THE NUTRITIVE VALUE OF HIGH FIBER CANOLA MEAL FOR RUMINANTS

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Arif F. Mustafa

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SUMMARY OF DISSERTATION

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DEGREE OF DOCTOR OF PHILOSOPHY

by

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The Nutritive Value of High Fiber Canola Meal for ruminants

Tail-end dehulling segregates canola meal (CM) into high fiber (HFCM) and low fiber (LFCM) meals. The objective of this study was to determine the nutritive value of HFCM as a protein source for ruminants. The first trial determine to chemical characteristics of HFCM relative to LFCM and CM. Results indicated that relative to CM, HFCM contained 23.6% more acid detergent fiber (ADF), 52.4% more acid detergent lignin (ADL) and 6.6% more crude protein (CP) while LFCM contained 24.5% less ADF, 23.8% less ADL and 6.6% more CP. The second trial determined *in situ* rumen effective nutrient degradability for HFCM, relative to LFCM and CM. At 5% h^{-1} rumen flow rate, effective dry matter (DM) degradability was higher ($P<0.05$) in LFCM than in CM and was higher in CM than in HFCM. However, effective crude protein (CP) degradability was higher in LFCM and CM than in HFCM. No difference in effective CP degradability was observed between CM and LFCM.

In the third trial, the *in situ* disappearance of amino acids from HFCM, LFCM and CM was determined following 12 hour of rumen incubation. In CM and LFCM *in situ* disappearance was highest ($P<0.05$) for glutamate and lowest ($P<0.05$) for phenylalanine while in HFCM it was highest for glutamate and lowest for isoleucine.

The fourth study determined nutrient digestibility coefficients and digestible energy (DE) value for HFCM and CM using ram lambs. The estimated DM and CP digestibility coefficients and DE (Mcal kg^{-1}) content for HFCM were 67.4%, 79.5% and 3.27, respectively. The corresponding values for CM were 70.4%, 84.1% and 3.37%, respectively.

The effects of feeding HFCM as a protein source relative to CM and soybean meal (SBM) to dairy cows were determined in the fifth trial. Results showed no differences in feed intake, milk yield and composition between treatments. However, cows fed HFCM and CM-based diets produced milk with lower ($P<0.05$) protein content than cows fed the SBM-based diet.

It was concluded that tail-end dehulling of CM resulted in a HFCM with a lower protein, a higher fiber (particularly ADF) content and reduced *in situ* and total tract nutrient digestibility relative to CM. However, incorporation of HFCM in dairy rations up to 10% of the ration did not adversely affect milk yield or composition relative to CM.

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CERTIFICATION OF THESIS WORK

We, the undersigned, certify that **Arif Fouad MUSTAFA.,** candidate for the degree of Doctor of Philosophy has presented a thesis with the following title: ***"The Nutritive Value of High Fiber Canola Meal for Ruminants."*** We consider that the thesis is acceptable in form and content, and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on January 15, 1996.

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ABSTRACT

Five trials were conducted to assess the nutritive value of high fiber canola meal (HFCM) as a protein supplement for ruminants. Trial one determined the chemical composition of HFCM relative to low fiber canola meal (LFCM) and canola meal in a completely randomized design using samples obtained from five different crushers. In the second trial, the *in situ* nylon bag technique was used to determine disappearance of dry matter (DMD), crude protein (CPD), neutral (NDFD) and acid (ADFD) detergent fiber from canola meal, LFCM and HFCM samples derived from five different crushers following 24 h of rumen incubation. The effect of crushing plant of origin on *in situ* nutrient disappearance in the three meals was also determined. In the third trial, rumen nutrient kinetic parameters and effective degradabilities was determined for the blended canola meal, LFCM and HFCM. *In situ* disappearance of different amino acids canola meal, LFCM and HFCM following 12 h of rumen incubation was determined in the fourth study. The fifth trial was designed to determine nutrient digestibility coefficients by growing lambs of seven diets containing dehydrated alfalfa and 0, 25, 50 and 75% HFCM or canola meal in a randomized complete block design. Milk yield and composition responses of early to mid lactation dairy cows to diets supplemented with HFCM, canola meal or soybean meal were also determined. Six Holstein cows and three heifers were used in a triple 3 x 3 Latin square design.

Results of the first trial indicated that tail-end dehulling of canola meal resulted in more fractionation of fiber than protein between HFCM and LFCM. Relative to canola meal, HFCM contained 23.8% more acid detergent fiber (ADF), 52.4% more acid detergent lignin (ADL) and 6.6% less CP while LFCM contained 25.4% less ADF, 23.8% less ADL and 6.6% more CP. Results of the second trial showed differences in CPD and DMD within LFCM and HFCM but not within canola meal samples. However, no meal by crusher interaction was observed indicating that *in situ* nutrient disappearances in the three

meals were consistent across crushers. *In situ* DMD was higher ($P<0.05$) in LFCM relative to canola meal and was higher ($P<0.05$) in canola meal relative to HFCM. *In situ* CPD was higher ($P<0.05$) in canola meal and LFCM than in HFCM. No difference was observed in CPD between canola meal and LFCM. Compared with canola meal and HFCM, LFCM had higher ($P<0.05$) NDFD and ADFD.

At 5% h^{-1} rumen flow rate, effective DM degradability (trial three) was higher ($P<0.05$) in LFCM than in canola meal and was higher in canola meal than in HFCM while effective CP degradability was higher in LFCM and canola meal than in HFCM. Effective NDF degradability was higher ($P<0.05$) in LFCM than in canola meal and HFCM. However, effective ADF degradability was higher in LFCM than in canola meal and was higher in canola meal than in HFCM.

Tail-end dehulling had little effect on *in situ* disappearance of amino acids from canola meal, LFCM and HFCM following 12 h of rumen incubation. Except for glutamate, concentration of amino acids was higher in the residues than in the unincubated samples. In canola meal and LFCM *in situ* disappearance was highest ($P<0.05$) for glutamate and lowest ($P<0.05$) for phenylalanine while in HFCM *in situ* disappearance was highest for glutamate and lowest for isoleucine.

Results from the fifth trial indicated that at 75% inclusion rate, the diet containing HFCM had lower ($P<0.05$) DM, CP and gross energy digestibility coefficients relative to canola meal diet. The estimated DM and CP digestibility coefficients and digestible energy content (Mcal kg^{-1}) of HFCM were 67.4%, 79.5% and 3.27, respectively. The corresponding values for canola meal were 70.4%, 84.1% and 3.37, respectively. Results of the dairy trial showed no treatment effect on feed intake. However, cows fed diets containing canola meal or HFCM, consumed more ($P<0.05$) NDF than cows fed the soybean meal-based concentrate. No differences in milk yield, milk fat %, total solids % and lactose % were observed between treatments. However, cows fed diets containing HFCM and canola meal produced milk with lower ($P<0.05$) protein content than

cows fed the soybean meal-based concentrate.

It was concluded that tail-end dehulling of canola meal resulted in a HFCM with a lower protein, a higher fiber (particularly ADF) content and reduced *in situ* and total tract nutrient digestibility relative to canola meal. However, incorporation of HFCM in dairy rations up to 10% of the ration did not adversely affect milk yield or composition relative to canola meal.

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CHAPTER 1. INTRODUCTION

Canola meal is extensively used in Canada in livestock feeds for pigs and poultry and is the main protein source for dairy and beef cattle. On average, canola meal contains 38.3, 3.6, 17.5 and 21.5% crude protein, ether extract, acid and neutral detergent fiber, respectively. Relative to soybean meal, canola meal contains higher fiber due to the high hull content (30% of the meal). The fiber content of canola hull varies according seed type with hull from yellow-seeded canola containing less fiber than hull from brown-seeded canola. The high hull content exerts a negative effect on the digestible and metabolizable energy values of canola meal relative to soybean meal for monogastric animals.

Removing or reducing hull content of canola meal will result in meal having lower fiber content and improved crude protein and digestible energy levels. Such meal would be more competitive with soybean meal and could be used at higher levels in rations of monogastric animals. Several approaches have been used to remove or reduce the hull content of canola meal before or after oil extraction. Problems associated with dehulling prior to oil extraction include loss of oil in the hulls, irregular seed size rendering dehulling more difficult, difficulty during solvent extraction if the hulls are not present, low nutritive value of the hulls for ruminants and the high cost of dehulling. Poor separation is expected if dehulling is carried out after oil extraction.

Tail-end dehulling of canola meal is an alternative technique which involves fractionation of canola meal into a high fiber, low protein (60% of the meal) and a high protein, low fiber (40% of the meal) meal fraction. The technique involves tempering canola meal to 16% moisture followed by disc milling and sieving. When compared to front-end dehulling, tail-end dehulling offers the advantage of not reducing the oil yield and less equipment and processing stages are involved.

The low fiber, high protein canola meal is anticipated to exhibit higher

digestible and metabolizable energy values and thus be more competitive to soybean meal as a protein supplement for monogastric animals. In order for tail-end dehulling to gain acceptability, information regarding the nutritive value of the high fiber, low protein canola meal for ruminant animals is required. This study will provide information about the chemical composition, ruminal degradability and total tract nutrient digestibility of high fiber canola meal. The effects of feeding high fiber canola meal as a protein supplement on feed intake, milk yield and milk composition of dairy cows relative to canola and soybean meals will also be determined.

CHAPTER 2. REVIEW OF LITERATURE

2.1 Methods of Protein Evaluation

Different methods have been developed to determine or estimate the amount of feed protein that is degraded in the rumen and the proportion of undegraded protein available postruminally. Methods of measuring protein degradability can be divided into three main groups; *in vivo*, *in vitro* and *in situ* methods.

2.1.1 *In Vivo* Methods

Methods of measuring protein digestibility, postruminally, require animals fitted with abomasal or duodenal cannulae. In these methods, the digesta flowing from the rumen to the omasum, abomasum and small intestine is collected and studied. *In vivo* measures of protein digestibility are considered as the standard to which other methods are compared (Nocek 1988). Some researchers used other animal such as rats and cecectomized roosters as models to estimate intestinal availability of rumen undegraded protein.

2.1.1.1 Estimation of Protein Degradability Using Cannulated Animals

Techniques that involve cannulated animals generally attempt to fractionate and study three protein fractions. These include microbial protein (the largest fraction), undegraded dietary protein and endogenous protein. Microbial protein is usually estimated using microbial markers, the most common of which are diaminopimelic acid (Stern et al. 1983) and purines (Zinn 1993; Grigsby et al. 1992). The undegraded feed protein can be estimated as the difference between total duodenal nitrogen and microbial nitrogen (difference method), or by feeding graded levels of the test feed in a basal diet with the increase in the protein flow to the duodenum attributed to the test feed. This approach eliminates the need for measuring microbial protein flow (Nocek 1988).

Two types of cannulae were described by Ørskov (1992) and Nocek

(1988). The duodenal re-entrant cannula gives an accurate estimate of the quantity of protein entering the small intestine. It allows for total digesta collection and eliminates the need for digesta phase markers. The usual method is to collect small quantities of digesta into a container inserted in ice, the digesta is sampled and then allowed to re-enter the cannula connected to the lower end of the duodenum after being heated to rumen temperature (Khorasani et al. 1990). Indigestible markers (e.g. Chromic oxide) can be used to estimate total tract digestibility .

The simple T cannula requires less surgical preparation and thus is less labor intensive. The technique involves frequent sampling (every 1 or 2 h) for a period of 24 or 48 h (Lardy et al. 1993). Liquid and solid phase markers are usually used. The most commonly used markers for the liquid phase are polyethylene glycol, chromium-EDTA and cobalt-EDTA and for the solid phase, chromium oxide (Lardy et al. 1993).

In vivo estimation of protein degradability results in several problems. The methods require considerable effort, both in sampling and subsequent analysis and thus they are not suitable for routine dietary protein evaluation (Nocek 1988). Digesta flow and microbial markers are main sources of variation. Ørskov (1992) indicated that the coefficient of variation associated with estimating duodenal dietary protein can be as high as 50%. Other sources of variation include differences between animals and in measurements of the indigestible markers. Nocek (1988) indicated that 50 to 95% of variation in the *in vivo* techniques could be attributed to variation between animals.

2.1.1.2 Rooster Assay

The use of the precision-fed, cecectomized rooster assay provides biologically meaningful estimates of intestinally available protein in situations where ileally cannulated animals are not available (Titgemeyer et al. 1990). Cecectomizing roosters removes most of their fermentive capacity and allows them to simulate the small intestine of ruminants (Griffin et al. 1993). In this method, duodenal digesta (Titgemeyer et al. 1990), abomasum content (Henning et al. 1989) or ruminally undegraded protein residues (Griffin

et al. 1993) are precision-fed to fasted cecectomized roosters and total fecal collection is conducted.

Titgemeyer et al. (1990) found that measurements of amino acid digestibility in cecectomized roosters were similar to those obtained in steers fitted with duodenal and ileal cannulae. In contrast Henning et al. (1989) observed lower and more variable nitrogen utilization values in roosters than in multiple-cannulated sheep. Griffin et al. (1993) used the rooster assay to estimate the intestinal availability of amino acids from ruminally undegraded soybean products. The results obtained correlated closely to growth responses of calves.

2.1.1.3 Rat Assay

As with the rooster assay, this assay is used to estimate intestinal availability of ruminally undegraded protein. It has the advantage over the rooster assay in that no surgery is needed. The assay involves feeding undegraded feed samples (residues from nylon bag incubation) as the sole protein source to growing rats (Mir et al. 1984). Chaudhry and Webster (1993) used the rat assay to estimate true digestibility, biological value and net protein utilization for feed ingredients containing different levels of acid detergent insoluble nitrogen. Mir et al. (1984) indicated that low feed intake by rats might result in an underestimation of protein quality for some protein supplements such as canola seed.

2.1.2 *In Vitro* Methods

Estimation of protein degradability and availability *in vivo* is expensive and labor-intensive, and require the use of surgically prepared animals. *In vitro* methods of protein evaluation are usually rapid and relatively inexpensive and can be used for a wide variety of protein supplements. Different *in vitro* methods have been developed using either rumen fluid or enzymes to estimate rumen degradability and intestinal availability of feed protein.

2.1.2.1 Methods Using Rumen Fluid

2.1.2.1.1 Batch Culture

In this method the rate of ruminal protein degradation and the proportion of escaped protein are estimated from the release of amino acids plus ammonia from a feed sample incubated with rumen fluid (Michalet-Doreau and Ould-Bah 1992). The amount of ammonia (NH_3) released will vary according to time of incubation and the proteolytic activity of the inoculum (Broderick 1978). The technique has several limitations. These include variations in the nature of the inoculum, uptake of NH_3 by microbes which will reduce estimates of protein degradability, accumulation of fermentation end products, and reduction in proteolytic activity due to difficulty in maintaining anaerobic conditions (Broderick 1978).

Several researchers have used *in vitro* ammonia release to study the effect of physical and chemical treatments on protein supplements (Calsamiglia et al. 1992; Stutts et al. 1988). McAllister et al. (1993) found that heating canola meal to 100 °C for 1 and 2 h reduced *in vitro* NH_3 release by 15.8 and 37.5%, respectively. However, Khorasani et al. (1989) reported less reduction (9.8%) when canola meal was heated to 105 °C for 20 h. The *in vitro* NH_3 release values for untreated canola meal reported by these authors were considerably different (15.7 vs 4.0 mg dL^{-1}).

2.1.2.1.2 Continuous Culture System

The dual flow continuos culture system was developed to simulate the differential flow of liquid and solid material that occurs in the rumen. Liquid and solid dilution rates and environmental conditions such as pH and temperature can be maintained and rumen fermentability of various substrates can be examined. A main advantage of this system is the ability to alter the ruminal environment so that factors affecting microbial growth can be studied (Michalet-Doreau and Ould-Bah 1992). However, the estimation of the rate and extent of digestion of individual feedstuffs is rather difficult since incorporation

of markers is required (Nocek 1988).

The main components of the system include fermenter flasks, heat exchanger attached to the fermenter flasks to maintain temperature at 39 °C and nitrogen sparger. Several infusing ports are also attached to the fermenters including sodium hydroxide, hydrochloric acid and buffer infusion ports. A feeding system is also attached to the fermenter to allow a variable feeding rate.

Waltz and Stern (1989) used the culture system to examine the effect of protection method on ruminal degradation of soybean meal protein. Parameters studied included CP degradability, total bacterial N output and total amino acid flow. Calsamiglia et al. (1992) used eight fermenters to evaluate the effect of feeding diets formulated to contain different levels of rumen undegraded protein on microbial fermentation and nutrient flow. Hannah et al. (1986) found that results from *in vivo* and the continuos culture system for different feedstuffs were similar in terms of ruminal OM, CP and amino acid degradabilities.

2.1.2.2 Enzymatic Methods

Enzymatic techniques have been proposed to estimate ruminal protein degradability and intestinal protein digestibility in an environment which simulates the rumen or the small intestine. Such laboratory procedures are relatively easy to standardize and do not require animals. Enzymatic techniques offer several advantages over other *in vitro* techniques which utilize rumen fluid. These include no interference from non-proteolytic enzymes, no contamination with rumen microbes and no cannulated animals are required (Nocek 1988). However, enzymatic techniques encounter several problems including source and type of enzymes, feed sample properties (e.g. level of starch), nature and pH of buffer, enzyme:substrate ratio, duration of incubation and enzyme inhibiting effect of the end products (Aufrère et al. 1991).

2.1.2.2.1 Enzymatic Methods to Estimate Ruminal Protein Degradability and Degradation Rates

Two types of enzymatic assays have been used. The first assay is used to simulate the amount of protein that will be degraded in the rumen at any time point (Aufrère et al. 1991; Roe et al. 1990; Krishnamoorthy et al. 1983).The second assay involves incubation of feeds for a number of time periods in order to generate a degradation curve which can be fractionated to describe the rate of degradation of individual protein fractions (Susmel et al. 1993; Krishnamoorthy et al. 1983; Pichard and Van Soest 1977).

2.1.2.2.1.1 Enzymatic Methods to Estimate Ruminal Protein Degradability

Several enzymes have been used to estimate protein degradability. Poos-Floyd et al. (1985) tested the accuracy of five proteolytic enzymes to predict ruminal degradation of various protein supplements. The five enzymes were bacterial protease, three plant proteases; papain, ficin and bromelain, and a neutral fungal protease. The use of all proteolytic enzymes resulted in a highly significant correlation with *in vivo* protein degradability with ficin and neutral fungal protease giving the highest correlation. Ficin was the enzyme of choice and was recommended at a level of 8.24 units mg^{-1} sample.

Assoumani et al. (1992) compared the use of neutral (*Bacillus subtilis*) and alkaline (*Streptomyces griseus*) for estimating ruminal protein degradability. At pH 6.5, neutral and alkaline protease enzymes explained 91 and 92%, respectively of the variation in effective ruminal degradability. Similarly, Aufrère et al. (1991) observed a close relationship between effective degradability and enzymatic degradation after 1 or 24 h of incubation. These authors also found that the *in vitro* method was more precise with feed mixtures than with single feeds.

In the French PDI (Digestible Proteins in the Intestine) system, an enzymatic method based of *S. griseus* is used (Aufrère et al. 1991). The method is based on a 1 h incubation with 0.5 g sample (enzyme concentration of 9.2 units g^{-1} sample assuming 4.6 units mg^{-1} solid).

A modified *Streptomyces griseus* method (Krishnamoorthy et al. 1983) was proposed by Roe et al. (1990). The method uses a higher enzyme concentration (0.33 units mL^{-1}) compared with Krishnamoorthy et al. (1983) (0.066 units mL^{-1}) and assumes that all proteins which remain insoluble after 18 h of incubation for concentrates or 48 h for forages are ruminally undegradable. Another difference is that the sample size is varied according to protein content and as the CP content of the sample increases, the sample size decreases. The method also allows for estimating intestinally available protein by subtracting acid detergent insoluble CP from ruminally undegraded protein.

The modified protease method is not suitable for feeds containing more than 8% fat, 40% acid detergent fiber or 50% starch. It has been recommended that samples containing more than 23% starch should be treated with a mixture of bacterial alpha amylase and fungal glucanase prior to protease treatment.

2.1.2.2.1.2 Enzymatic Methods to Estimate Rate of Protein Degradation

One of the problems associated with the *in situ* methods of protein evaluation is the assumption that the potentially degradable fraction is a single, homogenous pool and that the rate of degradation proceeds by first order kinetics (Nocek 1988). It is important not only to predict the amount of degradable and undegradable protein but also the quantity and rate of degradation of different protein fractions (Sniffen et al. 1992). Using protease enzyme (from *S. griseus*) and regression analysis (Michaelis-Menten plot), Pichrad and Van Soest (1977) detected two protein fractions with different degradation rates. A rapidly degradable fraction with half-life of about 10 min and a slowly degradable fraction with half-life of 4 h.

Krishnamoorthy et al. (1983) used a higher enzyme concentration (6.6 units mL^{-1}) to estimate degradation rates of different true protein sub-fractions by applying a curve peeling technique. For soybean meal the rates of degradation for the rapid, intermediate and slowly degradable fractions were infinity, 156 and 22% h^{-1}, respectively.

Such high values are most likely due to the substrate-saturating enzyme concentration used in that study to create substrate-limiting conditions. Despite this, the technique demonstrated the presence of several potentially degradable protein fractions each with different degradation rates, a fact which could not be detected by the nylon bag technique.

2.1.2.2.1 Enzymatic Methods to Estimate Intestinal Protein Digestibility (Pepsin-Pancreatin Assay)

This method is used to estimate intestinal availability of ruminal undegraded protein and has recently been described by Calsamiglia and Stern (1995). It involves incubation of dietary protein remaining after rumen incubation with HCl solution containing pepsin. Following neutralization with sodium hydroxide solution, samples are then incubated in a buffer solution containing pancreatin enzyme. The technique estimates abomasal (pepsin) as well as intestinal (pancreatin) digestion and it is used most often to evaluate physically or chemically treated proteins (Calsamiglia and Stern 1995; Antoniewicz et al. 1992; Vicini et al. 1983).

Vicini et al. (1983) reported that soybean meal treated with formaldehyde and exposed to ruminal degradation for 12 h released less α amino nitrogen following 6 h of *in vitro* incubation with pancreatin than did untreated or acetic acid treated soybean meal. These results indicated that formaldehyde treated soybean meal was less available postruminally compared with untreated or acetic acid treated soybean meal.

Antoniewicz et al. (1992) found that intestinal availability values for untreated and formaldehyde treated protein supplements obtained by the mobile nylon bag technique are significantly correlated with the values obtained by the pepsin-pancreatin technique. Similarly, Van Straalen and Dooper (1993) reported a high correlation coefficient ($r = 0.91$) between total tract digestible CP of different forages measured by the mobile nylon bag and pepsin-pancreatin techniques. Calsamiglia and Stern (1995) compared the pancreatin digestion of different protein supplements with *in vivo* CP digestion and found a strong relationship ($r = 0.91$ $P<0.001$) suggesting that the *in vitro*

technique was a good indicator of intestinal CP digestion.

2.1.3. *In Situ* Methods for Estimating Ruminal Degradability and Intestinal Availability of Feed Protein

2.1.3.1 *In Situ* Nylon Bag Technique

The nylon bag technique is by far the most common technique used to estimate protein degradability of single feed ingredients or mixed rations (Ørskov 1992; Nocek 1988; Michalet-Doreau and Ould-bah 1992). The nylon bag technique is regarded as a simple, quick and relatively inexpensive method for protein evaluation. Unlike *in vitro* techniques, it allows feeds to be incubated directly in the rumen of the animal. Moreover, the nylon bag technique has the advantage of making it possible to calculate the rate of protein degradation in the rumen (Ørskov 1992). Further, many samples can be tested at the same time in the same rumen conditions.

The nylon bag technique is strongly influenced by the methodology used. Different reviews (Ørskov 1992, Nocek 1988; Michalet-Doreau and Ould-bah 1992) have attempted to assess the importance of the factors which lead to variation in the nylon bag technique. These include the bag characteristics (pore and bag size), the sample characteristics (particle size, drying of wet samples) and the animal used in the experiment.

2.1.3.1.1 Sample Preparation

Prior to rumen incubation, feed samples are usually ground to mimic mastication and increase sample homogeneity (Michalet-Doreau and Ould-Bah 1992). Grinding also increases the surface area per unit weight accessible to rumen microbes which will result in increased rates of degradation (Michalet-Doreau and Cerneau 1991). Nocek (1988) indicated that coarser materials are associated with slower rates of degradation and greater variation while finely ground materials are subjected to more mechanical losses and thus possibly unrealistic rates of degradation. Ørskov (1992) indicated that the nylon bag technique might not be suitable for very finely ground materials

unless the pore size of the bags is adjusted accordingly.

Although rumen degradability of different feeds increases with fineness of grinding, the effect seems to differ according to time of incubation and type of feed. The influence of grinding is more pronounced during short rather than long incubation periods (Lindberg and Varvikko 1982). Michalet-Doreau and Cerneau (1991) found that CP degradability of concentrates increased as the fineness of grinding increased while that of forages was not affected. However, when fineness of grinding was defined by particle size rather than grinding screen aperture, the fineness of grinding caused the same increase in CP degradability for concentrates and forages. These results support the findings of Michalet-Doreau and Ould-Bah (1992) who found differences in rumen degradability of different feeds ground with the same screen size. Nocek (1988) indicated that obtaining a mean particle size is more important than grinding screen aperture. However, such a practice seems to be difficult to carry out.

Ørskov (1992) indicated that grinding may not be required for protein supplements such as canola and soybean meals. However, oil cakes should be ground to pass a 2.5 to 3.0 screen. Similar screen sizes can be used for dry forages and cereals. Nocek (1988) suggested that cereal grains, fibrous materials and hays should be ground to pass a 5 mm screen. Michalet-Doreau and Ould-Bah (1992) recommended a screen size of 1.5 to 3 mm for concentrates with a larger screen size for forages. McAllister et al. (1990) and Beauchemin et al. (1994) sectioned cereal grains into quarters and halves prior to rumen incubation. This resulted in a higher rumen disappearance for wheat and barley with little effect on corn kernels. According to the standard procedure of the ARC (1992), concentrates and forages should be ground to pass a 2.5- and a 4-mm screen, respectively, with fine particles removed by sieving across a 45-μ sieve.

2.1.3.1.2 Sample Weight to Bag Surface Ratio

The proper sample size depends on the anticipated ruminal disappearance in relation to incubation time and on the number of analysis to be conducted on the residues

(Nocek 1988). Generally less sample is required for short incubation periods (e.g. 2 and 4 h) compared with long incubation periods (e.g. 24 and 48 h). Michalet-Doreau and Ould-Bah (1992) indicated that sample size to bag surface ratio has a considerable effect on rumen degradation during long incubation periods with little or no effect during short incubation periods. This can be explained by the fact that rumen degradation over a short incubation periods is strongly correlated to the soluble fraction while degradation during long incubation period is correlated to the insoluble but degradable fraction (Ørskov 1992).

A wide range of sample weight to bag surface ratios have been reported. Nocek (1988) indicated that type of feed had little effect on sample size to bag surface ratio and suggested a range of 10 to 20 mg cm^{-2} irrespective of the type of feed. Ratios within that range (15 and 12 mg cm^{-2}) were proposed by Michalet-Doreau and Ould-Bah (1992) and the ARC (1992), respectively. In an effort to standardize the nylon bag technique among eight laboratories, Wilkerson et al. (1995) recommended a ratio of 11 mg cm^{-2} for forages. Setälä (1983) suggested a sample size to bag surface area (57-60 mg cm^{-2}) which was much higher than most of reported values

2.1.3.1.3 Bag Pore Size

The pore size is a compromise between minimal mechanical losses and making sure that the microbes have free access to the bag (Ørskov 1992). The bag pores should also allow the accumulated gas to escape so that the bags will not float on the top of the solid phase of the rumen. Generally, the recommended pore size ranges between 40 and 60 μm (Michalet-Doreau and Ould-Bah1992; Ørskov 1992; Nocek 1988). However, a smaller pore size (40-50 μm) was proposed by the ARC (1992). Wilkerson et al. (1995) proposed a pore size of 53 ± 10 μm for bags used to estimate ruminal protein degradability of forages.

2.1.3.1.4 Position of the Bags in the Rumen

In studies with sheep a 25 cm nylon cord is usually used to attach the bags to the cannula cap (Ørskov 1992). In case of cattle, a longer nylon cord (up to 50 cm) is usually used. De Boer et al. (1987a) suggested a modified technique to increase the number of bags incubated at one time and to eliminate the time consuming step of suspending the nylon bags from a string. In this technique the bags are placed in a polyester mesh bag (25 x 30 cm, mesh size 3 mm) to which two leads are attached. The first lead is attached to a weight and the second is attached the rumen cannula. When compared with the conventional method (using a string), the modified technique resulted in similar ruminal degradabilities.

2.1.3.1.5 Incubation Times

The shape of the degradation curve over time dictates the appropriate time at which the bags should be removed from the rumen (Ørskov 1992; Michalet-Doreau and Ould-Bah 1992). The most sensitive parts of the degradation curve should be well supported by observations and the asymptote well described (Nocek 1988). The kinetic parameters of most protein supplements are obtained from 4-6 incubation times with the first incubation time corresponds to 1 to 2 h with the asymptote reached at 24 to 48 h of incubation (Ørskov 1992; Michalet-Doreau and Ould-Bah1992; Nocek 1988). For forages and other fibrous materials, longer incubation periods (12, 24, 48 and 72 h) are usually required (Ørskov 1985). The ARC (1992) proposed incubation intervals of 2, 6, 8, 24 and 48h; 8, 12, 24, 48 and 72 h for concentrates and forages, respectively.

Estimation of zero time incubation is generally carried out by rinsing un-incubated bags under tap water or by incubating the bags for short periods of time (e.g. 0.1 h) in the rumen (Boila and Ingalls 1992). Lardy et al. (1993) estimated 0 h disappearance by regressing the natural logarithm of the percentage of potentially digestible DM or CP remaining on time of incubation.

2.1.3.1.6 Nylon Bag Handling Procedure

Nocek (1988) observed that the bag incubation sequence can influence rumen degradation. Lower digestion rates for DM and CP were observed when bags were placed in the rumen at once and removed at the designated time intervals compared with introduction of bags in reverse sequence and removing them all at once. Nocek (1988) recommended the later procedure indicating that the slower rate of degradation associated with the former procedure is likely due to interruption of digestion when bags are removed and reinserted into the rumen. Removing bags at specified times rather than all at once is also more likely to result in variation among final rinses of the bags (Cherney et al. 1990).

In contrast, Michalet-Doreau and Ould-Bah (1992) recommended the other procedure argued that if the bags are not introduced at the same time they will not be exposed to the same degradation conditions in the rumen. In the ARC (1992) standardized procedure, both methods of bag insertion and removal are acceptable.

2.1.3.1.7 Type of Animal

Sheep and cattle are the most common animals used for nylon bag studies (Nocek 1988). Type of animal has little effect of ruminal disappearance when similar feeds are fed (Ørskov 1992; ARC 1992). However, cattle have the advantage that larger number of bags can be incubated at one time.

Differences between animals and between days of incubation are major sources of variation in the nylon bag technique (Michalet-Doreau and Ould-Bah1992). Maherz and Ørskov (1977) found that variability between animals (6.2%) was higher than between days (4.9%) or bags (3.3%). In contrast, Wilkerson et al. (1995) reported higher variability between days (12.8%) than between animals.

Nocek (1988) indicated that one animal can be used to estimate rumen degradation of protein supplements providing that two or more replicates are used. However, Ørskov (1985) recommended at least three animals for protein supplements and two animals for fibrous materials such as straw. Similarly, the ARC (1992) proposed a

minimum of 3 animals with 1 bag per incubation time. The procedure recommended the use of a standard feed sample of known rumen degradability if less than three animals are used.

2.1.3.1.8 Type of Basal Diet

The diet given to the fistulated animal should be similar to diets to which the results are to be applied (Nocek 1988; Wilkerson et al. 1995). Differences in ruminal disappearance were observed for feed samples incubated in fistulated animals fed forage or concentrate based diets. McAllister et al. (1993) indicated that ruminal degradability of canola meal was lower in steers fed concentrate than in steers fed hay or straw. Marinucci et al (1992) found that *in situ* DM disappearance of alfalfa hay and a corn was 13.8 and 21.8%, respectively, higher in steers fed alfalfa than in steers fed corn based diet.

Fistulated animals are usually fed at or slightly above a maintenance level of intake (Ørskov 1992). Such practice is useful in comparing results between different laboratories. However, the results might differ from those under actual feeding situations where higher levels of feed intake are usually used (Nocek 1988). Fistulated animals should receive a 40:60 concentrate:forage maintenance ration. However, a 50:50 concentrate:forage maintenance ration can be used in lactating dairy cows in early lactation (ARC 1992).

2.1.3.1.9 Washing Procedure

The washing procedure can either be manual (McKinnon et al. 1991) or mechanical, using a washing machine (ARC 1992). De Boer et al. (1987a) suggested that machine washing would eliminate variation associated with hand washing due to factors such as differences in intensity of washing between and within individuals. Cherney et al. (1990) concluded that machine rinsing twice for 2 min is an acceptable alternative to hand rinsing.

2.1.3.1.10 Interpretation of the Results

Nutrient disappearance data obtained from the *in situ* nylon bag is usually fitted to the equation of Ørskov and McDonald (1979):

$$P = a + b\ (1\text{-}e^{-ct})$$

where P is nutrient disappearance at a given time (t), a is the rapidly or immediately soluble fraction (%), b is the insoluble but potentially degradable fraction (%) and c is the rate at which the b fraction is degraded (% h^{-1}). The percentage of totally undegradable nutrient is equal to 100 - $(a + b)$.

The soluble fraction (a) is usually estimated by washing bags containing feed samples in tap water (Ørskov et al. 1980) or by incubating the bags in the rumen for short periods of time (Boila and Ingalls 1992). The potentially degradable fraction (b) is estimated by extrapolating the exponential curve describing the degradation of the insoluble material to its asymptote (Ørskov 1992). The proportion of this fraction degraded in the rumen will depend on rumen retention time and on the rate by which this fraction is degraded per unit time . The rate of degradation of the b fraction will determine the amount of that fraction which will be degraded with the rumen retention time.

The equation of Ørskov and McDonald (1979) has been modified by Dhanoa (1988) to include a lag phase (L);

$$P = a + b\ [1\text{-}e^{-c(t-L)}]$$

A lag phase is particularly important in forages and other fibrous materials where the degradation of the b fraction is preceded by a time period during which hydration and microbial attachment occur (Ørskov and Ryle 1990). Incorporating a lag phase in the exponential equation results in an increase in the a fraction and a decrease in the b fraction.

However, using equation with or without lag phase resulted in a similar estimate of rumen degradability (Denham et al. 1989).

2.1.3.1.11 Calculation of Kinetic Parameters

The kinetic parameters can be estimated by an iterative least-squares procedure using the nonlinear regression procedure (Marquardt method) of the Statistical Analysis System Institute, Inc.(1989) until the change in the residual sums of squares meet the convergence criterion (McKinnon et al. 1995b; Boˈla and Ingalls 1992; Ha and Kennelly 1984). The equation is normally constrained so that $a + b \leq 100$ (Ørskov and McDonald 1979).

Other methods to estimate nutrient degradation rate have also been proposed. Mertens and Loften (1980) found that the logarithmic transformation standard least squares method and the nonlinear iterative least squares method agreed in estimating degradation rates of the same forage. Nocek and English (1986) concluded that the iterative least square method is adequate if only one rate of degradation appears to exist. However, if more than one rate is apparent, a curve peeling technique is preferred (Krishnamoorthy et al. 1983).

2.1.3.1.11 Calculation of Effective Degradability

The disappearance of dietary protein in the rumen is a function of degradation and passage rates (Sniffen et al. 1992). In the nylon bag technique, however, the passage of feed particles is prevented and thus only disappearance is measured. The flow rate from the rumen will only affect the fate of the potentially degradable fraction since the soluble fraction is assumed to be completely degraded in the rumen (Ørskov 1992). Therefore it is the degradation rate of the potentially degradable fraction which must be related to flow rate.

The equation for calculating effective degradability (*ED*) was described by Ørskov and McDonald (1979):

$$ED = a + [(b*c) / (c + k)]$$

where k represents the rumen flow rate (% h^{-1}) and *a*, *b* and *c* are the nonlinear parameters described above. Ørskov (1992) indicated that the rumen flow rates range from 1% h^{-1} with maintenance feeding to about 10% h^{-1} with high level feeding. Khorasani et al. (1993) used 4, 6 and 8% h^{-1} while Boila and Ingalls (1992) used 2, 5, and 8% h^{-1} to represent low, intermediate and high rumen flow rates, respectively.

Effective degradability of a feed source will be influenced by the choice of rumen flow rate. As rumen flow rate increases, effective degradability generally decreases (Deacon et al. 1988; Khorasani et al. 1993). In general, flow rate has little effect on protein supplements with a high proportion of soluble protein but little degradable protein and on protein supplements with a high degradable fraction and a high rate of degradation (Ørskov 1992). The greatest effect of correcting for outflow rate is with protein supplements with large degradable fractions and a low rate of degradation. Khorasani et al. (1993) found that effective CP degradability of untreated canola meal with soluble, degradable and degradation rate of 31.9%, 62.9% and 18.3 h^{-1}, respectively decreased by 9.5% while that of acetic acid treated canola meal (18.1%, 72.7% and 5.4% h^{-1}, respectively) was reduced by 21.1%.

2.1.3.1.12 Summary

The nylon bag technique is preferred to estimate dietary protein degradability. It is a method most closely related to the environment in which protein degradation takes place. However, a shortcoming associated with this technique is that it is strongly influenced by the methodology used to obtain the results. Thus values of protein degradability for the same protein supplement obtained in different laboratories might be of a little practical value. The ARC (1992) concluded that differences in escape protein values of feedstuffs among laboratories are so great that one cannot separate the difference in estimates of escape protein due to variations in *in situ* technique or feedstuffs.

A standardized procedure is needed to minimize the variation among and within research laboratories. Development of a standardized procedure is strongly recommended (Wilkerson et al. 1995; ARC 1992).

2.1.3.2 *In Situ* Estimation of Intestinal Protein Digestibility (Mobile Nylon bag)

This technique was originally developed to estimate protein digestibility in swine (Sauer et al. 1983) and was modified to estimate intestinal availability of ruminally undegraded protein (De Boer 1987b). The mobile nylon bag technique is now a standardized procedure for estimating intestinal protein availability in the new protein evaluation system in the Netherlands (Van Straalen and Dooper. 1993). The method involves incubation of small nylon bags containing feed samples in the rumen for designated period(s) of time followed by incubation in pepsin-HCl solution for 3 h at 39 °C. The preincubated bags are then inserted into the duodenum and subsequently recovered in the feces (Kirkpatrick and Kennelly 1984). Such technique allows for estimating ruminal, intestinal and total tract protein digestibility.

The total tract digestibility values obtained by the mobile nylon bag technique are usually higher than those obtained in conventional digestibility trials since the technique measures true rather than apparent digestibility (De Boer et al. 1987b). Several researchers have used the technique to study the effect of reducing ruminal degradability of protein supplements on intestinal availability (McKinnon et al. 1995a; Moshtaghi Nia and Ingalls 1992; Deacon et al. 1988). Using this technique, these researchers were able to identify the optimum level of treatment which resulted in ruminal undegraded protein being maximized without impairing post-ruminal protein availability.

2.2 The Cornell Net Carbohydrate and Protein System for Feed Evaluation

The Cornell Net Carbohydrate and Protein System (CNCPS) has been developed over a period of 15 years and is been described by Russell et al. (1992), Sniffen et al. (1992) and Fox et al. (1992). The CNCPS is based on a ruminal fermentation model

using feed intake, feed composition and rates of degradation of feed protein and carbohydrate as inputs (Figure 2.1). Based on these inputs, the amount of ammonia, and peptides produced in the rumen and used for microbial growth, are estimated, as well as the proportions of feed protein and carbohydrates that escape rumen degradation. Metabolizable energy and protein are estimated according to the intestinal digestibility of microbial protein and ruminally undegraded feed protein and carbohydrates.

2.2.1 Rumen Microbes

The CNCPS divides rumen bacteria into structural and non-structural carbohydrate groups according to energy source . The structural carbohydrate bacteria ferment cell wall (Cellulose and hemicelluose) and use only ammonia as nitrogen source (Russell et al. 1992). The non-structural carbohydrate bacteria ferment starch, sugars and pectins and utilize either peptides (66% of N requirements) or ammonia (34% of N requirements) as N sources. The growth rate of the non-structural carbohydrate bacteria is higher than the structural carbohydrate bacteria (Russell et al. 1992).

Under the CNCPS, both groups of bacteria have similar composition. On a dry matter basis, rumen bacteria are assumed to contain 62.5% CP, 21.1% carbohydrate, 12.0% fat and 4.4% ash. Bacterial protein consists of 60% true protein, 15% nucleic acid and 25% cell wall protein.

2.2.2 Bacterial Yield

In the CNCPS, bacterial yield is based on a maximum theoretical yield of 0.5 g cell dry weight per g of carbohydrates fermented. The maximum theoretical yield is then reduced by 20% to adjust for protozoal predation. The maximum theoretical bacterial yield is also adjusted for maintenance requirements which is assumed to be 0.15 and 0.05 g of carbohydrate per g of bacteria per hour for the non-structural and the structural carbohydrate bacteria, respectively.

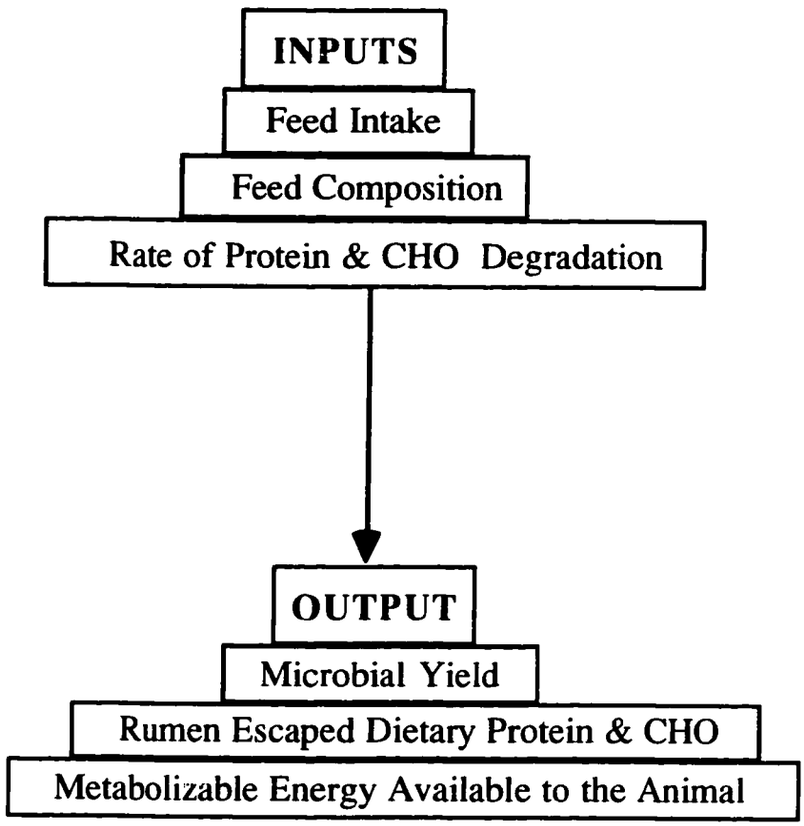

Figure 2.1. Ruminal fermentation model according to the Cornell Net Carbohydrate and Protein System.

Adapted from Russell et al. (1992).

One of the important factors affecting bacterial yield is rumen pH. In the CNCPS rumen pH can be predicted from the effective NDF content of the ration. The effective NDF is defined as the percent of NDF retained on a 1.18 mm screen and depends on particle size, degree of lignification, degree of hydration and bulk density (Fox and Barry 1994). According to the CNCPS, bacterial growth rate, particularly that of the non-structural carbohydrate bacteria decline rapidly as pH drops below 6.2 which corresponds to a diet effective NDF content of 20%. For each 1% drop in effective NDF below 20%, the microbial yield is reduced by 2.5% (Sniffen et al. 1992).

A supply of peptides increases the yield of the non-structural carbohydrate bacteria. The yield is increased up to 18.7% as the ratio of peptide to non-structural carbohydrate plus peptides increases from 0 to 14.0% with no further improvement in yield above 14.0% peptide (Russell et al. 1992). Ionophores (e.g. monensin) increase rumen peptides and decrease rumen ammonia production. The effect of ionophores is accommodated by a 34% reduction in the peptide intake rate constant.

2.2.3 Feed Protein Fractions

The CNCPS fractionates dietary protein into fraction A (non-protein nitrogen), fraction B (true protein) and fraction C (unavailable protein). True protein is further fractionated according to the inherent rate of degradation into rapid (B_1), intermediate (B_2) and slowly (B_3) degradable fractions. The B_1 fraction is completely degraded in the rumen, while most of the B_3 fraction will escape rumen degradation. The amount of the B_2 fraction which will be degraded in the rumen will depend on the relative rates of passage and digestion (Sniffen et al. 1992).

The fractionation of dietary protein is based on solubility in buffer and detergent solutions (Figure 2.2). The A and B_1 fractions are soluble in borate phosphate buffer (pH 6.7). The B_1 fraction can be separated from soluble protein as tungstic or trichloroacetic acid precipitant (Roe et al. 1990; Krishnamoorthy et al. 1982). The B_2 fraction is soluble in neutral detergent solution while the B_3 fraction is insoluble in neutral

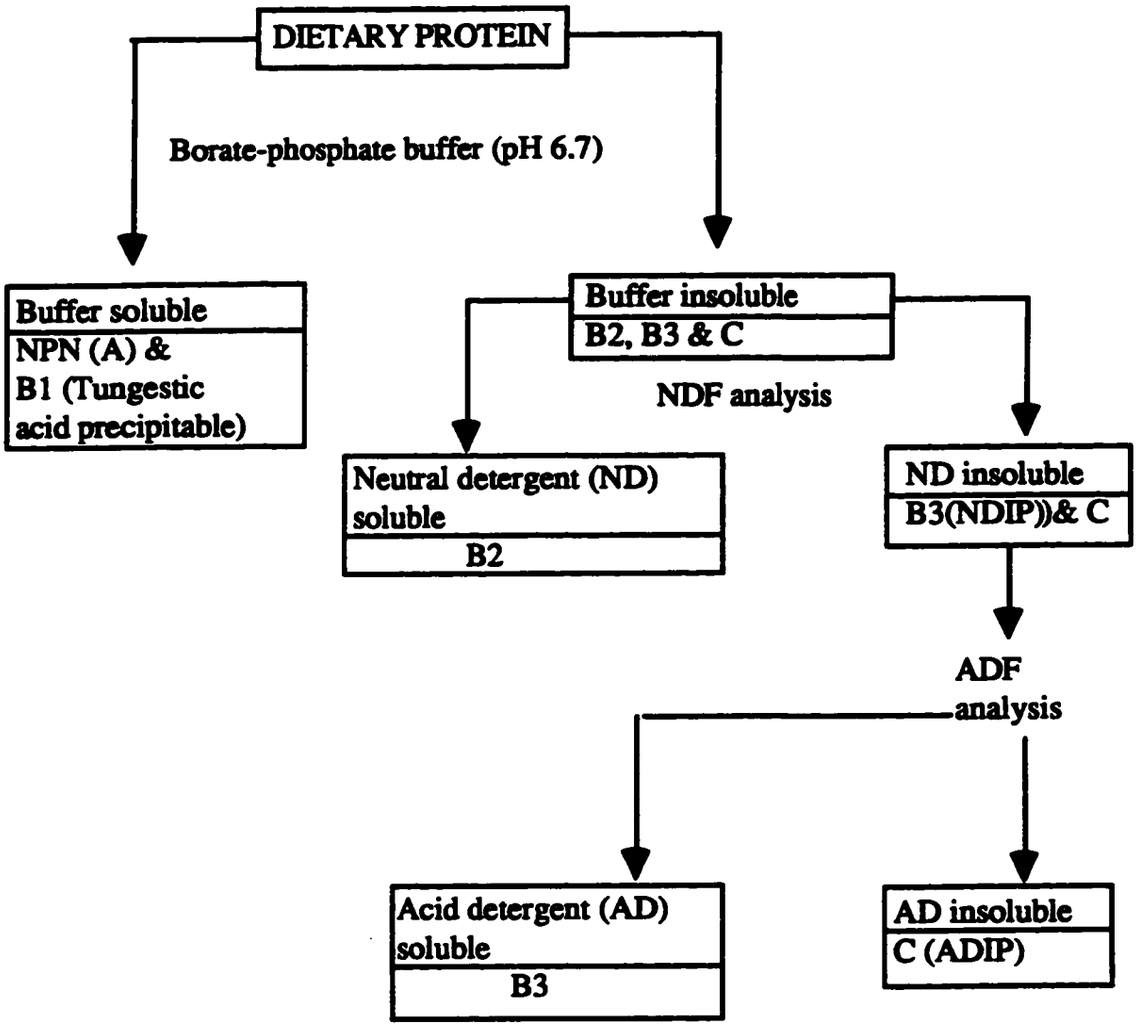

Figure 2.2. Feed protein fractions according to the Cornell Net Carbohydrate and Protein System.

Adpated from Roe et al. (1990).

but soluble in acid detergent solution. The C fraction is insoluble in acid detergent solution and is assumed to be indigestible by the animal (Sniffen et al. 1992).

Protein fractions differ considerably among protein supplements (Table 2.1). Soluble protein varies from 4% in brewers grains to 32% in canola meal. Unlike forages, protein supplements contain a considerable amount of soluble protein as true protein (B_1 fraction). It has been indicated that soluble protein can be used as an index for non-protein nitrogen (Krishnamoorthy et al. 1982). Most protein supplements contain less than 10% of total CP as unavailable protein (C fraction). However, some protein supplements such as brewers grains may contain higher levels (Van Soest and Fox 1992).

Within true protein, the B_2 fraction constitutes more than 50% followed by the B_1 and the B_2 fractions respectively (Sniffen et al. 1992; Van Soest and Fox 1992). In most protein supplements, the B_3 fraction makes less than 5% of the true protein while in some supplements such as sunflower meal, the B_1 fraction occurs in a considerable amount (19%, Van Soest and Fox 1992).

2.2.4 Feed Protein Degradation Rates

Degradation rate is an inherent property of the feed. The CNCPS acknowledges the fact that feed protein consists of different protein fractions with different degradation rates. The proportion of the feed protein being degraded in the rumen is a function of the competition between rate of passage and rate of degradation. Rate of degradation of the A fraction is assumed to be instantaneous (zero-order) while that of the C fraction is assumed to be zero.

Degradability of true protein is based on first-order kinetics and ranges from 0.04 to 260% h^{-1}. Degradation rates for the B_1, B_2, and the B_3 fractions range from 100 to 400, 2 to 6 and 0.05 to 0.55 % h^{-1}, respectively (Sniffen et al. 1992). Degradation rates of true protein are based on *in situ* and enzymatic (protease) digestion and estimated by curve peeling the natural log of residual available protein versus time (Krishnamoorthy 1983).

Table 2.1 . Protein fractions of common protein supplements.

	Canola meal	Soybean meal	Cottonseed meal	Sunflower meal	Brewers grains
Crude protein (CP)	42.3	49.0	45.6	25.9	26.0
Non-protein nitrogen[z] (A)	21.0	11.0	8.0	11.0	3.0
Available true protein[z] (B)	73.0	87.0	84.0	81.0	83.0
Unavailable Protein[z] (C)	6.0	2.0	8.0	5.0	12.0

[z] % of crude protein.

Adapted from Van Soest and Fox (1992).

Based on their inherent rate of degradation, the CNCPS assumes that all the A and B_1 fractions are degraded in the rumen while most of the B_3 fraction escapes rumen degradation. The fate of the B_2 fraction depends on the relative rates of passage and digestion (Sniffen et al. 1992). Chalupa (1992) indicates that 75-90% of the variability in rumen undegraded protein between and within feeds is accounted for by the B_3 fraction while about 90% of the effect of intake on rumen undegraded protein is accounted for by the B_2 fraction.

2.2.5 Feed Carbohydrate Fractions

Fractionation of feed carbohydrate in the CNCPS is less accurate than feed protein (Figure 2.3). Total carbohydrate is determined by difference (100 - protein - ash - fat) and thus depends on the accuracy of protein, ash and fat analysis. Feed carbohydrate is divided into structural and non-structural carbohydrate (Sinffen et al. 1992). Non-structural carbohydrate is soluble in neutral detergent solution and contains sugars (fraction A), starch and pectin (fraction B_1). Given the proportion of starch and pectin in the feed, the A fraction can be estimated by difference. The structural carbohydrate is insoluble in neutral detergent solution and includes cellulose and hemicellulose (fraction B_2) and lignin. The unavailable cell wall (fraction C) is lignin x 2.4 (Sniffen et al. 1992).

2.2.6 Feed Carbohydrate Degradation Rates

As for protein, feed carbohydrate can be fractionated according to inherent rate of degradation. Degradation rates of different carbohydrate fractions are based on in situ studies and unlike protein, no enzymatic technique has been proposed to estimates degradation rate. The A fraction (sugars) is rapidly degradable in the rumen (300% h^{-1}). The B_1 fraction (pectin and starch) is intermediately degradable (5 to 50% h^{-1}). The B_2 fraction (available cell wall) is slowly degradable (3 to 15% h^{-1}). The C fraction is completely unavailable.

The CNCPS assumes that all the A fraction is degraded in the rumen while

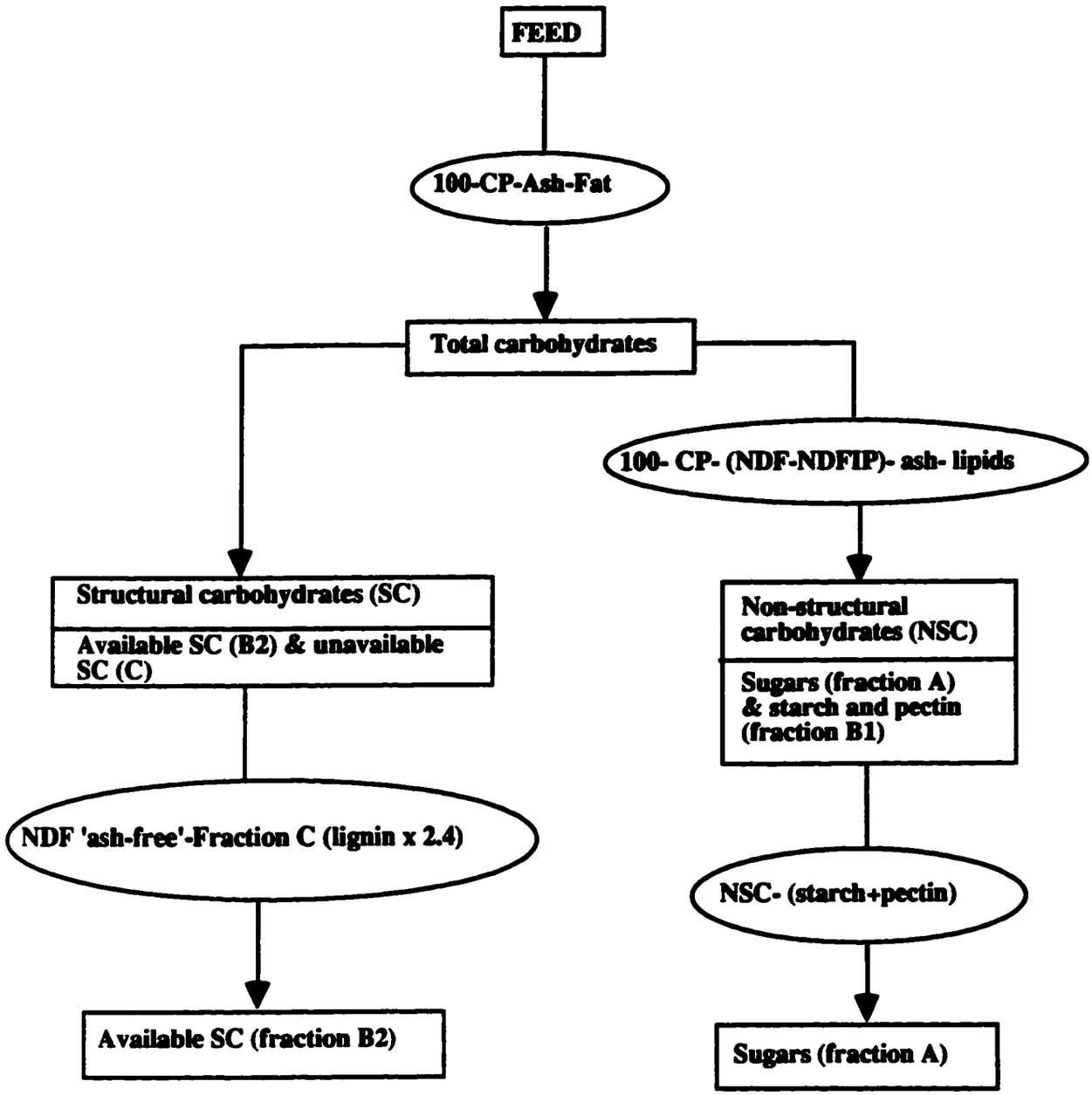

Figure 2.3. Feed carbohydrate fractions according to the Cornell Net Carbohydrate and Protein System.

Adapted from Sniffen et al. (1992).

different proportions of the B_1 and the B_2 fraction will escape rumen degradation depending on degradation and passage rates (Sniffen et al. 1992). All the C fraction will escape rumen degradation (Sniffen et al. 1992). The intestinal digestibility of the B_1 fraction (starch) is variable and assumed to be 85%. The intestinal digestibility of the B_2 fraction (available carbohydrate) is low (20%) while bacterial carbohydrate is almost entirely digestible (95%).

2.2.7 Rumen Passage Rates

Several factors affect ruminal passage rate including level of feed intake, particle size and density and hydration rate. The CNCPS estimates feedstuff passage rates at different levels above maintenance. As passage rates increase, the extent of degradation decreases. The following equations are used by the CNCPS to estimate ruminal passage rate (K_p) for forages and concentrates (Sniffen et al. 1992):

$$K_p \text{ (forages)} = 0.388 + (0.022 * \text{DM intake} / BW^{0.75}) + 0.002 * (\text{forage \% DM});$$

$$K_p \text{ (concentrates)} = -0.424 + 1.45 * (K_p \text{ [forage]}).$$

2.2.8 Intestinal Availability of Microbial and Dietary Protein

The amount of protein entering the small intestine is a function of dietary protein escaping rumen degradation and bacterial protein produced in the rumen. The CNCPS assumes that all microbes entering the small intestine are bacteria. The total tract digestibility of bacterial true protein is assumed to be 100% while bacterial cell wall protein is completely indigestible (Sniffen et al. 1992). Although the bacterial nucleic acid is completely digestible, it is excreted in the urine and does not contribute to the absorbed amino acid pool.

Intestinal availability of the B_1, B_2 and B_3 fractions are assumed to be 100,

100 and 80%, respectively. The C fraction is completely unavailable and does not contribute to the absorbed amino acid pool.

2.2.9 Applications of the CNCPS

The CNCPS predicts nutrient requirements and animal performance over a wide range of cattle, feed, management and environmental conditions using a mix of mechanistic and empirical approaches. The ability of the CNCPS to predict responses compared with the NRC system was determined by Fox et al. (1992). The CNCPS predicted metabolizable protein allowable average daily gain with a bias of 1.6% with a standard error of estimate of 0.07 kg compared with values of -30% and 0.1 kg, respectively for the NRC system.

The system can be applied at the farm level because rations are characterized according to fractions that can easily be measured using routine chemical analysis. The system can also be used to estimate ruminal degradability of dietary protein and whether ruminal microbes are provided with proper types and amounts of nitrogen (i.e. ammonia and peptides). Information on amino acid requirements and on the most limiting amino acids are also provided.

2.3 Canola Processing

Oil seed processing generally involves separation of the seed into an oil fraction and a meal fraction. Processing of canola has been described in detail by Unger (1990) and Campbell (1984). Processing is based on oil extraction of seed obtained from *Brassica napus* and *B. rapa* (Campbell 1984). Canola seed is graded according to the standards of the Canadian Grain Commission (Table 2.2). Canada No. 1 canola should be well matured, contain not more than 3% damaged seeds, 2% green seeds and 0.1% heated seeds (DeClercq et al. 1993). On average canola seed contains 41.8% oil and 21.3% crude protein. The oil from the seed must contain less than 2% erucic acid and the oil-free meal less than 30 μmol g^{-1} glucosinolates (Bell 1993a). Prior to processing, canola seed is

Table 2.2. Quality parameters for No. 1 western Canadian canola.

Quality Parameter	Harvest Year		
	1993	1992	Mean 1983-92
Oil[z] (%)	43.0	42.3	41.8
Crude protein[z] (%)	19.1	20.5	21.3
Glucosinolate[y] (μmoles g^{-1})	14.0	17.0	23.0
Chlorophyll (mg kg^{-1})	16.0	14.0	11.0
Palmitic acid (% in oil)	3.6	NR	NR
stearic acid (% in oil)	1.7	NR	NR
oleic acid (% in oil)	57.7	NR	NR
Linoleic acid (% in oil)	21.2	NR	NR
Linolenic acid (% in oil)	11.8	11.1	10.5
Erucic acid (% in oil)	0.5	0.5	0.6
Iodine value	119.0	118.0	116.0

[z] 8.5% moisture basis.

[y] Oil-free, 8.5% moisture basis.

NR = Not reported.

Adapted from DeClercq et al. (1993).

cleaned to less than 2.5% dockage in a cleaning process which involves a two-step screen separation to remove over- and under-sized particles (Unger 1990).

2.3.1 Reconditioning

The process involves heating of canola seed before flaking to 30 to 40 °C for 30 to 45 minute to prevent shattering and to improve oil extraction (Anonymous 1993). The operation is of particular importance in winter when seeds may shatter rather than flaking. Two methods of preheating were described by Unger (1990). These included direct preheating using hot air and indirect heating involving a rotary kiln with steam-heated tubes.

2.3.2 Flaking

Canola seed is flaked to break the cell wall and to rupture the oil cells. This process produces flakes with large surface area for efficient oil extraction (McCurdy 1990). Flaking is carried out in two successive steps. In the first step, preheated canola seed is flaked to about 0.4 to 0.7 mm flakes while in the second step, the cracked seed is flaked to a thickness of 0.2 to 0.3 mm (Unger 1990). The two step flaking process is carried out to reduce the possibility of seeds bypassing the flaking process and thus improves the overall oil extraction efficiency.

2.3.3 Cooking

Following flaking, the seed is cooked by passing through a series of steam heated cooking units. The cooking temperature ranges from 75 to 85 ° C with retention time ranging from 20 to 40 minute (Unger 1990). A higher cooking temperature (77 to 100 °C) and a shorter retention time (15 to 20 minute) was reported by McCurdy (1990). Cooking serves several purposes, including moisture adjustment (6 to 10%) to ensure proper screw pressing, coalescing of small oil droplets and deactivation of enzymes such as myrosinase which hydrolyzes glucosinolates (McCurdy 1990).

2.3.4 Screw Pressing

Screw pressing of the cooked flakes reduces the oil content by 60 to 70% and produces large cake fragments known as presscake (Campbell 1984). This will facilitate efficient solvent extraction the aim of which is to reduce the oil content of the meal to about 1%. On dry matter basis, presscake contains about 21% oil and 34% crude protein (Keith and Bell 1991). Oil from the screw pressing process contains 7 to 15% fine solids (by weight). It is clarified through settling and filtering operations. These operations reduce the solid content of the oil to 0.05% (Unger 1990).

2.3.5 Solvent Extraction

In this step, the oil in presscake is solvent-extracted using hexane. Liquid hexane is heated to 50 to 60 °C to accomplish rapid oil extraction (Unger 1990). The extracted canola oil consists mainly of triglycerides, and a small amount of oil soluble compounds such as phosphatides, chlorophyll products and free fatty acids. With proper operating conditions, the oil content of the of the extracted cake can be reduced to 1.0%.

2.3.6 Desolventizing

In this step the solvent is stripped from the marc (solvent saturated meal) which contains 25 to 35% hexane (Unger 1990). This takes place in a desolventizer-toaster vessel in a series of steam-heated metal trays or kettles. The final stripping and drying takes place in subsequent kettles at the desolventizer-toaster discharge by heating the extracted meal to 103 to 107 °C for 30 to 40 minutes (Unger 1990). With the combination of high moisture and temperature, complete inactivation of myrosinase is achieved. The moisture content of the discharged meal is 15 to 18%. Following drying and cooling, the moisture content of the meal is reduced to 8 to 10% with 2 to 3% residual oil content (Campbell 1984).

2.3.7 Degumming

Crude canola oil contains several phospholipid compounds known collectively as gums (Anonymous 1993). Degumming is carried out by hydration of these phospholipids compounds using hot deminerlized water. The hydrated phospholipids are then separated from the oil by passing the mixture through a stacked-disc centrifuge (Unger 1990). Gums removed during this process are added back to the meal in the desolventizer. Acidulated soapstock from vegetable oil refineries may also be added. Such additions serve to reduce the dustiness and enhance the digestible energy content of the meal.

2.4 Chemical Composition of Different Canola Products

2.4.1 Chemical Composition of Canola Meal

Canola meal is defined as the product resulting from the crushing and the extraction of canola seed. The removal of oil drastically alters the chemical composition of canola seed due to the concentration of the remaining ingredients (i.e. fiber and protein). Canola meal has been reported to contain 38.3% CP, 21.5% NDF, 17.5% ADF, 12% CF, 3.6% EE, 0.6% Ca, 0.9%, 1.0% P and 0.9% S (Bell 1993a).

2.4.1.1 Protein

Protein is the main nutrient in canola meal. The protein content varies according to the cultivar from which the meal is produced (Bell 1993a). Bell and Keith (1991) determined the CP content of canola meal samples obtained from seven western Canadian crushing plants. They found that on average, canola meal contained 37.7% CP with 66% of the samples falling within the range of 35.3 to 40.1%. They attributed the variation to regional differences in cultivar composition and quality of canola seed being processed. Bell (1993a) indicated that the CP content of canola meal varied from 36 to 41% over the ten-year period preceding 1987.

Canola meal protein is more soluble than soybean meal protein. However, the amount of protein associated with NDF and ADF is higher in canola meal than soybean

meal (Table 2.3). The high neutral and acid detergent insoluble CP of canola meal is mainly due to the seed hulls remaining with the meal following oil extraction. Reported levels of neutral and acid detergent insoluble CP (% CP) for canola meal ranges from 8.4 to 16.8% and from 5.1 to 6.7%, respectively (Moshtaghi Nia and Ingalls 1992; McAllister 1993; McKinnon et al. 1995a).

Canola meal protein consists of 21.0% non-protein nitrogen, 73.0% true protein and 6.0% unavailable protein (Van Soest and Fox 1992). The corresponding values for soybean meal are 11.0, 2.0 and 87.0%, respectively. True protein of canola meal consists of rapid (15.3%), intermediate (79.2%) and slowly degradable (5.5%) protein fractions (Van Soest and Fox 1992). Soybean meal true protein contains less rapid (10.5%) and slowly (3.5%) degradable protein and more intermediately degradable protein (86.0%) than canola meal. Both canola and soybean meal are rapidly degraded in the rumen due to a small proportion of slowly degradable true protein. Protein supplements such as brewers grain and blood meal which are slowly degraded in the rumen, contain a large proportion of slowly degradable true protein . As percentage of true protein, brewers grains and blood meal contain 28.0 and 46.0% slowly degradable true protein respectively (Van Soest and Fox 1992).

The amino acid composition of canola meal protein is similar to that of soybean meal (Table 2.4). However, canola meal contains more sulfur-containing amino acids and less lysine. Available lysine content of canola meal ranges from 1.98 to 2.37% (Bell and Keith 1991). Bell and Keith (1991) observed variations in amino acid composition of canola meal samples obtained from seven crushing plants. Exceptions included leucine, arginine and lysine. Differences in amino acid composition between canola varieties (*Brassica napus* and *B. rapa*) and environmental factors are believed to cause such variation.

Table 2.3. Protein fractions of canola and soybean meals.

	Canola Meal	Soybean Meal
Crude protein (% DM)	42.3	49.0
Soluble CP (% CP)	32.0	20.0
Non-protein nitrogen (% CP)	21.0	11.0
Neutral detergent insoluble CP (% CP)	11.0	5.0
Acid detergent insoluble CP (% CP)	6.0	2.0

Adapted from Van Soest and Fox (1992).

Table 2.4. Amino acid composition of canola and soybean meals (% CP).

Amino acid	Canola Meal[z]	Canola Meal[y]	Soybean Meal[y]
Essential			
Arginine	6.2	6.2	7.2
Histidine	3.8	3.0	2.9
Isoleucine	4.3	4.2	4.6
Leucine	7.3	7.4	7.8
Lysine	6.0	5.0	6.1
Methionine	2.1	1.7	1.1
Phenylalanine	4.1	4.2	5.1
Threonine	4.5	4.5	4.0
Valine	5.5	5.2	4.8
Non-essential			
Alanine	4.4	4.6	4.3
Aspartic acid	6.2	11.4	7.5
Cystine	1.2	2.7	1.9
Glutamic acid	19.1	17.7	18.3
Proline	6.0	5.0	6.0
Tyrosine	1.3	3.5	4.0

[z] Adapted from Bell and Keith (1991).

[y] Adapted from Zinn (1993).

2.4.1.2 Fiber

Unlike soybean, canola seed is not dehulled prior to oil extraction. This results in canola meal having a higher fiber content relative to soybean meal . Hulls constitute about 16% of canola seed and 30% of the oil-free meal (Bell 1984). Different assays have been used to measure fiber content of canola meal. These include crude fiber, total dietary fiber and detergent assays (Bell 1993b). On average, canola meal contains 13.1% crude fiber, 23.4% NDF and 19.1% ADF (Bell and Keith 1991). A large proportion of the NDF (hemicellulose) is associated with the embryo while most of the ADF (cellulose) is associated with the hulls (Bell 1993b).

Recently, Khorasani et al. (1994) determined fiber fractions for canola meal, soybean meal and solvent extracted linseed meal. They found that canola meal had higher NDF (30.3%), ADF (20.9%) and ADL (8.3%) than soybean meal or solvent extracted linseed meal. The NDF, ADF and ADL values for soybean meal and linseed meal were 8.5, 4.6 and 0.2% and 25.9, 14.6 and 5.8%, respectively.

2.4.1.3 Starch and Sugars

Canola meal contains a relatively small amount of starch (2.6%) and oligosaccharides (2.5%) regardless of seed type (Slominski and Campbell 1990). Canola meal from *Brassica rapa* (yellow seed) have been reported to be higher in non-starch polysaccharides (19.4%) than meal from *Brassica napus* (brown seed; 16.4%). About 15 and 40% of non-starch polysaccharides are soluble in water and neutral detergent solution, respectively (Slominski and Campbell 1995). The major components of non-starch polysaccharides in both types of canola meal are glucose (28.5%), arabinose (25.7%) and uronic acid (23.8%) (Slominski and Campbell 1990). The digestibility of non-starch polysaccharides by monogastric animals is low. For example, Slominski et al. (1994) reported that the digestibility of non-starch polysaccharides by laying hens fed a canola meal-based diet was 3.4%.

2.4.1.4 Minerals and Vitamins

Canola meal contains higher levels of minerals and vitamins than soybean meal (Table 2.5). canola meal is considered a good source of phosphorous (P), selenium and B vitamins (except pantothenic acid). The bioavailability of P, calcium and copper was reported to be 75, 68 and 74%, respectively (McKinnon and Christensen 1989). However, P bioavailability for monogastric animals is affected by the presence of phytin. Bell (1984) indicated that available P for monogastric animals ranged from 30 to 50% since 66% of P is bound with phytin. Significant differences in mineral composition (except for sulfur) of canola meal samples obtained from different crushing plants were observed by Bell and Keith (1991). They attributed such differences to variations in soil minerals and other environmental factors.

2.4.1.5 Energy

Gross energy (GE) of canola meal averages 4.4 ± 0.2 Mcal kg^{-1} (Bell and Keith 1991). Variation in GE content of canola meal can be due to differences in lipid, protein and fiber contents (Bell 1984). The high hull content of canola meal has a significant influence on its digestible energy content especially for monogastric animals (Bell 1993a). Bell (1993b) found that front-end dehulled canola meal had higher GE content (4.6 Mcal kg^{-1}) than hexane extracted hulls (4.3 Mcal kg^{-1}) or commercial canola meal (4.4 Mcal kg^{-1}).

The available energy value of canola meal varies between animal species and is usually higher for ruminants than for monogastric animals. For pigs, the digestible energy (DE) value varies from 3.0 to 3.3 Mcal kg^{-1} (Bell et al. 1991). For poultry, apparent metabolizable energy values are 1.9 and 2.0 Mcal kg^{-1} for growing and adult chickens, respectively (Sibbald et al. 1986). Using Holstein calves, Sharma et al. (1980) reported DE values of 3.7 and 3.8 Mcal kg^{-1} for Tower and Candle rapeseed meal, respectively. The DE value for soybean meal was 4.0 Mcal kg^{-1}. More recently, Zinn (1993) reported a DE of 4.2 Mcal kg^{-1} (88% of GE) for canola meal which is 28% higher

Table 2.5. Mineral and vitamin composition of canola meal and soybean meal (% DM).

	Canola Meal	Soybean Meal
Minerals[z]		
Calcium (%)	0.7	0.3
Magnesium (%)	0.6	0.3
Phosphorous (%)	1.1	0.7
Potassium (%)	1.4	2.0
Sulfur (%)	0.9	0.4
Copper (mg kg^{-1})	6.3	24.0
Iron (mg kg^{-1})	157.0	119.0
Manganese (mg kg^{-1})	62.9	35.0
Selenium (mg kg^{-1})	1.2	0.1
Zinc (mg kg^{-1})	69.4	66.0
Vitamins[y]		
Choline (%)	0.7	0.3
Niacine (mg kg^{-1})	160.0	29.0
Pantothenic acid (mg kg^{-1})	9.5	16.0
Thiamin (mg kg^{-1})	5.2	4.5
Riboflavin (mg kg^{-1})	3.7	2.9
Folic acid (mg kg^{-1})	2.3	1.3
Biotin (mg kg^{-1})	0.9	0.3

[z] **Adapted from Bell and Keith (1991) and NRC (1989).**

[y] **Adapted from Bell (1984).**

than that reported by NRC (1989).

2.4.1.6 Glucosinolates

The glucosinolate content of canola meal (less than 30 μmol g^{-1}) is lower than that of rapeseed meal (110 to 150 μmol g^{-1}) and of less nutritional importance (Bell 1993a). Glucosinolates are embryo components and are higher in *Brassica rapa* than in *Brassica napus* varieties (Bell and Shires 1982). Canola meal contains less glucosinolates than canola seed due to thermal degradation during the desolventizer-toaster stage. Bell and Keith (1991) found that glucosinolate destruction during canola processing varied from 15 to 77% among different crushing plants. Differences in processing conditions and glucosinolate content of different canola seeds result in wide variation in glucosinolate content of canola meal. Bell and Keith (1991) reported values ranging from 6.8 to 33.7 μmol g^{-1} for canola meal samples obtained from seven crushing plants.

2.4.2 Chemical Composition of Canola Seed and Presscake

Compared with canola meal, whole canola seed contains more EE, more GE and less CP (Table 2.6). The values for presscake are intermediate between whole canola seed and canola meal. On a fat-free basis canola seed and canola presscake have similar amino acid composition except for available lysine which is higher in canola seed than in canola presscake (Table 2.6).

Total glucosinolates are relatively higher in canola seed (38.4 μmol g^{-1}) than in canola presscake (35.8 μmol g^{-1}). However, the myrosinase activity of canola presscake is 65% less than the seed (Keith and Bell 1991).

2.4.3 Chemical Composition of Canola Hulls

Hulls constitute about 16% of canola seed and about 30% of canola meal (Bell 1993a). On average canola hull contains 12 to 16% CP, 44% CF, 3% EE, 4 to 5% ash and 4.5 Mcal kg^{-1} GE (Bell 1984). Bell (1993b) determined the chemical composition

Table 2.6. Chemical composition of canola seed and presscake relative to canola meal (DM basis).

	Processing stage		
	Canola Seed	Press Cake	Canola Meal
Crude protein	28.7	23.9	20.4
Ether extract	44.1	21.2	3.9
Gross energy (Mcal kg^{-1})	6.8	5.7	4.9
Total glucosinolates ($\mu mol\ g^{-1}$)	38.4	35.8	21.1
Amino acids (% of CP)			
Alanine	6.6	8.0	9.3
Arginine	9.1	11.3	12.8
Cystine	4.2	5.0	5.9
Glycine	7.7	9.2	10.8
Histidine	4.9	6.3	7.4
Isoleucine	6.3	8.0	8.8
Leucine	10.5	12.6	14.7
Lysine	9.4	10.9	12.3
Available lysine	8.4	9.6	10.9
Methionine	3.1	3.8	4.4
Phenylalanine	5.9	7.1	8.3
Threonine	6.6	8.0	9.3
Tryptophan	1.7	2.1	2.5
Tyrosine	4.5	5.4	6.4
Valine	8.0	9.6	11.3

Adapted from Keith and Bell (1991).

of hexane extracted canola hulls (*Brassica napus*; Westar cultivar) obtained from front-end dehulling. The hulls contained 22.5% CP, 37.3% CF, 1.4% EE, 52.1% ADF, 61.2% NDF and 4.7 Mcal kg^{-1} GE. Comparable values were reported for NDF (65.8%) and ADF (46.7%) by McKinnon et al. (1995b).

Varieties of *Brassica rapa* (yellow seed) have a thinner seed coat and thus less fiber content than *Brassica napus* (brown seed) varieties (Bell 1993a). Hulls from *B. napus* contain 42.3, 16.7, 22.8 and 20.0% more CF, NDF, ADF and ADL, respectively, than hulls from *B. rapa* (Table 2.7). The ADL content of brown seeded canola hulls (27.7%) is higher than yellow seeded canola hulls (5.5%) or soybean hulls (1.3%; Mitaru 1982).

The amino acid composition of the canola hull is very different from that of canola meal (Finlayson 1974). The most abundant amino acid is proline with small amounts of sulfur-containing amino acids. The tannin content of canola hulls is very low (range 0.02 to 0.22%; Mitaru et al. 1982).

Available energy from canola hulls is very low and varies with type of seed. Bell and Shires (1982) found that hulls from brown-seeded canola were 3% digestible by pigs while those from yellow-seeded canola were 30% digestible. McKinnon et al. (1995b) reported digestible energy value of 2.2 Mcal kg^{-1} for canola hulls fed to growing lambs.

2.4.4 Chemical Composition of Canola Screenings

Canola screenings are the fine materials separated during screening of canola seeds in the cleaning procedure prior to export or crushing and oil extraction (Tait et al. 1986). The major components of canola screenings are lamb's quarters (23.8%), stinkweed (22.5%), canola seed (17.1%) and hoary alyssum (14.1%) (Beames et al. 1986). The average chemical composition is 19.6% CP, 22.5% EE, 28.0% ADF and 7.4% ash (Beames et al. 1986). As a percentage of the total fatty acid content, canola screenings contain 52.2% oleic and 24.2% linoleic fatty acids (Wiesen et al. 1990).

Table 2.7. Fiber components of embryo and hull of two different types of canola seed (% DM).

Component	*Brassica rapa* (Yellow Seed)		*Brassica napus* (Brown Seed)	
	Embryo	Hull	Embryo	Hull
Crude fiber	3.6	20.3	3.1	39.7
Neutral detergent fiber (NDF)	17.7	52.6	12.7	71.2
Acid detergent fiber	9.0	41.0	7.4	59.9
Permanganate lignin	3.0	11.7	2.3	16.5
Lignin (% of NDF)	17.0	22.2	18.1	23.2

Adapted from Bell and Shires (1982).

2.5 Dehulling of Canola Meal

There have been several attempts to remove or reduce the hull content of canola meal before and after oil extraction (Hill 1991). The goal was to produce a meal which would contain a lower fiber and a higher protein content than commercially available canola meal and thus be more competitive with soybean meal.

2.5.1 Dehulling Prior to Oil Extraction

2.5.1.1 Disc Milling

Bell and Shires (1982) used a disk mill equipped with refiner plates to separate rapeseed into hull and embryo fractions. The pooled hulls were then passed over an 850 μm screen to remove fine embryo materials. Dehulling reduced the fiber content of the resulting embryo relative to the original seed with little effect on protein content. The reduction in fiber content was more pronounced in *Brassica napus* (brown seed) than in *Brassica rapa* (yellow seed) varieties. This was attributed to the fact that *Brassica napus* had higher hull content than *Brassica rapa*. The lack of improvement in CP content of the embryo fraction is likely due to the presence of embryo material in the hull fraction. This finding was supported by the high oil content of the hulls (20.7 and 10.6% for *Brassica rapa* and *Brassica napus* , respectively). The hull fraction from *Brassica napus* and *Brassica rapa* was estimated to be 82 and 60% hulls, respectively (Bell and Shires 1982).

In both types of meal, calcium (Ca) content of the embryo fraction was higher while phosphorous (P) content was lower than the original seed indicating that the hull fraction had higher Ca and lower P content than the embryo fraction. Dehulling increased glucosinolate content of the embryo fraction and the effect was more pronounced with *Brassica rapa* than with *Brassica napus*.

Inclusion of canola rapeseed hulls in pig diets at levels of 0, 15 and 30% depressed nutrient digestibility coefficients. The depression in nutrient digestibility was higher for *Brassica napus* than in *Brassica rapa*. The estimated CP digestibility of *Brassica napus* and *Brassica rapa* was 20 and 0%, respectively. The corresponding energy values

were 30 and 2%, respectively (Bell and Shires 1982).

2.5.1.2 Front-end Dehulling

Front-end dehulling of canola meal has been described by McCurdy and Fedec (1995). The technique involves adjustment of canola seeds to 5 to 6% moisture and 50 °C prior to milling. The seeds are then milled using a cracking mill. The milled seeds are aspirated and sieved to recover embryo, hulls and two fine fractions. Due to smaller seed size, the dehulling of *Brassica rapa* (Tobin)canola seed was not as efficient as Westar seed. The yield of embryo, hulls and fines were 79.2, 8.8 and 12.0%; 84.9, 4.7 and 10.4% for Westar and Tobin canola, respectively.

Bell (1993b) evaluated the nutritive value of front-end dehulled canola meal for pigs. Relative to the original canola seed, dehulled canola meal had 13.3% more CP, 48.2% less ADF and 39.3% less CF (Table 2.8). However the NDF content was not affected by the dehulling process. The hulls had 49.0% less CP, 164.3% more ADF, 156.8% more CF and 136.9% more NDF than the original seed. Front-end dehulling increased the amino acid contents of the dehulled meal except for lysine and tyrosine. Glucosinolate content of the dehulled meal was 83.2% lower than that of the original seed. The presence of glucosinolate in the hull indicated an incomplete separation of the embryo during the dehulling process since glucosinolates are embryo constituents. This finding was also supported by the high oil content of the hull (13.0%) as reported by McKinnon et al. (1995b).

Despite improvement in protein and fiber composition of dehulled canola meal, incorporation of the meal in pig diets (from 23 to 100 kg) did not improve performance over commercial canola meal (Bell 1993b). Digestibility of protein and energy of the dehulled canola meal was also less than that of soybean meal. The failure of pigs to respond to front-end dehulled canola meal was attributed to over heating during processing and to the excessive fineness of the dehulled meal.

Table 2.8. Effect of front-end dehulling of canola seed of chemical composition of canola hulls and dehulled meal[z].

	Canola Product			
	Seed	Dehulled Meal	Hulls	Commercial Meal
Crude protein	44.5	51.6	22.5	41.1
Crude fiber	14.6	7.8	37.3	11.9
Neutral detergent fiber	26.0	25.8	61.2	25.1
Acid detergent fiber	19.8	12.3	52.1	19.3
Gross energy (Mcal kg^{-1})	4.9	5.2	4.7	4.8
Total glucosinolates ($\mu mol\ g^{-1}$)	27.9	4.7	6.0	11.1

[z] **Chemical composition based on moisture-free, fat-free basis. Adapted from Bell (1993b).**

McKinnon et al. (1995b) examined the nutritive value of canola hulls produced from front-end dehulling for ruminants. Voluntary intake and nutrient digestion coefficients by lambs declined linearly as inclusion rate of canola hulls increased. Estimated digestibility coefficient of CP, NDF and ADF was 38.3, 25.6 and 13.6%, respectively. Ammoniation and / or solvent extraction failed to improve effective degradability of canola hull nutrients.

2.5.1.3 Dehulling Using Thermal Treatments

Thermal treatments of *Brassica napus* canola seed (Westar cultivar) to promote dehulling were described by Thakor and Sokhansanj (1995). The treatments involved soaking the seeds in distilled water or processing the seeds with saturated steam followed by drying. The drying step is followed by abrasive milling to break the hulls and aspirating to separate the hull fraction from the dehulled meal.

The dehulling technique fractionated canola seed into cotyledon (80%), hull (15.0%) and fines (5%). The average CP, oil and CF contents of the cotyledon, hull and fine fractions were 30.0, 49.3 and 3.5%; 17.8, 18.4 and 23.9%; and 26.7, 40.2 and 9.0%, respectively. The process resulted in a loss of about 6% of the total oil yield from the crushing of the dehulled meal only. The authors also concluded that such a dehulling technique was uneconomical under the current price structures.

2.5.1.4. Air Classification

Air classification involves separation of canola seed or meal into high and low hull fractions and thus will not result in complete separation of hull and embryo (Leslie et al. 1973; Bayley and Hill 1975). The technique was also used to produce starch-rich and protein-rich fractions from different cereals and legumes (Vose et al. 1976). Air classification is usually carried out using an air classifier in which separation cut size can be changed by adjusting the speed of the classifier wheel and the air flow rate (King and Dietz 1987).

Leslie et al. (1973) used air classification to separate rapeseed into low and high fiber fractions. The dehulling technique resulted in a low and a high fiber fraction (65.0 and 9.0% of the meal, respectively) and a mixture of both dehulled seed and hulls (26.0% of the meal). The low fiber fraction contained 28.2% CP, 45.2% EE and 7.9% CF. The corresponding values for the high fiber fraction were 13.8, 9.4 and 28.1%, respectively. These results together with those of Sarwar et al. (1981) demonstrate that air classification is more effective in separating fiber than protein between the two fractions.

2.5.2 Dehulling After Oil Extraction

2.5.2.1. Tail-End Dehulling

The loss of oil in hulls, lack of animal response to the dehulled meal and the lack of market for the hulls rendered front-end dehulling impractical. Although the separation of the hull and embryo is incomplete, tail-end dehulling does not reduce oil yield since dehulling is conducted after oil extraction (McCurdy and March 1992). Tail-end dehulling involves tempering the meal to 16% moisture followed by disc milling and sieving (Figure 2.4). The technique results in a low fiber, high protein fraction (40.0%) and a high fiber low protein faction (60.0%).

McCurdy (1993) studied the effect of meal source on tail-end dehulling using commercial canola meal batches obtained from five crushing plants in western Canada. Meal source had a significant effect on the yield and composition of the low fiber fraction. The yield of the low fiber fraction ranged from 38.0 to 54.0% of the original meal with CP and CF content ranging from 43.0 to 47.0% and 8.1 to 9.6%, respectively. The corresponding values for the unprocessed meals were 39.6 to 41.5% and 12.0 to 13.0%, respectively. An inverse relationship was observed between the yield and the CP content of the low fiber canola meal. For example, the most improved meal yielded 38.4% low fiber canola meal with 17.5% more CP and 38.5% less CF than the unprocessed meal . On the other hand the least improved meal had 46.3% yield, 5.6% more CP and 18.9% less CF

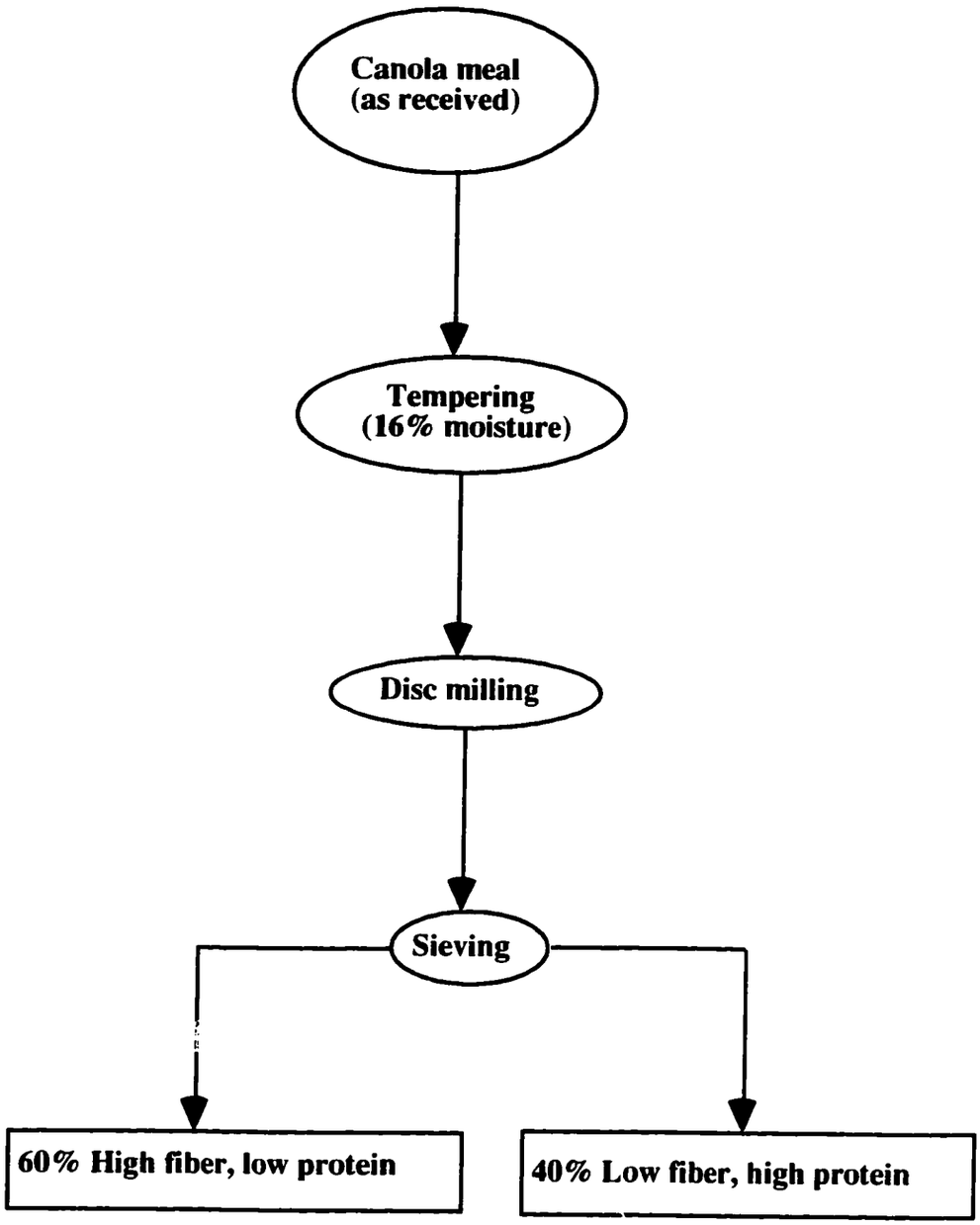

Figure 2.4. Tail-end dehulling of canola meal.

Adapted from McCurdy and March (1992).

than the original meal.

McCurdy and March (1992) determined the chemical composition of low fiber canola meal relative to commercial canola meal. Low fiber canola meal contained 13.6% more CP, 34.4% less NDF, 36.6% less ADF and 40.7% less ADL relative to commercial canola meal. These results demonstrated that tail-end dehulling, like front-end dehulling is more effective in fiber than protein separation between the low and the high fiber fractions.

The nutritive value of low and high fiber canola meal from tail-end dehulling is yet to be determined. However, McCurdy and March (1992) evaluated the nutritive value of low fiber canola meal as a protein source for trout and salmon. Inclusion of low fiber canola meal in salmon and trout diets to provide 25 and 40% dietary protein diets, respectively, did not improve performance over commercial canola meal. However, acid washing of the low fiber canola meal significantly improved fish growth rate and feed utilization, likely due to reduced glucosinolate and sinapine content.

2.5.2.2 Air Classification

Bayley and Hill (1975) found that rapeseed meal from *Brassica rapa* was improved by air classification to a greater extent than rapeseed meal from *Brassica napus*.. This finding was supported by glucosinolate analysis which showed higher levels of glucosinolates in the high fiber than in the low fiber fraction in *Brassica napus* while showing higher levels in the low fiber than in the high fiber fraction in *Brassica rapa*. This improvement can be related to *Brassica rapa* having thinner seed coat relative to *Brassica napus* . The high fiber fraction in both types of meal contained more calcium and less phosphorous than the low fiber fraction. King and Dietz (1987) air classified three rapeseed cultivars and achieved improvement in CP content of the low fiber fraction between 11.5 and 17.5%.

Air classification improved the metabolizable energy of the low fiber fraction for chicks by 47.4 and 32.% for *Brassica napus* and *Brassica rapa*, respectively

(Bayley and Hill 1975). However, incorporation of low fiber rapeseed meal in broiler diets resulted in poor bird performance. This was attributed to the fineness of the low fiber material which resulted in impaired feed intake and growth rate.

Air classification of rapeseed meal did not improve the digestible or metabolizable energy of the low fiber fraction for pigs (Bayley and Hill 1975). The digestible energy values for the original (*Brassica rapa*), low fiber and high fiber meals were 3.5, 3.7 and 3.4 Mcal kg^{-1}, respectively. Leslie et al. (1973) showed that air classification improved the DE and digestible nitrogen content of the dehulled meal for rats. Sarwar et al. (1981) found that while air classification improved the nutritive value of the dehulled meal, protein and energy digestibilities were still lower than those of soybean meal by 10.5 and 10.3%, respectively.

2.5.3 Problems Associated with Dehulling of Canola Seed and Meal

Despite the improvement in protein and energy value of dehulled or fiber reduced canola meals, dehulling of canola seed or meal, faces several obstacles. These include lack of uniform product due to small and uneven size of canola seed, variation in seed coat among different canola seed varieties, loss of oil if the hulls are removed prior to oil extraction, lack of market outlet for the hulls, poor separation if dehulling is conducted after oil extraction, difficulty in oil extraction if hulls are removed prior to oil extraction and excessive fineness of the dehulled meal (Downey and Bell 1990; Hill 1991).

2.6 Canola Products for Ruminant Animals

2.6.1 Feeding Value of Canola Meal

Canola meal has gained widespread acceptance as protein supplement in dairy and beef rations and is by far the most common protein supplement for ruminant animals in Canada (Anonymous 1993).

2.6.1.1 Canola Meal in Dairy Rations

2.6.1.1.1 Effect on Feed Intake

Most studies have showed good acceptability of canola meal by dairy cows. Early studies with high glucosinolate rapeseed revealed no adverse effect on feed intake by dairy cows (Laarveld and Christensen 1976; Papas et al. 1978). Sharma et al. (1977) found that inclusion of Tower and 1788 rapeseed meals at 12.5% of the total diet had no effect on dry matter intake by Holstein cows. Vincent et al. (1988a) found no deleterious effect on feed intake by pubertal heifers fed concentrate diets containing high glucosinolate extracted rapeseed meal and expeller rapeseed meal. The dry matter intake of extracted rapeseed meal and expeller rapeseed meal were 1.25 and 1.82 kg d^{-1}, respectively. This corresponded to a glucosinolate intake of 112.5 and 163.8 mmol d^{-1} for the extracted and the expeller rapeseed meals, respectively.

Feeding canola meal to lactating dairy cows up to 23.5% of the diet showed no adverse effect on dry matter intake (Rae et al. 1983). Similar results were also reported for lower inclusion levels (Khorasani et al. 1994; Beaulieu et al. 1990; DePeters and Bath 1986). Sánchez and Claypool (1983) found no difference in dry matter intake among high producing Holstein cows fed diets containing 11.7% canola, 10.4% cottonseed or 8.6% soybean meals.

Hill et al. (1990a) studied the voluntary intake by calves of two concentrate diets containing either 24% soybean meal or 30% low glucosinolate rapeseed meal (*Brassica napus* variety Dolar) during a short period (30 min after feeding). Calves fed rapeseed-meal based concentrate, consumed 10% less feed than those fed the soybean meal-based concentrate. However, in a three-week feeding period, calves consumed similar amount of concentrate containing either 25% rapeseed meal or 20% soybean meal.

2.6.1.1.2 Effect on Milk Yield and Composition

Several experiments have been conducted on the effect of canola meal on

milk yield and composition relative to other protein supplements such as soybean, cottonseed and sunflower meals. An early study by Sharma et al. (1977) showed that rapeseed meal could be included in a dairy ration up to 12.5% of the total ration without affecting milk yield or composition. Dairy cows fed grain mixtures containing 30% cultivar 1821 rapeseed meal or 26% Tower rapeseed meal produced 4.5% more milk than cows fed a control mixture containing 22% soybean meal (Papas et al. 1978). Milk composition was not affected by treatment.

Laarveld and Christensen (1976) evaluated two rapeseed meal varieties as protein supplements relative to soybean meal in three complete isonitrogenous rations (14% CP) for dairy cows. The results indicated that cows fed low glucosinolate, low erucic acid rapeseed meal tended to produce more milk than those fed high glucosinolate, low erucic acid rapeseed or soybean meal.

Emanuelson (1989) studied long-term effects of feeding a double low rapeseed cultivar to dairy cows. Compared with soybean and cottonseed meals, 2.5 kg of rapeseed (DM basis) could be included daily in dairy rations without any adverse effect on milk yield or milk composition.

Sánchez and Claypool (1983) compared canola with soybean and cottonseed meals as single protein supplements in total mixed rations (50% forage:50% concentrate) for high producing Holstein cows. The diets were isonitrogenous (15% CP DM basis) and contained 11.7% canola, 10.4% cottonseed and 8.6% soybean meals. The results showed that milk yield and composition did not differ among treatments (Table 2.9). However, cows fed canola meal tended to yield more milk than cows fed soybean or cottonseed meals. Similar results were also reported by DePeters and Bath (1985) who found that canola meal can replace cottonseed meal on an equivalent protein basis without affecting milk yield or composition.

Khorasani et al. (1994) incorporated canola meal and linseed meal in total mixed rations of late lactation dairy cows up to 10% (DM basis). Cows fed the canola

meal-based diet were found to produce milk with higher fat percentage. However, milk yield (average 13.2 kg), protein (average 3.5%) and lactose (average 4.4%) percentages were not influenced by dietary protein source.

Several studies were conducted in the United Kingdom to assess the nutritive value of low glucosinolate rapeseed meal (Dolar variety) for dairy cows. Vincent et al. (1990) compared Dolar rapeseed, sunflower and soybean meals as main protein sources in concentrate supplements given to Friesian cows. The results showed no treatment differences in milk yield or composition (Table 2.10). However, cows fed the rapeseed meal-based concentrate tended to produce more milk relative to those fed the sunflower- or the soybean-meal concentrate. Similar results were also observed by Vincent and Hill (1988) who found no differences in milk yield (average 28.6 kg d^{-1}), fat (average 3.4%) or protein (average 3.1%) percentages between cows fed concentrates containing either 30% Dolar rapeseed meal or 23% soybean meal.

2.6.1.1.3 Effects on Physiological and Reproductive Parameters

The hydrolysis products of glucosinolates (thiocyanates, isothiocyanates and nitriles) are goitrogenic and are responsible for the antithyroid (hypothyroidism) activity of rapeseed meal (Hill 1991; Bell 1993a). The elevation of milk thiocyanate and the depression of iodine levels in milk are usually indications of high glucosinolate intake (Papas et al. 1978). Vincent et al. (1988a) studied the response of heifers to large intakes of two types of high glucosinolate rapeseed meals during two 5-month periods. The results showed that daily intake of glucosinolate up to 144.0 mmol d^{-1} had no effect on ovarian activity or pregnancy rate of heifers. Emanuelson (1989) reported a slight negative effect on the thyroid function as well as on the fertility of primiparous cows fed high levels of rapeseed meal (about 3 kg d^{-1} DM; 40 mmol glucosinolates cow^{-1} d^{-1}). Thyroid glands of heifers given rapeseed meal showed histological evidence of goitrogenicity.

Table 2.9. Effect of protein supplement on milk yield and milk composition of dairy cows.

	Protein Supplement		
	Canola Meal	Soybean Meal	Cottonseed Meal
Yield (kg d^{-1})			
Total milk	37.7	34.5	36.5
Milk protein	1.2	1.0	1.1
Milk fat	1.1	1.0	1.0
Milk total solids	4.7	4.1	4.4
Composition (%)			
Milk fat	2.6	2.7	2.8
Milk protein	3.0	3.0	3.0
Milk total solids	12.0	12.0	12.1

Adapted from Sánchez and Claypool (1983).

Table 2.10. Performance of dairy cows fed low glucosinolate rapeseed meal, sunflower seed meal or soybean meal as protein supplements.

	Protein Supplement		
	Rapeseed Meal	Sunflower Seed Meal	Soybean Meal
Milk yield (kg d^{-1})			
Total	26.7	25.3	25.1
Fat	1.1	1.0	1.0
Protein	0.9	0.8	0.8
Lactose	1.3	1.2	1.2
Milk composition (%)			
Fat	3.9	4.0	4.1
Protein	3.2	3.2	3.3
Lactose	4.8	4.8	4.8

Adapted from Vincent et al. (1990).

Laarveld et al. (1981) using the thyrotropin-releasing hormone test showed that Tower rapeseed meal fed as 19% of the total diet did not affect the response of plasma thyroid stimulating hormone (TSH) whereas Midas rapeseed fed at 13% caused a significant increase in TSH and a significant reduction in serum thyroxine. In contrast, the results of Sánchez and Claypool (1983) showed that feeding canola meal up to 11.7% of the diet did not affect thyroid activity when fed to dairy cows during a 4 month period.

Vincent and Hill (1988) showed that dairy cows fed a concentrate diet containing 23% Dolar rapeseed (*Brassica napus*) meal (< 20 μmol g^{-1}) produced milk with 68.4% higher thiocyanate concentration relative to those fed a soybean meal based concentrate. Emanuelson (1989) found that inclusion of 3 kg Swedish double low rapeseed (*Brassica napus* or *B. rapa*) meal (glucosinolate intake of 40 mmol d^{-1}) to dairy cows significantly increased the thiocyanate and reduced the iodine content in the milk.

The depression in milk iodine content was not related to rapeseed inclusion rate which indicates that even at low levels, rapeseed meal exerts maximum effects on milk iodine concentration. Laarveld et al. (1981) observed no difference in thiocyanate concentration in the milk between two rapeseed cultivars even though the difference in total glucosinolate content between the two cultivars was 64.5 μmol g^{-1}. The study also found no relationship between the concentration of iodine and thiocyanate in the milk.

2.6.1.2 Feeding Canola Meal to Calves

Canola meal has been used in calf starter and grower diets with satisfactorily results. Early studies with commercial rapeseed meal showed no difference in DM intake, daily gain or feed conversion ratio when concentrate diets based on rapeseed meal or soybean meal were fed (Sharma and Ingalls 1974; Fisher 1980). Similarly, Wheeler et al. (1980) found that rapeseed meal could provide 100% of the supplemental protein in a 16% CP calf starter ration without reducing feed intake or impairing performance. More recently, Claypool et al. (1985) compared canola, soybean and cottonseed meals as protein supplements for forty five-day old Holstein calves. The results showed no treatment effect

on starter or milk consumption, average daily gain or plasma thyroxine concentration .

Canola meal protein was found to be less digestible by calves relative to soybean meal protein (Wood and Stone 1970; Sharma et al. 1980). Khorasani et al. (1990) used eight male Holstein calves to determine amino acid kinetics and digestibilities of concentrate diets (18% CP) containing canola or soybean meal. Apparent ileal and total tract digestibility of CP and amino acids (except methionine) were reduced by feeding canola meal relative to soybean meal. Total tract DM and CP digestibility of the canola meal-based diet were 7.7 and 10.3%, respectively lower than the corresponding values for the soybean meal-based diet.

2.6.1.3 Canola Meal for Beef Cattle

The performance of beef cattle fed canola meal as a sole protein source was studied by McKinnon et al. (1993a,b). Feeding a total ration containing 23.0% canola meal, supported higher daily gain (1.3 Vs 1.2 kg) by recently weaned large frame calves relative to a urea-based ration (McKinnon et al. 1993a). No treatment effect was observed for daily feed intake, feed conversion ratio or carcass quality. Feeding canola meal to large frame weaned calves or backgrounded yearlings up to 30% of the ration, did not adversely affect feed intake, daily gain or feed conversion ratio (Table 2.11).

Zinn (1993) determined ruminal and total tract digestibility by steers fed 80% concentrate diets containing either canola or soybean meals (20% of the diet). In a growing-finishing ration for feedlot cattle, canola meal had a ruminal escape protein value of 28% and digestible energy value of 4.12 Mcal kg^{-1} compare with 19.7% and 4.6 Mcal kg^{-1} for soybean meal (Zinn 1993). Total tract DM and CP digestibility were higher for soybean meal (92 and 91%, respectively) than for canola meal (82 and 88%, respectively). However, amino acid supply to the small intestine was similar for both meals with canola meal supplying more methionine.

Table 2.11. Performance of beef cattle fed diets containing different levels of canola meal.

	Level of Canola Meal (% DM)		
	4.3	11.5	21.7
Feed intake (kg d^{-1})			
Weaned calves	8.0	8.1	8.3
Yearlings	10.3	10.7	10.1
Daily gain (kg)			
Weaned calves	1.4	1.5	1.5
Yearlings	1.6	1.5	1.6
Feed:gain			
Weaned calves	5.7	5.5	5.5
Yearlings	5.8	6.4	6.2

Adapted from McKinnon et al. (1993b).

2.6.1.4 Canola Meal for Sheep

Few studies have been conducted on the nutritive value of canola meal for sheep. Bush et al. (1978) compared the nutritive value of two rapeseed cultivars that differ in fiber content when fed to sheep. Digestibility coefficients of DM, CP, NDF and ADF were significantly higher in the low fiber rapeseed meal based diet than in the high fiber rapeseed meal based diet.

Nitrogen balance and utilization efficiency were similar in growing lambs fed canola meal- or soybean meal-based diet although the canola meal based diet was slightly less digestible than the soybean meal-based diet (Matras et al. 1990). The nutritive value of rapeseed meal (no glucosinolate values were determined) was found to be similar to that of sunflower meal for growing lambs fed straw (Coombe 1985; Coombe 1987).

Glucosinolate content of rapeseed meal has little effect on sheep performance. Lambs fed a rapeseed meal-based concentrate containing up to 17.5 μmol g^{-1} glucosinolate had a similar feed intake (1.5 kg $^{-1}$) and gained at a similar rate relative to those fed a soybean meal-based concentrate . However, weights of thyroid gland from lambs fed the rapeseed meal-based diet were about 79% heavier than those of lambs fed the soybean meal-based diet (Hill et al. 1990b).

Vincent et al. (1988b) fed three concentrates containing three types of high glucosinolate British rapeseed meals to ewes over two reproductive cycles. Feeding high glucosinolate rapeseed meals (up to 20 μmol glucosinolates g^{-1} concentrate) had no effect on overall health, live weight or reproductive performance of the ewes. Milk yield was similar, fat percentage was slightly depressed while protein concentration was lower in milk from rapeseed meal than from soybean meal-fed ewes. Milk thiocyanate concentration of rapeseed meal-fed animals was 10 times that of soybean meal-fed animals.

2.6.2 Feeding Value of Whole Canola Seed and Presscake

The idea behind feeding high oil products is to increase the energy density of the ration. In addition to providing energy, whole unextracted oil seeds such as canola

seed, soybean and cottonseed can also be used to provide dietary protein. Whole canola seed contains 44% oil and 24% CP while press cake contains 21% oil and 34% CP (Jones 1993). Most of the studies with canola seed and presscake have been conducted with dairy cows.

2.6.2.1 Effect on Feed Intake

The effect of feeding of whole canola seed to dairy cows showed inconsistent results. Beaulieu et al. (1990) found that inclusion of whole canola seed up to 4.5% of the diet had no effect on dry matter intake by lactating dairy cows. Murphy et al. (1990) found that dairy cows fed ground full fat rapeseed up to 7.5% of the diet, had lower silage intake compared with those fed a control diet. However, inclusion of ungrounded full fat rapeseed at the same level did not affect silage intake. Feeding jet-sploded whole canola seed to dairy cows in early lactation up to 17.4% of the diet was found to have no effect on dry matter intake (Kennelly et al. 1993).

Kennelly (1987) reported a reduction in feed intake of dairy cows fed 6 or 8% whole canola seed. In contrast, Ingalls and Grumpelt (1987) found that dairy cows fed 8% whole canola seed had higher feed intake than those fed extruded canola seed or a control diet.

2.6.2.2 Effects on Milk Yield and Milk Composition

Studies on the impact of feeding high oil canola products in dairy rations, showed no adverse effect on milk yield. Beaulieu et al. (1990) studied the effect of supplementing a barley-based control diet with 3.5% canola oil, 22.0% presscake or 9.0% whole canola seed on milk yield of dairy cows. Addition of high oil canola products had no effect on milk (average 28.5 kg) and milk protein (average 0.88 kg) yield. However, cows fed canola oil- or whole canola seed-based diets produced less milk fat and 4% fat corrected milk relative to those fed the control or presscake-based diet.

Jones (1993) found that feeding presscake to dairy cows up to 11% of the

total ration (% as fed) increased milk yield by 6% and milk lactose yield by 7% relative to a control diet based on canola meal. However, feeding presscake was found to reduce milk fat and milk lactose percentage by 17.1 and 8.3%, respectively. The reduction in milk fat percentage was attributed to reduced synthesis of short chain fatty acids due to high uptake of rumen undegraded long chain fatty acids from presscake by the mammary gland.

Emanuelson (1989) studied long-term effects of feeding different levels of rapeseed products to dairy cows. The results indicated that 2.5 kg of rapeseed meal (average 24 μmol g^{-1} total glucosinolates) plus 0.9 kg full fat rapeseed can be included daily in dairy ration without adverse effects on milk yield compared with other protein supplements such as soybean meal, cottonseed cake and coconut cake.

Ingalls and Grumpelt (1987) studied the effect of feeding whole canola seed and extruded whole canola seed to dairy cows on milk yield. Cows fed extruded whole canola seed produced more milk, and reached peak production later than those fed whole canola seed. The difference in milk yield was attributed the higher fat digestion or the higher rumen escape protein value of extruded whole canola seed relative to whole canola seed. Kennelly et al. (1993) found that inclusion of jet-sploded whole canola seed up to 4.5% of the diet in early lactation increased milk yield by 6.1% with no benefits from further inclusion levels. No benefits were observed from adding jet-sploded whole canola seed for dairy cows in mid and late lactation.

2.6.2.3 Effects on Milk Fatty Acid Composition

Feeding high oil products generally alter the milk fatty acid profile by increasing the proportions of long chain fatty acids and decreasing those of short chain fatty acids. Feeding full fat soybean or rapeseed resulted in a significant reduction in C 8:0 (caprylic) to C 16:0 (palmitic) and a significant increase in C 18:0 (stearic) and C 18:1 (oleic) with little or no increase in C 18:2 (linoleic) and C 18:3 (linolenic) fatty acids (Murphy et al. 1990). However, feeding ground full fat rapeseed was less effective than feeding ungrounded full fat rapeseed. Similar results were also reported by Kennelly

(1987) and Ingalls and Grumpelt (1987). Kennelly et al. (1993) found a linear decline in the concentrations of short chain saturated fatty acids and a linear increase in the concentration of oleic acid with increasing levels of jet-sploded whole canola seed in dairy rations. No treatment effects were observed for linoleic or linolenic fatty acid.

Similar changes in milk fatty acid composition were also observed for canola presscake. Jones (1993) found that feeding canola presscake decreased concentration and yield of medium chain fatty acids. However, unlike canola seed, feeding canola presscake increased the concentration of long-chain polyunsaturated fatty acids (linoleic and linolenic acid).

Extensive rumen biohydrogenation of polyunsaturated vegetable oil might explain the lack of effect of feeding whole canola seed on the concentration of linoleic and linolenic fatty acids (Murphy et al. 1990). Kennelly et al. (1993) attributed the presence of elevated levels of oleic acid in milk of cows fed jet-sploded whole canola seed to either increased dietary levels of oleic acid as a result of incomplete biohydrogenation or increased desaturation of stearic acid in the gut wall and the mammary gland. The reduction in the concentrations of short- and medium- chain fatty acids is most likely due to the inhibition of de-vovo synthesis of those fatty acids due to increased uptake of long chain fatty acids (Murphy et al. 1990; Kennelly 1987). Kennelly et al. (1993) indicated that all short chain fatty acids with chain length less than 16 and about 50% of the C16 (palmitic) fatty acids are synthesized in the mammary gland while long chain fatty acids are incorporated directly into milk fat from dietary sources or adipose tissue reserves.

2.6.3 Canola Screenings

The feeding value of canola screenings for dairy cows was studied by Wiesen et al. (1990). Feeding canola screenings up to 14% of the ration had no effect on total milk (average 39.4 kg), fat (1.33 kg) or protein yield (1.92 kg). No treatment effects were observed on fat (3.09%) or protein (3.03%) levels. However, there were significant increases in milk unsaturated fatty acids (oleic and linoleic) for cows consuming the canola

screening-based diets. Canola screenings are fairly digestible by sheep. Digestibility coefficients of DM, OM and CP are 60.2, 63.9 and 77.4%, respectively (Tait et al. 1986).

2.7 Rumen Degradability of Canola Products

2.7.1 Rumen Degradability of Canola Meal

The rumen degradability of canola meal has been extensively studied. Most of the studies were conducted using the *in situ* nylon bag technique. It is evident from this research that canola meal is rapidly degradable in the rumen and thus is considered a poor source of rumen undegradable protein (Kirkpatrick and Kennelly 1987; Deacon et al. 1988; Khorasani et al. 1994).

2.7.1.1 Kinetic Parameters

Considerable variation in kinetic parameters and effective degradability of canola meal have been reported by different researchers. Soluble protein (*a* fraction) ranges from 18.6 to 31.9% (Kirkpatrick and Kennelly 1987; Khorasani et al. 1994). Potentially degradable protein (*b* fraction) ranges from 42.8 to 83.1% (Mir et al. 1984; Kirkpatrick and Kennelly 1987). The rate of degradation of the *b* fraction have been reported to range from 4.3 to 15.7% h^{-1} (Mir et al. 1984; Cheng et al. 1993).

Factors that influence results of the nylon bag technique have been discussed earlier. However, specific factors such as forage:concentrate ratio, level of CP in the basal diet, incubation time course and method of estimating the soluble fraction are most likely to contribute to such variation. Kendall et al. (1991) attributed differences in rumen degradability of canola meal samples obtained from different crushers to differences in processing conditions. However, such a conclusion might be acceptable if a standardized nylon bag technique was used across different laboratories.

2.7.1.2 Effective Degradability

Effective CP degradability of canola meal has been reported to range from 47.6 (Mir et al. 1984) to 82.3% (Baily and Hironaka 1984). Despite these extreme values, variations in effective CP degradability between different studies are less than those observed for the potentially degradable fraction (Table 2.12). This can be attributed to the fact that the potentially degradable fraction and its rate of degradation are adjusted in relation to the estimate of the soluble fraction so that less variation in effective degradability results between different trials (Boila and Ingalls 1992).

The effect of correcting for rumen flow rate on effective degradability of canola meal protein is relatively small and fairly constant. Khorasani et al. (1993) reported a reduction of 9.4% in effective CP degradability of canola meal when rumen flow rate increased from 4 to 8% h^{-1}. Boila and Ingalls (1992) and Deacon et al. (1988) reported a reduction of 11.9 and 12.3%, respectively, when rumen flow rate increased from 5 to 8% h^{-1}. Ørskov (1992) indicated that correction for rumen flow rate has its greatest effect for feeds with a large potentially degradable fraction and a small rate of degradation.

Effective CP degradability of canola meal has been compared with other protein supplements. Studies comparing canola meal with soybean meal revealed inconsistent results. Ha and Kennelly (1984) and Kirkpatrick and Kennelly (1987) found that effective CP degradability of canola meal was 18.5 and 16.7%, respectively, higher than soybean meal. However, Deacon et al. (1988) reported a slightly higher effective CP degradability for soybean meal (68.2%) than for canola meal (66.1%). Kendall et al. (1991) reported similar effective CP degradability for five canola meal samples (51.5% ± 5.4) and soybean meal (51.5%). Khorasani et al. (1994) determined effective CP degradability of canola meal relative to other protein supplements. Similar effective CP degradability was reported for canola, soybean and solvent extracted linseed meals (58.3%) but higher than that of expeller linseed meal (50.0%). DePeters and Bath (1986) reported similar effective CP degradability for canola and cottonseed meals (64.5%).

Table 2.12. Variations in ruminal crude protein kinetic parameters and effective degradability of canola meal.

Reference	Rumen kinetic parameter[z]			Effective degradability[y]
	a (%)	b (%)	c (% h^{-1})	
Boila and Ingalls (1992)	28.2	68.4	6.8	67.1
DeBoer et al. (1987)	28.2	66.7	13.0	76.4
Jones (1993)	26.1	74.0	6.8	68.4
Khorasani et al. (1993)	31.9	62.9	18.3	81.3
Khorasani et al. (1994)	18.6	56.7	11.2	57.8
Kirpatrick and Kennelly (1987)	18.6	77.1	9.0	63.2
Murphy and Kennelly (1987)	29.0	56.5	10.5	67.6
Mean	25.4	65.7	11.5	69.1
SD[x]	5.6	8.6	4.0	8.6

[z] a = soluble CP (% CP), b = degradable CP (% CP), c = degradation rate of b fraction (% h^{-1}).
[y] Calculated assuming rumen flow rate of 5% h^{-1}.
[x] SD = Standard deviation.

2.7.2 Rumen Degradability of Other Canola Products

Ruminal degradability of unextracted canola seed was studied by Deacon et al. (1988). At 5% h^{-1} rumen flow rate, effective CP degradability of whole canola seed was 23.8 and 21.3% higher than canola meal and soybean meal, respectively. Relative to canola meal, canola presscake has higher rapidly soluble CP (45.2 vs 25.2%), lower potentially degradable CP (53.3 vs 73.2%), similar degradation rate (6.1 vs 7.2% h^{-1}) and higher effective CP degradability (74.4 vs 68.3%) values (Jones 1993). Beaulieu et al. (1990) reported higher rumen CP disappearance for unextracted canola seed (93.5%) than for canola presscake (91.1%) or canola meal (75.1%), following 12 h of rumen incubation.

2.8 Intestinal and Total Tract Digestibility of Canola Products

Several studies have been conducted to estimate intestinal availability and total tract digestibility of canola meal using the mobile nylon bag technique (McKinnon et al. 1995b; Khorasani et al. 1994; De Boer et al. 1987) or cannulated steers (Lardy et al. 1993; Zinn 1993). These studies indicate high intestinal and total tract digestibility of canola meal protein. In most cases digestibility has exceeded 90%. Following 16 h of rumen incubation, the proportion of canola meal protein disappeared in the rumen, small intestine and the total tract were 74.4, 16.2 and 90.5%, respectively (Moshtaghi Nia and Ingalls 1992).

Khorasani (1994) reported similar total tract digestibility for canola meal and expeller and solvent extracted linseed meals (73.5%) but a lower value than soybean meal (83.5%). In agreement with these findings, Deacon et al. (1988) observed similar total tract digestibility (following 12 h of rumen incubation) for whole canola seed and canola meal, which was 5.9% lower than soybean meal.

Lardy et al. (1993) studied the effect of feeding rapeseed meal on the duodenal flow of amino acids of cattle fed forage-based diets. Rapeseed meal supplementation resulted in a higher duodenal flow of sulfur-containing amino acids than the soybean meal-based diet. Zinn (1993) indicated that on an isonitrogenous basis, canola

meal may provide more methionine to the small intestine than soybean meal when fed in a growing-finishing diet.

2.9 Summary of the Literature Review

- *In vivo* techniques (using cannulated animals) are usually the standard procedures for protein evaluation to which other methods are to be compared. A primary difficulty with *in vivo* techniques is to distinguish between microbial and dietary protein. The *in vivo* methods are also expensive, time consuming and not suitable for routine evaluation.

- The *In situ* nylon bag technique is the most common used technique for feed protein evaluation. The technique allows for the estimation of the extent as well as the rate of protein degradation in the rumen. In combination with rumen flow rate, the technique can be used to estimate effective ruminal degradability of feed protein. The method however, is yet to be standardized among different laboratories to minimize the variability in conditions under which the results are obtained.

- Cheaper and simpler *In vitro* methods of protein evaluation such as those based on protease enzyme have been developed and recently been used in some protein evaluation systems (e.g. French digestible proteins in the intestine system). These methods are important for screening and monitoring purposes. A major problem with the in vitro techniques is that the enzymes used (e.g. protease) can only partly simulate the activity of enzyme complexes in the rumen.

- Intestinal availability of rumen undegraded protein can be estimated by the mobile nylon bag technique or by a combination of the *in situ* nylon bag technique and an *in vitro* (pancreatin enzyme) or a biological (rat or cecectomized rooster) assay.

- The Cornell Net Carbohydrate and Protein System provides an improved description of

feed carbohydrate and protein fractions based on solubility in borate phosphate buffer and detergent solutions. However, fractionation of feed carbohydrate is not very accurate and methods of estimating the rates of degradation of carbohydrate and protein fractions are not well defined.

- Hulls constitute a relatively large proportion of canola seed (16%) and canola meal (30%). On average canola hull contains 22.5% CP, 61.2% NDF and 52.1% ADF. The corresponding values for canola meal are 37.7, 23.4 and 19.1%, respectively. The digestible energy value of canola hulls is low for both ruminant and monogastric animals.

- Canola meal is the protein supplement of choice in dairy and beef rations in Canada. Most of the studies demonstrated that canola meal sustain similar or improved performance relative to soybean meal. However, digestibility of canola meal is slightly lower than soybean meal. The following levels of canola meal can be fed (% of the diet): calves 20%, dairy cows 23.5% and beef cattle 30%.

- Research on the feeding value of other canola products is limited. Feeding whole canola seeds (4.5%), canola presscake (11%) and canola screenings (14%) had little effect on feed intake and milk yield. However, feeding high fat canola products reduced the percentages of myristic (C14:0), and palmitic (C16:0) fatty acids and increased the percentages of stearic (C18:0) and oleic (C18:1) fatty acids.

- Rumen degradability of canola meal is high and similar to that of soybean meal. The high rumen degradability of canola meal can be attributed to a high soluble protein fraction and a high rate of degradation of the potentially degradable protein fraction. Other canola products such as whole canola seed and presscake are more degradable than canola meal.
- Dehulling of canola seed or meal reduced the fiber content of the dehulled meal

particularly ADF. The improvement in CP content of the dehulled meal was less than the reduction in fiber content. Despite improvement in fiber and protein characteristics of the dehulled meals, performance of pigs and poultry was not encouraging.

- Problems associated with dehulling canola meal include irregular and small seed size, strong attachment between the embryo and the hull, loss of oil in the hulls, lack of market outlet for the hulls and extreme fineness of the dehulled meal.

The objectives of this thesis are:

1- To determine the effect of tail-end dehulling of canola meal on the chemical characteristics of the high fiber, low protein (HFCM) and the low fiber, high protein (LFCM) meal fractions relative to canola meal.

2- To examine in situ rumen disappearance of different nutrients from canola meal, LFCM and HFCM obtained from five crushing plants.

3- To determine rumen nutrient kinetic parameters and effective degradabilities for HFCM relative to canola meal and LFCM.

4- To determine nutrient digestibility coefficients for HFCM relative to canola meal.

5- To determine milk production and composition responses of early to mid lactation dairy cows to diets supplemented with HFCM, canola meal or soybean meal.

CHAPTER 3. The Nutritive Value of High Fiber Canola Meal for Ruminants I. Protein and Carbohydrate Fractions.

3.1 ABSTRACT

Tail-end dehulling separates canola meal into low (LFCM) and high (HFCM) fiber fractions. The effect of tail-end dehulling of canola meal on the chemical composition of the processed LFCM and HFCM fractions relative to canola meal was investigated in a completely randomized design using samples from five crushing plants. Relative to LFCM and canola meal, HFCM had higher ($P<0.05$) neutral (NDF) and acid (ADF) detergent fiber and acid detergent lignin (ADL) levels. Canola meal had higher ($P<0.05$) ADF and ADL but not NDF relative to LFCM. Crude protein was higher ($P<0.05$) in LFCM than in canola meal and was higher ($P<0.05$) in canola meal than in HFCM. Neutral and acid detergent insoluble CP followed the pattern of NDF and ADF, respectively. Protein fractionation showed no difference in non-protein nitrogen between the three meals. Unavailable protein was higher ($P<0.05$) in HFCM than in canola meal and was higher ($P<0.05$) in canola meal than in LFCM. True protein was higher ($P<0.05$) in canola meal and LFCM than in HFCM. True protein consisted of 14.8, 14.5 and 12.9% the B_1 fraction, 76.8, 76.9 and 75.1% the B_2 fraction and 8.4, 8.6 and 12.0% B_3 fraction in canola meal, LFCM and HFCM, respectively. Relative to canola meal and LFCM, HFCM had higher ($P<0.05$) calcium and lower ($P<0.05$) phosphorous contents. Magnesium content was higher ($P<0.05$) in LFCM than in canola meal and HFCM. Variations in ethanol insoluble sugars were as follows: glucose: HFCM > canola meal > LFCM; galactose and mannose: HFCM > canola meal = LFCM; arabinose: HFCM ≥ canola meal > LFCM. It was concluded that tail-end dehulling of canola meal resulted in two meal fractions each with a distinct chemical composition.

3.2 INTRODUCTION

Canola meal is an excellent source of protein for dairy and beef cattle (McKinnon et al. 1993; Zinn 1993; Sánchez and Claypool 1983; Laarveld and Christensen 1976). However, its use in poultry and swine diets is limited by protein quality and low digestible energy (Bell 1993a). The seed hull which has low digestibility for pigs and poultry constitutes 15 to 16% of the seed and about 25% of the meal (Bell and Shires 1982). Different methods have been used to reduce the hull content of rapeseed and canola meal. These include air classification (King and Dietz 1987; Bayley and Hill 1975) and front-end dehulling (Bell 1993b). However, the methods used to date have not proven to be commercially viable and little or no improvement in pig or poultry performance has resulted from their use (Bell and Shires 1982; Bell 1993b). Tail-end dehulling fractionates canola meal into high fiber, low protein (HFCM) and low fiber, high protein (LFCM) meals (McCurdy and March 1992). The technique involves tempering the meal to 16% moisture, disc milling and sieving . This technology should allow target marketing to specialized segments of the livestock industry. The LFCM would be targeted for swine and poultry while the HFCM would be utilized by the beef, dairy and sheep industries.

A new system for evaluating cattle diets based on chemical analyses has been developed (Sniffen et al. 1992; Fox et al. 1992). This system divides dietary protein and carbohydrates into specific fractions using detergent solutions and borate phosphate buffer (Roe et al. 1990). This system is expected to improve the prediction of ruminant performance by classifying feedstuffs according to their content of nutrients that meets rumen microbes and host animal needs. With respect to dietary protein, it is designed to clearly fractionate dietary protein into ruminally degradable and undegradable protein and into unavailable protein (Chalupa 1992). If tail-end dehulling is successful, one would anticipate that relative to canola meal, HFCM and LFCM would have distinctively different fiber and protein levels. Little or no information exists on the composition of the fiber and the nature of the resulting protein fractions. Such information is important to nutritionists

who would use these products in livestock diets.

The objectives of this study were to examine the effect of tail-end dehulling of canola meal on the carbohydrate, protein and mineral fractions of LFCM and HFCM with special emphasis on protein classification

3.3 MATERIALS AND METHODS

3.3.1 Sample Preparation and Chemical Analyses

Canola meal was obtained from five commercial crushers in western Canada. Fractionation into low (LFCM) and high fiber (HFCM) meals was carried out in the Protein Oil and Starch (POS) pilot plant in Saskatoon, Saskatchewan. The dehulling technique was described by McCurdy and March (1992). Briefly, aliquots of canola meal from each of five crushing plants were tempered to 16% moisture and milled using an 8-inch disc mill (Bauer Brothers Co. LTD., Brantford, ON). The milled meals were then sieved using a 35-mesh (U.S.A Sieve Series) screen to obtain a HFCM (60% of the original meal) and a LFCM (40% of the original meal). Prior to analyses all samples were ground through a 1 mm screen using a Christie-Norris mill. Samples were then analyzed for moisture (method No. 930.15), ash (method No. 924.05), ether extract (method No. 920.39), Kjeldahl nitrogen (method No. 984.13) using a Kjeltec 1030 auto analyzer, acid detergent fiber (ADF) (method No. 973.18) and acid detergent lignin (ADL) (No. 973.18) according to the Association of Official Analytical Chemists (AOAC 1990). Neutral detergent fiber (NDF) was determined according to the procedure of Van Soest et al. (1991). Neutral and acid detergent insoluble crude protein were determined on NDF and ADF residues, respectively , using Kjeldahl nitrogen (AOAC 1990 method No. 984.13). Mineral concentrations were 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). Phosphorous concentration was determined colorimtericaly (Pharmacia LKB utraspec. III). *In vitro*

soluble and degradable CP were determined using the procedure of Roe *et al.* (1990). For soluble CP, 0.5 g air dry sample was weighed into an Erlenmeyer flask to which 50 mL of borate-phosphate buffer was added. The sample was then incubated at 39 °C for 1 h. For degradable CP, equivalent of 0.2 g protein (air dry) was weighed into an Erlenmeyer flask and incubated with 40 mL borate phosphate buffer at 39 °C. Following 1 h incubation, 10 mL (0.33 units mL^{-1}) of fresh protease solution (protease enzyme from *Streptomyces griseus*, type XIV, Sigma Chemical Co., St. Louis, MO) was added and the sample was re-incubated for 18 h. Non-protein nitrogen content was estimated using sodium tungstate as a precipitating agent according to the procedure of Greenberg and Shipe (1979). Residues of the soluble CP, degradable CP and non-protein nitrogen procedures were recovered on Whatman No. 54 filter paper and residual nitrogen estimated by Kjeldahl method. Protein solubility, degradability and non-protein nitrogen were expressed as percent of total CP. Total starch was determined using the α amylase amyloglucosidase method (Megazyme kit, Megazyme, NSW, Australia).

Total and non-structural carbohydrates (CHO) of canola meal, LFCM and HFCM were estimated according to the equations of Sniffen et al. (1992):

$$\textit{Total (CHO)} = \textit{100} - \textit{CP} - \textit{ash} - \textit{EE};$$

$$\textit{Non-structural CHO} = \textit{100} - [(\textit{NDF} - \textit{Neutral Detergent Insoluble CP}) + \textit{CP} + \textit{EE} + \textit{ash})].$$

Total CP was fractionated according to Sniffen et al. (1992) into fraction A (non-protein nitrogen), fraction B (true protein) and fraction C (unavailable protein). True protein was calculated as the difference between total CP and non-protein nitrogen and acid detergent insoluble CP. Un-available protein was the acid detergent insoluble CP. True protein was further sub-fractionated into B_1 (highly degradable), B_2 (intermediately degradable) and

B_3 (slowly degradable) fractions (Sniffen et al. 1992):

B_1 = Buffer Soluble CP - Non-Protein Nitrogen;

B_2 = Buffer Insoluble CP - Neutral Detergent Insoluble CP;

B_3 = Neutral Detergent Insoluble CP - Acid Detergent Insoluble CP.

Ethanol insoluble sugar content was determined by extracting 20 mg of sample meal with 5 mL of 80% ethanol. The extraction procedure included incubation of the sample at 60 °C for 20 min. The insoluble residues were then recovered by centrifuging (1600 x *g*) the sample for 25 min. Following drying at low temperature (40 °C), the sample was hydrolyzed with 0.5 mL 72% sulfuric acid. The acid insoluble residues were filtered through a glass fiber prefilter and the neutral sugars in the hydrolysate reduced and acetylated as described by Harris et al. (1988). The neutral sugars were then determined as alditol acetates by gas-liquid chromatography using a Perkin-Elmer (Sigma 2000) gas chromatograph equipped with a flame ionization detector and a 30 meter fused silica capillary column. Helium gas flow rate was 38.5 cm sec^{-1}. The oven temperature was set at 200 °C for 10 min and increased by 10 °C min^{-1} to 230 °C for 5 min. Injector and detector temperatures were 250 and 300 °C, respectively.

3.3.2 Statistical Analysis

Data regarding the three treatments (canola meal, LFCM and HFCM) were subjected to analysis of variance using the General Linear Model procedure of the Statistical Analysis System Institute, Inc (1989). Data were analyzed as a completely randomized design with samples from the five crushing plants as replicates. Means were separated by Student Student-Newman-Keuls procedure (Steel and Torrie 1980).

3.4 RESULTS AND DISCUSSION

3.4.1 Chemical Composition

Tail-end dehulling of canola meal altered the carbohydrate components of the two processed meals (Table 3.1). Total carbohydrate was 10% higher ($P<0.05$) in HFCM than in canola meal and was higher ($P<0.05$) in canola meal than in LFCM. No difference in non-structural carbohydrate content was observed between these treatments (average 25.8%) indicating that differences in carbohydrate content are due to differences in structural carbohydrate content. Structural carbohydrates are insoluble in neutral detergent solution and include cellulose, hemicellulose and lignin. Non-structural carbohydrates are soluble in neutral detergent solution and contain sugars, starch and pectins (Sniffen et al. 1992). Other workers have also found low levels of non-structural carbohydrate in canola meal. Slominski and Campbell (1991) demonstrated that canola meal has low starch and soluble sugar levels. Bell (1993a) indicated that starch and sucrose comprise less than 10% of canola meal.

Tail-end dehulling of canola meal also altered the distribution of fiber components between the two processed fractions (Table 3.1). HFCM exhibited higher ($P<0.05$) levels of NDF, ADF and ADL relative to canola meal and LFCM while canola meal exhibited higher ($P<0.05$) ADF and ADL but not NDF values relative to LFCM. Relative to canola meal, the dehulling technique reduced NDF, ADF and ADL contents of LFCM by 7.9, 26.0 and 23.2% and increased those of HFCM by 30.0, 23.8 and 35.1%, respectively. The results agree with those of Bell (1993b) who indicated that front-end dehulling reduced NDF and ADF content of the meal by 2.5 and 39.3%, respectively. Bell and Shires (1982) found that hull removal of rapeseed by air classification is reduced NDF and ADF contents of the meal by 19 and 33%, respectively. The results of this study show that tail-end dehulling produces a LFCM that relative to canola meal reduced to a greater extent in ADF than in NDF. This finding suggests that much of the ADF (cellulose and lignin) content of canola seed is associated with the hulls and a considerable portion of

Table 3.1. Ash, ether extract and carbohydrate composition of regular, low and high fiber canola meals (mean ± SD, DM basis).

	Type of canola meal			
	Regular	Low fiber	High fiber	SEM
Ash	8.2	9.0	7.9	0.40
SD[z]	0.9	1.1	0.7	
Ether extract	4.7	4.8	4.6	0.31
SD	0.4	0.8	0.8	
Carbohydrates				
Total	49.6b	45.4c	54.6a	0.77
SD	1.2	2.0	1.9	
Non-structural (NSC)	27.0	25.4	24.9	0.96
SD	2.9	2.0	1.2	
Starch (% of NSC)	7.3	7.8	8.6	0.78
SD	0.7	1.9	2.3	
Neutral detergent fiber	26.7b	24.6b	34.7a	0.90
SD	1.7	2.5	1.6	
Acid detergent fiber	19.3b	14.4c	23.9a	0.57
SD	1.4	1.4	1.0	
Acid detergent lignin	6.3b	4.8c	9.6a	0.34
SD	0.7	0.8	0.8	
Hemicellulose[y]	7.4b	10.3a	10.8a	0.90
SD	1.9	1.7	2.3	
Cellulose[x]	13.1b	9.6c	14.3a	0.40
SD	1.3	0.7	0.6	

a, b, c Means in the same row followed by different letters differ (P<0.05).
SEM = Pooled standard error of the mean.
[z]SD = Standard deviation.
[y] Hemicellulose = Neutral detergent fiber - acid detergent fiber.
[x] Cellulose = Acid detergent fiber - acid detergent lignin.

NDF (hemicellulose) is associated with the seed embryo.

Crude protein (CP) was higher ($P<0.05$) in LFCM relative to canola meal and was higher ($P<0.05$) in canola meal relative to HFCM (Table 3.2). These results agree with those reported for rapeseed (*Brassica napus*) meal by King and Dietz (1987) who used air classification to achieve CP values of 41.8 to 46.1% in the fines fraction compared to 32.8 to 36.0% in the original meal. Bayley and Hill (1975) found that air classification of rapeseed meal resulted in a high fiber fraction with a lower CP content (33.3%) compared to the low fiber fraction (46.7%). Relative to canola meal and LFCM, HFCM exhibited increased ($P<0.05$) levels of neutral and acid detergent insoluble CP, similar soluble but reduced ($P<0.05$) degradable CP values (Table 3.2). LFCM was found to have lower ($P<0.05$) acid detergent insoluble CP and similar neutral detergent insoluble CP compared to canola meal. These results agree with those obtained for NDF and ADF, since neutral and acid detergent insoluble CP are associated with NDF and ADF, respectively. No differences were observed in soluble and degradable CP fractions between canola meal and LFCM. Non-protein nitrogen (% of CP) content was similar in canola meal, LFCM and HFCM (Table 3.2). The soluble CP and non-protein nitrogen values reported for canola meal are consistent with values reported in the literature (Sniffen et al. 1992; Krishnamoorthy et al. 1982).

It is clear that tail-end dehulling of canola meal is more effective in reducing the fiber content particularly ADF, than in increasing the protein content of LFCM. This might be explained by the high fiber and low CP content of canola hulls which is the main target of any dehulling technique. McKinnon et al. (1995) showed that canola hulls contain 65.8% NDF, 46.7% ADF and 15.4% CP. It should also be pointed out that tail-end dehulling is not a complete dehulling process and some of the hulls will remain in the LFCM. In agreement with our results, McCurdy and March (1992) found that tail-end dehulling of canola meal resulted in a fiber reduced meal with 16% more CP and 50% less crude fiber than the original canola meal. Similar results were also observed for front-end

Table 3.2. Protein fractions of regular, low and high fiber canola meals (mean ± SD, DM basis).

	Type of canola meal			
	Regular	Low fiber	High fiber	SEM
Crude protein	37.7b	40.2a	35.2c	0.73
SD[z]	1.0	2.0	2.1	
Protein fraction (% of crude protein)				
Soluble Protein	35.5	36.4	35.0	1.12
SD	1.8	3.1	2.5	
Non protein nitrogen	24.3	25.1	26.8	0.97
SD	1.8	3.1	1.1	
Soluble true protein	10.5ab	11.3a	8.7b	0.69
SD	1.7	1.7	1.2	
ND insoluble protein[y]	10.5b	9.5b	14.0a	0.85
SD	1.3	1.5	1.6	
AD insoluble protein[x]	4.6b	3.2c	6.2a	0.31
SD	0.6	1.0	0.3	
Degradable protein	65.4a	66.1a	60.2b	1.03
SD	2.8	2.2	1.8	

a-c Means in the same row followed by different letters differ (P<0.05).
SEM = Pooled standard error of the mean.
[z] SD = Standard deviation.
[y] ND = Neutral detergent.
[x] AD = Acid detergent.

dehulling (Bell 1993b). Sarwar et al. (1981) showed that air classification of rapeseed into hull and hull-free fractions, resulted in a greater separation of crude fiber than of crude protein. Similar results were also reported by Leslie et al. (1973).

According to Sniffen et al. (1992), feed protein can divided into three fractions, namely fraction A (non protein nitrogen), fraction B (true protein) and fraction C (unavailable protein). True protein constituted the largest portion of dietary protein in canola meal, LFCM and HFCM, followed by non-protein nitrogen and unavailable protein, respectively (Figure 3.1). Non-protein nitrogen was similar in canola meal, LFCM and HFCM averaging 25.4 ± 1.3 % of the total CP. Unavailable protein (acid detergent insoluble CP) was higher ($P<0.05$) in HFCM (6.2 % of the total CP) relative to canola meal and was higher ($P<0.05$) in canola meal (4.6 % of the total CP) relative to LFCM (3.2 % of the total CP). Canola meal and LFCM had similar true protein levels (average 71.4 % of the total CP) which was higher ($P<0.05$) than that of HFCM (67.0 % of the total CP). These results are consistent with other protein supplements such as rapeseed meal, soybean meal and cottonseed meal where true protein makes up the majority of the dietary protein followed by non-protein nitrogen and unavailable protein, respectively (Sniffen et al. 1992). Krishnamoorthy et al. (1982) found that in rapeseed meal, non-protein nitrogen, true protein and unavailable protein formed 23.0, 70.6 and 6.4 % of dietary protein, respectively.

Results of this study show little effect of tail-end dehulling of canola meal on the rapid (B_1), intermediate (B_2) and slowly (B_3) degradable true protein (Figure 3.2) fractions. The B_2 fraction which averaged 53% of the total CP was similar in the three meals. The B_1 fraction was lower ($P<0.05$) in HFCM (8.7% of the total CP) relative to LFCM (11.3% of the total CP). Values for the B_3 fraction did not differ between canola meal, LFCM and HFCM (6.0, 6.2 and 8.0% of the total CP, respectively). Krishnamoorthy et al. (1982) reported values of 9, 57.2 and 4.2 % for the B_1, B_2 and B_3 fractions, respectively for rapeseed meal. Similar values were also

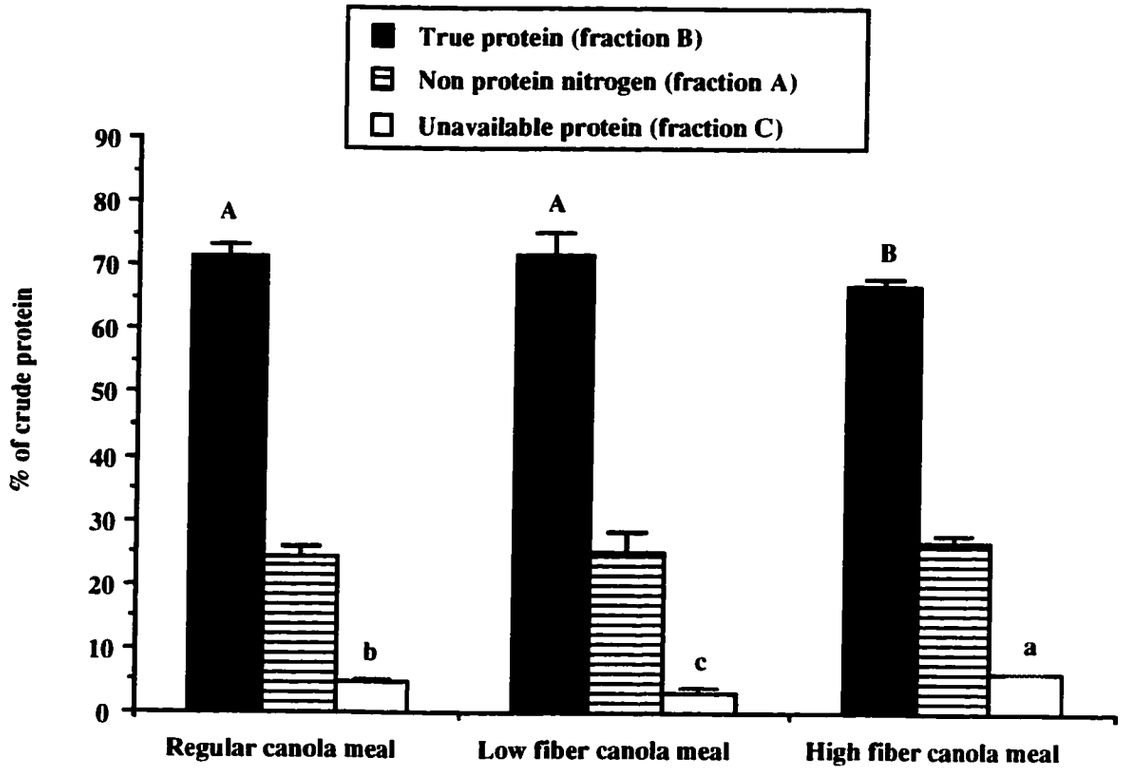

Figure 3.1. Crude protein fractions of regular, low and high fiber canola meal (mean ± SD). Columns with different letters are different ($P<0.05$).

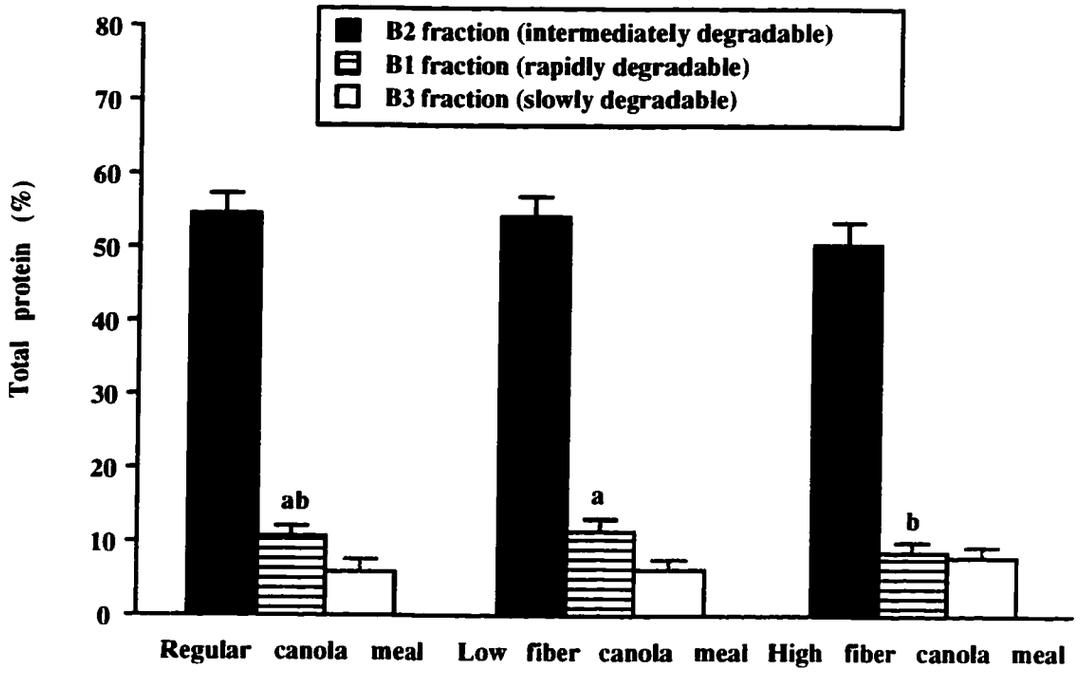

Figure 3.2. True protein fractions of regular, low and high fiber canola meal (mean ± SD). Columns with different letters are different ($P<0.05$).

reported for canola meal by Sniffen et al. (1992). Krishnamoorthy et al. (1983) found that 61.7% of soybean protein was in the B_2 fraction while 11.8 and 13.5 % was in the B_1 and the B_3 fractions, respectively.

The division of true protein into the B_1, B_2 and B_3 fractions is based on their inherent rate of rumen degradation (Sniffen et al. 1992; Krishnamoorthy et al. 1983). The rates of degradation of the B_1, B_2 and the B_3 fractions are assumed to be 100 to 300, 1 to 30 and 0 to 3% h^{-1}, respectively (Sniffen et al. 1992). Fractionation can be used to predict the amount of protein that will be degraded in the rumen. In highly degradable protein supplements such as canola and soybean meals, the B_2 fraction will form a large portion of the true protein. On the other hand, protein supplements with low rumen degradability such as brewers grains and heated soybean meal are characterized by a high B_3 fraction (Sniffen et al. 1992). Based on their carbohydrate and protein profile, HFCM and LFCM would be expected to be highly degraded in the rumen. The extent of degradation would, however, depend on rumen residence time and factors such as the nature of the basal diet (Nocek 1988).

HFCM had higher ($P<0.05$) calcium (Ca) and lower ($P<0.05$) phosphorous (P) levels relative to LFCM and higher ($P<0.05$) Ca and lower ($P<0.05$) magnesium contents relative to canola meal (Table 3.3). No differences were observed in mineral composition between canola meal and LFCM except for P which was higher ($P<0.05$) in LFCM relative to canola meal. These results agree with those of Bayley and Hill (1975) who fractionated canola meal using air classification. Bell and Shires (1982) showed that rapeseed hulls contained more Ca and less P than the embryo or the original seed. Similarly, Bell (1993b) found that front-end dehulling reduced Ca and increased P and Mg contents of the dehulled canola meal relative to commercial canola meal. No differences were observed in copper, zinc, and manganese contents between treatments. However, the high variation between crushing plants as indicated by the high standard deviation may explain the lack of significance. There is good agreement between

Table 3.3. Mineral composition of regular, low and high fiber canola meal (mean ± SD, DM basis).

	Type of canola meal			
	Regular	Low fiber	High fiber	SEM
Calcium (%)	0.65b	0.67b	0.78a	0.01
SD[z]	0.01	0.02	0.03	
Phosphorous (%)	1.24b	1.47a	1.10b	0.05
SD	0.10	0.10	0.14	
Magnesium (%)	0.61a	0.57ab	0.50b	0.02
SD	0.05	0.05	0.06	
Copper (mg kg^{-1})	6.26	7.10	6.80	0.38
SD	0.44	1.12	0.86	
Zinc (mg kg^{-1})	68.68	71.96	62.65	3.67
SD	12.70	3.39	5.36	
Manganese (mg kg^{-1})	49.52	51.27	48.98	1.48
SD	4.20	1.47	3.60	

a,b Means in the same row followed by different letters differ ($P<0.05$).
SEM = Pooled standard error of the mean.
[z] SD = Standard deviation.

the mean values reported in this study for canola meal and those reported by Bell and Keith (1991). Variation in mineral composition among crushers has been attributed to regional differences in soil minerals and other environmental factors (Bell and Keith 1991).

Tail-end dehulling of canola meal altered the ethanol insoluble sugar content of the LFCM and HFCM fractions (Table 3.4). Ethanol insoluble glucose was higher ($P<0.05$) in HFCM than in canola meal and was higher ($P<0.05$) in canola meal than in LFCM. This is consistent with the ADF analysis since most of glucose in canola meal is associated with cellulose (Slominski and Campbell 1990). Ethanol insoluble galactose and mannose were higher ($P<0.05$) in HFCM relative to canola meal and LFCM while ethanol insoluble arabinose was higher ($P<0.05$) in HFCM than in LFCM. No difference was observed in ethanol insoluble xylose between treatments.

Tail-end dehulling reduced the polysaccharide content of LFCM by 14.3% and increased that of HFCM by 38% relative to canola meal. Such a reduction might have an important impact upon the nutritive value of LFCM for monogastric animals. Studies have shown that non-starch polysaccharides of canola meal are poorly digestible (3%) by poultry (Slominski et al. 1991; Slominski et al. 1994).

Within each of the three meals, a consistent trend was observed for the relative proportions of ethanol insoluble sugars. Glucose always made up the largest percentage followed by arabinose. Xylose and galactose were intermediate to their contribution to the total insoluble sugar content while mannose consistently compromised the smallest proportion. The ethanol insoluble sugar profiles for canola meal, LFCM and HFCM were glucose 51.8, 45.5, 60.1%; arabinose 25.2, 27.6, 19.6%; xylose 10.6,13.8, 9.0; galactose 10.5, 11.0, 9.1% and mannose 1.9, 2.1, 2.2%, respectively. A similar neutral sugar profile for canola meal was reported by Slominski and Campbell (1990) and for rapeseed meal by Siddiqui and Wood (1977).

In conclusion, it is clear that tail-end dehulling of canola meal resulted in two meal fractions with different chemical and characteristics. A HFCM fraction with

Table 3.4. Ethanol insoluble sugars of regular, low and high fiber canola meal (mean ± SD, DM basis).

Sugar	Type of canola meal			SEM
	Regular	Low fiber	High fiber	
Glucose	4.6b	3.5c	7.4a	0.24
SD[z]	0.28	0.30	0.81	
Galactose	0.9b	0.8b	1.1a	0.04
SD	0.09	0.08	0.06	
Mannose	0.2b	0.2b	0.3a	0.02
SD	0.02	0.01	0.07	
Xylose	1.0	1.1	1.1	0.06
SD	0.09	0.14	0.14	
Arabinose	2.1b	2.1ab	2.4a	0.07
SD	0.34	0.20	0.11	

a-c Means in the same row followed by different letters differ (P<0.05).
SEM = Pooled standard error of the mean.
[z] SD = Standard deviation.

higher fiber and ethanol insoluble sugar contents and a lower CP content . The LFCM fraction exhibited lower fiber and ethanol insoluble sugar levels and a higher CP content relative to the original canola meal. The dehulling technique was more effective in separating the fiber component (specially ADF and ADL) than the protein fraction. Further research is needed to investigate the effects of tail-end dehulling of canola meal on the nutritive value of HFCM and LFCM for ruminant and monogastric animals.

CHAPTER 4. The Nutritive Value of High Fiber Canola Meal for Ruminants: II. Variations in Ruminal Nutrient Disappearance Due to Meal Source.

4.1 ABSTRACT

Two *in situ* trials were conducted to determine the influence of crushing plant of origin on rumen nutrient disappearance of canola meal samples and their tail-end dehulled products; low (LFCM) and high (HFCM) fiber canola meal fractions. In the first trial, rumen disappearance of dry matter (DMD), crude protein (CPD), neutral (NDFD) and acid (ADFD) detergent fiber from canola meal, LFCM and HFCM samples derived from five crushing plants, were determined following 24 h of rumen incubation. In the second trial, crushing plant differences in rumen kinetic parameters and effective degradability of dry matter (EDMD) and crude protein (ECPD) among canola meal, LFCM and HFCM samples were determined following incubation in the rumen for 2, 4, 6, 8, 12, 18 and 24 h. The results of the first trial showed differences in *in situ* nutrient disappearance between crushing plants for the LFCM and HFCM but not for the canola meal samples. The HFCM derived from crusher 4 had the lowest ($P<0.05$) DMD and CPD while that from crusher 5 had the lowest ADFD relative to the other HFCM samples. No differences in DMD or NDFD were observed among the LFCM samples. However, LFCM derived from crusher 4 had the lowest ($P<0.05$) ADFD relative to the other LFCM samples. Differences in rumen nutrient disappearance between canola meal, LFCM and HFCM was as follow DMD: LFCM > canola meal > HFCM; CPD: LFCM = canola meal > HFCM; NDF: LFCM > CM = HFCM and ADFD: LFCM > canola meal = HFCM. There was however, no crushing plant of origin by treatment interaction for any nutrient studied. The results of the second trial revealed crushing plant of origin differences in kinetic parameters within canola meal, LFCM and HFCM samples. However EDMD and ECPD varied only among the LFCM and the HFCM but not the canola meal samples. It was concluded that HFCM and LFCM have different *in situ* nutrient disappearance relative to canola meal and that further

work is required to define the differences. *In situ* nutrient disappearance of LFCM and HFCM and not canola meal were affected by crushing plant of origin, the differences, however, were only minor with respect to effective DM and CP degradability.

4.2 INTRODUCTION

Tail-end dehulling of canola meal results in two meal fractions with different chemical characteristics (experiment one, chapter three). The low fiber canola meal (LFCM) has 6.6% more crude protein, 25.3% less acid detergent fiber and 30.4% less acid detergent insoluble protein while the high fiber canola (HFCM) meal has 6.6% less CP, 23.8% more ADF and 34.8% more acid detergent insoluble protein than canola meal. Based on these differences in chemical composition, LFCM and HFCM are anticipated to have distinct rumen nutrient disappearance relative to regular canola meal.

The efficiency of dehulling might be affected by the source of the canola meal (Bell 1993; McCurdy 1993). For tail-end dehulling to be economically feasible, information regarding rumen nutrient disappearance of LFCM and HFCM relative to canola meal should be available. It is important however, to determine whether crushing plant of origin has any effect of rumen nutrient disappearance of canola meal and the two byproducts of tail-end dehulling, LFCM and HFCM. The objectives of this study were to determine *in situ* nutrient disappearance of LFCM and HFCM relative to canola meal following 24 h of rumen incubation and to determine the effects of crushing plant of origin on *in situ* dry matter and crude protein kinetic parameters and effective degradability within samples of canola meal, LFCM and HFCM derived from five crushing plants.

4.3 MATERIALS AND METHODS

4.3.1 Sample preparation and Chemical Analyses

Canola meal samples were obtained from five commercial crushers in western Canada. Fractionation into low (LFCM) and high (HFCM) fiber meal fractions was carried out in the Protein, Oil and Starch pilot plant in Saskatoon, Saskatchewan according to the procedure described McCurdy and March (1992). Samples were ground through a 1 mm screen using a Christie-Norris mill and then analyzed for dry matter (method 930.15), crude protein (method 984.13) and acid detergent fiber (method 973.18) according to the procedures of the Association of Official Analytical Chemists (1990). Neutral detergent fiber was determined by the procedure of Van Soest et al. (1991). The chemical composition has been reported previously (experiment one, chapter three).

4.3.2 *In Situ* Trials

One non-lactating Holstein cow fitted with a flexible rumen cannula was utilized. The cow was fed a 50:50 barleysilage:concentrate diet (DM basis) at 1.5% of body weight (DM basis). The concentrate diet contained 74.5% barley, 17.0% canola meal, 2.0% corn gluten meal, 2.0% molasses, 0.6% dicalcium phosphate, 0.5% canola oil, 0.3% cobalt-iodized salt, 3% mineral-vitamin mix and 0.1% ground limestone. The feed was introduced over a 4 week adaptation period and was offered twice daily in equal portions at 0800 and 1600 h.

For the first trial, triplicate air dry samples (seven grams) of canola meal and the corresponding LFCM and HFCM from each of the five crushing plant were placed in nylon bags (9 x 21 cm; 41 μm pore size) and incubated in the ventral sac of the rumen prior to the morning feeding for 24 h. Three consecutive incubations were carried out over three different days.

For the second trial, three separate sets of incubations were conducted. In the first incubation series, samples (seven grams) of canola meal were weighed in duplicate

into nylon bags and incubated in the rumen for 2, 4, 6, 8, 12, 18 and 24 h. The second series of incubations looked at the LFCM samples while the third involved the HFCM samples. Incubations were carried out over three different days.

Following removal from the rumen, the bags from both trials were washed as described by McKinnon et al. (1991). Bags containing the washed samples were dried in a forced air oven at 65 °C for 48 h and allowed to air equilibrate for 3 days. Residues from each of three replicate bags (trial one) or each of the two replicate bags (trial 2) were composited and dry matter determined on the pooled residues. Residues were then analyzed for Kjeldahl nitrogen, acid and neutral detergent fiber as described previously. *In situ* disappearance of these nutrients was calculated as the difference between the amount in the original sample and in the residues.

In trial two, ruminal DM and CP disappearance data were utilized to estimate ruminal kinetic parameters using the equation of Ørskov and McDonald (1979):

$$P = a + b\,(1-e^{-c\,t})$$

where P is rumen disappearance at time t (h), a is the soluble dry matter (DM) or crude protein (CP) fraction (%), b is the insoluble but degradable DM or CP fraction (%) and c is the rate constant at which the b fraction is degraded (% h^{-1}). The parameters a, b and c were estimated by an iterative least square method using the nonlinear regression procedure of the Statistical Analysis System (SAS) Institute, Inc. (1989) with the constraints that a + ≤ 100. Ruminal effective degradability (ED) of DM and CP at a rumen flow rate (k) of 5% h^{-1} was estimated using the equation of Ørskov and McDonald (1979):

$$ED = a + b * c\,/(c + k)$$

Where a, b, and c are defined as above.

4.3.4 Statistical Analysis

Data were subjected to analysis of variance using the General Linear Model procedure of SAS (1989). Data from the first trial were analyzed as a completely randomized design with a factorial arrangement (five crushing plants x three meals). Days of incubation were used as replicates. Data from the second trail were analyzed as a completely randomized design with days of incubation as replicates. Means were separated using the Student-Newman-Keuls procedure (Steel and Torrie 1980).

4.4 RESULTS AND DISCUSSION

Crushing plant differences in *in situ* 24 h nutrient disappearances were observed among LFCM and HFCM but not the canola meal samples (Table 4.1). Relative to the other HFCM samples, HFCM derived from crusher four had the lowest ($P<0.05$) CP disappearance while that derived from crusher five had the lowest ($P<0.05$) ADF disappearance. No difference in DM or NDF disappearance was observed among LFCM samples. However, LFCM from crusher four had the lowest ($P<0.05$) ADF disappearance relative to the other LFCM samples. Differences in rumen disappearance among canola meal, LFCM and HFCM samples were higher for NDF and ADF than for DM or CP as indicated by the higher coefficient of variation.

Although the reasons for these differences are not known, it is evident that differences occurred as a result of the dehulling process since no differences were observed among the original canola meal samples. McCurdy (1993) indicated that the yield of LFCM from different crushers ranged from 38 to 54% with meals from crusher one and three producing the highest proportion of LFCM while that from crusher four, produced the lowest. Bell (1993) also found meal source to influence the efficiency of front-end dehulling of canola seed. Hill (1991) attributed the lack of uniformity of dehulled canola meal to the strong attachment between the hull and the embryo and to the irregular size of canola seed.

Table 4.1. Effect of meal source on nutrient disappearance of different types of canola meal following 24 h rumen incubation.

Meal source	*In situ* rumen disappearance (%)			
	DM	CP	NDF	ADF
Regular canola meal				
Crusher 1	82.2	82.8	54.8	51.4
Crusher 2	83.1	85.1	52.7	48.5
Crusher 3	80.8	80.4	53.0	51.7
Crusher 4	79.8	79.3	60.4	43.0
Crusher 5	81.5	86.5	59.5	44.0
SEM	1.03	1.57	3.21	2.40
CV	2.65	4.10	9.51	11.39
Low fiber canola meal				
Crusher 1	85.0	84.9a	61.3	57.4a
Crusher 2	86.4	83.2ab	61.1	57.5a
Crusher 3	84.0	81.0ab	64.2	56.4a
Crusher 4	79.5	78.2b	57.9	44.7b
Crusher 5	84.9	86.2a	65.2	56.4a
SEM	0.36	0.58	1.60	1.38
CV	3.46	4.20	9.14	10.03
High fiber canola meal				
Crusher 1	77.1ab	79.9a	55.2ab	50.1a
Crusher 2	77.0ab	80.7a	57.2ab	45.6a
Crusher 3	78.4a	80.7a	58.3a	47.2a
Crusher 4	74.3b	74.4b	54.4ab	47.5a
Crusher 5	76.4ab	84.4a	50.1b	39.9b
SEM	0.73	1.35	1.68	1.58
CV	2.86	4.88	6.83	9.65

a,b Means in the same column within each meal followed by different letters are different ($P<0.05$).
SEM = Pooled Standard error of the mean.
CV = Coefficient of variation.

Pooled across crushing plants, *in situ* DM disappearance following 24 h of rumen incubation was higher ($P<0.05$) for LFCM relative to canola meal and was higher ($P<0.05$) for canola meal relative to HFCM (Figure 4.1).However, CP disappearance was lower for HFCM compared with canola meal and LFCM (Figure 4.1). No difference was observed between canola meal and LFCM. The *in situ* 24 h DM disappearance for canola meal, LFCM and HFCM was 81.5, 84.0 and 76.6%, respectively. The corresponding value for 24 h CP disappearance was 82.8, 82.7 and 80.0%, respectively. Rumen *in situ* NDF and ADF disappearances were higher ($P<0.05$) for LFCM relative to canola meal and HFCM (Figure 4.2). No differences were observed between canola meal and HFCM. The lower DM and CP disappearance of HFCM relative to canola meal and LFCM can be attributed to lower CP and higher acid detergent insoluble and cell wall contents (experiment one, chapter three). The reduction in DM and CP disappearance of canola meal as a result of increased levels of acid detergent insoluble CP and cell walls contents has been reported by several researchers (McKinnon et al. 1991; Moshtaghi Nia and Ingalls 1992; Khorasani et al. 1989). The difference in DM disappearance between canola meal and LFCM can be attributed to the higher NDF and ADF disappearance in LFCM compared with canola meal. These results agree with the chemical analysis in that canola meal was shown to have higher ADF and acid detergent lignin than LFCM (experiment one, chapter three).

No meal by crusher interaction was observed for LFCM, HFCM or canola meal samples. This indicates that differences in 24 h *in situ* nutrient disappearance among the three meals were consistent across crushers

The separate sets of time incubations were carried out to examine within meal type (i.e. canola meal, LFCM and HFCM), crushing plant differences in DM and CP rumen kinetic parameters and effective degradability. For canola meal samples, a relatively high coefficient of variation (CV) was observed for soluble DM (20.8%) and CP (15.3%) and rate of degradation of degradable DM (22.9%) and CP (9.6%, Table 4.2). However,

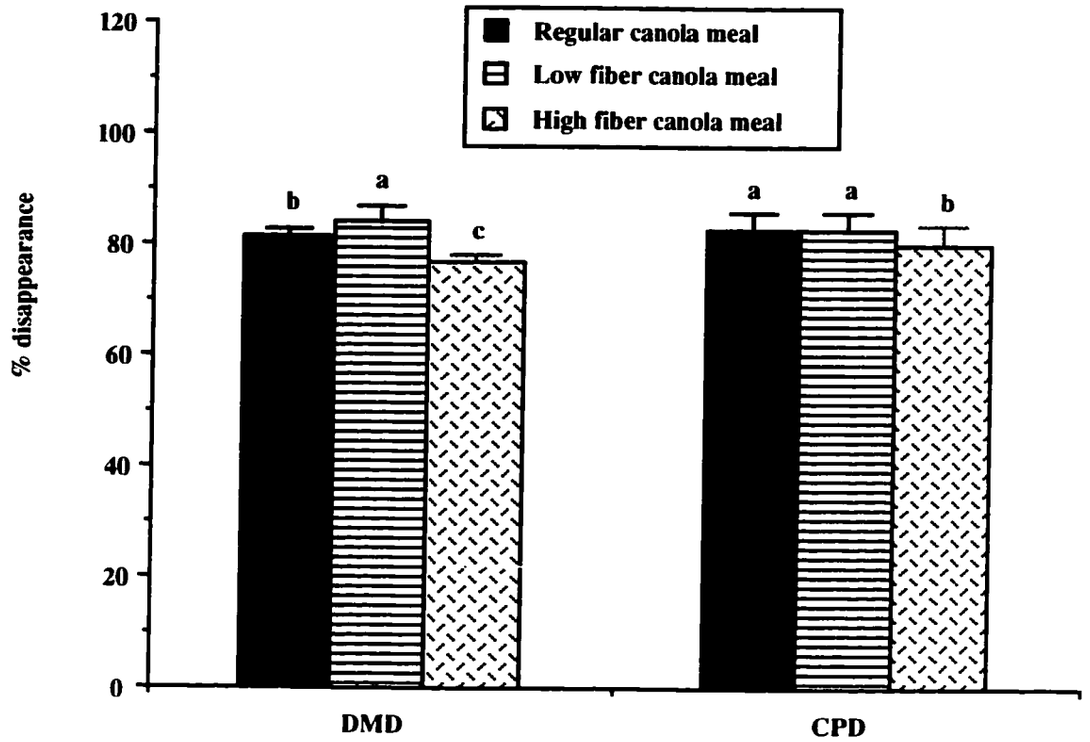

Figure 4.1. Effect of meal type on in situ dry matter (DMD) and crude protein (CPD) disappearance of different types of canola meal following 24 h of rumen incubation (mean ± SD). Columns with different letters are different ($P<0.05$).

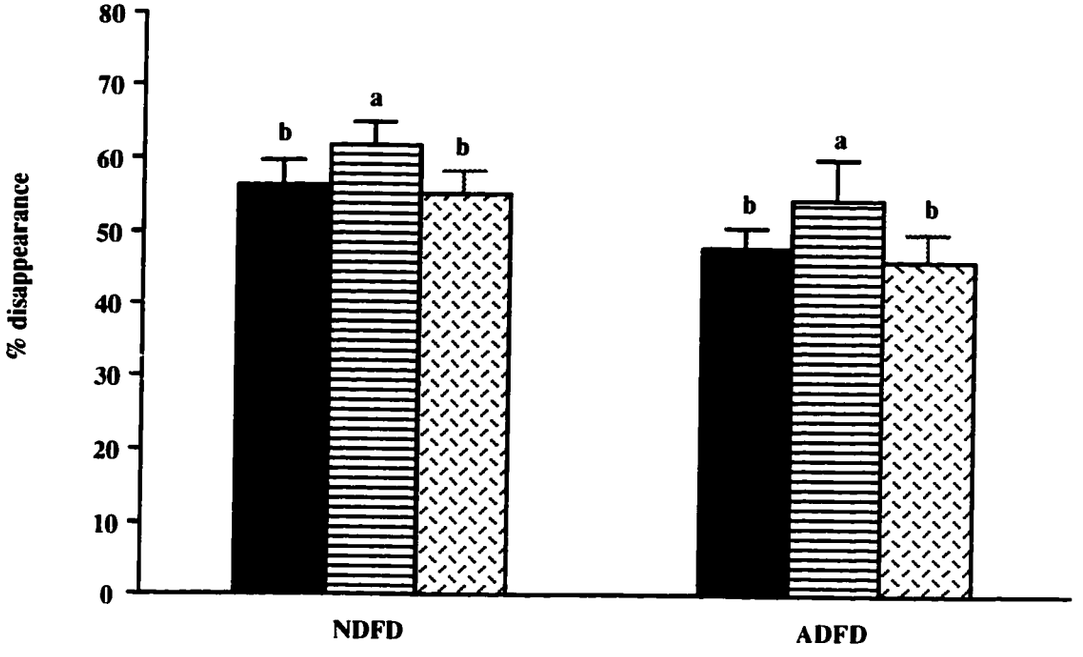

Figure 4.2. Effect of meal type on in situ neutral (NDFD) and acid (ADFD) detergent fiber disappearance of different types of canola meal following 24 h of rumen incubation (mean ± SD). Columns with different letters are different ($P<0.05$).

Table 4.2. Effect of meal source on rumen kinetic parameters and effective degradabilities of canola meal.

	Meal Source							
	Crusher 1	Crusher 2	Crusher 3	Crusher 4	Crusher 5	Mean	CV	SEM
Dry matter (DM)								
Soluble (% DM)	17.0b	24.9a	22.3b	16.9b	26.2a	21.5	20.8	1.35
Degradable (% DM)	71.6	72.1	67.4	68.3	67.9	69.4	4.1	1.29
Degradtion rate (% h^{-1})	11.2b	8.2c	10.9b	14.2a	8.2c	10.6	22.9	0.48
Effective degradability[y] (%)	66.5	69.6	68.4	67.4	68.2	68.0	2.4	0.85
Crude protein (CP)								
Soluble (% CP)	16.1	15.5	20.3	19.9	20.3	18.4	15.3	1.18
Degradable (% CP)	82.6	86.0	79.6	79.9	79.7	80.6	4.2	1.55
Degradation rate (% h^{-1})	8.1ab	8.5a	7.5ab	7.3ab	7.0b	7.7	9.6	0.31
Effective degradability[y] (%)	67.1	68.2	67.9	67.0	66.7	67.4	2.0	0.84

a-c Means in the same raw followed by different letters are different ($P<0.05$).
SEM = Pooled standard error of the mean.
CV = Coefficient of variation.
[y] Calculated assuming rumen flow rate of 5% h^{-1}.

these differences did not result in large plant differences in effective degradability of DM or CP.(i.e.. CV of 2.4 and 2.0%, respectively). These results agree with those of Kendall et al. (1991) who found no difference in effective degradability of DM and CP between canola meal samples obtained from five different crushers. In that study, effective degradability of DM ranged from 49.2 to 56.8% while that of CP ranged from 44.3 to 59.0%. The difference in magnitude between those values and the ones reported in this study is likely due to the concentrate:forage ratio (64:36) used in that study. McAllister et al. (1993) indicated that effective CP degradability of canola meal decreased as the level of concentrate in the diet increased.

Significant differences ($P<0.05$) were observed in soluble DM and soluble and potentially degradable CP between the five LFCM samples (Table 4.3). However, no differences were observed between crushing plants in potentially degradable DM, or in the rate of degradation of DM and CP. The average value (± SD) for these parameters were 64.5 ± 3.1% , 11.9 ± 1.5% h^{-1} and 12.9 ± 1.6% h^{-1}, respectively. Effective DM and CP degradability averaged 72.7 ± .62 and 74.8 ± 1.31%, respectively across crushers. LFCM derived from crusher four had lower effective DM degradability than that derived from crusher two (Table 4.3).

The five HFCM samples had similar soluble DM (average 25.2%) and soluble CP (average 23.7%) contents (Table 4.4). HFCM derived from crusher four and five had lower potentially degradable DM than yhat derived from crusher two while HFCM derived from four had lower rate of degradadtion of potentially degradable CP than HFCM derived from crusher one and two. Effective DM degradability was lower ($P<0.05$) for HFCM from crusher four and five while effective CP degradability was lower $P<0.05$) for HFCM from crusher four than for the other HFCM samples (Table 4.4). Effective DM and CP degradability for HFCM ranged from 63.7% to 66.5% and from 65.1% to 72.1%, respectively. These values are comparable with those reported for canola meal in other studies (Kirkpatrick and Kennelly 1987; Murphy and Kennelly 1987).

Table 4.3. Effect of meal source on rumen kinetic parameters and effective degradabilities of low fiber canola meal.

	Meal Source							
	Crusher 1	Crusher 2	Crusher 3	Crusher 4	Crusher 5	Mean	CV	SEM
Dry matter (DM)								
Soluble (% DM)	23.1b	27.9ab	32.0a	24.7b	29.7ab	27.5	15.1	1.67
Degradable (% DM)	67.6	68.0	62.2	62.9	61.7	64.5	6.4	1.86
Degradtion rate (% h^{-1})	12.7	10.0	10.9	13.7	12.4	11.9	18.1	1.14
Effective degradability[y] (%)	71.5bc	73.6ab	74.6a	70.6c	73.4ab	72.7	2.4	0.62
Crude protein (CP)								
Soluble (% CP)	21.3b	29.7a	20.4b	20.5b	28.0a	24.0	17.9	0.68
Degradable (% CP)	77.3a	70.2ab	73.3a	70.0ab	65.0b	71.2	7.1	1.90
Degradation rate (% h^{-1})	11.0	11.7	14.7	12.4	14.4	12.9	17.0	1.07
Effective degradability[y] (%)	74.3ab	78.7a	74.9ab	70.4b	76.0ab	74.8	4.6	1.31

a-c Means in the same raw followed by different letters are different ($P<0.05$).
SEM = Pooled standard error of the mean.
CV = Coefficient of variation.
[y] Calculated assuming rumen flow rate of 5% h^{-1}.

Table 4.4. Effect of meal source on rumen kinetic parameters and effective degradabilities of high fiber canola meal.

	Meal Source							
	Crusher 1	Crusher 2	Crusher 3	Crusher 4	Crusher 5	Mean	CV	SEM
Dry matter (DM)								
Soluble (% DM)	24.9	22.4	28.8	25.8	24.1	25.2	12.1	1.44
Degradable (% DM)	60.2ab	66.1a	63.0ab	57.0b	58.4b	60.9	6.8	1.66
Degradtion rate (% h^{-1})	10.8	9.7	7.9	10.5	10.8	9.9	21.4	1.23
Effective degradability[y] (%)	65.8[a]	65.5[a]	66.5[a]	64.3[b]	63.7[b]	65.2	1.7	0.30
Crude protein (CP)								
Soluble (% CP)	20.1	26.7	19.8	26.3	25.4	23.7	20.0	2.40
Degradable (% CP)	69.8ab	70.0ab	76.7a	70.1ab	64.4b	70.2	7.1	1.98
Degradation rate (% h^{-1})	12.4a	9.3ab	9.4ab	6.4b	12.2a	9.9	29.1	1.20
Effective degradability[y] (%)	69.8a	75.1a	69.2a	65.1b	71.1a	69.3	3.8	0.81

a-b Means in the same raw followed by different letters are different ($P<0.05$).
SEM= Pooled standard error of the mean.
CV = Coefficient of variation.
[y] Calculated assuming rumen flow rate of 5% h^{-1}.

In general, differences in effective DM and CP degradability between canola meal, LFCM and HFCM samples were less than the differences in kinetic parameters. For both DM and CP, the soluble fraction showed the highest variation followed by rate of degradation and the potentially degradable fraction, respectively. Boila and Ingalls (1992) indicated that the size and the rate of degradation of the potentially degradable fraction varied according to method used to estimate the size of the soluble fraction such that less variation will be observed in effective degradability compared with the kinetic parameters. Variation in CP kinetic parameters was more pronounced among LFCM and HFCM samples than among canola meal samples. These results agree with those of the first *in situ* trial which showed more differences in ruminal CP disappearance among the LFCM and the HFCM than among the original canola meal samples.

Although the differences in effective DM and CP degradability among the five LFCM and HFCM samples were statistically significant, the numerical differences are not likely to be of nutritional importance. The difference between the crusher with the highest effective DM degradability and that with the lowest is 5.6 and 4.3% for LFCM and HFCM, respectively. The corresponding values for effective CP degradability are 10.7 and 9.8%, respectively. Such variation must have occurred during the dehulling process since no differences were observed between the unprocessed canola meal samples. McCurdy (1993) reported that meal source had an important effect on the dehulling process, with meal from crusher four being the least improved and that from crusher two the most improved.

In conclusion, tail-end dehulling of canola meal altered the *in situ* rumen nutrient disappearance of LFCM and HFCM relative to canola meal. The differences in nutrient disappearance among LFCM and HFCM samples following 24 h of rumen incubation might occur during the dehulling process since such differences were not observed among the original canola meal samples. The study also showed no crusher by meal interaction indicating that differences in *in situ* nutrient disappearance were consistent

across crushing plants. Differences in effective dry matter and crude protein degradability among the LFCM and the HFCM samples were small and seems to be of little nutritional significance. More research is needed to determine differences in rumen nutrient kinetic parameters and effective degradabilities between canola meal, LFCM and HFCM.

CHAPTER 5. The Nutritive Value of High Fiber Canola Meal for Ruminants: III. *In Vitro* and *In Situ* Degradability.

5.1 ABSTRACT

The objectives of this study were to determine kinetic parameters and effective nutrient degradabilities for high fiber canola meal (HFCM) relative to regular canola and low fiber canola meal (LFCM). Protease enzyme from *Streptomyces griseus* was used to estimate *in vitro* crude protein (CP) kinetic parameters and effective degradability in a completely randomized design. A ruminally fistulated cow was utilized in a completely randomized design to estimate *in situ* rumen kinetic parameters and effective degradabilities of dry matter (EDMD), CP (ECPD), neutral (ENDFD) and acid (EADFD) detergent fiber for HFCM relative to canola meal and LFCM. Results indicated that *in situ* effective dry matter degradability was higher ($P<0.05$) in LFCM relative to canola meal and was higher ($P<0.05$) in canola meal relative to HFCM. At rumen flow rate (k) of 5 % h^{-1}, *in vitro* and *in situ* ECPD was higher ($P<0.05$) in canola meal and LFCM than in HFCM. ENDFD was higher ($P<0.05$) in canola meal and LFCM than in HFCM . However, at k = 8 % h^{-1}, ENDFD was higher in LFCM than in canola meal and HFCM. At both rumen flow rates, EADFD was higher ($P<0.05$) in LFCM relative to canola meal and was higher ($P<0.05$) in canola meal relative to HFCM. It was concluded that tail-end dehulling altered nutrient degradabilities of LFCM and HFCM relative to canola meal. The effect of tail-end dehulling was more pronounced on degradability of ADF than that of CP.

5.2 INTRODUCTION

Feed protein is usually divided into rumen degradable and undegradable protein (NRC 1989; ARC 1992). Rumen degradable protein contains non-protein nitrogen (fraction A), peptides and variable amounts of true protein (B_1, B_2 and B_3 fractions). Rumen undegradable protein consists of true protein which escapes rumen degradation (mainly B_2 and B_3 fractions) and unavailable protein (fraction C, Sniffen et al. 1992). The nylon bag technique is the most common procedure used to estimate rumen degradable and undegradable protein. It fractionates feed protein into soluble (*a*), potentially degradable (*b*) and indigestible (100 - (*a* + *b*) fractions (Ørskov 1992). The extent of degradation of the potentially degradable fraction can also be estimated. Effective rumen degradability can be estimated by combining ruminal disappearance data and rumen flow rate. The nylon bag technique is greatly affected by the conditions of measurement and it requires fistulated animals (Nocek 1988). An *in vitro* enzymatic technique based on protease enzyme has been proposed in a attempt to estimate ruminal protein degradation in an environment which simulates the rumen (Krishnamoorthy et al. 1983). The technique has been modified by Roe et al. (1990).

Tail-end dehulling of canola meal produced two meal fractions (low and high fiber canola meals) with distinct chemical composition (experiment one, chapter three). The HFCM with a reduced protein concentration and increased acid detergent insoluble CP and cell wall contents, is anticipated to exhibit a reduced ruminal degradability relative to LFCM and canola meal. An earlier study showed small variations in rumen dry matter and crude protein disappearance among samples of canola meal, LFCM and HFCM were derived from five different crushers (experiment two, chapter four). It is important to determine the effect of tail-end dehulling on kinetic parameters and effective nutrient degradability of HFCM relative canola meal and LFCM. The objectives of this study were to determine *in vitro* crude protein kinetic parameters and effective degradability using protease enzyme and to determine *in situ* kinetic parameters and

effective degradability of dry matter, crude protein, neutral and acid detergent fiber of HFCM relative to LFCM and canola meal.

5.3 MATERIALS AND METHODS

5.3.1 Sample Preparation and Chemical Analyses

Tail-end dehulling of canola meal was carried out in the Protein Oil and Starch (POS) pilot plant in Saskatoon, Saskatchewan (McCurdy 1993). The technique involved tempering the meal to 16% moisture, disc milling (8-inch disc mill, Bauer Brothers Co. Ltd., Brantford, Ontario) and sieving through a 35-mesh screen (U.S.A Sieve Series). The process resulted in a high fiber, low protein meal (HFCM, 60% of total) and a high protein, low fiber meal (LFCM, 40% of total) .

Samples of canola meal and the corresponding LFCM and HFCM (approximately 5 kg each) from five different crushers in western Canada were obtained from the POS plant. Equal portions (about 200 g) of canola meal, LFCM and HFCM from the five crushers were composited and ground through a 1 mm screen using a Christie-Norris mill. Subsamples from each meal fraction were then analyzed for moisture (method No. 930.15), ash (method 924.05), ether extract (method No. 920.39), Kjeldahl nitrogen (method No. 984.13), acid detergent fiber (ADF) and acid detergent lignin (ADL) (method No. 973.18) according to the procedures of the Association of Official Analytical Chemists (AOAC, 1990). Neutral detergent fiber (NDF) was determined according to the procedure of Van Soest (1991). Neutral and acid detergent insoluble nitrogen were determined on NDF and ADF residues, respectively using the Kjeldahl method (AOAC method No. 984.13). Total starch was determined using the α amylase amyloglucosidase assay (Megazyme kit, Megazyme, NSW, Australia).

The technique of Roe et al. (1990) was used to estimate soluble and degradable CP. Non-protein nitrogen was determined by precipitating true protein using tungstic acid as a precipitant (Greenberg and Shipe 1979) . Total and non-structural carbohydrate (CHO) contents of canola meal, LFCM and HFCM were estimated using the

equations of Sniffen et al. (1992). Total CP was fractionated into the A (non-protein nitrogen), B (true protein) and C (unavailable protein) fractions (Sniffen et al. 1992). The B fraction was subfractionated into the B_1 (rapidly degradable), B_2 (intermediately degradable) and B_3 (slowly degradable) fractions (Sniffen et al. 1992). Intestinally available CP was estimated using the equation of Roe et al. (1990):

$$\textit{Intestinally available CP} = 100 - \textit{Degradable CP} - \textit{Acid detergent insoluble CP}$$

5.3.2 *In Vitro* Trials

Rumen proteolysis was simulated by using protease enzyme (0.33 units mL^{-1}, protease enzyme from *Streptomyces griseus*, type XIV, Sigma Chemical Co., St. Louis, MO) according the procedure of Roe et al 1990. A series of 125 mL Erlenmeyer flasks containing the equivalent of 0.2 g air dry protein of canola meal, LFCM and HFCM were incubated for 1, 2, 4, 6, 8, 12, 18 and 24 h. The incubation procedure was similar to that used for degradable CP. Zero time disappearance was determined by incubating samples in 40 mL borate phosphate buffer for 1 h without protease solution. *In vitro* crude protein disappearance data were fitted to the equation of Ørskov and McDonald (1979) :

$$P = a + b * (1\text{-}e^{-c\ t})$$

where P is crude protein disappearance at time t (h), a is soluble protein (%), b is potentially degradable protein (%) and c is the rate of degradation (% h^{-1}) of fraction b. The constants a, b and c were estimated using an iterative least square method by applying the nonlinear regression procedure of the Statistical Analysis System (SAS) Institute, Inc., (1989). *In vitro* effective CP degradability (ECPD) was calculated according to the equation of Ørskov and McDonald (1979):

$$ECPD = a + [(b * c) / (c + k)]$$

where k is the rumen flow rate (% h^{-1}).

5.3.3 *In Situ* Trial

One non-lactating Holstein cow fitted with a flexible rumen cannula was utilized. Treatments included canola meal, LFCM and HFCM. The cow was fed a 50:50 barley silage:concentrate diet at 1.5% of body weight (DM basis). The concentrate diet contained 74.5% barley, 17.0% canola meal, 2.0% corn gluten meal, 2.0% molasses, 0.6% dicalcium phosphate, 0.5% canola oil, 0.3% cobalt-iodized salt, 3% mineral-vitamin mix and 0.1% ground limestone. The diet was gradually introduced over a 4 week adaptation period and was fed in two equal portions at 0800 and 1600 h daily. Approximately seven grams of canola meal, LFCM and HFCM were weighed into duplicate nylon bags (9 x 21 cm; 41 µm pore size). For the last two incubation times (18 and 24 h), bags were weighed in quadruplicate. The bags were then placed into polyester mesh bags (25 x 33 cm) and incubated in the ventral sac of the rumen for 2, 4, 6, 8, 12, 18 and 24 h. Three incubations were carried out over three consecutive days. All incubations commenced prior to morning feeding with bags inserted at appropriate times and removed at the same time the following morning.

Following removal from the rumen, the bags were washed as described by McKinnon et al. (1991). Bags containing samples of canola meal, LFCM and HFCM which were not incubated were washed at the same time to estimate zero time disappearance. The washed nylon bags were then dried in a forced air oven at 65 °C for 48 h and allowed to air equilibrate for 3 days. Contents of replicate bags at each incubation time were composited and ground using a small coffee grinder. Dry matter content was determined in the whole residues which were then subjected to CP, NDF and ADF analyses as described above.

The percent disappearance of DM (DMD), CP (CPD), NDF (NDFD) and ADF (ADFD) at each incubation time was calculated from the concentrations of these nutrients in the original samples and the residues and used to estimate ruminal kinetic parameters according to the equation of Ørskov and McDonald (1979) with the addition of a discrete digestion lag time (Khorasani et al. 1994):

$$P = a + b\ (1\text{-}e^{-c\ (t\ -\ lag)})$$

Where P is rumen disappearance at time t and a, b and c are defined as above. The constants a, b and c were estimated using the same procedure used in the *in vitro* trial. Ruminal effective degradability (ED) of DM, CP, NDF and ADF was estimated using the equation of Ørskov and McDonald (1979), assuming a rumen flow rate (k) of 5 and 8% h^{-1}:

$$ED = a + [(b * c) / (c + k)]$$

5.3.4 Statistical Analysis

Data from *in vitro* and *in situ* trials were subjected to analysis of variance using the General Linear Model (GLM) procedure of SAS Institute, Inc. (1989). Data were analyzed as a completely randomized design where meals served as treatments and days of incubation as replicates. Means were separated at the 5% level of significance using the Student-Newman-Keuls procedure (Steel and Torrie 1980).

5.4 RESULTS AND DISCUSSION

5.4.1 Chemical Composition

Chemical composition (Table 5.1) and protein fractions (Fig. 5.1 and 5.2) of canola meal, LFCM and HFCM reported in this study agree with the average chemical composition reported earlier for five samples of canola meal, LFCM and HFCM derived from the individual crushing plants (experiment one, chapter three).

5.4.2 *In Vitro* Trials

In vitro crude protein disappearance (CPD) of canola meal, LFCM and HFCM is shown in Figure 5.3. At 18 and 24 h incubation, CPD was higher ($P<0.05$) for LFCM and regular canola meal than for HFCM. No differences were observed between LFCM and regular canola meal. At 24 h incubation, CPD for canola meal, LFCM and HFCM was 70.0, 70.6 and 63.5%, respectively. *In vitro* crude protein kinetic parameters (Table 5.2) showed no difference in soluble protein (average 40 ± 1.0%) or in the rate by which the potentially degradable protein is degraded (average 11.5 ± 0.9%). However, the potentially degradable protein content was higher ($P<0.05$) in canola meal and LFCM than in HFCM. At both rumen flow rate (5 and 8% h^{-1}), effective CP degradability was higher ($P<0.05$) in LFCM (69.4 and 64.8%, respectively) relative to canola meal (66.4 and 62.3%, respectively) and was higher ($P<0.05$) in canola meal relative to HFCM (63.3 and 59.7 %, respectively).

5.4.4 *In Situ* Trial

Greater differences were observed for *in situ* dry matter disappearance (DMD) than for *in situ* crude protein disappearance (CPD) between the three meals. Differences in DMD between canola meal, LFCM and HFCM were observed as early as 4 h of incubation (Fig. 5.4) while the only variation in CPD was observed at 24 h incubation (Fig. 5.5). At both the 18 and 24 h incubations, DMD was higher ($P<0.05$) in

Table 5.1. Chemical composition of different types of canola meals (DM basis).

Item	Type of canola meal		
	Regular	Low fiber	High fiber
Ash	7.8	9.2	7.0
Ether extract	3.8	4.2	3.7
Carbohydrate (CHO)			
Total CHO	49.5	44.9	53.7
Non-structural CHO	24.7	25.4	22.8
Starch (% of non-structural CHO)	4.2	6.8	7.6
Neutral detergent fiber (NDF)	28.8	23.7	35.2
Acid detergent fiber	19.3	14.8	23.4
Acid detergent lignin (% of NDF)	24.0	22.7	19.0
Protein			
Crude protein (CP)	38.9	41.7	35.6
Soluble protein (% of CP)	36.3	37.1	36.9
Non-protein nitrogen (% of CP)	27.1	29.0	27.8
ND insoluble protein[z] (% of CP)	10.5	10.0	12.1
AD insoluble protein[y] (% of CP)	4.5	2.9	7.0
Degradable protein (% of CP)	61.4	62.1	59.7
IA protein[x] (% of CP)	34.1	35.0	33.3

[z] ND = Neutral detergent.
[y] AD = Acid detergent.
[x] IA = Intestinally available

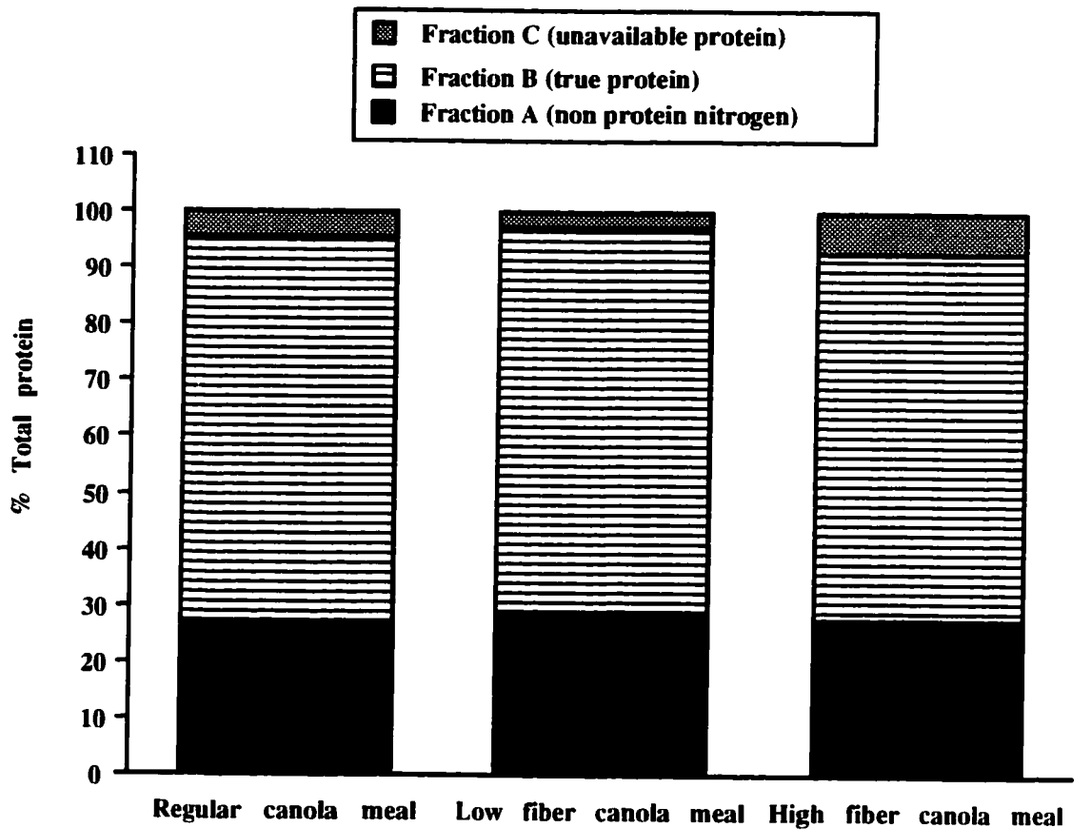

Figure 5.1. Protein fractions of regular, low and high fiber canola meal (DM basis).

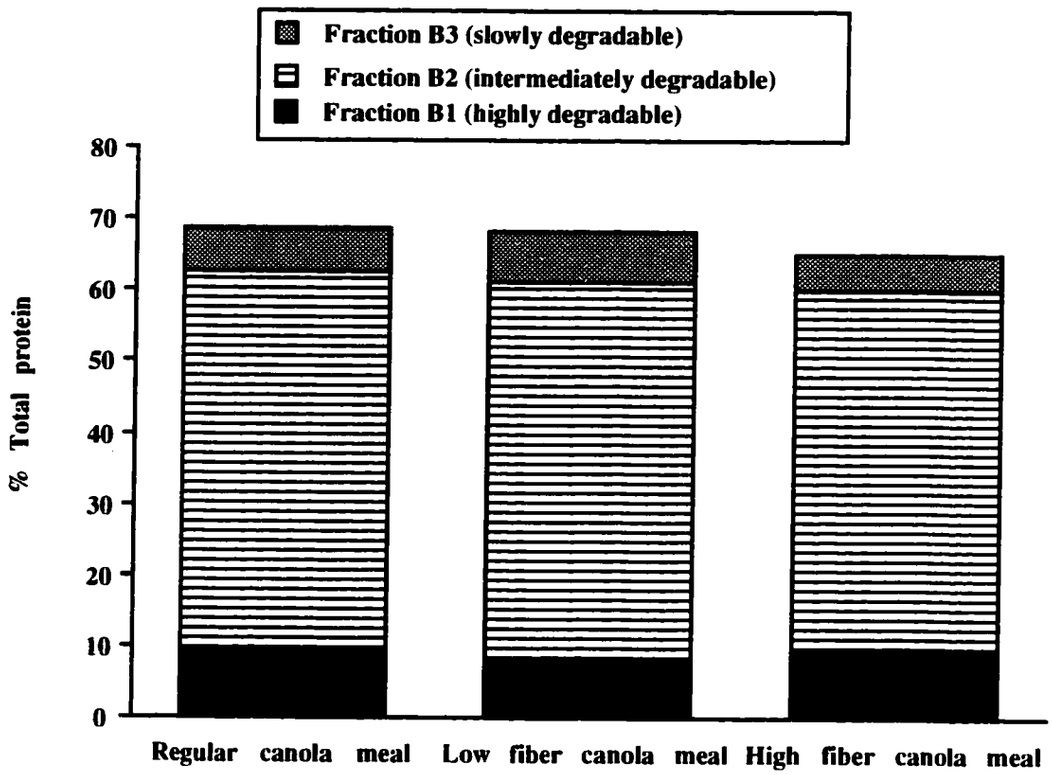

Figure 5.2. **True protein fractions of regular, low and high fiber canola meal (DM basis).**

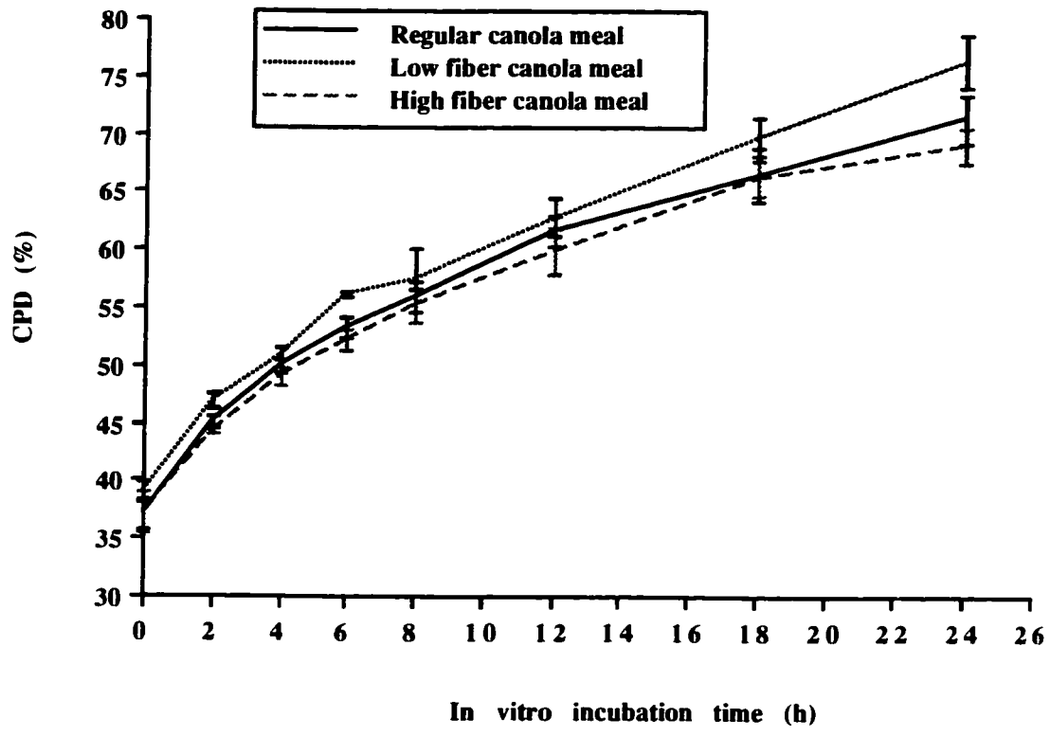

Figure 5.3. Effect of incubation time with protease enzyme (0.33 units/mL) on in vitro crude protein disappearance (CPD) of regular, low and high fiber canola meal (mean ± SD).

Table 5.2. *In vitro* crude protein kinetic parameters and effective degradability of regular, low and high fiber canola meal (DM basis).

	Type of canola meal			
	Regular	Low fiber	High fiber	SEM
Soluble fraction (% CP)	39.7	41.1	39.3	0.57
Degradable fraction (% CP)	38.7a	41.9a	33.84b	1.35
Degradation rate (% h^{-1})	11.8	10.5	12.2	1.37
Effective degradability[z]	66.4b	69.4a	63.3c	0.67
Effective degradability[y]	62.3b	64.8a	59.7c	0.64

a-c Means within rows followed by different letters differ ($P<0.05$).
SEM = Standard error of the mean.
[z] Calculated assuming rumen flow rate 5 % h^{-1}.
[y] Calculated assuming rumen flow rate of 8 % h^{-1}.

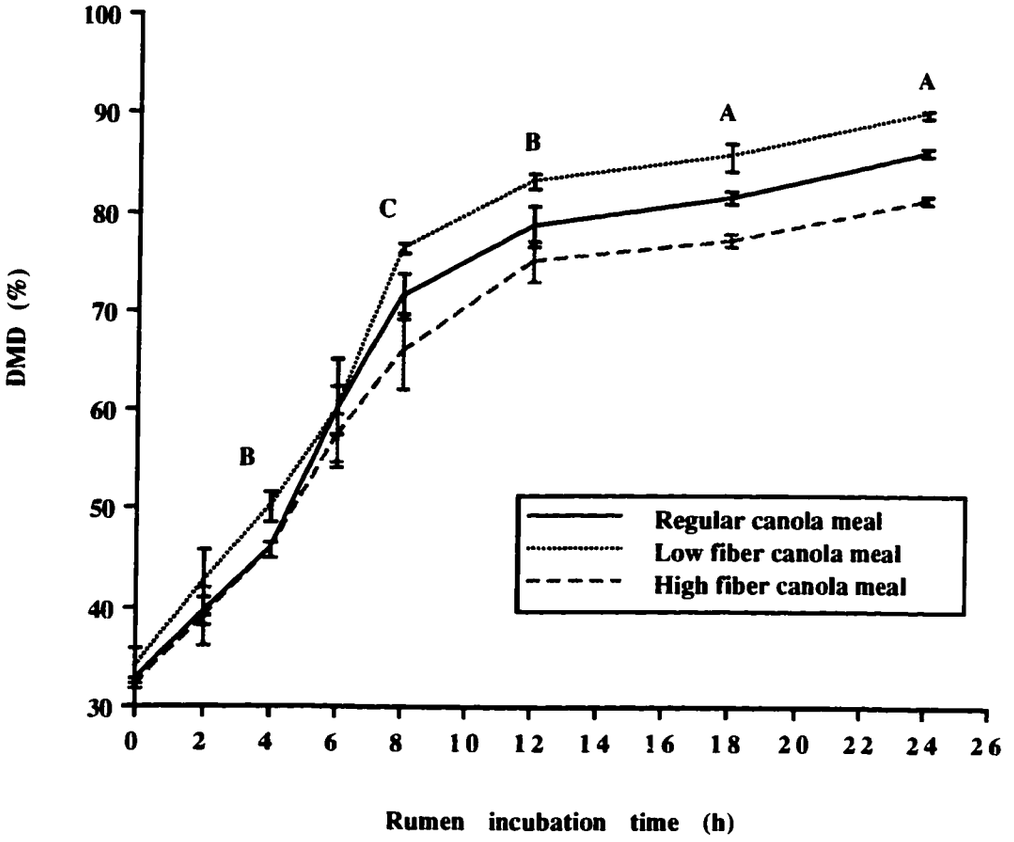

Figure 5.4. **Effect of rumen incubation time on in situ dry matter disappearance (DMD) of regular, low and high fiber canola meal (mean ± SD). Letters indicate a significant ($P<0.05$) difference at a given incubation time.**

A: Low fiber canola meal > Regular canola meal > High fiber canola meal.

B: Low fiber canola meal > Regular canola meal > High fiber canola meal.

C: Low fiber canola meal = Canola meal > High fiber canola meal.

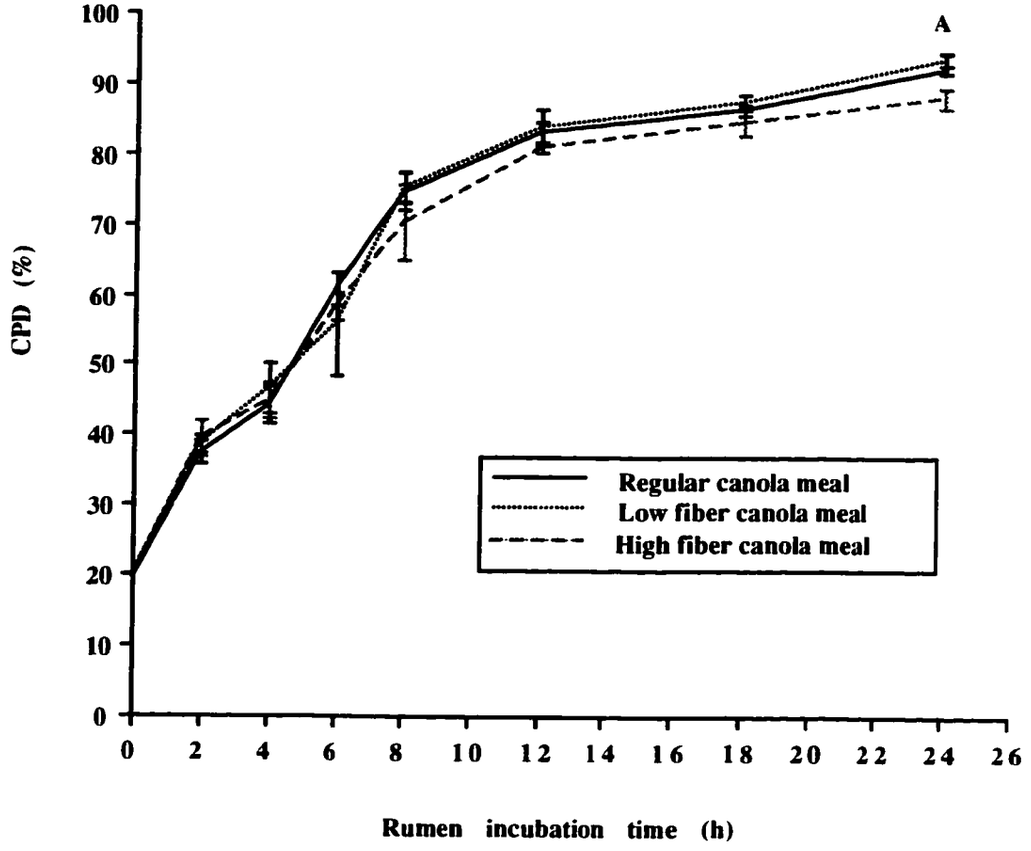

Figure 5.5. **Effect of rumen incubation time on in situ crude protein disappearance of regular, low and high fiber canola meal (mean ± SD). Letters indicate a significant difference at a given incubation time.**

A: Low fiber canola meal = Regular canola meal > High fiber canola meal.

LFCM relative to canola meal and was higher (P<0.05) in canola meal relative to HFCM. However, at 24 h of incubation, CPD was higher (P<0.05) in canola meal and LFCM relative to HFCM. The *in situ* disappearance data from this study are in agreement with what has been reported in other studies (Murphy and Kennelly 1987; Khorasani et al. 1989; Kirkpatrick and Kennelly 1987).

Ruminal *in situ* dry matter kinetic parameters (Table 5.3) showed no difference in the soluble dry matter fraction (average 30.2 ± 1.0%) and in the rate by which the potentially degradable fraction is degraded (average 11.6 ± 0.1%). Potentially degradable DM was higher (P<0.05) in LFCM than in canola meal and was higher (P<0.05) in canola meal than in HFCM. At a rumen flow rate (k) of 5 % h^{-1}, effective DM degradability was higher (P<0.05) in LFCM (76.0%) relative to canola meal and was higher (P<0.05) in canola meal (72.3%) relative to HFCM (68.7 %). However, at k = 8% h^{-1}, effective DM degradability was higher (P<0.05) in LFCM than in canola meal and HFCM. Similar effective DM degradability values for canola meal were reported by Khorasani et al. (1993 and 1989).The effective DM degradability of HFCM was similar to that of canola meal as reported by Murphy and Kennelly (1987) while that of LFCM was similar to that of soybean meal and was lower than that of whole canola seed (Deacon et al. 1988).

Similar to what was observed in the *in vitro* trial, *in situ* soluble CP fraction and rate of degradation of the potentially degradable CP were similar in canola meal, LFCM and HFCM averaging 19.3 ± 0.6 and 13.5 ± 0.3%, respectively. However, the potentially degradable CP fraction (b CP) was higher (P<0.05) in canola meal and LFCM than in HFCM. No difference was observed between canola meal and LFCM. This resulted in both canola meal and LFCM having similar effective CP degradability (k = 5% h^{-1}) which was higher (P<0.05) than that of HFCM. However, at a higher rumen flow rate (k = 8% h^{-1}), no difference was observed in effective CP degradability between canola meal, LFCM and HFCM. Similar effective CP degradability values for canola meal were

Table 5.3. Dry matter and crude protein ruminal kinetic parameters and effective degradabilities of regular, low and high fiber canola meal.

	Type of canola meal			
	Regular	Low fiber	High fiber	SEM
Dry matter (DM)				
Soluble (% of DM)	29.1	31.1	30.3	0.85
Degradable (% of DM)	62.0b	64.5a	56.7c	0.47
Degradation rate (% h^{-1})	11.6	11.5	11.7	0.76
Lag (h)	0.2c	0.6b	1.4a	0.10
Effective degradability (%)[z]	72.3b	76.0a	68.7c	0.25
Effective degradability (%)[y]	65.7b	69.1a	62.5b	0.24
Crude protein (CP)				
Soluble (% of CP)	18.8	19.9	19.2	1.21
Degradable (% of CP)	77.9a	79.0a	72.5b	1.19
Degradation rate (% h^{-1})	13.5	13.2	13.8	0.61
Lag (h)	0.2	0.0	0.1	0.12
Effective degradability (%)[z]	74.9a	75.3a	72.5b	0.48
Effective degradability (%)[y]	67.0	66.9	65.1	0.59

a-c Means within rows followed by different letters differ ($P<0.05$).
SEM = Pooled standard error of the mean.
[z] Calculated assuming rumen flow rate of 5 % h^{-1}.
[y] Calculated assuming rumen flow rate of 8 % h^{-1}.

reported by Khorasani et al. (1989), Murphy and Kennelly (1987) and Lindberg et al. (1982).

The *in situ* effective CP degradability of canola meal, LFCM and HFCM was 12.0, 8.0 and 13.0%, respectively, higher than what has been obtained by the protease technique. This might be explained by the lower *in vitro* potentially degradable CP value relative to that obtained in the *in situ* trial. This is consistent with what has been reported by Susmel et al. (1993) and Assoumani et al. (1992) who found a low correlation between *in vitro* and *in situ b* CP values. Krishnamoorthy et al. (1983) and Broderick (1978) attributed lower *in vitro* CP degradability to the accumulation of degradative end products (enzyme inhibition effect).

The lower effective CP degradability of HFCM can be explained by the lower CP and higher acid detergent insoluble CP (unavailable CP) content of HFCM relative to canola meal and LFCM. The chemical analysis showed that LFCM had 35% lower acid detergent insoluble CP while HFCM had 57% higher acid detergent insoluble CP than canola meal. Increasing the acid detergent insoluble CP levels have been shown to decrease ruminal CP disappearance (McAllister et al. 1993; Moshtaghi Nia and Ingalls; 1992; McKinnon et al. 1991). Despite the significant difference in effective CP degradability between canola meal and HFCM, the effective CP degradability reported in this study for HFCM is comparable to those reported in the literature for canola meal (Biola and Ingalls 1992; Ha and Kennelly 1984). These results indicate that tail-end dehulling of canola meal had little effect in altering rumen degradability or the escape protein value of LFCM and HFCM compared to the original canola meal. This may be because tail-end dehulling is more effective in separating the fiber fraction than the protein fraction.

Rumen NDF kinetic parameters (Table 5.4) showed no difference in soluble NDF between canola meal, LFCM and HFCM (average 1.2 ± 0.6%). Potentially degradable NDF was higher ($P<0.05$) in canola meal (89.0 %) than in HFCM (70.4 %). No difference was observed in potentially degradable NDF between canola meal and

Table 5.4. Neutral and acid detergent fiber ruminal kinetic parameters and effective degradabilities of regular, low and high fiber canola meal.

	Type of canola meal			
	Regular	Low fiber	High fiber	SEM
Neutral detergent fiber (NDF)				
Soluble (% of NDF)	1.7	0.6	1.4	0.51
Degradable(% of NDF)	89.0a	77.9ab	70.4b	4.10
Degradation rate (% h^{-1})	5.1b	8.3a	6.5b	0.44
Lag (h)	2.8a	1.9b	1.6b	0.17
Effective degradability (%) [z]	45.9a	49.3a	41.1b	1.13
Effective degradability (%)[y]	35.8b	40.3a	32.9b	1.13
Acid detergent fiber (ADF)				
Soluble (% of ADF)	2.7a	2.0a	-1.4b	0.46
Degradable (% of ADF)	57.2a	62.8a	43.4b	2.92
Degradation rate (% h^{-1})	5.9b	8.5a	8.3a	0.74
Lag (h)	0.0b	0.0b	0.1a	0.02
Effective degradability (%)[z]	33.2b	41.2a	25.7c	1.20
Effective degradability (%)[y]	26.6b	34.1a	20.7c	1.05

a-c Means within rows followed by different letters differ ($P<0.05$).
SEM = Pooled standard error of the mean.
[z] Calculated assuming rumen flow rate of 5 % h^{-1}.
[y] Calculated assuming rumen flow rate of 8% h^{-1}.

LFCM or between LFCM and HFCM although a numeric difference of 7.5% was noticed. The rate by which the potentially degradable NDF is degraded was higher ($P<0.05$) in LFCM than in canola meal or HFCM. At a 5 % h^{-1} rumen flow rate, effective NDF degradability was higher ($P<0.05$) in canola meal (45.9 %) and LFCM (49.3 %) than in HFCM (41.1 %). However, at rumen flow rate of 8 % h^{-1}, effective NDF degradability was higher ($P<0.05$) in LFCM (40.3 %) than in canola meal (35.8 %) and HFCM (32.9 %). No difference was observed in effective NDF degradability between canola meal and HFCM.

Khorasani et al. (1994) determined effective NDF degradability of canola meal using forage-fed fistulated cows . They reported values of 49.7 and 40.9% at 5 and 8% h^{-1} rumen flow rate, respectively. The difference between these values and the ones reported in this study can be attributed to the difference in the type of diet fed to the fistulated cows. Nocek (1988) and Michalet-Doreau and Ould-Bah (1992) indicated that cell wall degradability decreased as the level of concentrate in the diet increased.

Little information is available about cell wall degradation rates for protein supplements and other concentrate ingredients. Varga and Hoover (1983) measured rates and extents of NDF disappearance for different concentrate feeds. They found that protein supplements had a rate of NDF degradation that ranged from 4.8 to 7.2% h^{-1} which agrees with those of canola meal and HFCM and is comparable to that of LFCM. Khorasani et al. (1994) estimated degradation rate of potentially degradable NDF for different protein supplements. Reported value for linseed meal, canola meal and soybean meal were 5.9, 10.3 and 10.3 % h^{-1}, respectively.

More differences in acid detergent fiber (ADF) kinetic parameters were observed between canola meal, LFCM and HFCM than for NDF (Table 5.4). Soluble and potentially degradable ADF fractions were higher ($P<0.05$) in canola meal and LFCM than in HFCM. At both rumen flow rates (5 and 8% h^{-1}), effective ADF degradability was higher ($P<0.05$) in LFCM (41.2 and 34.1%, respectively) relative to canola meal (33.2

and 26.6 %, respectively) and was higher ($P<0.05$) in canola meal relative to HFCM (25.7 and 20.7 %, respectively). These results show that tail-end dehulling of canola meal had more effect on effective ADF than on effective NDF degradability indicating that such a process was more effective in separating the ADF than the NDF fraction. Bell (1993a) indicated that canola seed embryo has a considerable amount of cell wall content such that dehulled canola meal may contain over 20% NDF. The results also indicate that the difference in effective DM degradability between canola meal, LFCM and HFCM can be explained by differences in the degradability of ADF rather than CP or NDF.

In conclusion, it is clear that tail-end dehulling of canola meal resulted in two meal fractions with different rumen degradability characteristics. The high fiber meal fraction had reduced ruminal DM, CP and ADF degradabilities relative to the original canola meal. Tail-end dehulling seemed to have little effect in altering ruminal CP degradability of LFCM relative to canola meal and the difference in ruminal DMD between canola meal, LFCM and HFCM can be attributed mainly to differences in ruminal ADF degradability.

CHAPTER 6. The Nutritive Value of High Fiber Canola Meal for Ruminants: IV. Amino acid Degradability.

6.1 ABSTRACT

The effect of tail-end dehulling on amino acid composition of low (LFCM) and high fiber (HFCM) canola meal relative to canola meal was determined as well as *in situ* disappearance of amino acids of LFCM, canola meal and HFCM following 12 h of rumen incubation using a fistulated cow. Amino acid composition was similar for LFCM and canola meal. Essential amino acid content (% of crude protein) was 9% higher in HFCM than in LFCM or canola meal. Non-essential amino acid content was similar in the three meals. However, HFCM contained 15 and 25% more alanine and aspartate, respectively, and 31% less glutamate than LFCM and canola meal. Amino acid profiles of rumen undegraded residues were different from the non-incubated samples. Higher amino acid concentrations were found in the undegraded residues except for glutamate and alanine which were higher in the non-incubated samples. *In situ* amino acid disappearance was similar in LFCM, canola meal and HFCM except for threonine and glutamate which were lower ($P<0.0$) in HFCM than in LFCM and canola meal. Within each meal, glutamate was the most degraded amino acid while phenyalalanine was the least degraded in LFCM and canola meal and isoleucine in HFCM. It was concluded that while improving the amino acid content of HFCM (% crude protein), tail-end dehulling did not alter the amino acid content of LFCM relative to canola meal. *In situ* ruminal disappearance of most amino acids of LFCM and HFCM were not different from that of canola meal.

6.2 INTRODUCTION

The nylon bag technique is widely used to estimate the degree to which amino acids of dietary origin are degraded in the rumen and thus the amount that escapes rumen degradation (Biola and Ingalls 1992; Kendall et al. 1991; Crooker et al. 1986; Varvikko 1986). Results on the effect of rumen incubation on amino acid profile of undegraded protein is inconsistent. Various studies indicated that feed amino acids are not degraded equally by the rumen microbes, suggesting that residual amino acid composition of feed protein is different from the original (Biola and Ingalls 1992; Crooker et al. 1986; Varvikko 1986). However, other studies did not find selective degradation of feed amino acids by rumen microbes (Varvikko et al. 1983; Setälä and Syrjälä-Qvist 1984). The inability to detect differences in amino acid profile between feed protein and rumen undegraded protein can be in part attributed to the contamination of feed samples by microbes during rumen incubation (Crooker et al. 1986). However, microbial contamination has been shown to have a small influence on the amino acid composition of undegraded residues of protein supplements such as canola meal (Varvikko 1986).

Tail-end dehulling of canola meal produced two meals with different protein characteristics (experiment one, chapter three). The low fiber, high protein fraction contained 40.2% CP, 9.5% neutral and 3.2% acid detergent insoluble CP. The high fiber, low protein meal (HFCM) contained 37.7% CP, 14.0% neutral and 6.2% acid detergent fiber. At 5% rumen flow rate, effective CP degradability was found to be higher in canola meal and LFCM than in HFCM (experiment three, chapter five). Differences in the distribution of feed protein between cell wall components (i.e. neutral and acid detergent fiber), is anticipated to alter the amino acid composition of LFCM and HFCM relative to canola meal. Muscato et al. (1983) reported variations in amino acid profiles of different protein fractions (i.e. soluble CP, neutral and acid detergent insoluble CP) among different feedstuffs. Sniffen et al. (1992) indicated that amino acid degradability is influenced by the relationship of the protein to other plant components (cell wall, cell content). The objectives

of this study were to determine the amino acid composition of LFCM and HFCM relative to canola meal and to determine the effect of rumen incubation on amino acid composition of undegraded residues of LFCM, HFCM and canola meal and to determine *in situ* ruminal amino acid disappearance from LFCM, HFCM and canola meal following 12h of rumen incubation.

6.3 MATERIALS AND METHODS

Samples of regular canola, low (LFCM) and high (HFCM) canola meals were obtained from the Protein Oil and Starch (POS) pilot plant in Saskatoon, Saskatchewan. Samples were ground through 1 mm screen and analyzed for moisture (method No. 930.15) and Kjeldahl nitrogen (method No. 984.13) according to the procedures of the Association of Official Analytical Chemists (AOAC 1990). Amino acid concentrations were determined using a Perkin-Elmer (Series 4) liquid chromatograph following 24 h of acid hydrolysis (6 N HCl) at 110 °C (AOAC 1984 method No. 43.263) .

Samples (seven g) of canola meal, LFCM and HFCM were weighed in duplicate in nylon bags (9 x 21 cm; 41μm pore size) and incubated in the rumen of a fistulated non-lactating Holstein cow for 12 h. The incubation was repeated three times in three different days. The cow was fed a 50% concentrate: 50% barley silage diet at 1.5% body weight (DM basis). The concentrate diet contained 74.5% barley, 17.0% canola meal, 3% mineral and vitamin mix, 2% corn gluten meal, 2% molasses, 0.6% dicalcium phosphate, 0.5% canola oil, 0.3% cobalt-iodized salt and 0.1% ground limestone.

Following removal from the rumen, the bags were washed and dried as described by McKinnon et al. (1991). Residues were analyzed for moisture, Kjeldahl nitrogen and amino acids as described earlier. Ruminal disappearance of amino acids was calculated from the concentration in the original samples and the residues following rumen incubation.

Data were analyzed as a completely randomized design (3 meals and 3 replicates) using the General Linear Model of the Statistical Analysis System Institute, Inc.

(1989). Where appropriate, means were separated using the Student-Newman-Keuls procedure (Steel and Torrie 1980).

6.4 RESULTS AND DISCUSSION

It was not possible to statistically analyze differences in amino acid composition (% CP) between canola meal and LFCM and HFCM since only a single batch of each meal was available. Essential amino acid contents (% CP) were however, 9% higher in HFCM than in canola meal and LFCM (Table 6.1). This was mainly due to higher levels of isoleucine, phenylalanine and valine in HFCM. Non-essential amino acid contents were similar in the three meals (Table 6.1). However, HFCM contained 15 and 25% more alanine and aspartate, respectively and 31% less glutamate than regular canola meal or LFCM. These differences in amino acid composition can be attributed to differences in amino acid contents of the hull and the embryo of canola seed. Sarwar et al. (1980) indicated that canola hull protein contained more lysine, threonine, valine, aspartate, glycine, proline, serine and tyrosine and less arginine, histidine and tryptophan than dehulled meal protein.

The results of this study indicate that tail-end dehulling did not alter the amino acid contents of LFCM relative to regular canola meal (Table 6.1). In contrast, Bell (1993) found that front-end dehulled canola meal contained higher arginine and cystine and lower valine and lysine levels than commercial canola meal. The similarity in amino acid composition between regular canola meal and LFCM in the present study can be explained by the fact that front-end dehulling is a more effective dehulling process than tail-end dehulling. The amino acid contents of the three meals are in good agreement with the values reported in the literature for canola meal (Bell and Keith 1991; Kendall et al. 1991; Zinn 1993) indicating little effect of tail-end dehulling on the amino acid composition of LFCM and HFCM relative to canola meal.

Amino acid profiles of undegraded residues of the three meals differed from the non-incubated samples (Table 6.1). Amino acid concentrations (except arginine and

Table 6.1. Total and residual amino acid composition of different types of canola meal (% of CP).

	Type of canola meal					
	Regular		Low fiber		High fiber	
	Total	Residual	Total	Residual	Total	Residual
Essential						
Arginine	6.2	5.5	6.0	5.1	5.9	5.4
Histidine	2.8	3.1	2.9	2.7	3.1	3.6
Isoleucine	3.3	4.4	3.1	4.8	4.2	5.3
Leucine	7.2	9.6	7.4	8.0	7.8	7.5
Lysine	5.9	5.8	5.8	5.6	5.8	4.8
Phenylalanine	3.3	4.8	3.4	4.5	4.8	5.4
Threonine	5.4	5.5	5.0	5.1	5.1	4.7
Valine	4.6	5.8	4.8	5.3	5.6	6.0
Non-essential						
Alanine	4.9	5.5	4.6	5.6	5.6	5.0
Aspartate	7.7	9.6	7.4	8.2	8.1	8.6
Glutamate	17.7	14.7	17.5	15.4	13.4	12.9
Glycine	4.9	6.2	4.8	6.4	6.5	6.9
Proline	5.9	6.2	5.8	6.1	6.2	6.4
Serine	4.9	5.5	4.6	5.6	5.1	5.0
Tyrosine	3.1	3.4	3.1	3.5	3.4	3.2

glutamate) were higher in the residues than in the non-incubated meals. Arginine and glutamate concentrations were higher in the non-incubated meals than in the residues. For instance, in regular canola meal, glutamate and arginine contents were 17.0 and 11.3% higher in the non-incubated meal than in the residues. In accordance with our results, Biola and Ingalls (1992) reported higher concentrations of phenylalanine (+ 24%), valine (+ 20%), isoleucine (+ 17%) and threonine (+ 17%) and a lower concentration of glutamate (- 28%) in the residues than in the non-incubated canola meal following 36 h of rumen incubation. Varvikko et al. (1983) reported a reduction in the concentration of methionine and glutamate rapeseed meal following 5, 12 or 24 h rumen incubation. Ganev (1979) reported a similar reduction in glutamate concentration for sunflower meal. The lower concentration of glutamate in the residues is a result of the high degradability of canola meal glutamate (Varvikko et al. 1983; Setälä and Syrjälä-Qvist 1984; Varvikko et al. 1986). The high rumen degradability of canola glutamate is likely the reason for the higher concentration of other amino acids in the undegraded residues (Boila and Ingalls 1992).

Following 12 h of rumen incubation, *in situ* disappearance of threonine and glutamate were higher ($P<0.05$) in LFCM than in canola meal and HFCM (Table 6.2). Despite statistical differences, the rumen degradabilities of these amino acids were relatively similar across the three meals. The *in situ* disappearance of the other amino acids were similar in the three meals (Table 6.2). These results indicate that tail-end dehulling did not alter the amino acid degradability of LFCM and HFCM relative to canola meal. These results are in good agreement with the result of experiment three (chapter five) which showed higher effective CP degradability for canola meal and LFCM than for HFCM at 5% h^{-1} rumen flow rate and a similar effective CP degradability for the three meals at a higher rumen flow rate (8% h^{-1}).

In situ disappearance of canola meal amino acids was higher ($P<0.05$) for glutamate than alanine, aspartate, glycine, isoleucine, leucine, phenylalanine, serine and valine(Figure 6.1).

Table 6.2. *In situ* amino acid disappearance from different types of canola meals following 12 h of rumen incubation.

	Type of canola meal			
	Regular	Low fiber	High fiber	SEM
Essential				
Arginine	83.7	86.6	83.1	1.44
Histidine	82.5	85.6	83.6	0.94
Isoleucine	74.4	76.7	72.6	1.10
Leucine	79.5	81.8	80.3	1.61
Lysine	82.1	84.5	82.6	1.15
Phenylalanine	73.2	75.9	74.0	1.39
Threonine	81.7b	84.7a	79.8b	0.89
Valine	77.2	80.6	77.7	1.16
Non-essential				
Alanine	79.1	81.0	77.3	1.33
Aspartate	77.5	80.1	72.6	0.77
Glutamate	85.2b	87.5a	84.1b	0.66
Glycine	77.0	79.5	77.6	1.07
Proline	80.0	81.6	80.9	0.65
Serine	78.7	78.9	77.3	1.68
Tyrosine	80.7	83.6	80.5	1.25

a,b Means followed by different letters are different ($P<0.05$).
SEM = Pooled standard error of the mean.

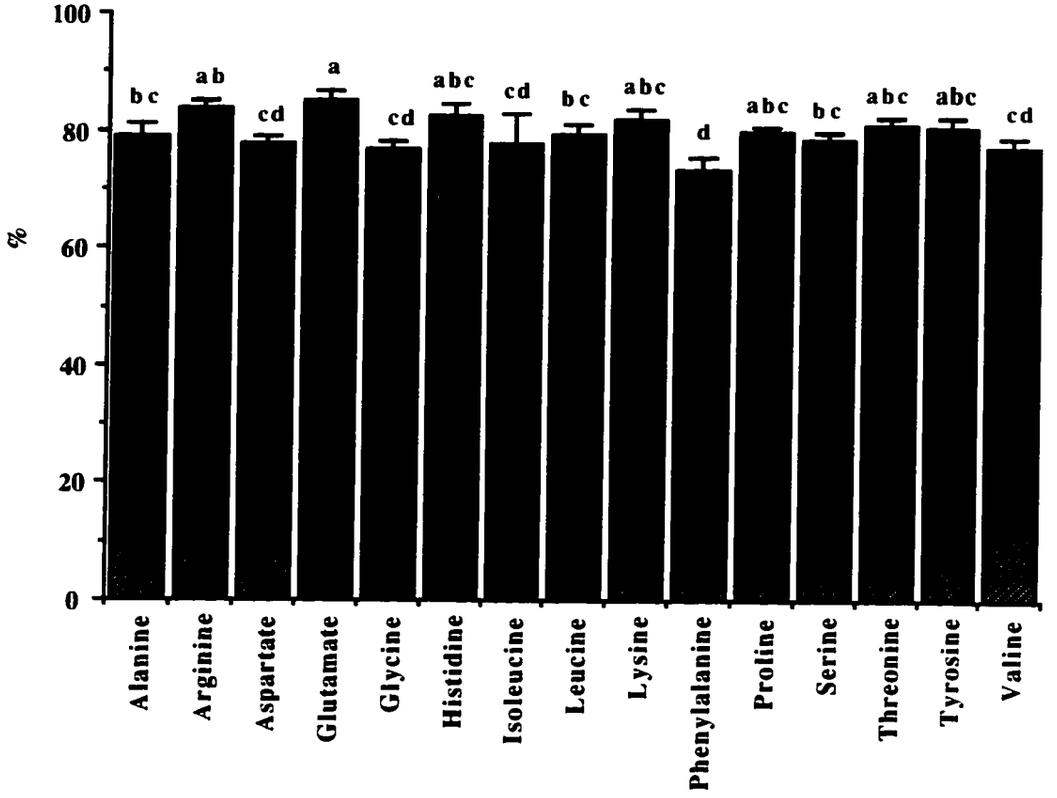

Figure 6.1. *In situ* amino acid disappearance of regular canola meal following 12 h of rumen incubation (mean ± SD). Columns with different letters differ (P<0.05).

A similar order of disappearance was also observed for LFCM (Figure 6.2). In HFCM, *in situ* disappearance was higher ($P<0.05$) for glutamate, arginine, histidine and lysine than for phenylalnine and isoleucine (Figure 6.3).

The *in situ* disappearances of non-essential amino acids in the three meals were higher than the essential amino acids. This was mainly due to the high degradability of glutamate. Similar results were also reported by other researchers (Varvikko et al. 1983; Setälä and Syrjälä-Qvist 1984; Varvikko et al. 1986). Varvikko (1986) found that phenylalanine was the least degraded while histidine and gultamate were the most degraded amino acids of canola meal, following 5 h of rumen incubation. Boila and Ingalls (1992) attributed the lower rumen degradability of canola meal tyrosine, phenylalanine and isoleucine to their lower soluble fractions, lower rates of degradation and longer lag times.

In conclusion, the results of this study indicate that while improving the concentration of several amino acids (% CP) of HFCM, tail-end dehulling did not alter the amino acid composition of LFCM relative to canola meal. The dehulling process had little effect on *in situ* disappearance of different amino acids of LFCM and HFCM relative to canola meal following 12 h rumen incubation and the increased concentration of several amino acids following 12 h of rumen incubation was mainly due to the high rumen degradability of canola glutamate.

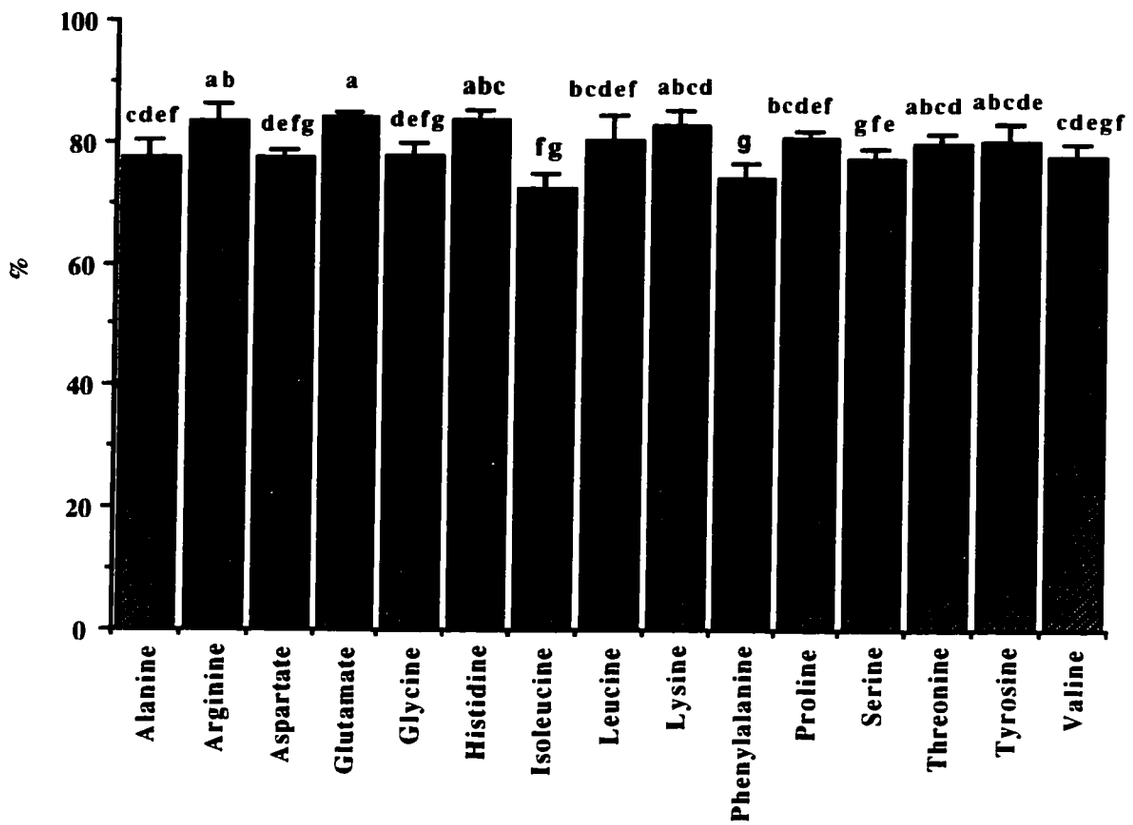

Figure 6.2. *In situ* amino acid disappearance of low fiber canola meal following 12 h of rumen incubation (mean ± SD). Columns with different letters differ (P<0.05).

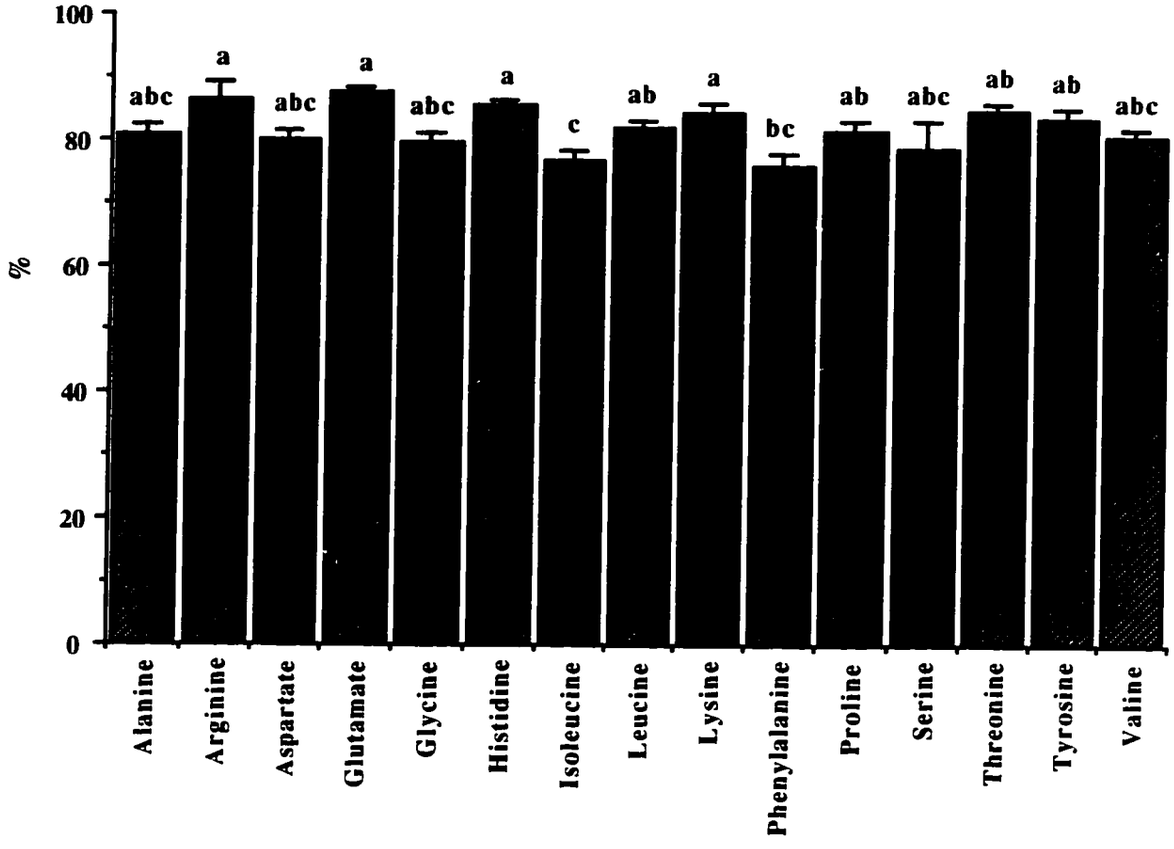

Figure 6.3. ***In situ*** **amino acid disappearance of high fiber canola meal following 12 h of rumen incubation (mean ± SD). Columns with different letters differ (P<0.05).**

CHAPTER 7. The Nutritive Value of High Fiber Canola Meal for Ruminants: V. Total Tract Digestibility and Effect on Lactation.

7.1 ABSTRACT

Two studies were undertaken to evaluate the nutritive value of high fiber canola meal (HFCM) relative to regular canola meal for ruminants. In the first study, 21 growing lambs were utilized in a randomized complete block design to determine the total tract digestion coefficients of dry matter (DMD), crude protein (CPD), gross energy (GED), neutral (NDFD) and acid (ADFD) detergent fiber and the digestible energy (DE) contents of seven dehydrated alfalfa based diets containing 0, 25, 50 and 75% HFCM or canola meal. In the second study, the effect of feeding HFCM as a protein supplement to dairy cows relative to canola meal and soybean meal (SBM) was examined in a triple 3 x 3 Latin square. Results of the first study showed that HFCM had lower ($P<0.05$) DMD, CPD, GED and DE content than canola meal. The estimated DMD, CPD and GED and DE content for HFCM were 67.4, 79.5 and 69.5% and 3.27 (Mcal kg^{-1}), respectively . The corresponding values for canola meal were 70.7, 84.1 and 72.7% and 3.37 (Mcal kg^{-1}), respectively. Results of the second study showed that protein supplement source had no effect on dry matter intake, milk yield, milk fat %, lactose % and total solid %. However, cows fed HFCM- and canola meal- based diets produced milk with lower ($P<0.05$) protein content than those fed the SBM- based diet. It was concluded that HFCM had lower total tract nutrient digestion coefficients and DE content compared to canola meal. Incorporation of HFCM in dairy rations up to 10% of the ration had no adverse effect on milk yield or milk composition compared to canola meal.

7.2 INTRODUCTION

Canola meal is a product of the crushing and oil extraction of canola seed. The oil contains less than 2% of the total fatty acids as erucic acid and the meal less than 30 micro-moles g^{-1} glucosinolate (Bell 1993a). Canola meal is used extensively in Canada in livestock feeds (Anonymous 1993). Bell and Keith (1991) reported that canola meal has about 42% crude protein (CP), 24% neutral detergent fiber, 19% acid detergent fiber and 13% crude fiber . The fiber content of canola meal is about three times that of soybean meal. This is due to the high hull content of canola seed. The hull represents about 16% of the seed and about 30% of the meal. As a consequence, the digestible energy (DE) value of canola meal relative to soybean meal is reduced (Bell 1993a).

The nutritive value of canola meal can be improved by removing or reducing hull content. Sarwar et al. (1981) showed that dehulling of rapeseed meal (RSM) increased DE and digestible CP contents and improved the protein quality of the dehulled meal. In contrast, Bayley and Hill (1975) found that dehulling of RSM did not improve the metabolizable energy content of the dehulled meal over the original RSM for pigs. Recently, Bell (1993b) evaluated the nutritive value of dehulled canola meal for growing pigs. The processing, which involved front-end dehulling, resulted in an improved CP and a reduced fiber content. However, no improvement in pig performance was observed over the original canola meal.

Tail-end dehulling can be used to fractionate canola meal into low (LFCM) and high (HFCM) fiber fractions (McCurdy and March 1992). The technique involves tempering, disc milling and sieving of canola meal. The average yield is about 40% LFCM and 60% HFCM. A previous study has shown that LFCM contained 40.2% crude protein, 24.6% neutral detergent fiber and 14.4% acid detergent fiber . The corresponding values for HFCM were 35.2, 34.7 and 23.9%, respectively (experiment one chapter three).

Tail-end dehulling would allow for target marketing to specialized areas of the livestock industry. A LFCM with an improved DE value would be used by the poultry

and swine industries while HFCM would logically be used in ruminant rations. If the Canadian crushing industry is to market the HFCM, it will be necessary to determine its' market value based on estimates of nutrient digestibility coefficients and its acceptance and efficiency in ruminant rations. The objectives of this study were to determine and compare nutrient digestibility coefficients and DE values of HFCM and canola meal and to determine milk yield and composition responses of early to mid lactation dairy cows fed diets supplemented with HFCM as a protein supplement relative to those fed canola meal and soybean meal based diets.

7.3 MATERIALS AND METHODS

7.3.1 Feed Preparation

Tail-end dehulling of canola meal was carried out in the Protein Oil and Starch (POS) pilot plant in Saskatoon, Saskatchewan using commercial canola meal samples obtained from five western Canadian crushing plants. The dehulling technique was described by McCurdy and March (1992). Briefly, samples of canola meal from each of the five crushing plants were tempered to 16% moisture and milled using an 8-inch disc mill (Bauer Brothers Co. Ltd., Brantford, ON). The milled meals were then sieved using a 35-mesh (U.S.A. Sieve Series) screen to obtain a high fiber low protein fraction (HFCM) and a low fiber high protein fraction. For the purpose of this trial, batches of canola meal and HFCM representing the five crushing plants were obtained from POS and were blended together to obtain one batch of canola meal and one of HFCM.

7.3.2 Total Tract Digestibility Trial

Seven diets were formulated using graded levels of HFCM and canola meal in combination with dehydrated (Dehy) alfalfa. The diets were composed of the following dry matter ratios of dehy alfalfa and HFCM or canola meal; 100:0; 75:25; 50:50; 25:75. The Dehy alfalfa pellets were ground (3 mm screen) prior to mixing. The diets were then pelleted (6 mm diameter) using a Kahn L175 pelleting press (Amandus Kahl Nachf,

Hamburg, Germany). Diets were fed twice daily at 0800 and 1500 h. Each animal was fed daily 10 g of a trace mineral salt mixture containing 160 g Ca, 160 g P, 1.5 g Zn, 25 mg I, 100 mg Fe, 640 mg Mn, 14 mg Co, 3 g F, 151800 IU vitamin A, 15180 IU vitamin D and 500 IU vitamin E kg^{-1}. The diets were evaluated in a total tract digestibility trial with two 21-day feeding periods.

Twenty-one growing Suffolk lambs weighing an average of 30.4 ± 2.4 kg were used. After weighing, the animals were randomly allocated to one of the seven dietary treatments (3 animals per treatment). During a 7-day adaptation period, the animals were kept in floor pens (3 animals per pen) and gradually introduced to the diets. Following the adaptation period the animals were transferred to individual metabolism crates and voluntary feed intake was determined over a 7-day period. During this period the animals were fed to leave about 10 to 15% orts. The voluntary intake period was followed by three days of restricted feeding (85% of ad libitum intake) and five days of total fecal collection. After the completion of the first period, the animals were reweighed and reallocated randomly to the dietary treatments. A similar protocol as in period one was followed for period two.

During the collection period, feces were collected twice daily immediately before feeding, subsampled (10% aliquot) and dried in a forced air oven at 65 °C for 48 h. The feces from each animal were composited and ground through a 1 mm screen using a Christie-Norris mill. Feed samples collected during the same period were dried and ground similarly to the fecal samples. Fecal and feed samples were analyzed for moisture (method No. 930.15), Kjeldahl nitrogen (method No. 984.13) using a Kjeltec 1030 auto analyzer, acid detergent fiber (ADF) and acid detergent lignin (ADL) (method No. 973.18) according to the procedures of the Association of the Official Analytical Chemists (AOAC, 1990). Neutral detergent fiber (NDF) was determined according to the procedure of Van Soest et al. (1991). Gross energy (GE) was determined using an adiabatic oxygen bomb calorimeter. Acid and neutral detergent insoluble CP in feed samples were determined on

ADF and NDF residues, respectively, using the Kjeldahl method (AOAC 1990 method No. 984.13).

Feed samples were also analyzed for soluble and degradable CP as described by Roe et al. (1990). For soluble CP, 0.5 g of sample was incubated with 40 mL of borate phosphate buffer for 1 h at 39 °C. The sample was then filtered and insoluble nitrogen determined by the Kjeldahl method (AOAC 1990 method No. 984.13). For degradable CP, equivalent of 0.2 g air dry protein was incubated in 40 mL of borate phosphate buffer for 1 h and then in 10 mL protease solution (protease type XIV from *Streptomyces griseus*, Sigma Chemical Co., St. Louis, MO) for 18 h at 39 °C. The sample was then filtered and undegradable nitrogen determined using the Kjeldahl method (AOAC 1990 method No. 984.13). Both soluble and degradable CP (nitrogen x 6.25) were expressed as a percentage of total CP.

7.3.4 Dairy Trial

Six multiparous and three primiparous Holstein cows were utilized. At the start of the experiment, the cows averaged 86 ± 13 days postpartum. Three concentrates were formulated to meet NRC (1989) requirements for dairy cows using HFCM, canola meal and soybean meal as protein sources. The HFCM based concentrate was formulated to contain 20% HFCM (DM basis). The concentrate diets were fed in a 50:50 ratio (DM basis) with roughage which consisted of 80% barley silage and 20% second cut alfalfa hay. Forage was fed twice daily while concentrate was fed three times. The cows were fed ad libitum and water was continuously available. The guidelines of the Canadian Council of Animal Care were followed in dealing with animals in both the sheep and dairy trials.

The experimental design was a triple 3 x 3 Latin square (3 periods and 3 protein supplements). Each experimental period lasted 28 days with the first 6 days for diet adaptation. During days 15 to 25, feed intake and milk yield were measured. Milk samples were collected and composited over the last three days of each period. Body weight changes were also monitored in the last three days of each period and blood samples were

taken from the tail vein two hours post feeding, on the final day of each period.

Feed samples were collected on days 15 through 25, composited and analyzed for DM, CP, NDF and ADF as described, previously. Calcium and phosphorous contents of the feed samples were determined following digestion with a perchloric-nitric acid mixture (AOAC 1990 method No. 935.13). Calcium concentration was measured using a Perkin-Elmer Model 5000 atomic absorption spectrophotometer (Technicon GTPC auto analyzer II) while phosphorous concentration was measured colorimetericaly (Pharmacia LKB utraspec.III). Milk samples were analyzed for milk fat by the Babcock method (AOAC 1990 method No. 989.04), milk lactose by infrared spectroscopy (AOAC 1990 Method No. 972.16) and total solids by the oven method (AOAC 1990 method No. 925.23). Milk protein was determined by multiplying percent nitrogen in milk by 6.38 (AOAC 1990 method No. 920.105). Milk and blood (BUN) urea nitrogen levels were measured with a Beckman BUN analyzer 2 (Beckman Instruments, Ca).

7.3.5 Statistical Analysis

Data from the digestibility trial were analyzed as a randomized complete block design (7 treatments) using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS) Institute Inc. (1989). Data were blocked by period. The data were examined for linear or quadratic effects of HFCM or canola meal inclusion rate and regression equations were developed to estimate nutrient digestion coefficients for HFCM and canola meal (Steel and Torrie, 1980). Dairy trial data were analyzed as a Latin square design using the GLM procedure of SAS institute Inc. (1989) with cow, period and protein source as main effects. Where appropriate, means were separated using the Student-Newman-Keuls test (Steel and Torrie 1980).

7.4 RESULTS AND DISCUSSION

7.4.1 Total Tract Digestibility Trial

All digestibility trial diets (Table 7.1) exceeded the crude protein requirement for finishing lambs gaining 295 g d^{-1} (NRC 1985). Fiber (NDF and ADF) levels decreased as inclusion rate of either HFCM or canola meal increased. However, the reduction was more noticeable for canola meal- than for HFCM-based diets. This result indicates that HFCM has a higher fiber content than canola meal. Relative to the control diet, HFCM- and canola meal-based diets, had higher CP, soluble CP and degradable CP levels and lower neutral and acid detergent CP levels. At the 75% inclusion rate, the HFCM based diet contained 6.1% less CP, 3.6% less degradable CP, 16.3% more neutral detergent insoluble CP and 35.8% more acid detergent insoluble CP compared with the 75% canola meal based diet. These results are consistent with differences in fiber and CP contents of HFCM and canola meal as previously reported (experiment one, chapter three).

Dry matter (DM) intake (g $kg^{-0.75}$ body weight) of the lambs decreased linearly ($P<0.05$) as HFCM inclusion rate increased (Table 7.2). However, canola meal inclusion rate had no effect on DM intake (g $kg^{-0.75}$ body weight). The lower DM intake of lambs fed the HFCM-based diets may be a result of higher ADL levels of those diets relative to the control and the canola meal-based diets. For instance, at the 75% inclusion rate, ADL was 21.2% higher in the HFCM than in the canola meal based diet.

Apparent total tract digestibility of dry matter (DMD), crude protein (CPD) and gross energy (GED) increased linearly ($P<0.05$) as the inclusion level of both canola meal and HFCM increased (Table 7.2). DMD, CPD and GED were higher ($P<0.05$) in canola meal- than in HFCM-based diets. At 75% inclusion rate, DMD, CPD and GED were 65.5, 75.2 and 63.8% and 67.5, 78.7, and 70% for HFCM- and canola meal- based diets, respectively. The significant difference in CPD between HFCM and canola meal can be attributed to lower CP and higher acid detergent insoluble CP contents of the HFCM

Table 7.1. Chemical composition of diets used in the digestibility trial (DM basis).

	Inclusion rate (% in diet)						
		High fiber canola meal			Regular canola meal		
Dehy alfalfa inclusion rate (% in diet)	0	25	50	75	25	50	75
	100	75	50	25	75	50	25
Parameter							
Crude protein	19.9	23.8	27.3	30.8	25.0	28.8	32.8
Neutral detergent fiber	41.5	40.5	38.3	36.4	41.6	34.5	31.4
Acid detergent fiber	23.2	23.5	22.8	22.1	22.4	20.5	19.9
Acid detergent lignin	6.9	7.4	8.5	8.5	6.8	6.3	6.7
ND insoluble protein[z]	40.3	34.8	26.6	19.0	28.0	20.1	15.6
AD insoluble protein[y]	10.9	9.6	9.2	9.1	9.5	7.5	6.7
Soluble protein[x]	23.4	28.0	29.1	31.9	27.4	28.4	31.5
Degradable protein[w]	50.1	52.3	59.7	62.0	55.7	58.9	64.3
Gross energy (Mcal kg^{-1})	4.5	4.6	4.6	4.7	4.6	4.6	4.7

[z] Neutral detergent insoluble protein (% of crude protein).
[y] Acid detergent insoluble protein (% of crude protein).
[x] % of crude protein.
[w] % of crude protein.

Table 7.2. Effect of high fiber and regular canola meal inclusion rate on dry matter intake (DMI) and total tract nutrient utilization of dehy alfalfa based diets.

	Inclusion rate (% in diet)								
		High fiber canola meal (HFCM)			Regular canola meal (CM)				Contrast (P value)[z]
		25	50	75	25	50	75		HFCM CM
Dehy alfalfa inclusion rate (% in diet)	100	75	50	25	75	50	25	SEM	
Dry matter intake									
kg d^{-1}	2.3	2.1	1.8	1.9	2.2	2.3	2.1	0.11	.03 NS
g $kg^{-0.75}$	129.7	121.7	114.0	112.5	124.5	128.7	112.7	5.36	0.01 NS
Apparent nutrient digestibility coefficient (%)									
Dry matter	59.2	62.8	63.2	65.5	62.4	65.2	67.5	0.61	0.0001 0.0001
Crude protein	63.8	69.7	72.4	75.2	70.8	74.4	78.7	0.60	0.0001 0.0001
Neutral detergent fiber	51.1	50.5	47.9	50.6	54.0	49.1	50.5	1.15	NS NS
Acid detergent fiber	34.2	35.4	33.7	32.6	35.2	32.6	37.2	1.18	NS NS
Gross energy	61.0	63.3	65.4	67.7	63.8	66.7	70.0	0.79	0.0001 0.0001
Digestible energy (Mcal kg^{-1})	2.8	2.9	3.0	3.2	2.9	3.0	3.1	0.04	0.0001 0.0001

[z] Significant polynomial contrast indicates linear effect of HFCM and CM inclusion rate (NS = not significant at P = (0.05). No quadratic effects detected.

SEM = Pooled standard error of the mean.

based diets relative to those based on canola meal. Chaudhry and Webster (1993) determined true CP digestibility of different feed ingredients containing different amounts of naturally occurring or added acid detergent insoluble CP. They concluded that naturally occurring acid detergent insoluble CP is completely indigestible and may have antinutritional properties. Similar results were also observed by Waters et al. (1992). However, with heat damaged protein, the acid detergent insoluble CP may be partially digestible but does not contribute to animal growth (Nakamura et al. 1994).

The following linear regression equation relates apparent CP digestibility (*Y*) and acid detergent insoluble CP content (*X*) of the digestibility trial diets :

$$Y = 98.94 - 3.02X \quad r^2 = 0.723 \quad (\text{Residual SD} = 2.51\%)$$

The equation indicates a negative relationship between apparent CP digestibility and acid detergent insoluble CP concentration. It also shows that the decline in apparent CP digestibility with increasing acid detergent insoluble CP concentration is greater than one. Waters et al. (1992) using a similar approach reported a regression coefficient of 3.84 for conventional feeds. The high regression coefficient in both studies can be attributed to acid detergent insoluble CP protecting some of the dietary protein from being degraded and digested (Chaudhry and Webester 1993) or to the presence of soluble indigestible CP which was not recovered in acid detergent insoluble CP (Van Soest and Manson 1991) . A positive linear relationship was observed between *in vitro* degradable protein (*X*) and apparent CP digestibility (*Y*) of the experimental diets:

$$Y = 26.81 + 0.786X \quad r^2 = 0.72 \quad (\text{Residual SD} = 1.59\%)$$

Similarly, Assoumani et al. (1992) found a close relationship ($r^2 = 0.92$) between *in situ* theoretical CP degradability and *in vitro* CP degradability using protease technique.

No linear or quadratic effects of HFCM or canola meal inclusion rates on NDFD or ADFD were observed (Table 7.2). At the 75% inclusion rate, NDFD and ADFD of the HFCM based diet were 50.6 and 32.6% respectively. The corresponding value for the canola meal based diet was 50.5 and 37.2%, respectively. The ADFD values at the 75% inclusion rate of HFCM and canola meal are in good agreement with that of Tower rapeseed meal (33.2 ± 5) as reported by Sharma et al. (1980). These results indicate that the lower DMD of HFCM relative to canola meal is likely due to the lower CPD of HFCM since no difference was observed in NDFD or ADFD between HFCM- and canola meal-based diets.

Linear regression equations (Table 7.3) were used to predict nutrient digestion coefficients and DE values of HFCM and canola meal (Table 7.4). The estimated DMD, CPD and GED and DE content of HFCM were 67.4, 79.4 and 69.5% and 3.27 (Mcal kg^{-1}), respectively. The corresponding values for canola meal were 70.7, 84.1 and 72.7% and 3.37 (Mcal kg^{-1}), respectively. The estimated DMD, CPD and GED content of HFCM was 5, 6 and 4% lower than the respective canola meal values, indicating that tail-end dehulling of canola meal had little effect on altering nutrient digestibilities of HFCM. Few studies on total tract digestibility of canola meal have been published for ruminants. Wood and Stone (1970) determined nutrient digestibility coefficients for rapeseed meal by the "difference method". These workers reported values of 74, 85 and 81% for DMD, CPD and GED, respectively. The estimated values reported for canola meal in this study were lower than that reported for canola meal (Zinn 1993) or those reported for Candle and Tower rapeseed (Sharma et al. 1980). This difference may be attributed to these authors using a concentrate diet as a control while an alfalfa diet was used in our study. In addition, the nutrient digestibilities in those studies were calculated using the difference method which might result in an overestimation of apparent digestibility, especially for CP. For instance, Sharma et al. (1980) reported a CPD value of 103.8% for soybean meal using the difference method. The estimated CPD reported in this study for canola meal is comparable

Table 7.3. Linear regression parameters relating apparent nutrient digestibility and digestible energy content (Y) to inclusion rate (X) of high fiber and regular canola meal[z].

	Apparent digestibility (%)			
	Dry matter	Crude protein	Gross energy	Digestible energy
High fiber canola meal				
Intercept (a)	59.67	64.73	61.12	2.77
Slope (b)	0.08	0.15	0.08	0.01
r^2	0.69	0.83	0.53	0.55
RSD[y]	1.53	1.94	2.32	0.13
P>| T |	0.001	0.001	0.001	0.001
Regular canola meal				
Intercept (a)	59.40	64.66	60.88	2.77
Slope (b)	0.11	0.19	0.12	0.01
r^2	0.79	0.92	0.74	0.68
RSD	1.72	1.69	2.03	0.12
P>| T |	0.001	0.001	0.001	0.001

[z] Y = a + bX (no quadratic effects of high fiber or regular canola meal inclusion rate were detected).
[y] Residual standard deviation.

Table 7.4. Estimated Nutrient digestion coefficients and digestible energy content of high fiber and regular canola mealz.

Item	Type of canola meal	
	High fiber	Regular
Digestion coefficient (%)		
Dry matter	67.4	70.7
Crude protein	79.5	84.1
Gross energy	69.5	72.7
Digestible energy (Mcal kg^{-1})	3.27	3.37

z Based on equations in Table 7.3.

with that reported for Candle rapeseed meal while the estimated GED value is comparable with that of Tower rapeseed meal (Sharma et al. 1980).

Reported DE values for canola meal range from 3.2 to 4.2 Mcal kg^{-1} (Bell 1984; NRC 1989; Wood and Stone 1970; Zinn 1993). The estimated DE for HFCM and canola meal were 3.27 and 3.37 Mcal kg^{-1}, respectively. These values are in close agreement with the above values despite differences in the techniques used to estimate the values. These result indicate that tail-end dehulling had little effect on the DE value of the resulting HFCM relative to canola meal. The dehulling technique resulted in a 3% reduction in the estimated DE value of HFCM relative to canola meal. Bayley and Hill (1975) found that air classification of rapeseed meal (RSM) into low (LFRSM) and high (HFRSM) fiber fractions had no influence on DE values for pigs.

7.4.2 Dairy Trial

The total mixed rations (Table 7.5) were formulated to contain similar CP levels (17% DM basis), however, the CP content of the soybean- and canola meal-based rations were higher than that of the HFCM-based ration by 2 and 1% units, respectively. Such differences are not expected to affect the overall objectives of the study since all diets meet the total CP requirements for high producing dairy cows (NRC 1989). The lower NDF and ADF content (39.8 and 18.9%, respectively) of the soybean-based ration relative to the HFCM- and canola meal-based rations (average 42.7 ± 0.14 and 20.7 ± 0.07, respectively) is a result of the high fiber content of HFCM and canola meal relative to soybean meal.

Dry matter intake averaged 19.9 ± 0.22 kg d^{-1} and was not affected by dietary protein source (Table 7.6). In contrast, Sánchez and Claypool (1983) found that cows fed canola meal as a protein supplement consumed more feed than those fed SBM or cottonseed meal. Cows fed diets containing HFCM and canola meal consumed more ($P<0.05$) NDF (average 1.25 ± 0.01 % body weight) than those fed the soybean meal-based diet (1.17% body weight). The higher NDF intake can be attributed to the higher

Table 7.5. Ingredient and chemical composition of diets fed to dairy cows (DM basis).

	Protein source		
	High fiber canola meal	Regular canola meal	Soybean meal
Ingredient (%)			
Barley silage	40.0	40.0	40.0
Alfalfa hay	10.0	10.0	10.0
Barley grain	36.0	37.25	39.85
High fiber canola meal	10.0	0.0	0.0
Regular canola meal	0.0	8.7	0.0
Soybean meal	0.0	0.0	5.9
Mineral-vitamin premix[z]	1.5	1.5	1.5
Other[y]	2.5	2.55	2.75
Chemical composition (%)			
Crude protein	17.2	18.1	19.2
Neutral detergent fiber	42.8	42.6	39.8
Acid detergent fiber	20.6	20.7	18.9
Calcium	0.9	1.0	1.1
Phosphorous	0.6	0.7	0.8

[z] Contained 161 g Ca, 85 g P, 103 g Cl, 63 g Na, 33 g Mg, 18 g K kg^{-1}. Supplied 63 mg Zn, 45 mg Mn, 16 mg Cu and 0.36 mg Se, 10000 IU vitamin A, 1800 IU vitamin D3 and 30 IU vitamin E kg^{-1} of concentrate.

[y] All diets contained 1% corn gluten meal, 1% molasses, 0.25% canola oil, 0.05% ground lime stone and 0.15 cobalt-iodized salt. Dicalcium phosphate was added to high fiber canola meal-, canola meal - and soybean meal- based diets at a level of 0.05, 0.1 and 0.3%, respectively.

Table 7.6. Effect of protein supplement on dry matter intake and utilization of dairy cows.

	Protein source			
	High fiber canola meal	Regular canola meal	Soybean meal	SEM
Dry matter intake				
Forage (kg d^{-1})	9.9	9.9	10.1	0.12
Concentrate (kg d^{-1})	9.7	9.9	10.0	0.13
Total (kg d^{-1})	19.6	19.9	20.1	0.22
Neutral detergent fiber intake				
% of dry matter	39.3a	38.9b	36.2c	0.10
% of body weight	1.25a	1.24a	1.17b	0.01
Body weight change (kg d^{-1})	+0.2	+0.2	+0.3	0.14
Blood urea nitrogen (mmol L^{-1})	7.0b	7.0b	8.1a	0.17
Milk urea nitrogen (mmol L^{-1})	6.0	6.6	6.5	0.25

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

levels of NDF in HFCM- and canola meal- based diets. Mertens (1987) indicated that with diets that resulted in maximum 4% fat corrected milk yield, daily NDF intake was 1.2 ± 0.1% body weight d^{-1}.

There was no treatment effect on body weight change and all cows tended to gain weight during the experimental period suggesting that energy intake was adequate. The average weight gain was 0.2 ± 0.02 kg d^{-1}. Blood urea nitrogen was lower ($P<0.05$) in cows fed HFCM- and canola meal- based diets than in those fed the soybean meal- based diet (Table 7.6). Blood urea nitrogen can be used as an indicator of the amount of CP degraded in the rumen, since, excess ruminal ammonia enters the blood stream (Beaulieu et al. 1990). The soybean meal concentrate was found to have a slightly higher CP content than the HFCM and canola meal concentrates, which might explain the higher level of blood urea nitrogen. West (1994) found that blood urea nitrogen levels in dairy cows increased from 12.50 to 15.24 mg dL^{-1} when dietary CP increased from 17.7 to 19.1% (DM basis). Rae et al. (1983) attributed high blood urea nitrogen levels found with high protein diets to the increased absorption of amino acids from the gut. Beaulieu et al. (1990) suggested that blood urea nitrogen values higher than 3.73 mmol L^{-1} might indicate high rumen degradation of dietary protein. High rumen degradation of soybean meal and canola meal is well documented (Kirkpatrick and Kennelly 1987; Ha and Kennelly 1984; Khorasani et al. 1994).

Protein supplement had no effect on actual or 3.5% fat-corrected milk. Respective averages were 33.6 ± 0.42 and 30.9 ± 0.17 kg d^{-1} (Table 7.7). The lack of any influence on milk yield when canola meal replaced soybean meal agrees with previous studies (Emanuelson 1989; Sánchez and Claypool 1983; Sharma et al. 1977; Laarveld and Christensen 1976). There were no differences in milk fat (average 3.0 ± 0.04%), total solids (average 11.8 ± 0.11%) or lactose (average 4.8 ± 0.03%) between dietary treatments (Table 7.7). Sánchez and Claypool (1983) found no differences in milk components when canola meal replaced soybean meal in dairy rations. Similar results were also reported by

Table 7.7. Effect of protein supplement on milk yield and milk composition of dairy cows.

	Protein source			
	High fiber canola meal	Regular canola meal	Soybean meal	SEM
Milk yield (kg d^{-1})				
Actual	33.8	33.4	33.6	0.52
FCM (3.5%)[z]	31.0	31.0	30.7	0.50
Protein	1.01	1.03	1.02	0.02
Fat	1.01	1.00	1.00	0.02
Lactose	1.62	1.61	1.61	0.02
Milk composition (%)				
Protein	3.02b	3.01b	3.10a	0.02
Fat	3.03	2.95	3.02	0.06
Lactose	4.78	4.83	4.80	0.03
Total solids	11.85	11.76	11.97	0.08

a,b Means in the same row followed by different letters differ ($P<0.05$).
SEM = Pooled standard error of the mean.
[z] FCM = Fat corrected milk.

Papas et al. (1978) and Laarveld and Christensen (1976). These results demonstrated that HFCM can replace canola meal and soybean meal as a protein supplement without affecting milk fat and lactose percentages.

Cows fed HFCM- and canola meal- based diets produced milk with lower ($P<0.05$) protein content ($3.01 \pm 0.01\%$) than those fed the soybean meal- based diet (3.1%). Despite the fact that the milk protein percentage was higher for cows fed the soybean- based diet than those fed HFCM- and canola meal- based diets, milk protein yield was similar among the three treatments (average 1.02 ± 0.01 kg d^{-1}, Table 7.7). The difference in milk protein percentage between treatments can be attributed to the higher CP content of soybean meal- based diet relative to HFCM- and canola meal- based diets. Emery (1978) reported that milk protein percentage increases by 0.02% for each 1.0% increase of dietary CP. Sharma et al. (1977) compared two types of rapeseed meal (RSM) (1788-RSM and commercial RSM) and soybean meal as protein supplements for dairy cows. They found that cows fed 1788-RSM- based diet (18.2% CP) produced milk with lower protein percentage than those fed commercial RSM- (19.0% CP) or a soybean meal-based diet (19.4% CP).

In conclusion, the results of this study show that tail-end dehulling of canola meal resulted in a HFCM which exhibits reduced total tract CP and GE digestibilities and a lower digestible energy content relative to canola meal. However, incorporation of HFCM in dairy rations up to 10% of the ration had no adverse effect on milk yield or milk composition relative to canola meal. When compared to soybean meal, the only adverse effect was a reduction in milk protein percent, an effect which was also observed for canola meal.

CHAPTER 8. GENERAL DISCUSSION

The main goal of dehulling canola meal is to produce a low fiber, high protein meal which will be competitive with soybean meal. Dehulling of canola seed prior to oil extraction (e.g. front-end dehulling) has several problems including loss of oil in the hull fraction (McKinnon et al .1995a), poor feeding performance by monogastric animals fed the dehulled meal (Bell 1993a), low nutritive value of the hulls for ruminants (McKinnon et al. 1995a) and high cost of dehulling (McCurdy 1995). Although the separation of the hull and the embryo is incomplete, tail-end dehulling overcomes some of the problems associated with front-end dehulling. These include no reduction in oil yield since the dehulling takes place after oil extraction and the high fiber, low protein meal fraction would be more competitive than the hulls as a feed source for ruminants. The main objective of this thesis was to determine the nutritive value of HFCM as a protein supplement for ruminants.

Results of the first study indicated that tail-end dehulling increased the acid detergent fiber and reduced the crude protein content of high fiber, low protein canola meal (HFCM) relative to canola meal by 23.8 and 6.6%, respectively. For the low fiber, high protein (LFCM) meal, the dehulling process reduced the acid detergent fiber and increased the crude protein content by 25.4 and 6.6%, respectively, relative to canola meal. These results indicate that the dehulling process was more efficient in fiber than in protein fractionation. The shift in neutral detergent fiber content between LFCM and HFCM was less than that observed for acid detergent fiber indicating high hemicellulose content of the canola embryo. This shift in fiber content between LFCM and HFCM was also reflected in the distribution of crude protein between the neutral and acid detergent fiber. Mineral contents of LFCM and HFCM indicated that tail-end dehulling reduced calcium (Ca) and increased the phosphorous (P) and magnesium (Mg) contents of LFCM relative to HFCM. These results support the findings of Bell (1993a) who reported lower

Ca and higher P and Mg contents for dehulled canola meal relative to canola meal.

The change in chemical composition of LFCM and HFCM relative to canola meal is consistent with the results obtained for front-end dehulling (Bell 1993a). However, the improvement in the protein and fiber composition of LFCM was less than that reported for front-end dehulled canola meal. These differences were anticipated since nutrient fractionation in tail-end dehulling is not as thorough as in front-end dehulling.

The objective of the second study was to determine the effect of meal source on *in situ* nutrient disappearance following 24 h of rumen incubation. Crushing plant differences in effective dry matter and crude protein degradability within the canola meal, LFCM and HFCM samples were also determined. The results showed no differences due to crushing plant of origin in dry matter or crude protein disappearance among the regular canola samples following 24 h of rumen incubation. However, differences *in situ* DM and crude protein disappearance were observed among the LFCM and HFCM samples, particularly those derived from crusher four. The reasons for these differences are unknown. However, McCurdy (1993) indicated that the efficiency of tail-end dehulling is most dependent on the meal source. Commercial canola meal may vary in separation characteristics primary due to the treatments received during the expeller and desolventizer stages and due to varietal differences (Downey and Bell 1990). These factors may affect the ability of the meal components (hull and cotyledon) to absorb moisture and to respond to milling during the dehulling process.

Relative to canola meal and LFCM, HFCM had lower 24 h *in situ* dry matter and crude protein disappearances. *In situ* 24 h crude protein disappearance was similar for canola meal and LFCM. A reduction in crude protein and an increase in acid detergent insoluble protein levels are believed to cause the reduction in *in situ* crude protein disappearance of HFCM relative to canola meal. However, the improvement in crude protein and acid detergent insoluble crude protein composition did not increase the *in situ* crude protein disappearance of LFCM relative to canola meal, most likely due to

the already high rumen disappearance of canola meal. Effective dry matter and crude protein degradability differed among the LFCM and HFCM but not among the canola meal samples. This is consistent with the results of the *in situ* 24 h rumen incubation study.

Despite the presence of some crusher differences in rumen nutrient disappearance, no crusher by meal interaction was observed in the 24 h of rumen incubation study, indicating that differences in rumen nutrient disappearance in the three meals were consistent across the crushing plants. Samples were then pooled to obtain the blended samples of canola meal, LFCM and HFCM, each representing all five crushing plants. This allowed for further studies to investigate differences in rumen kinetic parameters and effective nutrient degradability between the three meals using *in vitro* and *in situ* techniques and to determine nutrient utilization and production responses by animals fed HFCM-based diets.

In the third study, the *in vitro* and *in situ* nutrient disappearance of the blended meals were determined. The chemical composition of the blended meals were consistent with the composition of canola meal, LFCM and HFCM obtained in the first study. The results showed that HFCM exhibited lower *in vitro* and *in situ* effective crude protein degradability relative to canola meal and LFCM. This can be attributed to the lower crude protein and higher acid detergent insoluble crude protein of HFCM relative to canola meal and LFCM. The results are in agreement with the results of the second study which showed a lower *in situ* crude protein disappearance for HFCM relative to canola meal and LFCM following 24 h of rumen incubation. Effective degradability of the cell wall components (neutral and acid detergent fiber) of canola meal, LFCM and HFCM, indicated more differences in effective degradability for acid than for neutral detergent fiber. The is most likely due to the fact that tail-dehulling of canola meal resulted in more separation of acid detergent fiber than of neutral detergent fiber between LFCM and HFCM. These results are again consistent with the results of

the second study which showed more differences in *in situ* acid detergent than neutral detergent fiber disappearance between canola meal, LFCM and HFCM following 24 h of rumen incubation.

The effect of tail-end dehulling on amino acid composition of LFCM and HFCM relative to canola meal was determined in the fourth study. On a dry matter basis, amino acid composition was similar for canola meal, LFCM and HFCM (data not shown) and was consistent with values reported in the literature for canola meal. However, as a percentage of crude protein, HFCM had higher alanine and aspartate and lower glutamate content than canola meal and LFCM. This is mainly due to the high alanine and aspartate levels in canola hulls (Sarwar et al. 1980).

The high concentration of amino acids (e.g. isoleucine, leucine and glycine) in the undegraded residues following 12 h of rumen incubation agrees with other studies and is most likely due to the high rumen degradability of canola glutamate (Boila and Ingalls 1992; Varvikko et al. 1983).The results of this study indicated that canola meal and LFCM had a similar pattern of amino acid disappearance. This is consistent with the results of the second and the third trial which showed small differences in rumen crude protein disappearance or effective degradability between canola meal and LFCM.

The fifth study determined nutrient digestibility coefficients of canola meal and HFCM-based diets fed to growing lambs. The results indicated that HFCM had lower dry matter and crude protein digestibility and lower digestible energy content than canola meal. Differences in total tract crude protein digestibility between canola meal and HFCM were similar to those obtained in the *in situ* trails which indicates little postruminal crude protein digestibility of canola meal and HFCM protein. This in agreement with other studies which showed high ruminal degradability of canola meal protein with little left for digestion potruminally (Murphy and Kennelly 1987; Kirkpatrick and Kennelly 1987; De Boer et al. 1987). McKinnon et al. (1995b) used mobile nylon bag technique to estimate ruminal and total crude protein disappearance of canola meal.

They reported values of 80.5 and 93.0% for ruminal and total tract crude protein disappearance, respectively.

The lack of differences in neutral and acid detergent fiber digestibility coefficient between canola meal and HFCM as opposed to those observed in the in situ trial can be attributed to compensatory hind gut fiber fermentation (Sultan and Loerch 1992; Lewis and Dehority 1985). De Gregorio et al. (1982) found that large intestine acid detergent fiber digestion accounted for 85% of the total tract digestible acid detergent fiber in lambs fed 80% corn-based diet.

The results obtained in the digestibility trial showed little effect of tail-end dehulling on the digestible energy content of HFCM relative to canola meal. These findings were supported by the results of the dairy trial which indicated no adverse effect of feeding HFCM (up to 10% of the diet) as a sole protein supplement for early to mid lactation dairy cows. The results showed that HFCM supported similar feed intake, milk yield and milk composition as canola meal. When compared to soybean meal, the only adverse effect of HFCM was a reduction in milk protein percentage, an effect which was also observed for canola meal.

In conclusion, it is clear that tail-end dehulling of canola meal produced two meal fractions with different composition. The HFCM had lower crude protein and higher cell wall content (particularly acid detergent fiber and lignin) than canola meal and LFCM. These changes in chemical composition were reflected in a reduced ruminal and total tract dry matter and crude protein disappearances as well as a lower digestible energy content relative to canola meal. However, these differences did not affect feed intake, milk yield or milk composition of dairy cows fed the HFCM.

CHAPTER 9. REFERENCES

Anonymous. 1993. Canola meal: Feed industry guide. D. Hickling, ed. Canola Council of Canada, Winnipeg, MB.

Antoniewicz, A. M., van Vuuren, A. M., van der Kolen, C. J and ARC, 1992. Nutrient requirement of ruminant animals: Protein. AFRC Technical Committee on responses to nutrients. Report No. 9. Nutr. Abstr. Rev. (Series B) 62: 832-835.

Association of Official Analytical Chemists. 1984. Official methods of analysis, 14th ed. AOAC, Arlington, VA.

Association of Official Analytical Chemists. 1990. Official methods of analysis, 15th ed. AOAC, Arlington, VA.

Assoumani, M. B., Vedeau, F., Jacquot, L. and Sniffen, C. J. 1992. Refinement of an enzymatic method for estimating the theoretical degradability of proteins in feedstuffs for ruminants. Anim. Feed Sci. Technol. 39: 357-368.

Aufrère, J., Graviou, D., Vérité, R., Michalet-Doreau, B. and Chapoutot, P. 1991. Predicting in situ degradability of feed proteins in the rumen by two laboratory methods (solubility and enzymatic degradation). Anim. Feed Sci. Technol. 33: 97-116.

Bailey, C. B. and Hironaka, R. 1984. Estimation of the rumen degradability of nitrogen and of non-protein organic matter in formaldehyde-treated and untreated canola meal. Can. J. Anim. Sci. 64: 183-185.

Bayley, H. S. and Hill, D. C. 1975. Nutritional evaluation of low and high fiber fractions of rapeseed meal using chickens and pigs. Can. J. Anim. Sci. 55: 223-232.

Beames, R. M., Tait, R. M. and Litsky, J. 1986. Grain screenings as a dietary component for pigs and sheep. I. Botanical and chemical composition. Can. J. Anim. Sci.

66: 473-481.

Beauchemin, K. A. McAllister, T. A., Dong, Y., Farr, B. I. and Cheng, K. J. 1994. Effects of mastication on digestion of whole cereal grains by cattle. J. Anim. Sci. 72: 236-246.

Beaulieu, A. D., Olobobokun, J. A. and Christensen, D. A. 1990. The utilization of canola and its constituents by lactating dairy cows. Anim. Feed Sci. Technol. 30: 289-300.

Bell, J. M. 1984. Nutrients and toxicants in rapeseed meal: A review. J. Anim. Sci. 58: 996-1010.

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

Bell, J. M. and Keith, M. O. 1991. A survey of variation in the chemical composition of commercial canola meal produced in western Canadian crushing plants. Can. J. Anim. Sci. 71: 469-480.

Bell, J. M. and Shires, A. 1982. Composition and digestibility by pigs of hull fractions from rapeseed cultivars with yellow or brown seed coats. Can. J. Anim. Sci. 62: 557-565.

Bell, J. M., 1993a. Nutritional evaluation of dehulled canola meal for swine. P 64-72. Tenth project report: Research on Canola Seed, Oil and Meal. Canola Council of Canada, Winnipeg, Manitoba.

Bell, J. M., Keith, M. O. and Hutcheson, D. S. 1991. Nutritional evaluation of very low glucosinolate canola meal. Can. J. Anim Sci. 71: 479-506.

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

Boila, R. J. and Ingalls, J. R. 1992. in situ rumen digestion and escape of dry matter, nitrogen and amino acids in canola meal. Can. J. Anim. Sci. 72: 891-901.

Broderick, G. A. 1978. In vitro procedures for estimating rates of ruminal protein degradation and proportions of protein escaping the rumen undegraded. J. Nutr. 108: 181-190.

Bush, R. S., Nicholson, J. W. G., Macintyre, T. M. and McQueen, R. E. 1978. A comparison of Candle and Tower rapeseed meals in lamb, sheep and beef steer rations. Can. J. Anim. Sci. 58: 369-376.

Calsamiglia, S. and Stern, M. D. 1995. A three-step in vitro procedure for estimating intestinal digestion of protein in ruminants. J. Anim. Sci. 73: 1459-1465.

Calsamiglia, S., Stern, M. D. and Crooker, B. A. 1992. Effects of diets formulated to contain different amounts of rumen non-degradable protein on microbial fermentation and nutrient flow from a continuos culture system. Anim. Feed Sci. Technol. 39: 239-252.

Campbell, S. J. 1984. Quality control in a canola crushing plant. J. Am. Oil Chem. 61: 1097-1101.

Chalupa, W. V. 1992. A model to estimate rumen escape protein and amino acid composition. p 87-95. Distillers Feed Conference. Cincinnati, OH.

Chaudhry, A. S. and Webster, A. J. F. 1993. The true digestibility and biological value for rats of undegraded dietary nitrogen in feed for ruminants. Anim. Feed Sci. Technol. 42: 209-221.

Cheng, K. J., McAllister, T. A. and Rode, L. M. 1993. Use of acidulated fatty acids to increase the rumen undegradable protein value of canola meal. p178-188. Tenth Project Report: Research on canola seed, oil, meal and meal fractions. Canola Council of Canada, Winnipeg, MB.

Cherney, D. J. R., Patterson, J. A. and Lemenager, R. P. 1990. Influence of

in situ rinsing technique on determination of dry matter disappearance. J. Dairy Sci. 73: 391-397.

Claypool, D. W., Hoffman, C. H., Oldfield, J. E. and Adams, H. P. 1985. Canola meal, cottonseed, and soybean meals as protein supplements for calves. J. Dairy Sci. 68: 67-70.

Coombe, J. B. 1985. Rapeseed and sunflower seed meals as protein supplements for sheep fed oat straw. Aust. J. Agric. Res. 36: 717-728.

Coombe, J. B. 1987. Rapeseed and sunflower seed meals as supplements for sheep grazing cereal stubbles. Aust. J. Exp. Agric. 27: 513-523.

Crooker, B. A., Clark, J. H., Shanks, R. D. and Hatfield, E. E. 1986. Effects of ruminal exposure on the amino acid profile heated and formaldehyde-treated soybean meal. J. Dairy Sci. 69: 2648-2657.

De Boer, G. Murphy, J. J. and Kennelly, J. J. 1987a. A modified method for determination of in situ rumen degradation of feedstuffs. Can. J. Anim. Sci. 67: 93-102.

De Boer, G., Murphy, J. J. and Kennelly, J. J. 1987b. Mobile nylon bag for estimating intestinal availability of rumen undegradable protein. J. Dairy Sci. 70: 977-982.

De Gregrio, R. M., Tucker, R. E., Mitchel, G. E. and Gill, W. W. 1982. Carbohydrate fermentation in the large intestine of lambs. J. Anim. Sci. 54: 855-862.

Deacon, M. A., De Boer, G. and Kennelly, J. J. 1988. Influence of jet-sploding® and extrusion on ruminal and intestinal disappearance of canola and soybeans. J. Dairy Sci. 71: 745-753.

DeClercq, D. R., Daun, J. K. and Tipples, K. H. 1993. Quality of western Canadian canola. Canadian Grain Commission, Winnipeg, MB.

Denham, S. C., Morantes, G. A., Bates, D. B. and Moore, J. E. 1989. Comparisons of two models used to estimate in situ nitrogen disappearance. J. Dairy Sci. 72: 708-714.

DePeters, E. J. and Bath, D. L. 1986. Canola meal versus cottonseed meal as the protein supplement in dairy diets. J. Dairy Sci. 69: 148-154.

Dhanoa, M. S. 1988. On the analysis of dacron bag data for low degradability feeds. Grass forage Sci. 43: 441-444.

Downey, R. K. and Bell, J. M. 1990. New developments in canola research p 37-46. In Canola and rapeseed production, chemistry, nutrition and production. Shahidi, F. (Editor). Van Nostrand Reinhold, NY.

Emanuelson, M. 1989. Rapeseed products of double low cultivars to dairy cows. ph.D. Thesis. Swedish University of Agricultural Science, Uppsala, Sweden.

Emery, R. S. 1978. Feeding for increased milk protein. J. Dairy Sci. 61:825-828.

Finlayson, A. J. 1974. The amino acid composition of rapeseed hulls. Can. J. Anim Sci. 54: 495-496.

Fisher, L. J. 1980. A comparison of rapeseed meal and soybean meal as a source of protein and protected lipid as a source of energy for calf starter diets. Can. J. Anim. Sci. 60: 359-366.

Fox, D. G. and Barry, M. C. 1994. Predicting cattle net energy and protein requirements and supply under widely varying conditions p 41-58. In Livestock Production for the 21st Century. P. A. Thacker (ed.). University of Saskatchewan.

Fox, D. G., Sniffen, C. J., O'Connor, J. D., Russell, J. B. and Van Soest P. J. 1992. A Net Carbohydrate and Protein System for evaluation cattle diets: III. Cattle requirements and diet adequacy. J. Anim. Sci. 70: 3578-3596.

Ganev, G., Ørskov, E. R. and Smart, R. 1979. The effect of roughage or concentrate feeding and rumen retention time on total degradation of protein in the rumen. J. Agric. Sci. 93: 651-656.

Greenberg, N. A. and Shipe, W. P. 1979. Comparison of the abilities of

trichloroacetic, picric, sulfosalicylic, and tungstic acids to precipitate protein hydrolysates and proteins. J. Food Sci. 44: 735-737.

Griffin, C. D., Bunting, L. D., Sticker, L. S. and Vora, B. 1993. Assessment of protein quality in heat-treated soybean products using the growth responses in lambs and calves and a nylon bag-rooster assay. J. Anim Sci. 71: 1924-1931.

Grigsby, K. N., Kerley, M. S., Paterson, J. A. and J. C. Weigal, J. C. 1992. Site and extent of nutrient digestibility by steers fed a low-quality bromegrass hay diet with incremental levels of soybean hull substitution. J. Anim. Sci. 70: 1941-1948.

Ha, J. K. and Kennelly, J. J. 1984. In situ dry matter and protein degradation of various protein sources in dairy cattle. Can. J. Anim. Sci. 64: 443-452.

Hannah, S. M., Stern, M. D. and Ehle, F. R. 1986. Evaluation of a dual flow continuos culture system for estimating bacterial fermentation in vivo of mixed diets containing various soya bean products. Anim. Feed Sci. Technol. 16: 51-62.

Harris, P. J., Blakeney, A. B., Henry, R. J. and Stone, B. A. 1988. Gas chromatographic determination of the monosaccharide composition of plant cell wall preparation. J. Assoc. Off. Anal Chem. 71: 272-275.

Henning, P. H., Meyer, J. H. F. and Prinsloo, J. J. 1989. A note on the use of the chicken to predict protein digestibility in the small intestine of sheep. Anim. Prod. 48: 457.

Hill, R. 1991. Rapeseed meal in the diets of ruminants. Nutr. Abst. Rev. (Series B). 61: 139-155.

Hill, R., Vincent, I. C. and Thompson, J. 1990a. The effects on food intake in weaned calves of low-glucosinolate rapeseed meal as the sole protein supplement. Anim. Prod. 50: (Abstr.)

Hill, R., Vincent, I. C. and Thompson, J. 1990b. The voluntary food intake and weight gain of lambs given concentrate foods containing rapeseed meal with a range of glucosinolate contents. Anim. Prod. 50: (Abstr.).

Ingalls, J. R. and Grumpelt, B. P. 1987. Unextracted canola seed in rations for ram lambs and dairy cows. p 263-269. Eighth Project Report: Research on canola seed, oil, meal and meal fractions. Canola Council of Canada, Winnipeg, MB.

Jones, R. A. 1993. Effect of heat-treated and untreated canola presscake on dairy cow performance and milk fat composition. M. Sc. Thesis. University of Saskatchewan. Saskatoon, Ca.

Keith, M. O. and Bell, J. M. 1991. Composition and digestibility of canola press cake as feedstuff for use in swine diets. Can. J. Anim. Sci. 71: 879-885.

Kendall, E. M., Ingalls, J. R. and Boila, R. J. 1991. Variability in the rumen degradability and postruminal digestion of the dry matter, nitrogen and amino acids of canola meal. Can. J. Anim. Sci. 71: 739-754.

Kennelly, J. J. 1987. Full-fat canola seed for lactating dairy cows. p 257-262. Eighth Project Report: Research on canola seed, oil, meal and meal fractions. Canola Council of Canada, Winnipeg, MB.

Kennelly, J. J. Khorasani, G. R., Robinson, P. H. and De Boer, G. 1993. Effect of jet-sploding and extrusion on the nutritive value of canola meal and whole canola seed for dairy cattle. p130-159. Tenth Project Report: Research on canola seed, oil and meal. Canola Council of Canada, Winnipeg, MB.

Khorasani, G. R. Robinson, P. H. and Kennelly, J. J. 1994. Evaluation of solvent and expeller linseed meals as protein sources for dairy cattle. Can. J. Anim. Sci. 74: 479-485.

Khorasani, G. R., Robinson, P. H. and Kennelly, J. J. 1989a. Effect of chemical treatment on in vitro and in situ degradation of canola meal crude protein. J. Dairy Sci. 72: 2074-2080.

Khorasani, G. R., Robinson, P. H. and Kennelly, J. J. 1993. Effects of canola meal treated with acetic acid on rumen degradation and intestinal digestibility in lactating dairy cows. J. Dairy Sci. 76: 1607-1616.

Khorasani, G. R., Sauer, W. C., Ozimek, L. and Kennelly, J. J. 1990. Digestion of soybean meal and canola meal protein and amino acids in the digestive tract of young ruminants. J. Anim. Sci. 68: 3421-3428.

King, R. D. and Dietz, H. M. 1987. Air classification of rapeseed meal. Cereal Chem. 64: 411-413.

Kirkpatrick, B. K. and Kennelly, J. J. 1987. In situ degradability of protein and dry matter from single protein sources and from a total diet. J. Anim. Sci. 65:567-576.

Kosmala, I. 1992. Intestinal digestibility of rumen undegraded protein of formaldehyde-treated feedstuffs measured by mobile nylon bag and in vitro technique. Anim. Feed Sci. Technol. 39: 111-124.

Krishnamoorthy, U., Muscato, T. V., Sniffen, C. J. and Van Soest, P. J. 1982. Nitrogen fractions in selected feedstuffs. J. Dairy Sci. 65: 217-225.

Krishnamoorthy, U., Sniffen, C. J., Stern, M. D. and Van Soest, P. J. 1983. Evaluation of a mathematical model of rumen digestion and an in vitro simulation of rumen proteolysis to estimate the rumen-undegraded nitrogen content of feedstuffs. Br. J. Nutr. 50: 555-568.

Laarveld, B. and Christensen, D. A. 1976. Rapeseed meal in complete feeds for dairy cows. J. Dairy Sci. 59: 1929-1935.

Laarveld, B., Brockman, R. P. and Christensen, D. A. 1981. The effects of Tower and Midas rapeseed meals on milk production and concentrations of goitrogens and iodide in milk. Can. J. Anim. Sci. 61: 131-139.

Lardy, G. P., Catlett, G. E., Kerley, M. S. and Paterson, J. A. 1993. Determination of the ruminal escape value and duodenal amino acid flow of rapeseed meal. J. Anim. Sci. 71: 3096-3104.

Leslie, A. J., Summers, J. D. and Jones, J. D. 1973. Nutritive value of air-classified rapeseed fractions. Can. J. Anim. Sci. 53: 153-156.

Lewis, S. M. and Dehority, B. A. 1985. Microbiology and ration digestibility in hind gut of the Ovine. Appl. environ. Microbiol. 50: 356-363.

Lindberg, J. E., and Varvikko, T. 1982. The effect of bag pore size on the ruminal degradation of dry matter, nitrogenous compounds and cell walls in nylon bag. Swed. J. Agric. 12: 163-175.

Lindberg, J. E., Soliman, H. S. and Sanne, S. 1982. A study of the rumen degradability of untreated and heat treated rape seed meal and of whole rape seed, including a comparison between two nylon bag techniques. Swedish J. Agric. Res. 12: 83-88.

Marinucci, M. T., Dehority, B. A. and Loerch, S. C. 1992. In vitro and in vivo studies of factors affecting digestion of feeds in synthetic fiber bags. J. Anim. Sci. 70: 296-307.

Matras, J., Bartler, S. J. and Preston, R. L. 1990. Effects of ruminal escape proteins and canola meal on nitrogen utilization by growing lambs. J. Anim. Sci. 68: 2546-2554.

McAllister, T. A., Cheng, K. J., Beauchemin, K. A., Bailey, D. R. C., Pickard, M. D. and Gilbert, R. P. 1993. Use of lignosulfonate to decrease the rumen degradability of canola meal protein. Can. J. Anim. Sci. 73: 211-215.

McAllister, T. A., Rode, L. M., Major, D. J., Cheng, K. J. and Buchanan-Smith, J. G. 1990. Effect of ruminal microbial colonization on cereal grain digestion. Can. J. Anim. Sci. 70: 571-579.

McCurdy, S. M. 1990. Effects of processing on the functional properties of canola and rapeseed protein. J. Am. Oil Chem. Soc. 67: 281-284.

McCurdy, S. M. 1993. Tail-end dehulling of canola meal: Research report to canola council of Canada. POS Pilot Plant Corp., Saskatoon, SK.

McCurdy, S. M. and Fedec, P. 1995. Assessment of dehulling of canola seed. p 1-29. 11th project report: Research on seed, meal. Canola Council of Canada, Winnipeg,

MB.

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

McKinnon, J. J., Cohen, D. H., Jones, S. D. M. and Christensen, D. A. 1993a. Crude protein requirements of large frame cattle fed two levels of energy as weaned calves or as backgrounded yearlings. Can. J. Anim. Sci. 73: 315-325.

McKinnon, J. J., Cohen, R. D. H., Jones, S. D. M. and Christensen, D. A. 1993b. Crude protein requirements of large frame cattle fed two levels of energy as weaned calves or as backgrounded yearlings. Can. J. Anim. Sci. 73: 315-325.

McKinnon, J. J., Mustafa, A. F. and Cohen, R. D. H. 1995a. Nutritional evaluation and processing of canola hulls for ruminants. Can. J. Anim. Sci. 75: 231-237.

McKinnon, J. J., Olubobokum, J. A., Christensen, D. A. and Cohen, R. D. H. 1991. The influence of heat and chemical treatment on ruminal disappearance of canola meal. Can. J. Anim. Sci. 71: 773-780.

McKinnon, J. J., Olubobokum, J. A., Mustafa, A. F., Cohen, R. D. H. and Christensen, D. A. 1995b. Influence of dry heat treatment of canola meal on site and extent of nutrient disappearance in ruminants. Anim. Feed Sci. Technol. 56: 243-252.

McKinnon, J. J., Olubobokun, J. A., Christensen, D. A. and Cohen, R. D. H. 1990. The influence of heat and chemical treatment on ruminal disappearance of canola meal. Can. J. Anim. Sci. 71: 773-780.

McKinnon, P. J. and Christensen, D. A. 1989. Canola meal for livestock and poultry. In Vegetable Protein Utilization in Human Foods and Animal Feedstuffs. T. H. Apple white (ed.). American Oil Chemists' Society.

Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. J. Anim. Sci. 64: 1548-1558.

Mertens, D. R. and Loften, J. R. 1980. The effect of starch on forage fiber

digestion kinetics in vitro. J. Dairy Sci. 63: 1437-1446.

Michalet-Doreau, B. and Cerneau, P. 1991. Influence of foodstuff particle size on in situ degradation of nitrogen in the rumen. Anim. Feed Sci. Technol. 35: 69-81.

Michalet-Doreau, B. and Ould-Bah, M. Y. 1992. In vitro and in sacco methods for the estimation of dietary nitrogen degradability in the rumen: a review. Anim. Feed. Sci. Technol. 40: 57-86.

Mir, Z., MacLeod, G. K., Bushanan-Smith, J. G., Grieve, D. G. and Grovoum, W. L. 1984. Methods for protecting soybean and canola proteins from degradation in the rumen. Can. J. Anim. Sci. 853-865.

Mitaru, B. N. and Blair, R. 1985. Comparison of the effects of dark and yellow rapeseed hulls, soybean hulls and a purified fiber source on growth, feed consumption and digestibility of dietary components in starter pigs. Can. J. Anim. Sci. 65: 231-237.

Mitaru, B. N. Blair, R., Bell, J. M. and Reichert, R. 1982. Tannin and Fiber contents of rapeseed and canola hulls. Can. J. Anim. Sci. 62: 661-663.

Mitaru, B. N. Blair, R., Bell, J. M. and Reichert, R. 1983. Effect of canola hulls on growth, feed efficiency, and protein and energy utilization in broiler chickens. Can. J. Anim. Sci. 63: 655-662.

Moshtaghi Nia, S. A. and Ingalls, J. R. 1992. Effect of heating on canola meal protein degradation in the rumen and digestion in the lower gastrointestinal tract of steers. Can. J. Anim. Sci. 72: 83-88.

Murphy, J. J. and Kennelly, J. J. 1987. Effect of protein concentration and protein source on the degradability of dry matter and protein in situ. J. Dairy Sci. 70: 1841-1849.

Murphy, J. J., McNeill, G. P., Connolly, J. F. and Gleeson, P. A. 1990. Effect of cow performance and milk fat composition of including full fat soybeans and rapeseeds in the concentrate mixture for lactating dairy cows. J. Dairy Res. 57: 295-306.

Muscato, T. V., Sniffen, C. J., Krishnamoorthy, U. and Van Soest, P. J. 1983. Amino acid content of noncell and cell wall fractions in feedstuffs. J. Dairy Sci. 66: 2198-2207.

Nakamura, T., Klopfenstein, T. J., Gibb, D. J. and Britton, R. A. 1994. Growth efficiency and digestibility of heated protein fed to growing ruminants. J. Anim. Sci. 72: 774-782.

National Research Council. 1985. Nutrient requirements of sheep. National Academy Press, Washington, DC.

National Research Council. 1989. Nutrient requirements of dairy cattle. National Academy Press, Washington, DC.

Nocek, J. E. 1988. In situ and other methods to estimate ruminal protein and energy digestibility: A review. J. Dairy Sci. 71: 2051-2069.

Nocek, J. E. and English, J. E. 1985. In situ degradation kinetics: Evaluation of rate determination procedure. J. Dairy Sci. 69: 77-87.

Ørskov, E. R. 1985. Evaluation of crop residues and agroindustrial by-products using the nylon bag method. In FAO/ILCA guidelines for research of crop residues. Preston, T. R., Kossila, V. V., Goodwin, J. and Reed, S. (ed.). Food and Agriculture Organization, Rome.

Ørskov, E. R. 1992. Protein nutrition in ruminants. Academic press, Toronto, Ca.

Ørskov, E. R. and McDonald, I., 1979. The estimation of protein degradability in the rumen from incubation measurements weighed according to rate of passage. J. Agric. Sci., 92: 499-503.

Ørskov, E. R. and Ryle, M. 1990. Energy nutrition in ruminants. Elsevier Applied Science, London. U.K.

Ørskov, E. R., Hovell, F. D., and Mould, F. 1980. The use of nylon the bag technique for the evaluation of feedstuffs. Tropical Animal Production. 5: 195-213.

Papas, A. Ingalls, J. R. and Cansfield, P. 1978. Effects of Tower and 1821 rapeseed meals and Tower gums on milk yield, milk composition and blood parameters of lactating dairy cows. Can. J. Anim. Sci. 58: 671-679.

Pichard, G and Van Soest, P. J. 1977. Protein solubility of ruminant feeds. Proc. Cornell Nutr. Conf. P 91-98. Ithaca, NY.

Poos-Floyd, M., Klopfenstein, T. and Britton, R. A. 1985. Evaluation of laboratory techniques for predicting ruminal protein degradation. J. Dairy Sci. 68: 829-839.

Rae, R. C., Ingalls, J. R. Mckirdy, J. A. 1983. Response of dairy cows to formaldehyde-treated canola meal during early lactation. Can. J. Anim. Sci. 63: 905-915.

Roe, M. B., Sniffen, C. J. and Chase, L. E. 1990. Techniques for measuring protein fractions in feedstuffs. In Proc. Cornell Nutr. Conf. p 81. Ithaca, NY.

Russell, J. B., O'Connor, J. D., Fox, D. G., Van Soest, P. J. and Sniffen, C. J. 1992. A Net Carbohydrate and Protein System for evaluation cattle diets: I. Ruminal fermentation. J. Anim. Sci. 70: 3551-3561.

Sánchez, J. M. and Claypool, D. W 1983. Canola meal as a protein supplement in dairy rations. J. Dairy Sci. 66: 80-85.

Sarwar, G., Bell, J. M., Sharby, T. F. and Jones, J. D. 1981. Nutritional evaluation of meals and meal fractions derived from rape and mustard seed. Can. J. Anim. Sci. 61: 719-733.

Sauer, W. C., Jorgensen, H. and Berzins, R. 1983. A modified nylon bag technique for determining apparent digestibilities of protein in feedstuffs of pigs. Can. J. Anim. Sci. 63: 233-

Setälä, J. 1983. The nylon bag technique in the determination of ruminal feed protein degradation. J. Scient. Agric. Soc. Finl. 55: 1-78.

Setälä, J. and Syrjälä-Qvist, L. 1984. Degradation of crude protein and quality of undegradable protein in untreated or formaldehyde-treated rapeseed meal. Anim. Feed Sci. Technol. 12: 19-27.

Sharma, H. R. and Ingalls, J. R. 1974. Effects of treating rapeseed meal and casein with formaldehyde on apparent digestibility and amino acid composition of rumen digesta and bacteria. Can. J. Anim. Sci. 54: 157-167.

Sharma, H. R., Ingalls, J. R. and Devlin, T. J. 1980. Apparent digestibility of Tower and Candle rapeseed meals by Holstein bull calves. Can. J. Anim. Sci. 60: 915-918.

Sharma, H. R., Ingalls, J. R. Mckirdy, J. A. 1977. Effect of feeding a high level of Tower rapeseed in dairy rations on feed intake and milk production. Can. J. Anim. Sci. 57: 653-662.

Sibbald, I. R. 1986. The TME system of feed evaluation: Methodology, feed composition data and bibliography. Anim. Res. Centre. Contribution 85-9, Ottawa, ON.

Siddiqui, I. R. and Wood, P. J. 1977. Carbohydrates of rapeseed: A review. J. Sci. Food Agric. 42: 530-538.

Slominiski, B. A. and Campbell, L. D. 1990. Non-starch polysaccharides of canola meal: Quantification, digestibility in poultry and potential benefit of dietary enzyme supplementation. J. Sci. Food Agric. 53: 175-184.

Slominiski, B. A. and Campbell, L. D. 1995. The carbohydrate content of yellow-seeded canola. P 40-43. 11th Project Report: Research on Canola seed and Meal. Canola Council of Canada, Winnipeg, MB.

Slominski, B. A. and Campbell, L. D. 1991. The carbohydrate content of yellow-seeded canola. Pages 1402-1407 in Proc. 8th Int. Rapeseed Congress, Saskatoon, Sk.

Slominski, B. A., Campbell, L. D. and Guenter, W. 1994. Oligosaccharides in canola meal and their effect on nonstarch polysaccharide digestibility and true metabolizable energy in poultry. Poultry Sci. 73: 156-162.

Sniffen, C. J., O'Connor, J. D., Van Soest, P. J., Fox, D. J. and Russell, J. B. 1992. A net carbohydrate and protein system for evaluating cattle diets: II Carbohydrate and protein availability. J. Anim. Sci. 70: 3562-2577.

Statistical Analysis System Institute, Inc. 1989. User's guide, version 6, 4th ed., vol 2, Cary, NC.

Steel, R. G. D. and Torrie, J. H. 1980. Principles and procedures of statistics. McGraw-Hill Book Co., New York, NY.

Stern, M. D., Rode, L. M., Pranger, R. W., Stauffacher, R. H. and Satter, L. D. 1983. Ruminal protein degradation of corn gluten meal in lactating cattle fitted with duodenal T-type cannulae. J. Anim Sci. 56: 194-205.

Stutts, J. A., Nipper, W. A., Adkinson, R. W., Chandler, J. E. and Achacoso, A. S. 1988. Protein solubility, in vitro ammonia concentration, and in situ disappearance of extruded whole cottonseed and other protein sources. J. Dairy Sci. 71: 3323-3333.

Sultan, J. I and Loerch, S. C. 1992. Effect of protein end energy supplementation of wheat straw-based diet on site of nutrient digestion and nitrogen metabolism of lambs. J. Anim. Sci. 70: 2228-2234.

Susmel, P., Mills, C. R., Colitti, M. and Stefanon, B. 1993. In vitro solubility and degradability of nitrogen in concentrate ruminant feeds. Anim. Feed Sci. Technol. 42: 1-13.

Tait, R. M., Beames, R. M. and Litsky, J. 1986. Grain screenings as a dietary component for pigs and sheep. II. Animal utilization. Can. J. Anim. Sci. 66: 483-494.

Thakor, N. S. and Sokhansanj, S. 1995. Dehulling of canola by hydrothermal treatments. p 30-39. 11th project report: Research on seed, meal. Canola Council of Canada, Winnipeg, MB.

Titgemeyer, E., Merchen, N., Man, Y., Parsons, C. and Baker, D. 1990. Assessment of intestinal amino acid availability in cattle by use of precision-fed cecectomized rooster assay. J. Dairy Sci. 73: 690-693.

Unger, E. H. 1990. Commercial processing of canola and rapeseed: crushing and oil extraction p 235-249. In Canola and rapeseed production, chemistry, nutrition and processing technology. Shahidi, F. (editor). Van Nostrand Reinhold. New York

Van Soest and Fox, D. G. 1992. Discounts for net energy and protein-fifth revision. p 40-68. In: proc. Cornell Nutr. Conf. Ithaca, NY.

Van Soest, P. J. and Mason, V. C 1991. The influence of the maillard reaction upon the nutritive value of fibrous feeds. Anim. Feed Sci. Technol. 32: 45-53.

Van Soest, P. J. Fox, D. J., Mertens, D. R. and Sniffen, C. J. 1992. Discounts for net energy and protein-fifth revision. Proc. Cornell Nutr. Conf. P 67-68. Ithaca, NY.

Van Soest, P. J., Robertson, J. B. and Lewis, B. A. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74: 3583-3597.

Van Straalen, W. M. and Dooper, F. M. H. 1993. Intestinal digestibility in dairy cows of protein from grass and clover measured with mobile nylon bag and other methods. J. Dairy Sci. 76: 2970-2981.

Varga, G. A. and Hoover, W. H. 1983. Rate and extent of neutral detergent fiber degradation of feedstuffs in situ. J. Dairy Sci. 66: 2109-2115.

Varvikko, T. 1986. Microbially corrected amino acid composition of rumen-undegraded feed protein and amino acid degradability in the rumen of feeds enclosed in

nylon bags. Br. J. Nutr. 56: 131-140.

Varvikko, T. Lindberg, J. E., Setälä, J. and Syrjälä-Qvist, L. 1983. The effect of formaldehyde treatment of soya bean meal and rapeseed meal on the amino acid profiles and acid-pepsin solubility of the rumen undegraded protein. J. Agric. Sci. 101: 603-612.

Vicini, J. L., Clark, J. H. and Crooker, B. A. 1983. Effectiveness of acetic acid and formaldehyde for preventing protein degradation in the rumen. J. Dairy Sci. 66: 350-354.

Vincent, I. and Hill, R. 1988. Low-glucosinolate rapeseed meal as protein source for milk production. Anim. Prod. 46: 505-506 (Abstr.).

Vincent, I. C., Hill, R. and Campling, R. C. 1990. A note on the use of rapeseed, sunflower and soya bean meals as protein sources in compound foods for milking cattle. Anim. Prod. 50: 541-543.

Vincent, I. C., Hill, R. and Williams, H. LL. 1988b. Rapeseed meal in the diet of pubertal heifers during early pregnancy. Anim. Prod. 47: 39-44.

Vincent, I. C., Williams, H. LL. and Hill, R. 1988a. Feeding British rapeseed meals to pregnant and lactating ewes. Anim. Prod. 47: 283-289.

Vose, J. R., Basterrechea, M. J., Gorin, P. A., Finlayson, A. J. and Youngs, C. G. 1976. Air classification of field peas and horse bean flours: Chemical studies of starch and protein fraction. Cereal Chem. 53: 928-933.

Waltz, D. M. and Stern, M. D. 1989. Evaluation of various methods for protecting soya-bean protein from degradation by rumen bacteria. Anim. Feed Sci. Technol. 25: 111-122.

Waters, C. J., Kitcherside, M. A. and Webster, A. J. F. 1992. Problems associated with estimating the digestibility of undegraded dietary nitrogen from acid-detergent insoluble nitrogen. Anim. Feed Sci. Technol. 39: 279-291.

West, J. W., Ely, L. O. and Martin, S. A. 1994. Wet brewers grain for lactating

dairy cows during hot humid weather. J. Dairy Sci. 77: 196-204.

Wheeler, E. E., Veira, D. M. and Stone, J. B. 1980. Comparison of Tower rapeseed meal and soybean meal as sources of protein of protein in pelleted calf starter rations. Can. J. Anim Sci. 60: 93-97.

Wiesen, B. Kincaid, R. L. and Hillers, J. K. 1990. The use of rapeseed screenings in diets for lactating cows and subsequent effects on milk yield and composition. J. Dairy Sci. 73: 3555-3562.

Wilkerson, V. A., Klopfenstein, T. J. and Stroup, W. W. 1995. A collaborative study of in situ forage protein degradation. J. Anim. Sci. 73: 583-588.

Wood, S. A. and Stone, B. J. 1970. Digestibility, Nitrogen retention and caloric value of rapeseed and soybean meals when fed at two dietary levels to calves. Can. J. Anim. Sci. 50: 507-512.

Zinn, R. A. 1993. Characteristics of ruminal and total tract digestion of canola meal and soybean meal in a high-energy diet for feedlot cattle. J. Anim. Sci. 71: 796-801.