Table 3.4 in a 50/50 blend of aspiration and cleaner sieve fractions.

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Effects of Processing and Fat content of Coarse Canola Screenings on Voluntary Intake and Total Tract Nutrient Digestibility of Beef Steers

INTRODUCTION

Increased world demand for canola seed and oil in the last decade has resulted in close to a doubling in size of the Canadian canola industry. As a result, domestic processing of canola has increased tonnage of by-products, such as canola screenings. Tait et al. (1986) reported that canola screenings contained on a DM basis 196 g kg^{-1} CP, 225 g kg^{-1} EE and 280 g kg^{-1} ADF. These relatively high nutrient levels suggest that canola screenings have the potential to serve as a valuable protein, fiber and energy feedstuff for ruminants. Dietary fat or oil at levels greater than 60 g kg^{-1} of DM have been shown to disrupt ruminal fermentation causing negative effects on fiber digestion (Moore et al. 1986; Zinn and Plascencia 1996) and feed intake (Zinn 1988). These effects are more pronounced when fat levels in the diet increase or when there is a higher degree of unsaturation of dietary fat (Palmquist and Jenkins 1980). Canola seed contains 400 g kg^{-1} fat, which consists primarily of oleic (510 g kg^{-1}), linoleic (250 g kg^{-1}) and linolenic (140 g kg^{-1}) acids (Khorasani et al. 1991).

It has been suggested that feeding crushed full fat canola seed may minimize the inhibitory effects of supplemental fat on feed intake and nutrient digestion in ruminants (Murphy et al. 1987; Hussein et al. 1995). These researchers attribute their observations to a slow release of unsaturated fatty acids from the cellular structure of the seed, which minimizes the negative effects on rumen metabolism. In light of the fact that canola screenings contain a significant proportion of intact canola and weed seeds that are high in fat, it may be possible to use this product to increase the energy density of the diet by feeding higher than recommended fat levels. However, information on the feeding value of canola screenings is limited (Tait et al. 1986; Weisen et al. 1990). No research exists in regard to nutrient availability in ruminants fed raw or processed canola screenings. Therefore, the objectives of these experiments were to determine the voluntary intake and apparent nutrient digestibility of unprocessed and processed canola screenings and the effects of increasing fat level from canola screenings on voluntary dry matter intake and apparent nutrient utilization of growing beef steers.

MATERIALS AND METHODS

Animals and Housing

Two groups of twelve medium frame steers were used in Trial 1 (355 ± 15 kg) and 2 (313 ± 25 kg), respectively. The steers were housed and fed individually in the Livestock Research Barn at the University of Saskatchewan (Saskatoon, SK). Pen design consisted of a 13 m^2 steel panel structure with rubber floor matting. The environmental temperature ranged from 15 to 20° C. Animal care protocols were set and carried out according to the Canadian Council for Animal Care (1993).

Trail One

The four dietary treatments used in Trial 1 were designated: unprocessed canola screenings; processed canola screenings; unprocessed alfalfa-brome hay / barley and processed alfalfa-brome hay/barley. Canola screenings were obtained from a commercial canola crushing plant. The collection protocol included compositing four tonnes of canola screenings weekly over eight weeks to obtain a representative sample. A leg elevation system in the crushing plant was used to mix the screenings prior to their transport. Upon arrival at the research barn, large tote bags were filled with unprocessed canola screenings and stored at the University of Saskatchewan. The remaining canola screenings were processed by hammer milling through a 3.2-mm screen and pelleted through a 4.7-mm diameter die at a local feed processor.

Square bales of alfalfa-brome hay obtained from the University of Saskatchewan farm were processed through a Bear Cat hay shredder (19-mm screen). The hay was utilized as a control to compare VI and nutrient digestibility of processed and unprocessed canola screenings to a commonly used forage source. A quantity of hay was ground through a 5 mm screen and combined with rolled barley / tallow at a mixing rate of 790 kg hay and 210 kg barley / tallow per tonne and pelleted using a 5-mm die. The barley/tallow mixture consisted of 952 g kg^{-1} barley and 48 g kg^{-1} tallow (as-fed) and was added to the hay to assist with pelleting. A quantity of shredded alfalfa-brome hay and rolled barley/tallow were bagged separately for use in the feeding trial as an unprocessed control treatment.

In each 29-d period, an adaptation period of 14 d was allowed for the steers to become accustomed to their diets and environment. Steers were offered fresh feed at 0800 and 1600 h daily with *ad libitum* access to water. Voluntary intake was determined for each steer from d 15 to 21. Following the VI period, the steers were restricted to 85% of VI for 3 d followed by 5 d of total fecal collection.

Trial Two

In Trial 2, four diets that differ in fat content were formulated. Canola screenings were obtained from two commercial canola crushing plants (plant A and plant B) based on their fat content (162 and 67 g kg^{-1} EE, respectively). The diets were prepared using canola screenings from both plant A and B. The fat levels (as-fed) were 67 (100% plant A), 100 (65% plant A and 35% plant B), 128 (35% plant A and 65% plant B) and 162 g kg^{-1} (100% plant B), respectively. The canola screenings from plant A were the same screenings used in Trial 1. The canola screenings from plant B were collected by delivering and piling four two-tonne loads for four weeks at the University of Saskatchewan Beef Cattle Research Station. These screenings were then thoroughly mixed using a loader tractor and processed in the same manner as those used in Trial 1.

In each 27-d period, steers were allowed an adaptation period of 12 d to become accustomed to their diets and environment. Steers were offered fresh feed in wooden feed bunks at 0800 and 1600 h daily with *ad libitum* access to water. Voluntary intake was determined for each steer from d 13 to 19. Feed intake was then restricted to 85% of VI for 3 d and followed by a 5-d total fecal collection period.

Data Collection and Analysis

In both trials, feed samples were collected during the VI and total collection periods. Fecal sub-samples were dried at 55 °C in a forced air oven for 48 h. Feed and fecal samples were ground through a 1-mm screen using a hammer mill. Fecal samples for each day were then composited by steer in each period and analyzed along with feed samples for moisture, EE, CP (Kjeldahl nitrogen x 6.25), ADF and ash according to the Association of Official Analytical Chemists (AOAC 1990). Neutral detergent fiber was determined using the method

of Van Soest et al. (1991). Fiber (ADF and NDF) analysis of feed and fecal samples was conducted on fat free samples. Gross energy was determined using an adiabatic bomb calorimeter.

Fatty acid content of feed and fecal samples was measured by a modified one-step methylation method according to the procedure of Sukhija and Palmquist (1988). The methyl esters were separated using a Hewlett-Packard 5890 Gas Chromatograph with a HP 7693 Autosampler fitted with a SupelcoWax 10 fused silica column (15m x 0.32 mm). The injector temperature was 300°C with an initial column temperature of 160°C (held for 1 min) and then programmed to increase at a rate of 5°C min^{-1} to 220°C (held for 2 min) accompanied by a detection temperature of 300°C. A split ratio of 22.4:1 was used with hydrogen as the carrier gas with a flow rate of 0.7 mL min^{-1}. The initial pressure setting was 5.9 psi (initial 5.0 min) and was then ramped at 1 psi min^{-1} to a final pressure of 15 psi min^{-1}.

Apparent nutrient digestibility coefficients were calculated as the difference between the amount of nutrients in feed and feces and were expressed as a proportion of total nutrient intake.

Statistical Analysis

Data from each trial were analyzed as a randomized complete block design using the General Linear Model procedure of the Statistical Analysis System (SAS) Institute Inc., (1991) using periods as blocks. The treatment structure of Trial 1 was a 2 x 2 factorial arrangement with the main effects of feed type and degree of processing and their interactions included in the model (Steel and Torrie 1980). Non-orthogonal contrasts were used to detect treatment differences (Steel and Torrie 1980). These included unprocessed vs processed feed and canola screenings vs alfalfa-brome hay / barley. When significant interactions were detected, the contrasts included unprocessed vs processed canola screenings and unprocessed vs processed alfalfa-brome hay / barley. Polynomial contrasts were used to detect linear, quadratic and cubic treatment effects of fat level on DM intake, nutrient intake and apparent nutrient digestibility (Trial 2). Coefficients for polynomial orthogonal contrasts with unequally spaced treatments were calculated using the regression procedures of Robson (1959) using Minitab Statistical Software (Minitab Inc. 1992).

RESULTS AND DISCUSSION

Trial One

Processing did not appear to markedly influence the chemical composition of either the canola screenings or the alfalfa-brome hay/barley diets (Table 1). Slight differences in the nutrient profile of unprocessed and processed canola screenings may be a reflection of their heterogeneous composition or due to error in sampling. Canola screenings in the current study were lower in CP (mean = 176 vs 196 and 217 g kg^{-1}, respectively) and EE (mean = 168 vs 213 and 194 g kg^{-1}, respectively) than values reported by Tait et al. (1986) and Weisen et al. (1990) and intermediate in ADF content (mean = 260 vs 317 and 209 g kg^{-1}, respectively).

Intake by cattle fed the alfalfa-brome hay/barley diets tended ($P < 0.10$) to be higher than that by cattle fed canola screenings (Table 2). Apparent total tract DMD, NDFD, ADFD, and FAD were also higher ($P < 0.05$) for the alfalfa-brome hay/barley diets than respective values for canola screening diets. Apparent GED tended ($P = 0.09$) to be higher for alfalfa-brome hay/barley diets. However, DE content (MJ kg^{-1}) was higher ($P < 0.05$) for canola screening diets. No treatment differences in total tract CPD were detected. Processing of feeds resulted in a decrease ($P < 0.05$) in VI, NDFD, and ADFD. In contrast to these findings, CPD, FAD, and GED were increased ($P < 0.05$) by processing and resulted in a higher ($P < 0.05$) DE value (11.6 *versus* 10.7 MJ kg^{-1} DM) for processed *versus* unprocessed feeds. However, DE intake was lower ($P < 0.05$) for processed feeds due to the drop in VI of canola screenings when processed.

Feed source x processing interactions were detected ($P < 0.05$) for VI, and digestibility of specific nutrients (Table 2). Processing of the alfalfa-brome hay / barley diet had no effect on VI. However, DMD, NDFD and ADFD were reduced ($P < 0.01$) by 8.3, 25.3, and 30.4 %, respectively. In contrast, processing of canola screenings resulted in a reduction ($P < 0.01$) in VI (30.6%) and an increase ($P < 0.01$) in DMD, CPD, and FAD. Total tract ADFD of processed canola screenings was reduced ($P < 0.01$) by 14.8% with no effect on NDFD.

A reduction in DMD of 10% or more has been reported as a result of feeding pelleted over chopped forages (Fahey and Berger 1988). Finer particles reduce the coarse fiber mat in the

rumen and induce less rumination resulting in faster rates of passage and depressions in structural carbohydrate digestion (Van Soest 1994). This would, in part, explain the observed reduction in DMD, and concurrent reduction in NDFD and ADFD when steers were fed the processed alfalfa-brome hay / barley diet (Table 2). In relation to this, it would be expected that VI would have been increased in steers consuming the processed alfalfa-brome hay / barley diet to compensate for the reduction in fiber and GE digestibility. However, the magnitude of the decrease in GED was only 4% and may not have been sufficient to increase VI.

The reduction in VI observed when processed canola screenings were fed was likely due to exposure of canola oil due to the breaking of the seed coat. Disruption of ruminal digestion by addition of fat to the diet has been well documented (Palmquist and Jenkins, 1980; Moore et al. 1986; Zinn 1989) and is more pronounced when polyunsaturated fatty acids are fed relative to saturated fatty acids (Ferlay et al. 1991). Canola oil, the primary source of fat used in the present study is high in polyunsaturated fatty acids.

Disruption of ruminal fermentation due to exposure of rumen microbes to polyunsaturated fatty acids from processed canola screenings would also explain the depression in ADFD ($P < 0.01$) in cattle fed processed canola screenings. Other researchers (Zinn 1989; Tamminga and Doreau 1991; Hussein et al. 1995) have reported a reduction in ruminal fiber digestion and a shift in the site of fiber digestion from the rumen to the hind gut when high-fat diets are fed. These latter results may explain why no effect on NDFD was observed as a result of exposing the dietary fat to ruminal fermentation in the present study.

Improvements in DMD, CPD and FAD would have resulted in part from improved nutrient availability of processed canola screenings. Similar to the results of the present study, Aldrich et al. (1997) reported that organic matter digestibility by steers fed crushed canola seed was higher than that by steers fed unprocessed canola seed. A decrease in DM intake as observed in this study may also have contributed to improved nutrient utilization (Tyrell and Moe 1975).

In spite of the improvement in FAD, digestible energy intake was depressed by processing of canola screenings (Table 2). This is a consequence of the large reduction in VI (Table 2).

These results suggest that processing of canola screenings improves nutrient availability through disruption of the protective seed coat of oil bearing seeds. However, as noted in this study, the resulting level and availability of fat in the diet may have suppressed ruminal fermentation resulting in depressed ADF digestion and reduced dry matter and energy intakes.

Trial Two

Ingredients and chemical composition of the four dietary treatments used in Trial 2 are given in Table 3. Crude protein, EE, GE, and ash content increased while NDF content decreased as the level of high fat canola screenings from plant B increased. Increasing the level of dietary fat from 67 to 162 g kg^{-1} resulted in a quadratic decrease ($P < 0.05$) in VI. Voluntary intake increased by 4% as the level of dietary fat increased from 67 to 100 g kg^{-1} and then decreased by 9% and 20%, respectively for the medium-high (128 g kg^{-1}) and high fat (162 g kg^{-1}) treatments (Table 4). The negative effect on VI as a result of increasing dietary fat is well documented (Moore et al. 1986; Brandt 1995; Jenkins 1993). Factors that may influence VI are lower palatability of dietary lipids, chemostatic control of DM intake (Baumgardt 1970) or an antimicrobial effect of polyunsaturated fatty acids on ruminal fermentation (Jenkins 1993).

Apparent digestibility of DM, CP, ADF, and GE were not affected by dietary fat level (Table 4). Other researchers have found that dietary fat either improved (Jenkins and Jenny 1992) or had no effect (Doreau et al. 1993) on total tract digestibility of CP. Total tract digestibility of NDF improved linearly ($P < 0.05$) as dietary fat level increased. Ngidi et al. (1990) reported similar observations for NDFD as a result of increased fat in the diet. These authors concluded that the response might have been due to reduced intake of fermentable organic matter, which would result in a slower passage rate of particulate matter. As reported previously in Trial 1, other researchers have reported shifts in fiber digestion to the hind gut to compensate for depressed microbial activity in the rumen when high fat levels are fed (Zinn 1989; Tamminga and Doreau 1991; Hussein et al. 1995).

Apparent fatty acid digestibility decreased linearly ($P < 0.01$) from 822 to 640 g

kg^{-1} as dietary fat content increased from 67 to 162 g kg^{-1}. Reduced fat digestion has also been observed by other researchers (; Jenkins and Palmquist 1984; Moore et al. 1986; Ngidi et al. 1990) when fat levels were increased in the diet. Brandt (1995) reviewed research involving different sources and levels of dietary fat and concluded that intake of digestible dietary lipid may be limited to 450 to 500 g d^{-1} in ruminants. In the current study, total fatty acid intakes for the low, medium low, medium high and high fat diets were 344.3, 551.6, 631.8 and 697.8 g d^{-1}, respectively (Table 5). However, digestible fatty acid intakes were 283.0, 404.6, 467.2 and 445.7 g d^{-1}, respectively. These results support the concept of Brandt (1995) that ruminants have a limited ability to absorb fatty acids. This study also indicates that on the high fat diets, daily fatty acid intake exceeded the animal's ability to absorb dietary lipid. These results are in agreement with Palmquist and Conrad (1978) and Doreau and Farley (1994).

Digestible energy content of the diet increased in a linear manner ($P < 0.05$) in response to incremental increases in dietary fat (Table 5). This improvement in DE content from 3.03 to 3.19 MJ kg^{-1} DM from added fat reflects the linear increase ($P < 0.05$) in digestible fatty acid intake (Table 5). When compared with the low fat diet, total fatty acid intake was increased by 60, 83 and 103% in the medium low, medium high and high fat diets, respectively. Corresponding increases in digestible fatty acid intake were 43, 65, and 57%.

Despite the fact that the DE content of diets increased linearly with increasing fat level of the diet, DE intake decreased in a quadratic ($P < 0.05$) fashion (Table 5). This is a reflection of the fact, that VI decreased quadratically ($P < 0.05$) and that while digestible fatty acid intake increased linearly, it actually plateaued at about 446 g d^{-1} on the high fat diets. The nature of the quadratic response in DE intake was such that relative to the low fat diet it was improved by 10% as the fat content of the diet increased to 100 g kg^{-1}. However, it progressively declined by 5.4 and 10.7% as fat level increased to 128 and 162 g kg^{-1}, respectively (Table 6). These data suggest that the observed reduction in VI of cattle fed the high fat canola screenings was not the result of animals reaching energy satiety. As discussed earlier, diet acceptability or depression in rumen fermentation may have influenced VI.

The current observation of 100 g kg^{-1} dietary fat stimulating a higher energy intake in growing steers poses questions as to the physical form that fat is added to the diet. Current

recommendations suggest that dietary fat levels in excess of 40 to 50 g kg^{-1} for finishing diets (Brandt 1995) and 40 to 70 g kg^{-1} for high roughage diets (Jenkins and Palmquist 1984; Moore et al. 1986) may depress feed intake and rumen fermentation resulting in a compromised DE intake. However, in the current study dietary fat was supplied primarily in the form of processed full fat canola and weed seeds, which were present in canola screenings. Supplementing fat in this form may have minimized its negative effects on rumen fermentation resulting in a greater DE intake at the 100 g kg^{-1} dietary fat level. Similar to the results of the present study, Hussein et al. (1995) reported no effect on VI when 8.8% dietary fat was fed with half being supplied in the form of crushed whole canola seed. These workers attributed these results to the fact that fat from full fat seeds is slowly released in the rumen due to the protection provided by the seed coat. As a result, disruption of rumen fermentation is minimized. Similar results have been reported by other workers (Murphy et al. 1987; Khorasani et al.1992). The results of this study would therefore suggest that although higher levels of fat intake may be achieved when provided in the form of whole seeds from canola screenings, the maximal inclusion level appears to be in the range of 100 g kg^{-1} in the diet.

CONCLUSIONS

Consumption and utilization of unprocessed canola screenings was similar to that of chopped alfalfa-brome hay / barley diets. Grinding and pelleting of canola screenings depressed DM intake but improved apparent digestibility of DM, CP and FA. It is unclear whether improved nutrient utilization was a result of physical disruption of the seed coat of canola seeds in canola screenings or due to the observed reduction in DM intake. Feeding dietary fat up to 100 g kg^{-1} of DM in the form of processed canola screenings did not result in the commonly negative associative effects on ruminal digestion and feed intake typically seen with this level of fat supplementation. Further research is required to elucidate the mechanism which allows a higher level of dietary fat to be fed to ruminants, and to determine the true impact of dietary fat inclusion level on microbial fermentation.

ACKNOWLEGEMENT

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Table 1. Chemical composition of unprocessed and processed diets used in Trial 1 (DM basis).

	Diets			
	Raw Canola screenings	Pelleted canola screenings	Alfalfa-brome hay/ barley	Pelleted alfalfa-brome hay/ barley
Nutrient				
Crude Protein (g kg^{-1})	174	178	128	140
Acid detergent fiber (g kg^{-1})	280	240	306	291
Neutral detergent fiber (g kg^{-1})	378	334	490	466
Ether Extract (g kg^{-1})	160	176	26	28
Ash (g kg^{-1})	143	130	70	78
Gross energy (MJ kg^{-1})	19.9	20.6	18.4	18.6

Table 2. Effects of processing canola screenings and alfalfa brome hay / barley diets on voluntary intake and nutrient digestibility coefficients of steers.

	Diet						Contrasts[Z] (P-value)			
	Canola screenings			Alfalfa-brome hay/barley			Main effects		Interaction	
	Unprocessed	Processed	SEM[Y]	Unprocessed	Processed	SEM[Y]	Feed source	Processing	Canola screenings	Alfalfa-bron hay/ barley
Voluntary intake (DM basis)										
% body weight	2.8	2.3	0.13	2.74	2.63	0.13	NS	< 0.05	< 0.01	NS
Kg d^{-1}	10.7	7.4	0.51	10.55	9.71	0.53	0.06	< 0.01	< 0.01	NS
G $kg^{-0.75}$	125.6	91.5	5.16	121.26	115.23	5.29	0.09	< 0.01	< 0.01	NS
Apparent nutrient digestibility coefficient (DM basis)										
Dry matter (g kg^{-1})	495.3	582.4	11.6	611	561	11.8	< 0.01	NS	< 0.01	< 0.01
Crude protein (g kg^{-1})	570.8	681.6	9.5	621	623	9.8	NS	< 0.01	< 0.01	NS
Neutral detergent fiber (g kg^{-1})	371.1	372.2	15.4	492	368	15.8	< 0.01	< 0.01	NS	< 0.01
Acid detergent fiber (g kg^{-1})	330.6	281.6	15.9	419	292	16.3	< 0.01	< 0.01	< 0.05	< 0.01
Fatty acid (g kg^{-1})	487.7	625.5	2.16	772	785	22.9	< 0.01	< 0.01	< 0.01	NS
Gross energy (J kJ^{-1})	515.1	615.3	12.1	608	565	12.5	0.09	< 0.05	< 0.01	< 0.05
Digestible energy (MJ kg^{-1})	10.3	12.7	0.26	11.2	10.5	0.28	< 0.05	< 0.01	< 0.01	NS
Digestible energy intake (MJ d^{-1})	90.3	77.8	4.1	98.8	85.9	4.16	NS	< 0.05	< 0.05	< 0.05

[Z] Main effects: Feed source = Canola screenings vs alfalfa brome hay / barley; Processing = Unprocessed vs processed.
[Z] Interaction: Canola screenings = Unprocessed vs processed; Alfalfa brome hay / barley = Unprocessed vs processed.
[Y] Pooled standard error of the mean.

Table 3. Ingredient and chemical composition of diets fed to steers in Trial 2.

	Diets			
	Low fat (67 g kg^{-1})	Medium low fat (100 g kg^{-1})	Medium high fat (128 g kg^{-1})	High fat (162 g kg^{-1})
Ingredient (g kg^{-1} as-fed basis)				
Low fat canola screenings, Plant A	994	645	349	0
High fat canola screenings, Plant B	0	349	645	994
Mineral vitamin mix[Z]	3	3	3	3
Iodized cobalt salt[Y]	3	3	3	3
Chemical Composition (DM basis)				
Crude protein (g kg^{-1})	140	149	157	167
Acid detergent fiber (g kg^{-1})	256	251	247	242
Neutral detergent fiber (g kg^{-1})	401	376	355	331
Ether extract (g kg^{-1})	67	100	128	162
Ash (g kg^{-1})	70	88	103	121
Gross energy (MJ kg^{-1})	19.3	19.7	20.1	20.6

[Z] 180 g kg^{-1} Ca, 180 g kg^{-1} P, 9 g kg^{-1} Mg, 10,500 mg kg^{-1} Zn, 90 mg kg^{-1} I, 9000 mg kg^{-1} Fe, 5250 mg kg^{-1} Mn, 3150 mg kg^{-1} Cu, 45 mg kg^{-1} Co, 3,000 mg kg^{-1} Fl, 500,000 IU kg^{-1} vitamin A, 50,000 IU kg^{-1} vitamin D_3, 500 IU kg^{-1} vitamin E.
[Y] 990 g kg^{-1} NaCl, 120 mg kg^{-1} Co, 180 mg kg^{-1} I

Table 4. Effect of increasing levels of fat in canola screening diets on dry matter and nutrient digestibility.

Parameter	Diets				SEM[Y]	Contrasts[Z] (P-value)	
	Low fat (67 g kg^{-1})	Medium low fat (100 g kg^{-1})	Medium high fat (128 g kg^{-1})	High fat (162 g kg^{-1})		L	Q
Voluntary intake (DM basis)							
% body weight	2.26	2.29	2.10	1.83	0.09	.01	.02
Kg^{-1}	7.04	7.33	6.54	5.68	0.34	.03	.02
G $kg^{-0.75}$	94.84	97.00	79.65	80.14	4.84	.03	NS
Apparent nutrient digestibility coefficient (DM basis)							
Dry matter (g kg^{-1})	631	612	637	632	11.0	NS	NS
Crude protein (g kg^{-1})	734	694	702	715	14.2	NS	NS
Acid detergent fiber (g kg^{-1})	278	265	307	333	23.7	.16	NS
Neutral detergent fiber (g kg^{-1})	335	331	376	413	23.8	.05	NS
Fatty acid (g kg^{-1})	822	735	741	640	22.1	.01	NS
Gross energy (J kJ^{-1})	658	644	666	647	12.2	NS	NS
Digestible energy (MJ kg^{-1})	12.7	12.7	13.4	13.3	0.25	0.05	NS

[Z] Contrasts were the linear (L) and quadratic (Q) effects of increasing fat levels. No cubic effects were detected.
[Y] Pooled standard error.

Table 5. Fatty acid intake and estimated digestible energy intake of steers fed four levels of fat in pelleted canola screenings diets

	Diets					Contrasts[Z] (P-value)	
	Low fat (67 g kg^{-1})	Medium low fat (100 g kg^{-1})	Medium high fat (128 g kg^{-1})	High fat (162 g kg^{-1})	SEM[Y]	L	Q
Total fatty acid intake (g d^{-1})	344.3	551.6	631.8	697.8	33.2	< .01	NS
Digestible fatty acid intake (g d^{-1})	283.0	404.6	467.2	445.7	28.3	< .01	NS
Digestible energy intake (MJ d^{-1})	71.1	78.2	74.0	66.1	4.1	NS	< .05

[Z] Contrasts were linear (L) and quadratic (Q) effects of increasing fat level. No cubic effects were detected.
[Y] Pooled standard error of the mean

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Canola Screenings as a Fiber Source in Barley-Based Feedlot Diets: Effects on Rumen Fermentation and Performance of Steers

INTRODUCTION

Formulation of finishing diets for beef cattle to attain desired levels of productivity can involve numerous feed ingredients. Some factors influencing choice of dietary ingredients include cost, availability, animal acceptability and desired level of performance. Current finishing rations for western Canadian beef cattle are formulated with limited roughage levels (50 to 150 g kg^{-1} DM basis). The use of low roughage diets allows for the formulation of energy-dense diets and improves the ability to mix and deliver large quantities of feed. In finishing diets, roughages are primarily used to maintain rumen function and to minimize the incidence of metabolic disorders including acidosis, laminitis, rumenitis and liver abscesses (Britton and Stock 1987). These conditions are commonly associated with rapid digestion of diets that contain high levels of starch (i.e. cereal grains).

Addition of fat, to increase the energy content of cereal grain-based finishing diets has been shown to improve ADG and feed to gain ratios (Zinn 1989; Huffman et al. 1992; Krehbiel et al. 1995). However, in a recent review by Brandt (1995), the greatest response to feeding fat has been in rapidly fermented diets with the greatest potential for acidosis. It has been postulated that supplemental fat may serve as a means to reduce the rate of starch digestion in the rumen (Brandt 1995). With this in mind, the benefits of added fat may serve to improve energy density in the diet and lead to more consistent patterns of intake and reduce the risk of health problems associated with erratic feed consumption patterns.

Canola screenings have been shown to contain on average 250 to 300 g kg^{-1} ADF and 70 to 160 g kg^{-1} EE (Pylot et al. Accepted). Research on the feeding value of canola screenings is limited. When fed to sheep, canola screenings were limited to about 30% of the diet due to possible negative associative effects of weed seeds and fat on intake (Tait et al. 1986). Weisen et al. (1990) found that feeding canola screenings to dairy cows at inclusion rates of 0, 7 and 14% of the diet DM had no negative effects on DM intake, milk yield or milk composition. Canola screenings would appear to be a good source of fiber and energy for growing and finishing cattle and may be an effective feed ingredient for western Canadian finishing diets. No information exists, however, on the feeding value of canola screenings for

beef cattle when fed in combination with barley. Similarly, little is known about the ruminal fermentation characteristics of canola screenings and their ability to minimize pH changes when fed with a rapidly fermentable feedstuff such as barley grain. The objectives of this research were to determine the effects of feeding canola screenings in combination with barley grain on the rumen environment and to evaluate the inclusion level of canola screenings in finishing diets on performance and carcass characteristics of feedlot steers.

MATERIALS AND METHODS

Metabolism Trial

Four Hereford steers (698 $\pm$ 70 kg) with cannulas in the rumen were used in a 4 x 4 Latin square feeding trial to evaluate the effects of canola screenings inclusion rate on ruminal fermentation parameters. Animals were housed and fed in individual pens in the metabolism barn of the Department of Animal and Poultry Science at the University of Saskatchewan. Pen design consisted of a 13 m^2 steel panel structure with rubber floor matting and nipple water bowls. Animal care protocols were set and carried out according to the Canadian Council for Animal Care (1993).

Four experimental treatments were utilized based on the ratio of canola screenings to barley in the diet. These included 100:0; 75:25; 50:50; 25:75 (as fed basis), respectively (Table 1). Canola screenings were supplied from a western Canadian canola crushing plant in the form of a 10-mm pellet. Canola screenings were ground through a 3-mm screen prior to pelleting. Barley grain was provided by the university farm and dry rolled to ensure hull breakage and endosperm exposure. Mineral and salt were offered daily to meet animal requirements. Prior to the experiment, steers were fed ad libitum, a basal ration for 7 d consisting of 500 g kg^{-1} canola screenings, 250 g kg^{-1} rolled barley and 250 g kg^{-1} chopped alfalfa hay to allow adaptation to the feed ingredients and environment.

In each 29-d period, steers were gradually adjusted to the experimental diets from d 1 through d 16 and were fed twice daily at 0800 and 1600 h. Voluntary intake was measured on d 17 through d 23 by offering experimental diets at levels approximately 10% in excess of ad libitum intake. Feed samples were collected for chemical analysis during the last 10 days of each period. Feed restriction (85% of VI) to ensure complete consumption of diets

occurred on d 24 followed by rumen fluid collections on d 27 to 29. Across diets, restricted intake during this period averaged 15.2 kg (as fed). Ruminal fluid was collected from each steer at 0800 (immediately prior to the morning feeding), 1000, 1200, 1400, 1600 (immediately prior to the afternoon feeding), 1800, 2000 and 2200 h. Fluid samples were obtained by sampling the rumen at the cranial-ventral, ventral and caudal-ventral regions. The combined fluid samples were then strained through four layers of cheesecloth and immediately measured for pH using a portable pH meter (Fisher Accumet model 825 MP, Pittsburgh, PA, USA). Two (40 mL each) rumen fluid samples were acidified with 6 N sulfuric acid, capped and frozen at -20°C for analysis of NH_3N and volatile fatty acids.

Feedlot Trial

Sixty-six Charolais crossbred steers with an average weight of 430 ± 31.4 kg were used in an 84-d finishing trial at the Agriculture and Agri-Food Canada Research Station at Lethbridge, Alberta. Steers were ranked by weight and within weight group randomly assigned to treatment. Cattle were housed individually and fed with a Data Ranger (American Calan Inc., Northwood, NH). Dietary treatments were the same as those used in the metabolism trial with the exception that in all diets, 50 g kg^{-1} of the canola screenings were replaced with 50 g kg^{-1} of a supplement premix consisting of 621.5 g kg^{-1} canola screenings, 230 g kg^{-1} limestone, 116 g kg^{-1} mineral/vitamin premix, 0.01 g kg^{-1} sodium selenite, 10 g kg^{-1} urea, 10 g kg^{-1} molasses, 10 g kg^{-1} canola oil and 2.5 g kg^{-1} pellet binder. A fifth treatment that consisted of 750 g kg^{-1} barley grain, 200 g kg^{-1} barley silage, and 50 g kg^{-1} supplement (as fed-basis) was also included. This treatment was included as a base line to compare the performance of cattle fed canola screening-based diets with that of steers fed a diet commonly used in western Canada.

The cattle were adapted from a silage-based backgrounding diet to their assigned diets over a 2-wk period. The composition of the initial diet on an as-fed basis was 850 g kg^{-1} barley silage, 100 g kg^{-1} supplement and 50 g kg^{-1} barley grain. The step-ups were completed by reducing the silage by 10% and increasing barley grain and / or canola screenings until the desired level was reached in the diet.

The pelleted canola screenings utilized in this feeding trial were provided from the same plant and batch as used in the rumen metabolism trial. Barley silage and barley grain were supplied by the Lethbridge Research Center (Lethbridge, Alberta). Steers were fed once daily between 0800 and 1000 h in individual pens in an open-front building and bedded with wood shavings with ad libitum access to both feed and water. Orts were collected weekly.

Steers were individually weighed on two consecutive days at the commencement of the study, on single days at 21-d intervals and on two consecutive days prior to shipment for slaughter. Animals were slaughtered at Maple Leaf Foods in Lethbridge, Alberta with carcass measurements obtained though the Agriculture and Agri-Food Canada Blue Tag Program. The left side of each carcass was knife ribbed on the morning following slaughter between the 12^{th} and the 13^{th} ribs. Measurements taken on the exposed surface of the longissimus muscle included longissimus muscle area, average thickness of subcutaneous fat, marbling score (1 = very abundant, 5 = moderate, 7 = trace, 10 = devoid), and lean meat yield.

Chemical Analysis

Feed samples collected during the metabolism and the feeding trials were ground through a 1-mm screen using a Retch mill (Brinkmann Corp.) and were analyzed for moisture, CP (Kjeldahl nitrogen x 6.25), ADF, ash and EE according to the procedures of the Association of Official Analytical Chemists (AOAC 1990). Neutral detergent fiber was determined according to the method of Van Soest et al. (1991). Non-structural carbohydrate was estimated according to Sniffen et al. (1992).

Ruminal fluid samples were thawed and centrifuged at 3000 x *g* for 10 min for VFA analysis. One mL of supernatant was combined with 0.2 mL of 25% (wt vol^{-1}.) metaphosphoric acid and 0.3 mL of 1% crotonic acid (internal standard). The samples were allowed to stand for 10 min and then centrifuged (14,000 x *g* for 12 min). Approximately 0.75 mL was transferred to a glass vial and subsequently injected into a Varian Star 3400CX gas chromatograph with a 8200CX Autosampler fitted with a Stabilwax DA capillary column (30m x .25 mm i.d., Restek, Bellefonte, PA). The isothermal injector temperature was held constant (220 °C) with an initial column temperature of 140 °C (held for 5 min) and then

programmed to increase at a rate of 50°C min^{-1} to 240 °C (held for 2 min) accompanied by a detection temperature of 230 °C. Rumen fluid samples were also analyzed for NH_3N using a Cole Parmer ammonium electrode (Model No. 27502-02, Vernon Hills, IL, USA).

Statistical Analysis

The General Linear Model procedure of the SAS Institute Inc. (1991) was used to carry out the analysis of variance for all results. The results from the metabolism trial were analyzed as a 4 x 4 Latin square with treatment, period and animal as terms in the model. Polynomial regression was used to test the linear, quadratic and cubic effects of canola screenings inclusion rate. The feeding trial results were analyzed as a completely randomized design. Treatment effects were analyzed in two ways. Initially, polynomial regression was used to test the linear, quadratic and cubic effects of canola screenings inclusion rate on feedlot performance and carcass characteristics of steers. This was done to be consistent with the metobolism trial. Secondly, means of all five treatments were separated where appropriate, using the Student Newman-Keuls test (Steel and Torrie 1980).

RESULTS AND DISCUSSION

Metabolism Trial

Replacement of canola screenings with barley grain in the experimental diets resulted in reduced CP, NDF, ADF and EE and increased non-structural carbohydrate levels (Table 1). Observed changes in nutrient profiles are the result of differences in chemical composition of canola screenings and barley grain.

Ruminal pH was highest prior to the morning feeding. It then declined substantially following feeding up to 1200 h and then increased to 1600 h (Table 2). Although diminished, a similar pattern developed after the 1600 h feeding. Diurnal patterns in ruminal pH are well documented and are more pronounced when discrete meals containing high concentrations of soluble carbohydrates are consumed (Khorasani et al. 1992;Yang et al. 1997). The diurnal pH patterns were somewhat different between treatments and after each feeding. Following the morning feeding, ruminal pH in steers consuming barley supplemented diets dropped

below 5.5 at 1000 h and remained at this level through 1400 h and then recovered sharply at 1600 h. In contrast, steers consuming only canola screenings maintained pH values above 5.5 and showed a more gradual recovery in pH. It was also noted that ruminal pH declined in a linear ($P < 0.05$) fashion at each time of sampling as barley grain increased in the diet, with the exception of 1200 and 1400 h where a quadratic decrease was noted (Table 2). These results indicate a greater resistance to ruminal pH change when canola screening-based diets are fed relative to barely-based diets.

No differences were noted in total VFA concentrations prior to the morning feeding. However, total VFA levels rose sharply after feeding following an inverse pattern to ruminal pH. Increasing the level of barley in the diet resulted in a linear increase ($P < 0.05$) in total VFA levels at 1000 and 1400 h (Table 3). Our results are consistent with other studies which showed reduced ruminal pH and increased total VFA levels as the amount of rapidly fermented carbohydrate from barley grain in the diet increased (McAllister et al. 1990; Feng et al. 1995; Hatfield et al. 1997).

Molar percentage of ruminal acetate decreased ($P < 0.05$) while that of propionate increased ($P < 0.05$) linearly as the level of barley increased in the diet (Table 3). This resulted in a lower ($P < 0.05$) acetate:propionate ratio for the barley-based diets. These results are in agreement with other researchers who reported similar responses for molar proportions of ruminal acetate and propionate to increased levels of readily fermentable carbohydrates in the diet (Hatfield et al. 1997; Reinhardt et al. 1997). The observed changes in molar ratios of acetate:propionate are related to a decline in ruminal pH after feeding to or below 5.5, as a result of barley grain inclusion. Kaufmann et al. (1980) found that ruminal pH decreased with higher starch intake and the concentration of propionic acid increased and that of acetic acid decreased until the ratio was approximately 1:1 at pH of 5.2.

Ruminal NH_3N levels were higher in steers fed 1000 g kg^{-1} canola screenings and declined in a linear manner ($P < 0.05$) when barley grain incrementally replaced canola screenings (Table 2). This is despite the fact that barley protein is highly degraded in the rumen (McAllister et al. 1990). The higher ruminal NH_3N concentration for the canola screening- relative to the barley-based diets is likely due to the higher levels of CP in the canola screening-based diets (Table 1). Other researchers have reported an increased

concentration of ruminal NH_3N as the level of rapidly degradable protein in the diet increased (Thomas et al. 1984; Shain et al. 1998;). Another explanation is that protein of canola screenings could be rapidly degraded in the rumen. This conclusion is supported by the findings of Deacon et al. (1988) and Wang et al. (1997) who reported high ruminal degradability of canola seed protein (870 to 910 g kg^{-1} of CP).

Contrary to expectation, variations in NH_3N were not similar in all diets. Steers fed 750 or 1000 g kg^{-1} canola screenings were noted to have diurnal patterns in NH_3N levels which peaked 2 h post-prandial (1000 and 1800 h). In contrast, steers fed 250 or 500 g kg^{-1} canola screenings experienced declining concentrations of NH_3N post-prandial (Table 2). Boss and Bowman (1996) also reported declining NH_3N levels in steers post-prandial when 80% barley was included in the diets. Obara et al. (1991) suggested that the relationship between lowered ruminal NH_3N levels in energy-supplemented animals post-prandial, is associated with increased rates of rumen fermentation, stimulating an increased uptake of NH_3N for microbial protein synthesis. Satter and Slyter (1974) suggest a critical threshold of 5 mg dL^{-1} NH_3N may be needed for maximum microbial protein synthesis. However, Mehrez et al. (1977) suggested that maximum rumen fermentative activity was obtained when ruminal NH_3N reached 19 to 23 mg dL^{-1}. As noted in Table 2, ruminal NH_3N levels for steers fed 250 or 500 g kg^{-1} canola screenings were lower than the critical level suggested by Mehrez et al. (1977) and thus may have limited microbial growth.

Feeding Trial

Canola screenings used in the finishing trial contained 150 g kg^{-1} CP, 296 g kg^{-1} ADF, and 248 g kg^{-1} starch (Table 1). Replacement of canola screenings with barley grain resulted in lower concentrations of CP and ADF and higher levels of starch.

For steers fed the canola screening-based diets, dry matter intake increased ($P < 0.05$) with barley grain inclusion rate from d 1 to 42, was unaffected from d 43 to 83, and no treatment differences were noted over the entire trial (Table 4). Feed efficiency (kg gain kg^{-1} feed) responded linearly and positively ($P < 0.05$) throughout the trial to increased levels of barley grain with efficiencies being generally higher in the last half of the feeding trial. Furthermore, increasing the level of barley grain in the diet resulted in a linear ($P < 0.05$)

improvement in ADG from d 1 to 42, from d 43 to 84, and over the course of the entire trial. The extent of improvement included increases of 36, 70, and 76% in overall ADG as the level of barley grain in the diet increased to 250, 500, and 750 g kg^{-1}, respectively (Table 4).

Lower ADG (0.43 and 0.75 vs. 1.06 and 1.24 kg d^{-1}) and feed efficiency (0.04 and 0.07 vs 0.12 and 0.14) in the first 42 d of the experiment for steers fed 750 and 1000 g kg^{-1} relative to those fed 250 or 500 g kg^{-1} canola screening-based diets may have been related to complications with diet adaptation. During this period, the incidence of bloat defined as a score of three or better using the system of Majak et al. (1995) was 15 and 6 cases for the 1000 and 750 g kg^{-1} canola screening diets, respectively. No cases of bloat were reported for 500 and 250 g kg^{-1} canola screening diets, respectively. No fatalities were reported due to feedlot bloat. It is likely that the reduced intake and poor feed efficiency of steers fed the 1000 and 750 g kg^{-1} canola screening diets during the first 42 d of the trial were due in part to digestive disturbances which resulted in increased incidence of bloat.

The linear response in overall ADG with increasing levels of barley in the diet is likely due to the higher dry matter intake during the first 42 d of the trial and the better feed efficiency during the entire feeding period for steers fed diets with increasing levels of barley (Table 4). As noted in the metabolism trial, steers fed diets with increasing levels of barley had higher total volatile fatty acid levels and lower acetate:propionate ratios (Table 3). A lowering of the acetate:propionate ratio improves feedlot performance since propionate is energetically more efficient than acetate (Jenkins and Thonney 1988). Propionate is also the primary precursor for glucose metabolism in ruminants (Brockman and Laarveld 1986). The results of the present study agree with recent research (Zinn et al. 1994 and Hatfield et al. 1997) where improved efficiencies were reported in cattle fed higher levels of cereal grains as compared with forage diets. In the current study, replacement of canola screenings with barley yielded higher dietary levels of readily soluble carbohydrates providing greater yields of propionate for ruminal fermentation.

Steers fed the higher levels of barley grain had a lower ($P = 0.05$) lean meat yield, contained more fat ($P < 0.05$) and tended to finish heavier ($P = 0.09$) than steers fed diets containing canola screenings (Table 5). These results reflect the improved ADG and feed efficiency noted as the level of barley grain in the diet increased.

It is of interest to compare the performance of canola screening-fed cattle with that of cattle fed a standard finishing diet (Table 4). In this study, cattle fed a diet consisting of 750 g kg^{-1} barley grain, 200 g kg^{-1} barley silage, and 50 g kg^{-1} supplement gained 1.23 kg d^{-1} and had a gain:feed ratio of 0.13. Cattle fed 250 and 500 g kg^{-1} canola screenings exhibited similar gains and gain to feed ratios as conventional barley fed cattle. Feed costs kg^{-1} gain for the barley grain / barley silage control, and the 250 and 500 g kg^{-1} canola screening diets were $ 1.20, and $ 1.12 and $ 1.20, respectively. It was only when canola screenings comprised more than 500 g kg^{-1} of the diet that performance declined and consequently the cost of gain increased.

CONCLUSIONS

Addition of barley grain to diets based on canola screenings resulted in shifts in ruminal fermentation towards lower ruminal pH, higher overall levels of VFA and lower acetate:propionate ratios. The current findings indicate that canola screenings used as a fiber source in finishing diets, while superior to barley grain, were marginal in providing a stable ruminal environment to buffer against fluctuations in rumen pH. The incidence of bloat increased, during the first 43 d of the trial, when canola screenings exceeded 50% of the diet. Improvements in daily gain and feed efficiency occurred as barley replaced canola screenings suggesting that although canola screenings were readily fermented, barley grain was more digestible and yielded more fermentable energy than canola screenings. Nonetheless, cattle performed in a cost efficient manner with acceptable gains when fed 250 or 500 g kg^{-1} canola screenings in the diet, indicating that canola screenings may serve as a viable feed ingredient in high grain rations.

Table 1. Ingredients and chemical composition of diets used in the rumen metabolism (Trial 1) and the finishing (Trial 2) trials.

	Canola screenings:barley grain			
	25:75	50:50	75:25	100:00
		Metabolism trial		
Ingredient composition (g kg^{-1} as-fed)				
Canola screenings	247.0	496.0	745.0	992.0
Barley grain	745.0	496.0	247.0	0.0
1:1 Mineral-vitamin mix[Z]	4.0	4.0	4.0	4.0
Stock salt[Y]	4.0	4.0	4.0	4.0
Chemical composition (g kg^{-1} dry matter)				
Crude protein	102.0	111.0	121.0	130.0
Acid detergent fiber	111.0	155.0	198.0	241.0
Neutral detergent fiber	237.0	268.0	298.0	328.0
Ether extract	41.0	64.0	87.0	110.0
Ash	43.0	64.0	85.0	106.0
Non-structural carbohydrates	577.0	493.0	409.0	326.0
		Finishing trial		
Ingredient composition (g kg^{-1} as-fed)				
Canola screenings	200.0	450.0	700.0	950.0
Barley grain	750.0	500.0	250.0	0.0
Supplement[X]	50.0	50.0	50.0	50.0
Chemical composition (g kg^{-1} dry matter)				
Crude protein	133.0	140.0	144.0	150.0
Acid detergent fiber	117.0	194.0	239.0	296.0
Starch	505.0	404.0	335.0	248.0

[Z] 180 g kg^{-1} Ca, 180 g kg^{-1}P, 9 g kg^{-1} Mg, 10,500 mg kg^{-1} Zn, 90 mg kg^{-1} I, 9000 mg kg^{-1} Fe, 5250 mg kg^{-1} Mn, 3150 mg kg^{-1} Cu, 45 mg kg^{-1} Co, 3,000 mg kg^{-1} Fl, 500,000 IU kg^{-1} Vit. A, 50,000 IU kg^{-1} Vit. D_3, 500 IU kg^{-1} Vit. E.

[Y] 990 g kg^{-1} NaCl, 120 mg kg^{-1} Co, 180 mg kg^{-1}I.

[X] 621.5 g kg^{-1} canola screenings, 230 g kg^{-1} limestone, 116 g kg^{-1} vitamin/mineral premix, 0.01 g kg^{-1} sodium selenite, 10 g kg^{-1} urea, 10 g kg^{-1} molasses, 10 g kg^{-1} canola meal, and 2.5 g kg^{-1} pellet binder.

Table 2. Effects of increasing levels of barley on ruminal pH and NH_3N concentration for steers fed canola screening-based diets (n = 4).

		Canola screenings:barley grain					Contrasts[Z]	
Time		25:75	50:50	75:25	100:00	SEM[Y]	L	Q
0800	pH	6.82	6.84	6.91	7.00	00.05	0.04	0.55
	NH_3N mg dL^{-1}	16.9	16.7	21.7	25.5	2.03	0.01	0.36
1000	pH	5.19	5.39	5.41	5.79	0.07	0.01	0.28
	NH_3N mg dL^{-1}	13.2	13.8	24.8	30.5	2.75	0.01	0.39
1200	pH	5.10	5.16	5.27	5.65	0.04	0.01	0.01
	NH_3N mg dL^{-1}	12.0	11.4	16.4	19.8	1.58	0.01	0.25
1400	pH	5.37	5.45	5.49	5.91	0.09	0.01	0.12
	NH_3N mg dL^{-1}	11.9	12.3	15.2	17.1	1.65	00.05	0.67
1600	pH	5.81	5.99	60.05	6.15	0.12	0.10	0.75
	NH_3N mg dL^{-1}	12.9	14.5	15.8	17.9	1.32	0.03	0.86
1800	pH	5.15	5.21	5.42	5.46	00.05	0.01	0.89
	NH_3N mg dL^{-1}	13.3	15.0	20.5	24.2	2.29	0.02	0.69
2000	pH	5.04	5.11	5.25	5.48	0.07	0.01	0.32
	NH_3N mg dL^{-1}	12.1	13.1	18.5	20.7	2.04	0.01	0.79
2200	pH	5.17	5.28	5.41	5.55	0.07	0.01	0.83
	NH_3N mg dL^{-1}	12.6	13.0	17.7	20.0	1.89	0.02	0.63

[Z] Polynomial contrasts were linear (L) and quadratic (Q) effect of barley level.
[Y] Pooled standard error of the mean.

Table 3. Effect of increasing levels of barley on total ruminal volatile fatty acid (VFA), molar amounts and acetate: propionate ratio for steers fed canola screening-based diets (n = 4)

		Canola screenings:barley grain					Contrasts[Z]	
Time		25:75	50:50	25:75	100:00	SEM[Y]	L	Q
0800	Total VFA (mM)	64.60	61.08	65.15	61.75	7.62	0.90	0.99
	Acetate (%)	51.92	52.73	57.92	66.20	1.70	0.01	0.07
	Propionate (%)	34.54	31.46	27.43	18.72	1.63	0.01	0.14
	Acetate:propionate	1.52	1.72	2.16	3.58	0.17	0.01	0.01
1000	Total VFA (mM)	158.95	134.30	133.82	117.95	7.85	0.01	0.60
	Acetate (%)	50.58	51.75	56.47	62.00	1.84	0.01	0.28
	Propionate (%)	39.37	35.89	30.27	22.90	2.04	0.01	0.38
	Acetate:propionate	1.30	1.47	1.89	2.87	0.17	0.01	0.07
1200	Total VFA (mM)	151.25	139.67	145.47	116.47	12.46	0.13	0.51
	Acetate (%)	48.62	48.38	54.56	61.70	2.39	0.01	0.17
	Propionate (%)	40.87	38.99	33.21	24.42	2.40	0.01	0.20
	Acetate:propionate	1.22	1.28	1.67	2.63	0.22	0.01	0.08
1400	Total VFA (mM)	134.80	130.70	127.60	96.35	6.99	0.01	0.10
	Acetate (%)	48.94	47.35	53.68	61.58	2.58	0.01	0.12
	Propionate (%)	40.61	39.47	34.40	24.11	2.49	0.01	0.11
	Acetate:propionate	1.26	1.23	1.58	2.63	0.20	0.01	0.03
1600	Total VFA (mM)	120.60	97.95	97.03	94.22	11.20	0.16	0.41
	Acetate (%)	48.89	47.58	54.93	62.55	2.50	0.01	0.12
	Propionate (%)	40.49	37.80	33.36	22.74	2.65	0.01	0.18
	Acetate:propionate	1.26	1.28	1.67	2.88	0.22	0.01	0.04
1800	Total VFA (mM)	146.37	130.0	119.0	124.90	10.81	0.17	0.35
	Acetate (%)	50.09	48.67	55.31	58.92	2.48	0.02	0.35
	Propionate (%)	40.09	38.77	33.11	25.44	2.35	0.01	0.25
	Acetate:propionate	1.30	1.27	1.70	2.40	0.19	0.01	0.01
2000	Total VFA (mM)	143.93	136.17	145.80	117.70	12.70	0.27	0.45
	Acetate (%)	48.69	46.59	52.89	58.39	2.66	0.03	0.20
	Propionate (%)	41.47	40.11	35.81	26.64	2.80	0.01	0.21
	Acetate:propionate	1.25	1.18	1.49	2.27	0.21	0.01	0.09
2200	Total VFA (mM)	130.20	129.75	127.65	125.25	8.04	0.27	0.45
	Acetate (%)	48.11	45.01	52.28	58.64	3.11	0.03	0.18
	Propionate (%)	41.83	39.37	36.55	26.33	3.59	0.02	0.33
	Acetic:Propionate	1.26	1.56	1.44	2.30	0.24	0.02	0.09

[Z]Polynomial contrasts: linear (L) and quadratic (Q) effects of barley grain inclusion rate.
[Y]Pooled standard error of the mean.

Table 4. Weights, average daily gain (ADG), dry matter intake and feed efficiency of steers fed diets consisting of different ratios of canola screenings and barley grain (as-fed), and a barley grain / barely silage-based control diet.

		Canola screenings:barley grain					Contrasts[z],	
Item	Barley grain / barley silage-based diet	25:75	50:50	75:25	100:0	SEM[y]	L	Q
Days on test	83	83	83	83	83			
Treatment replicates	14	13	13	13	13			
Start of test weight (kg)	434.9	423.3	423.9	439.3	429.2	8.8	0.44	0.57
End of test weight (kg)	537.0a	542.1a	538.5a	521.4a	490.9b	9.26	0.0002	0.167
Day 1 through 42								
Dry matter intake (kg d^{-1})	9.1b	10.7a	10.9a	9.8ab	9.5ab	0.38	0.01	0.53
ADG (kg)	1.21a	1.46a	1.27a	0.75b	0.43c	0.10	0.0001	0.157
Gain:feed (kg kg^{-1})	0.13a	0.14a	0.12a	0.07b	0.04b	0.01	0.0001	0.57
Day 43 through 83								
DM intake (kg d^{-1})	9.2	10.2	10.9	10.4	9.6	0.55	0.43	0.22
ADG (kg)	1.26ab	1.40ab	1.49a	1.23ab	1.06b	0.11	0.015	0.25
Gain:feed (kg kg^{-1})	0.14	0.14	0.14	0.11	0.11	0.01	0.032	0.89
Day 1 to slaughter								
DM intake (kg d^{-1})	9.2b	10.4ab	10.9a	10.1ab	9.6ab	0.41	0.09	0.27
ADG (kg)	1.23a	1.43a	1.38a	0.99b	0.74c	0.08	0.0001	0.25
Gain:feed (kg kg^{-1})	0.13a	0.14a	0.13a	0.09b	0.08b	0.01	0.0001	0.70

a-c Means in the same row followed by different superscripts are different ($P < 0.05$).

[z]Orthogonal polynomial contrasts were linear (L) and quadratic (Q) effects of barley grain inclusion rate.

[y]Pooled standard error of the mean.

Table 5. Carcass characteristics of steers fed diets consisting of different ratios of canola screenings and barley grain (as-fed), and a barley grain / barely silage-based control diet.

Item	Barley grain / barely silage-based diet	Canola screenings:barley grain				SEM[Y]	Contrasts[Z]	
		25:75	50:50	75:25	100:0		L	Q
Treatment replicates	13	13	12	13	13			
Carcass weight (kg)	300.6	300.6	309.0	290.5	290.8	6.19	0.08	0.52
Average fat (cm)	12.2a	11.7ab	11.3ab	8.9ab	7.7b	1.11	0.006	0.73
Ribeye area (cm^2)	76.9	78.8	79.6	78.8	77.9	2.31	0.74	0.70
Marbling[X]	8.2	8.2	7.8	7.9	7.9	0.54	0.80	0.75
Lean meat yield (%)	56.9	57.5	57.8	58.6	60.2	1.01	0.05	0.49

[Z] Polynomial contrasts linear (L) and quadratic (Q) effects of barley grain inclusion rate.
[Y] Pooled standard error of the mean.
a,b Means in the same row followed by different letters are different ($P < 0.05$).
[X] Marbling score: 1 = very abundant, 5 = moderate, 7 = trace, 10 = devoid.

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Nutrient Value of High Fat Canola Screening Pellets with Increasing Levels of Added Calcium.

INTRODUCTION

The demand for canola seed and oil in the world market has increased the capacity of the Canadian canola crushing industry over the last decade. As a result, domestic processing of canola seed has resulted in an increased supply of by-products such as canola screenings. The production of canola screenings has almost doubled from 1.5 to 2.7 million kg per year from 1987 to 1997 (Pylot et al. unpublished data). The average chemical composition of canola screenings is 19.6, 22.5, 28.0 and 92% for crude protein, ether extract, acid detergent fiber and dry matter, respectively (Tait et al. 1986). As a percentage of total fatty acid content, canola screenings contain 52.2% oleic and 24.2% linoleic fatty acids (Wiesen et al. 1990). These relatively high nutrient contents suggests that canola screenings are a valuable feedstuff for ruminants. Tait et al. (1986) reported canola screenings to be fairly digestible. These workers reported digestibility coefficients by sheep of 60.2, 63.9 and 77.4% for dry matter, organic matter and crude protein, respectively.

Supplementation of dietary fat to ruminant diets has been shown to depress dry matter intake and fiber digestibility. These effects are more pronounced as the fat level in the diet increases or when there is a high degree of unsaturation (Palmquist and Jenkins, 1980). Henderson (1973) reported that one reason for the reduction in fiber digestibility is inhibition of growth and metabolism of rumen microbes by long-chain fatty acids. High fat canola screening diets have been shown to depress dry matter intake and nutrient digestibility. Pylot et al. (unpublished data) reported a quadratic decrease ($P<0.05$) in dry matter intake when the fat content of canola screenings increased from 6.7 to 16.2%. Exceeding 10% added fat appeared to be detrimental to both intake and nutrient digestibility (Pylot et al., unpublished data). In addition, they showed that total fatty acid intake and digestible fatty acid intake increased ($P>0.05$) in a linear fashion as the fat content of the diet increased. However, apparent fatty acid digestibility decreased ($P>0.05$) in a linear fashion as dietary fat level increased.

The addition of divalent cations, particularly calcium, to ruminant diets may improve digestibility of high fat diets. Grainger et al. (1957) postulated that fiber digestibility may improve because insoluble calcium soap formation removes fatty acid inhibition of the rumen bacteria. If formation of insoluble fatty acid soaps from divalent cations and fatty acids occurs in the rumen, it may be an important reaction in helping to maximize the utilization of high fat diets by ruminants. Divalent cations react with fatty acids to form insoluble soaps that do not reduce ruminal digestibility of fiber (Jenkins and Palmquist, 1984). Palmquist et al. (1986) showed improved fiber digestibility both in vitro and in vivo by replacing fatty acids with their soluble calcium salts. They also reported that insoluble soap formation is relatively slow and incomplete due to the fact that common calcium supplements in ruminant diets are insoluble in the rumen. Little is known about the extent of this reaction in the rumen and the factors affecting it. In addition, if the proportion of total rumen fatty acids as insoluble fatty acid soap could be increased, fiber digestibility would be expected to increase as well (Jenkins and Palmquist, 1982). No research exists in regard to nutrient availability in ruminants fed processed high fat canola screenings with supplemental calcium. The objective of this experiment was to study the effects of feeding increasing levels of added calcium from ground limestone (0, 1, 1.5 and 2% added calcium) in pelleted high fat (12% ether extract) canola screenings on voluntary intake and nutrient digestibility of cattle.

MATERIALS AND METHODS

Experimental Animals and Housing

Twelve yearling medium frame Hereford steers (337 ± 53 Kg) were assigned to one of four processed high fat (12% ether extract) canola screening diets differing in calcium concentration in a completely randomized block design with two periods of 30 days each. The animals were housed in 3.6 x 3.6 m individual pens with rubber mats with unrestricted access to water and fed individually in the Livestock Research Barn of the Department of Animal and Poultry Science, at the University of Saskatchewan. The cattle were cared for according to guidelines of the Canadian Council for Animal Care (1995).

Experimental Diets and Processing

The basal diet (no added calcium) consisted of canola screenings which were mixed, ground and blended with canola fines to obtain a canola screening pellet with 12% ether extract (DM basis). Prior to pelleting, ground limestone was added to diets 2, 3 and 4 to obtain 1, 1.5 and 2% added calcium. Each treatment was mixed and pelleted at New-Life Feeds in Saskatoon. The canola screenings were purchased from Cargill in Clavet and the canola fines were purchased from AG-PRO Canada in Saskatoon. A sample of the 12% fat canola screenings were retained for use as a control treatment (i.e. no added calcium).

Feeding Protocol

The four dietary treatments used in the feeding trial consisted of high fat (12%) canola screenings pellets (control) with increasing levels of supplemental calcium (1.0, 1.5 and 2.0%). Fresh feed was offered twice daily at 0800 and 1700h with ad libitum access to fresh water. During the adaptation period, the steers were gradually increased in the amount of canola screenings fed, until peak consumption was reached.

Data Collection

Prior to the feeding trial, a sample of pellets from each treatment were taken during processing and subjected to chemical analysis. Analytical analysis included the determination of moisture (method No. 930.15), Kjeldhal nitrogen (method No. 984.13) using a Kjeltec auto analyzer, acid detergent fiber (method No. 973.18), ash (method No. 924.05) and ether extract (method No. 920.39) according to the Association of Official Analytical Chemists (AOAC 1990). Gross energy was determined using an oxygen bomb calorimeter (Parr Model No. 1241) and a calorimeter controller (Parr Model No. 1720). Neutral detergent fiber was determined using the method of Van Soest et al. (1991). Calcium concentration was determined following digestion with a perchloric -nitric acid mixture (AOAC 1990 method No. 935.13) using a Perkin-Elmer Model 5000 atomic absorption spectrophotometer (Technicon GTPC auto analyzer II). Phosphorus concentration was determined calorimetrically (Pharmacia LKB ultraspec. III). The nutrient composition of the diets is shown in Table 1.

The steers were weighed individually at the start and the end of the voluntary intake period. The weighing was carried out before the morning feeding and averaged over two consecutive days. Total feed given to each individual animal was recorded daily and any feed removed from the bunks during the trial was weighed back to record individual total feed consumption. The daily gain was computed from duplicate individual initial and final weights.

Each period lasted 30 days. There was a 14 day period for adaptation to treatment diets, followed by a 7 day period of voluntary intake during which diets were fed ad libitum to provide approximately 10% orts. On day 22, the animals were moved into individual crates allowing a 3 day adaptation period prior to fecal collection. Fecal collection pans were placed under the crates and feces were collected daily during the last 5 days of each feeding period, weighed, and a 5% aliquot dried at 65 °C. At the end of the experiment, fecal samples from each steer were composited, ground through a 1 mm screen using a Christie-Norris mill and subjected to
chemical analysis according to the methods of the Association of Official Analytical Chemists (AOAC 1990) as described previously. Feed samples were collected daily during the collection period, composited, ground through a 1 mm screen and subjected to chemical analysis according to the methods mentioned earlier

Statistical Analysis

Feed intake and apparent dry matter, neutral detergent fiber, acid detergent fiber, crude protein, ether extract and energy digestibility as well as digestible energy values were subjected to analysis of variance in a randomized complete block design using the General Linear Model procedure of the Statistical Analysis System (SAS Institute Inc. 1990) computer program at the University of Saskatchewan. Polynomial orthogonal contrasts were used to detect linear, quadratic and cubic treatment effects on dry matter intake and nutrient digestibility.

RESULTS AND DISCUSSION

During the course of period 1, one animal on treatment 3 had to be removed from the trial Two animals on day three from treatment three and four, respectively, during the adaptation period of the second period were removed due to sickness. The two sick animals in the second period were replaced by new animals but the one from the first period was eliminated and his data were not included in the analysis. The two animals from period 2, were diagnosed polioencephalomalacia likely due to thiamine deficiency.

Chemical analysis of the feeds showed that the diets varied between 0.39 to 0.40% sulfur on dry matter basis. The maximum tolerable concentration of dietary sulfur in ruminants has been estimated at 0.40 percent (National Research Council, 1980). However, dietary sulfur levels above 0.3 to 0.4% may cause toxic effects (Kandylis, 1984). Therefore, it was concluded that thiamine deficiency may have been caused by excess sulfur in the diet. Thiamine can also be destroyed by lipid hydroperoxides or free radicals arising from their decomposition (Pokorny and Velisek, 1995). These researchers have observed losses of 20 to 60% of thiamine under normal storage conditions of dehydrated cereal, dairy and meat products. It is also possible that a proportion of thiamine had been destroyed by the high fat content in the diet, causing the thiamine deficiency in these animals. To prevent further problems it was decided to supplement all animals with 5.0 grams of thiamine per day mixed in the feed during the duration of period 2 (personnel communication, Carruthers, T.).

The nutrient composition (Table 3.1) of the diets used in the current study shows that thecrude protein content decreased slightly with increasing dietary calcium level. This decrease is likely due to sampling error. The nutrients in screenings can also vary among samples due to the variation in their physical composition. The crude protein content of canola screenings used inthis trial were similar to those used in other studies (Pylot et al. unpublished data). Despite, this slight variation in crude protein content, all diets were above the National Research Council (1996) requirements for growing beef cattle. The overall average ether extract was 12.8%. The rations were balanced for approximately 12% ether extract based on results obtained in previous

studies with canola screenings. This level of fat in canola screenings was shown to decrease dry matter intake and nutrient digestibility (Pylot et al. unpublished data). Neutral detergent fiber as well as acid detergent fiber were consistent among treatments with an overall average of 39.7 and 25.4% (DM basis), respectively. Moreover, ash content as well as calcium level were consistent with increasing level of added calcium carbonate. In addition, the calcium to phosphorus ratio increased from 1.7:1 (control) to 6.6:1 (2% added calcium) diet. The National Research Council (1980) reports that with adequate phosphorus (0.3% of DM), ruminant animals have been observed to perform satisfactorily with dietary calcium to phosphorus ratios between 1:1 and 7:1. Depressed performance has been observed with calcium to phosphorus ratios above 7:1, but these effects were not as severe as those below 1:1.

Voluntary dry matter intake (% of body weight) and the apparent digestibility coefficients for dry matter, organic matter, crude protein, neutral detergent fiber, acid detergent fiber, ether extract and gross energy (DM basis) for the control diet were 2.1, 57.3, 60.4, 71.4, 35.1, 28.5, 60.2 and 58.1%, respectively. These results are consistent with other canola studies. Pylot et al. (unpublished data) fed four canola screening diets ranging from 6.7 to 16.2% fat to cattle and showed a linear decrease ($P>0.05$) in dry matter intake with increasing fat content. They also showed that digestibility of dry matter, crude protein and gross energy were not significantly ($P>0.05$) affected by treatment, however, neutral detergent fiber digestibility showed a significant ($P<0.05$) linear increase. Fatty acid digestibility, however, showed a significant ($P<0.05$) linear decrease. Voluntary dry matter intake (% of body weight) and digestibility coefficients (% of DM) of dry matter, crude protein, acid detergent fiber, neutral detergent fiber, fatty acids and gross energy for the medium high fat diet which averaged 12.8% ether extract were 2.1, 63.7, 70.2, 30.7, 37.6, 74.1 and 66.6, respectively. The fat level in this study was similar to the medium high fat diet used of Pylot et al (unpublished data). Dry matter intake was 2.1% of body weight and was not affected by increasing supplemental calcium in the diet. Digestibility coefficients of the control diet in this study for DM,OM, CP, NDF and ADF were similar to those for the canola screenings of Pylot et al (unpublished

data) containing 12.8% fat. However, the digestibility coefficients for ether extract and gross energy were lower.

Table 3.2 shows the effect of increasing calcium level on dry matter intake and nutrient digestibility. Calcium had no effect (P>0.05) on dry matter intake, irregarless of whether it was expressed on a dry matter basis or on a body weight basis. Dry matter intake (% of body weight) was 2.11, 2.18, 2.05 and 2.19% (dry matter basis) for the 0.0, 1.0, 1.5 and 2.0 percent added calcium treatments, respectively. This agrees with the study of Zinn and Shen (1996), who fed Holstein steers a diet containing 6.8% fat and showed no effect on dry matter intake by increasing supplemental calcium from 0.0 to 0.45 and 0.90%, respectively. On the other hand, Schauff and Clark (1992) reported a linear decrease in dry matter intake when increasing amounts (0, 3, 6 and 9%) of calcium soaps of long-chain fatty acids were fed to lactating dairy cows, but only the diet with 9% added calcium soaps of long-chain fatty acids extensively depressed intake. These authors suggested that palatability of calcium soaps of long-chain fatty acids may be a problem, but the exact cause was unknown.

Dry matter and organic matter digestibility showed a quadratic decrease with increasing calcium level. The nature of the response was such that relative to the control, dry matter and organic matter digestibility decreased to the same degree at the 1.0 and 1.5% calcium level and further decreased at the 2.0% calcium treatment. These results are consistent with previous studies by Boggs et al. (1987) and Zinn, (1989) when increasing calcium levels were fed. In contrast, Schauff and Clark (1992) showed that organic matter digestibility was not changed by feeding increasing (0, 3, 6 and 9%) amounts of preformed calcium soaps of long chain fatty acids.

Increasing calcium concentration in the diet resulted in a cubic decrease (P>0.05) in crudeprotein digestibility as shown in Table 3.2. Highest crude protein digestibility (72.5%) was observed with the diet containig 1.5% added calcium and lowest (67.1%) for the diet containing 2.0% added calcium.

Supplemental calcium resulted in a linear decrease (14.2%, P>0.05) in apparent total tract neutral detergent fiber digestibility when calcium level increased from 0.0 to 2.0% in the diet. In contrast, White et al. (1958) reported that the depressive effect of

supplemental fat (5% corn oil) on total tract digestibility was completely reversed by increasing the dietary calcium from 0.3 to 0.9%. Since this study, numerous feeding trials have indicated that increasing dietary calcium in fat supplemented diets, results in improved digestibility of fiber (Grainger et al., 1961; Galbraith et al., 1971; Jenkins and Palmquist, 1982 and Drackley et al., 1985). Grainger et al. (1961) reported that the role of calcium in overcomming the negative effect of supplemental fat on fiber digestion is related to ruminal concentration of nonesterified free fatty acids. Later, Jenkins and Palmquist (1982), Drackley et al. (1985), Palmquist (1986) and Chalupa et al. (1986) reported that calcium reacts with nonesterified free fatty acids to form insoluble calcium soaps, thus eliminating the negative effect of fat on fiber digestion. It would appear, however, that in this study the formation of insoluble calcium soaps did not occur.

Several factors may limit formation of soap in the rumen when fat and minerals are fed. These include type and amount of mineral supplement, type of fat, rumen pH and possibly turnover rate of ruminal solids (Jenkins and Palmquist, 1982). Drackley et al. (1985) and Palmquist et al. (1986) reported that addition of calcium as limestone to fat supplemented diets did not result in appreciable changes in calcium soap formation. Calcium supplements in the form of limestone are not soluble enough to react with free fatty acids and form calcium soaps in the rumen (Jenkins and Palmquist, 1984). Palmquist et al. (1986) used soluble calcium sources such as calcium chloride and dicalcium phosphate to study the effects of calcium addition to fat supplemented diets. They reported that calcium chloride was more effective than dicalcium phosphate in promoting insoluble soap formation in the rumen, probably due to its higher solubility. Moreover, in vitro cell wall digestibility was greater with added calcium chloride than with dicalcium phosphate. Jenkins and Palmquist (1982) reported that the addition of calcium to high fat diets as 2% dicalcium phosphate increased the insoluble fatty acid soap formation and cell wall digestibility in vitro only slightly. Supplemental calcium from calcium chloride reacted more quickly with nonesterified fatty acids to form insoluble soaps, and cell wall digestibility was substantially improved. Moreover, they reported that both increasing saturation and increasing chain length of the fatty acid increased the extent to which a fatty acid forms an insoluble soap.

Common calcium supplements such as limestone in ruminant diets are insoluble in the rumen and it is unclear whether significant soap formation occurs in vivo. The relative insolubility of calcium in the form of limestone is likely the reason we did not see effective calcium soap formation in this study. Calcium chloride has a bitter taste and therefore tends to decrease feed intake if included in the diet at a higher concentration. Palmquist et al. (1986) used 1.25% calcium chloride in the total dry matter and showed that the bitterness of this salt decreased feed intake. They reported that smaller amounts, perhaps 0.5% of diet dry matter of calcium chloride should be explored to improve the rumen environment for fiber digestion with supplemental fat diets.

No significant treatment effects were found on digestibility of acid detergent fiber although the standard error of the mean was relatively large and may have masked a treatment effect (Table 3.2). Jenkins and Palmquist (1984) reported no significant effect on acid detergent fiber digestibility when 4.5% calcium soaps of long-chain fatty acids were supplemented to Holstein steers, which is consistent with the results of this study. However, Schauff and Clark (1992) reported that as the level of supplemental calcium soaps of long-chain fatty acids (0, 3, 6 and 9) increased, there was a cubic decrease on acid detergent fiber digestibility. Apparent ether extract digestibility averaged 53.3% and was not significantly ($P>0.05$) affected by increasing levels of added dietary calcium. It should be pointed out that the standard error of the mean for this parameter was also high and may have masked a treatment effect. Zinn and Shen (1996) showed no effect of increasing dietary calcium concentration from 0.0 to 0.45 and 0.90%. Pylot et al. (unpublished data) showed an average apparent ether extract digestibility in canola screenings of 73.4% and noted a linear decrease in fat digestibility as fat level increased in the diet. Apparent ether extract digestibility of the control diet in this study (60.2%) was lower than that (74.1%) of the 12.8% ether extract canola screening diet of Pylot et al. (unpublished data) but similar to the high fat diet (64%). Jenkins and Palmquist (1984) observed reduced fatty acid digestibility when 4.5% calcium soaps of long-chain fatty acids were included in the diets of lactating dairy cows. Ngidi et al. (1989) reported apparent digestibility of fatty acids decreased quadratically ($P>0.05$) by calcium soap addition. Fatty acid digestibility was similar among 0, 2 and 4% added calcium soap diets

but was decreased for the diet that contained 6% added calcium soaps of long-chain fatty acids.

Calcium supplementation had a negative linear effect on energy digestibility as well as on digestible energy value (Mcal/kg). Digestibility of energy was highest (58.1%) for the control diet and lowest (49.7%) for the diet with 2.0% added calcium. Digestibility of energy was not altered greatly until the diet containing 2.0% added calcium was fed. Digestible energy content (2.4 Mcal/kg DM) was similar for the diet containing 1.0 and 1.5% added calcium, highest (2.6 Mcal/kg DM) for the control diet and lowest (2.1 Mcal/kg DM) for the 2.0% calcium added diet. Schauff and Clark (1992) reported a quadratic decrease ($P>0.05$) in digestible energy content when diets were fed with increasing levels (0, 3, 6 and 9%) of calcium soaps of long-chain fatty acids to lactating dairy cows. The lowest digestible energy value was for the diet with 9% added calcium soaps of long-chain fatty acids, similar to the results of the present study.

Martinez and Church (1970) reported that 450 mg/kg of calcium in rumen fluid is toxic to rumen bacteria. Palmquist (1986) recommends 0.9 to 1.0% dietary calcium (soluble) when high fat diets are fed, which is consistent with the toxicity level of calcium reported by Martinez and Church (1970). However, calcium chloride above 0.5% in the total diet dry matter may have a bactericidal effect. The calcium concentration in this study was 0.83% for the control diet and 1.83, 2.37 and 2.98% for the 1.0, 1.5 and 2.0% supplemental calcium treatment diets, respectively. Therefore, it might be concluded that the 1.5 and 2.0% supplemental calcium diets provided calcium levels that were toxic to rumen microbes, thus leading to a reduced nutrient digestibility.

CONCLUSIONS

Increasing the level of added calcium to high fat canola screening diets showed a slight but non-significant effect on dry matter intake. Digestibility of acid detergent fiber and ether extract were not significantly ($P>0.05$) affected by increasing the dietary calcium level.

Dry matter and organic matter digestibility showed a quadratic ($P < 0.05$) decrease with increasing dietary calcium level. Crude protein digestibility decreased in a cubic ($P < 0.05$) fashion as dietary calcium level increased. Energy digestibility and digestible energy content (Mcal/kg DM) showed a linear ($P < 0.05$) decrease with increasing calcium level in the diet. Similarly, neutral detergent fiber also showed a linear ($P<0.05$) decrease with increasing dietary calcium level.

Supplemental fat increases the free fatty acid concentration in the rumen and decreases rumen and total tract digestibility of organic matter. High concentration of free fatty acids in the rumen are detrimental to the rumen bacteria. Free fatty acids in the rumen bind to calcium forming calcium soaps of fatty acids and thereby play a role in overcoming the negative effects of supplemental fat on fiber digestion. Studies have indicated that when dietary calcium is increased in fat supplemented diets, digestibility of fiber usually increases (Grainger et al., 1961; Galbraith et al., 1971; Jenkins and Palmquist, 1982 and Drackley et al., 1985). However, the results of this study indicated that was not appreciable soap formation of fatty acids with calcium in the rumen. Therefore, this study does not support the idea that traditional calcium supplements improve rumen function and nutrient digestibility of high fat diets by increasing the formation of calcium soaps of fatty acids in the rumen. The results in fact show that supplemental calcium actually resulted in a negative effect on digestibility, possibly due to excess calcium levels in the rumen fluid.

Table 1. Chemical composition of the diet used in the digestibility trial.

	Supplemental calcium (% of DM)			
	0.0	1.0	1.5	2.0
Crude protein (%)	17.3	16.3	16.1	15.5
Ether extract (%)	12.7	13.0	13.0	12.3
Neutral detergent fiber (%)	39.2	40.3	40.0	39.4
Acid detergent fiber (%)	25.2	26.4	24.7	25.5
Ash (%)	8.2	10.6	11.7	12.8
Gross energy (MJ kg^{-1})	18.8	18.4	17.6	17.6
Calcium (%)	0.8	1.8	2.4	3.0
Phosphorous (%)	0.5	0.5	0.5	0.5

Table 2. Effect of calcium level in processed canola screening diets of dry matter intake and nutrient digestibility coefficients.

	Supplemental calcium (% of DM)					Contrast		
	0.0	1.0	1.5	2.0	SEM	L	Q	C
Dry matter intake								
kg d^{-1}	7.2	7.6	6.7	7.2	1.9	NS	NS	NS
% of body weight	2.1	2.2	2.1	2.0		NS	NS	NS
g $kg^{-0.75}$	90.3	93.8	87.5	93.8		NS	NS	NS
Apparent nutrient digestibility coefficient (%)								
Dry matter	57.3	54.7	54.5	46.5	1.2	0.0001	0.01	NS
Organic matter	60.4	58.7	58.9	52.4	1.1	0.0007	0.03	NS
Crude protein	71.4	69.5	72.6	67.1	1.0	NS	NS	0.01
Neutral detergent fiber	35.1	28.6	31.9	20.9	2.9	0.01	NS	NS
Acid detergent fiber	28.5	27.7	29.9	16.6	3.2	NS	NS	NS
Ether extract	60.2	51.9	52.2	48.8	4.1	NS	NS	NS
Gross energy	58.1	55.1	55.3	49.7	1.3	0.0008	NS	NS
Digestible energy (MJ kg^{-1}	10.9	10.0	10.0	8.8	0.06	0.0001	NS	NS

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Publications Arising From This Project

The following manuscripts based on the work reported from this study have either been published, are accepted or will be submitted for publication in scientific journals:

- Pylot, S. 1999. Composition and nutritive value of canola screenings for ruminants. M.Sc. Thesis, University of Saskatchewan

- Klassen-Wiebe, N. 1999. Effect of calcium addition to high fat canola screening diets on voluntary intake and nutrient utilization in growing steers. M.Agri. Thesis, University of Saskatchewan

- Pylot, S., McKinnon, J.J., Mustafa, A., Racz, V., and Christensen, D. 2000. Effects of processing and fat content of coarse canola screenings on voluntary intake and total tract nutrient digestibility of beef steers. Accepted Canadian Journal of Animal Science.

- Pylot, S., McKinnon, J.J., McAllister, T., Mustafa, A., Popp, J., and Christensen, D. 2000. Canola screenings as a fibre source in barley-based feedlot diets: Effects on rumen fermentation and performance of steers. Accepted Canadian Journal of Animal Science.

- Pylot, S., McKinnon, J.J., Mustafa, A., Racz, V., and Christensen, D. 2000. Physical and chemical composition of western Canadian Canola screenings. In preparation for Canadian Journal of Animal Science.