LOW LIGNIN HULL, HIGH OIL GROAT OAT GRAIN

IN LACTATING DAIRY COW RATIONS

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ABSTRACT

LLH-HOG oat grain (low in ADL and high in EE) was compared to Derby oat, and CDC Dolly barley grain. Twenty-one Suffolk wethers were randomly assigned diets, 100% barley silage or barley silage with 50, 75, or 90% (DM) LLH-HOG oat or CDC Dolly barley. Apparent digestibility of DM, CP, EE, NDF, ADF, and GE were determined. Linear and quadratic regressions were fitted and apparent digestibility at 100% grain was determined. DM apparent digestibility was estimated at 79.1% for CDC Dolly barley and 74.0% for LLH-HOG oat grain. LLH-HOG oat provided 3550 Kcal per kg DE and CDC Dolly barley provided 3582 Kcal per kg DE. A non-lactating Holstein cow with a rumen fistula was used to determine LLH-HOG oat, Derby oat, and CDC Dolly barley grain degradability. Samples were incubated in the rumen for 48, 36, 24, 12, 08, 04, and 00 hour. The *in situ* degradability of DM, CP, and NDF were determined. An *in vitro* study was conducted using a Daisy *II* Incubator for incubations of 48, 30, and 24 hour. The DM ED of CDC Dolly barley (77.0%) was greater than both oat (68.0 and 68.9%). The NDF ED in LLH-HOG oat (26.6%) was higher than that of Derby oat (24.0%). Nine lactating Holsteins were randomly assigned treatments in a triple replicate three x three Latin square. Treatments were 50:50 forage to concentrate (DM basis) TMR with grain sources of CDC Dolly barley, Derby oat, or LLH-HOG oat. Milk production, dietary consumption data, and apparent digestibility were collected. DMI of the different TMR were similar. Milk yield tended (P=0.09) to be highest in LLH-HOG oat fed cows. FCM, MF, and MP yields were not different. MP concentration was lowest in LLH-HOG oat fed cows. Cows fed LLH-HOG oat, compared to Derby oat, trended

(P=0.08) towards requiring less DM to produce 100 kg FCM. The TMR DE and apparent digestibility of DM and NDF were higher in cows fed LLH-HOG or CDC Dolly barley compared to Derby oat. LLH-HOG oat had superior nutritional characteristics for dairy cows compared to conventional oat and was equal to barley.

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AAT – amino acids apparently absorbed in the intestine

ADF – acid detergent fibre

ADICP – acid detergent insoluble crude protein

ADL – acid detergent lignin

AIA – acid insoluble ash

BUN – blood urea nitrogen

BW – bodyweight

CDC – Crop Development Centre

CP – crude protein

CW – Canadian Western

DE – digestible energy

DM – dry matter

DMI – dry matter intake

EAA – essential amino acid

ECM – energy-corrected milk

ED – effective degradability

EE – ether extract

FCM – fat-corrected milk

FEm – Feed Unit milk

GE – gross energy

IVDMD – *in vitro* dry matter disappearance

LLH-HOG – low-lignin hull and high-oil groat

MF – milk fat

ML – milk lactose

MP – milk protein

MUN – milk urea nitrogen

NDF – neutral detergent fibre

NDICP – neutral detergent insoluble crude protein

NE – net energy

NE_L – net energy for lactation

NFC – non-fibre carbohydrate

NIT – near-infrared transmission

NPN – non-protein nitrogen

RUP – ruminally undegraded feed protein

SCC – somatic cell count

SCM – solids-corrected milk

SCP – soluble crude protein

tdCP – truly digestible crude protein

tdFA – truly digestible fatty acid

TDN – total digestible nutrient

tdNDF – truly digestible neutral detergent fibre

tdNFC – truly digestible non-fibre carbohydrate

TMR – total mixed ration

TS – total solids

TW – test weight

1.0 INTRODUCTION

The primary grain used in western Canadian dairy cattle rations is barley (*Hordeum vulgare*). Studies of oat (*Avena sativa*) as an alternative cereal grain have been conducted (Fisher and Logan 1969; Tommervik and Waldern 1969; Schingoethe et al. 1982; Moran 1983; Moran 1986; Martin and Thomas 1987). The studies revealed marginal reasons to select oat grain over other cereal grains as an energy source in dairy rations. As a result, few recent studies (Rowe and Crosbie 1988; Petit and Alary 1999; Ekern et al. 2003) have been conducted on oat grain in dairy rations.

Oat is best grown in cool, moist climates and is versatile from a crop production viewpoint. Oat can provide a needed disease 'break' by limiting the build-up of soil-borne pathogens, and when grown under some conditions may out-yield barley. Nevertheless, the feed value of oat grain has been considered inferior to barley. This is due to the hull content of oat, which ranges from 20 to 30% (Crosbie et al. 1985). Oat hulls are fibrous and contain substantial amounts of indigestible lignin. Lignin impedes the digestion of associated nutrients. Fortunately, the groat is radically different in composition from the oat hull. Oat is also unique among cereals in that it has both higher lipid levels and the majority of the lipids are in the endosperm. Since lipids yield more than twice as much available energy per unit compared to carbohydrates or protein, higher lipid content can potentially give oat grain an advantage over other cereals in terms of energy content.

Oat grain has not recently been widely used in dairy rations, but this trend may be reversed with recent development of a new oat type, the low-lignin hull and high-oil groat (LLH-HOG) oat (01-499-04). LLH-HOG oat combines a hull of greater ruminal degradability with a higher energy high lipid groat, creating a superior oat for ruminant feeding. The Crop Development Centre, University of Saskatchewan, developed the LLH-HOG oat. Although LLH-HOG oat is reported to have a low-lignin hull, it is actually low in acid detergent lignin (ADL). ADL includes true lignin and also other compounds such as silica. Section 2.3.2.3 examines the characteristics of lignin and the measure of ADL.

This study was conducted to determine the nutrient content and nutritional value in ruminants of LLH-HOG oat in comparison to conventional oat and barley grains. This study was in two major sections. The first section included a comparison of total tract digestibility of LLH-HOG oat grain and CDC Dolly barley grain accompanied by *in situ* and *in vitro* degradability studies of oat grains compared to CDC Dolly barley. The second major section was conducted to determine the nutritional impact of LLH-HOG oat grain and Derby oat grain when replacing CDC Dolly barley in high production, lactating dairy cow rations. It was hypothesized that LLH-HOG oat has superior nutritional characteristics for dairy cows when compared to conventional oat and is equal to barley.

2.0 LITERATURE REVIEW

2.1 The Oat Grain Crop

Oat is the fourth most important cereal crop in Canada after wheat, barley, and corn (Baker 1995). Oat use in the human food sector has recently increased because of the positive health benefit attributed to oat, but livestock feeding remains the primary use of oat grain. As whole crop forage, oat is a good feed for ruminants. A common practice in Canada is to grow oat for silage, green feed, or for grazing. However, oat grain has lost favour as a ruminant feed. The metabolizable energy content of oat grain is less than that of wheat, barley, or corn. For this reason, improvements to oat will need to be made before oat grain becomes a favored feed for ruminants.

2.1.1 History of Oat Grain

The evolution of oat as a cereal crop has been closely associated with the sociocultural development of communities in the Western World (Moore-Colyer 1995). In northern areas the prevailing climate was wet and cool, making it suitable for oat. In prehistory, oat was considered a weed contaminant of the more popular wheat and barley. Cultivated oat made their first appearance around 1000 BC in the northerly regions of Western Europe (Barker 1985). While used as a human food source, oat was also grown for livestock, particularly horses. With the popularization of the horse, in some areas, oat became the prominent cereal grown. Oat became the foremost feed for horses in the eighteenth century. With the increasing population of horses that paralleled industrial development, the demand for oat grain expanded. The increases in horse numbers for industrial, military and social purposes, coupled with the need to maintain the supply of bread making cereals, forced some Northern European countries to become net importers of oat grain.

North America became a main source of oat imported by European countries in the mid to late nineteenth century. Oat had been introduced to North America in the early seventeenth century by Dutch and English settlers (Moore-Colyer 1995). At this point, oat was grown in New Hampshire, Massachusetts, and Manhattan, and within the next 30 years oat cultivation reached Maryland and Virginia. Though widely accepted as a spring crop in Europe, it became apparent by the mid eighteenth century that oat could be grown as a winter crop in America. Oat accompanied settlers as colonization proceeded westward. In the early nineteenth century oat was also introduced to the Pacific coast by Spanish missionaries (Coffman 1961). In new settlements oat was grown for local consumption. By 1840 the major concentration of oat in America was east of the Mississippi. Within the next 40 years the upper Mississippi Valley and adjacent areas in Canada would become the chief oat-growing region on the continent. More recently, the most concentrated area of oat production is in the north central states of Iowa, Wisconsin, Minnesota, South Dakota, North Dakota, and Michigan and the Prairie Provinces of Canada (Kelling and Fixen 1992).

Over the past one hundred years oat has been predominantly used as feed for ruminants and horses. During the early nineteen hundreds, Canadian dairy herds used oat as the primary grain in feed. Recommendations for lactating cows commonly called for one to one and a half kilograms of ground oat with two kilograms of wheat bran and one half to one kilogram protein source (Dean 1914). The practice of using oat for feed continued into the mid 1900s. MacEwan (1945) stated that oat was the most widely used Canadian feed grain, and was second only to wheat in total acres seeded in 1943. This author also stated that oat grain was the basis of most rations for dairy cattle, whereas barley was only considered suitable when supported by protein rich feeds. American authors also considered oat as the most popular dairy feed during the mid 1900s (Morrison 1957). However, at this time barley was replacing oat as the major grain fed to dairy cattle. In describing barley as a dairy feed, Morrison (1957) advised including crushed barley at 40 to 60% of the total concentrate. As the twentieth century came to a close western Canadian dairies were almost exclusively using barley as the main grain source in rations.

Since 1964 the Prairie Provinces have accounted for 78% of the total oat and 91% of the total barley produced in Canada (Canada Grains Council 2006). Barley has become a preferred energy source over oat grain because of its nutrient composition. Grain producers' strive to produce malting barley, flooding the feed market with feed barley. For these reasons barley production in Canada and the Prairie Provinces has continued to remain greater than that of oat, although oat has shown an uptrend in recent years (Figure 2.1 and Figure 2.2).

2.1.2 Agronomic Characteristics of Oat

Oat is versatile and is grown on many different soil types around the world. It has been shown that oat can tolerate acidic soils with a pH of 4.5 (Stoskopf 1985) but higher yields require a pH of 5.3 to 5.7 (Alam and Adams 1979). Saline soils can be harmful to

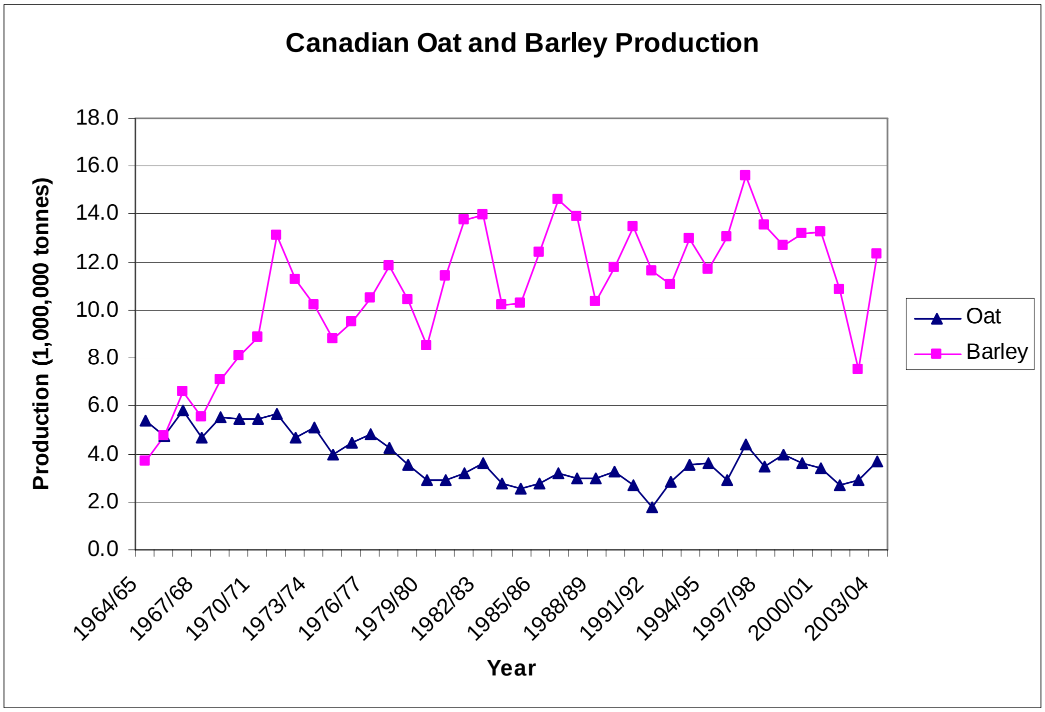

Figure 2.1 Annual amounts of oat and barley produced in Canada starting in the year 1964/65 (Canada Grains Council 2006)

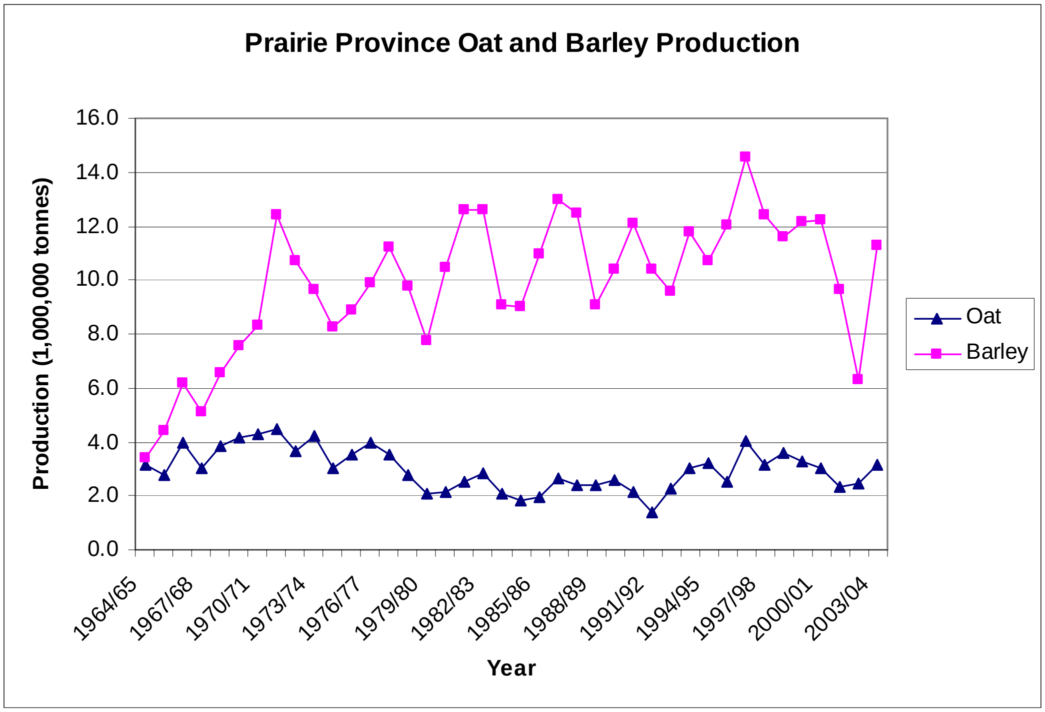

Figure 2.2 Annual amounts of oat and barley produced in the Prairie Provinces (Alberta, Manitoba, and Saskatchewan) starting in the year 1964/65 (Canada Grains Council 2006)

oat growth. Oat is ranked as having a medium tolerance to salts with a 50% yield reduction occurring between 0.8 and 1.0 salt-to-moisture ratio (Kelling and Fixen 1992). Oat is less salt tolerant than either wheat or barley.

Important climactic factors affecting the growth of oat are temperature and moisture. Oat grows best in cool, moist climates. Forsberg and Reeves (1995) explain that oat requires more moisture to produce a unit of dry matter than any other cereal except rice. As such, oat is likely to be injured by hot, dry weather. Due to their moisture holding capacity, medium-textured soils are more suitable for growing oat. However, with adequate water, oat may be successfully grown on sandy soils. Sorrels and Simmons (1992) state that annual precipitation in oat-growing regions ranges from 38 to 114 cm, but often it is 76 cm or less. Variation in precipitation distribution may prove unfavorable to oat production. Water stress imposed during reproductive stages, particularly anthesis, greatly reduces oat grain yield. Coffman and Frey (1961) indicated that production of oat was limited when precipitation was less than 20 to 30 cm during the critical May to August period in Canada. The major oat growing areas of North America, Europe, and Asia are found between the latitudes of 40^{o} and 60^{o} north.

In North America the oat-growing season is short (80-110 days) limiting oat grain yield. Oat germination will occur at soil temperature of 3 to 5 ^{o}C, indicating that early season seeding of oat is possible (Forsberg and Reeves 1995). However, Nielson et al. (1960) achieved higher straw and grain yields in greenhouse grown oat at a soil temperature of 19 ^{o}C compared to 5 ^{o}C. Early seeding ensures the use of available moisture, avoids midsummer drought and heat, and circumvents damage by disease, particularly leaf (crown) and stem rust. Forsberg and Reeves (1995) cite a 34-year study in Nebraska that observed delaying oat seeding by 10 and 20 d caused reduced yields of 10 and 26%, respectively. These authors also reported that later seeding dates often reduces test weight. In general, highest oat yields have been found after seeding on the earliest possible date. Temperatures from approximately 13 to 19 ^{o}C result in the highest grain and straw yields (Sorrels and Simmons 1992). Lower growth temperatures can increase the oil content of oat, and may also influence oil fatty acid composition (Welch 1995).

2.1.3 Chemical Composition of Oat

There are a wide variety of oat products that can be derived from the oat plant at various stages of growth and from different parts of the crop. These include whole crop silage or hay, straw, grain and grain derivatives. These products are utilized in animal feed, for human food or as industrial raw materials.

The nutrient composition of oat grain is variable. Much of the variation arises from differences between growth environments, variation in genotype, and from interactions between environment and genotype. Other differences may transpire as a result of harvest conditions, storage, and post-harvest treatments or other processes that the crop is subject to before its final use. Further apparent differences in composition may be a result of variations in the analytical methods.

Whole oat grain consists of groat and the husk that encases the groat. The hull (husk) is composed of the lemma and palea of the floret. The hull consists mainly of fibre and acts as a protective layer for the groat (caryopsis). Naked, hull-less, or dehulled oat, is oat that has been threshed free of the hull. Whole oat or oat grain refers to the entire kernel, hull and groat inclusive (Figure 2.3). This thesis will focus on whole oat grain.

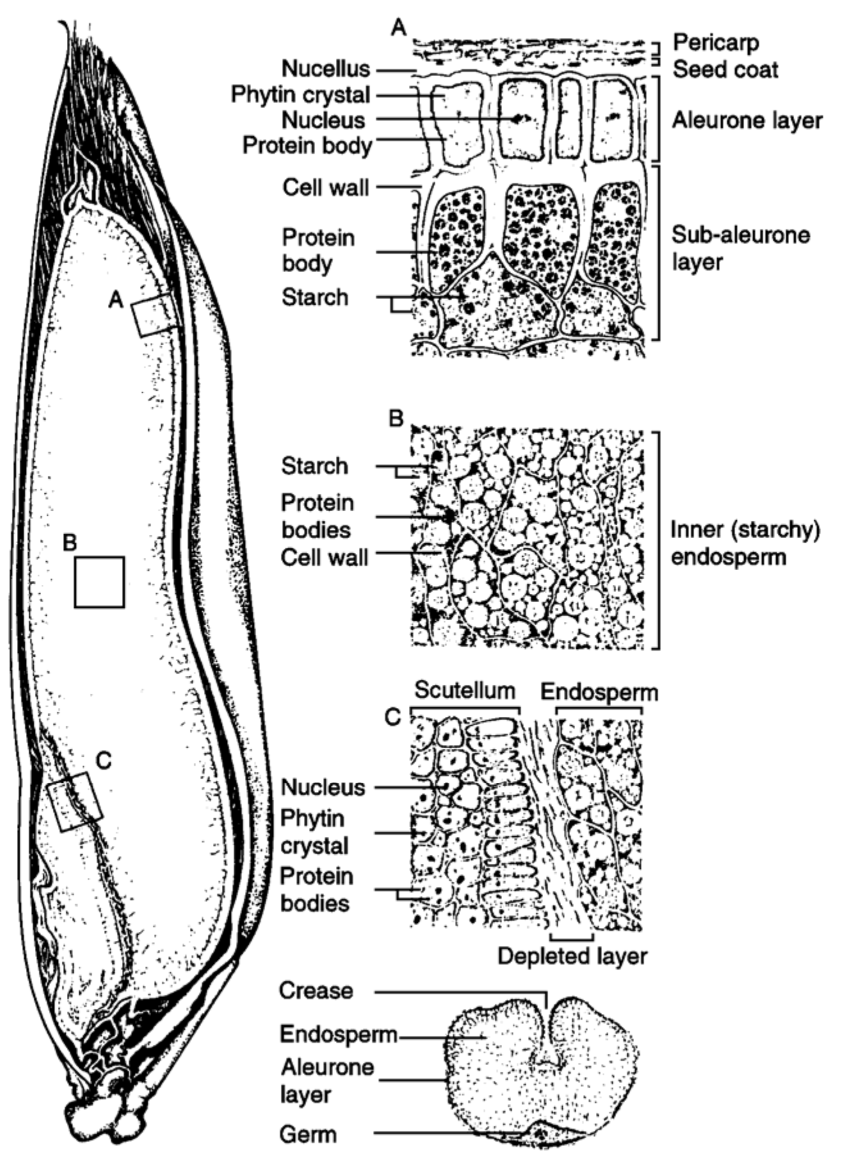

Figure 2.3 Structure of oat kernel. On the left is a longitudinal section, including the hull. Shown are the locations of the major tissues, which are enlarged in A (bran), B (starchy endosperm), and C (embryo and germ). On the lower right is a cross section of the kernel (modified from White 1995).

2.1.3.1 The Whole Oat Grain

The groat and hull contribute different aspects to the overall nutritive composition of oat grain. The major difference is the type of functional carbohydrates they contain. The hull is primarily composed of structural carbohydrates that are low in digestibility and negatively affect the overall digestibility of oat grain. The groat contains mostly storage carbohydrates, which are rapidly soluble and provide energy. The proportion of the groat in the grain accounts for variation in oat grain quality. Like all cereals, other nutritional fractions contained in oat are protein, lipids, vitamins, and minerals. Although important, these nutrients do not make as large a contribution to cereal grains as do carbohydrates. However, of the common cereal grains, oat usually has the highest protein and lipid content (Peterson 1992).

When compared to barley grain, oat has a high, lignin content (Table 2.1). The neutral detergent fibre (NDF) content of oat may be in excess of 30% of dry matter (Moe et al. 1973; Rowe and Crosbie 1988; National Research Council 2001). Similarly, acid detergent fibre (ADF) comprises 10 to 15% of moisture free oat. The carbohydrates that are components of dietary fibre include hemicellulose, cellulose, gums, pectins and mucilages. Although it is not a carbohydrate, lignin is often included as dietary fibre. Lignin is a highly indigestible compound that hinders the digestion of any associated nutrients. This is very important in oat because its lignin content is variable, affecting digestibility. When classifying the lignin content of oat Rowe et al. (2001) observed most cultivars to be high-lignin with about 3% in the whole grain (6 to 10% in the hull), or low-lignin with about 1% lignin in the whole grain (1 to 3% in the hull).

Table 2.1 Nutrient content of oat and barley grain (% of DM)

	Oat Grain[1]			Barley Grain[1]		
Nutrient	n	Mean	SD	n	Mean	SD
Dry Matter	176	90.0	2.0	823	91.0	3.5
Crude Protein	308	13.2	1.8	795	12.4	2.1
Ether Extract	145	5.1	0.9	247	2.2	0.6
NDF	120	30.0	10.5	331	20.8	8.6
ADF	173	14.6	5.6	727	7.2	2.8
NDICP	--	1.8	--	60	1.8	1.1
ADICP	2	0.3	--	61	0.5	0.4
Lignin	6	4.9	2.5	69	1.9	1.1
(1X)TDN	--	78.5	--	--	82.7	--
NE_L (Mcal/kg)	--	1.80	--	--	1.91	--
DE (Mcal/kg)	--	3.47	--	--	3.64	--

[1]National Research Council (2001)

NE_L=(TDNx0.0245)-0.12; Weiss et al (1992)

Carbohydrates include simple sugars and starch as well as the non-starch polysaccharides that comprise dietary fibre. The sugars that include monosaccharides, glucose and fructose, and the disaccharides, maltose and sucrose have been observed at 1.1% of whole oat grain (Welch 1995). Oligosaccharides, raffinose, stachyose, and verbascose, make up an even smaller fraction of whole oat grain. Wood et al. (1991) analyzed 11 Canadian samples and observed 54.9 to 63.6% starch in oat groat. Morrison et al. (1984) analyzed five Canadian oat cultivars for amylose and observed 25.2 to 29.4% amylose in oat starch. This range is much narrower compared to other cereal grains.

The protein concentration in oat is higher than in other cereals and also displays a wide range in content between varieties. The protein concentration of the oat hull is very low, making the variation in oat protein a function of the variation of groat protein and hull percentage. Youngs and Senturia (1976) derived a prediction equation that shows the relationship between oat and groat protein:

$$P_g (\%) = 0.81 + 1.27 \times P_o \qquad (2.1)$$

Where P_g is the predicted groat protein concentration and P_o is the whole kernel protein concentration. The primary storage proteins of oat are globulins, which account for up to 75% of the total protein present (Peterson 1992). This is different from other cereals, except rice, where prolamins are the predominant protein. Prolamins represent only about 10% of the protein in oat. Other proteins found in the oat kernel include albumins and glutelins. Albumins represent enzymes from the germ and aleurone while glutelins are the residual proteins remaining after albumins, globulins, and prolamins are extracted.

Welch (1995) cited several studies from Europe and North America that observed significant negative correlations between protein and lipid content of oat grains. However, the same author cited several more studies in the same regions that found no consistent relationship between oat protein and lipid content. The lipid and protein contents of oat are generally higher than other cereal grains.

Sahasrabudhe (1979) stated that high-lipid oat contains a greater proportion of triglycerides and a lower proportion of phospholipids than low-lipid oat. The major fatty acids in oat are long-chain fatty acids, either in triglycerides or in other acyl lipids. Free fatty acids make up 4.0 to 10.5% of total lipid (Sahasrabudhe 1979). The lipid content of nine different oat types grown in Saskatchewan, Manitoba and Ontario were reported by de la Roche et al. (1977). They observed that 53 to 73% of the total oat lipid extracted was fatty acids and 7 to 22% was phospholipids. Glycolipids comprise 7 to 12% of lipid in oat while, depending on method of measurement, the sterols can account for 0.1 to 9% (Welch 1995). The major fatty acids found in oat were palmitic (16:0), oleic (18:1), and linoleic (18:2), while stearic (18:0), and linolenic (18:3) acids made minor contributions. This study was supported by the findings of Sahasrabudhe (1979) who also observed large quantities of palmitic, oleic, and linoleic acids in oat. Oleic acid is generally the major fatty acid in the triglyceride fraction whereas linoleic acid commonly predominates in the phospholipid and glycolipid fractions.

The mineral composition of oat is similar to that of other cereal grains. Most of the minerals in oat are associated with the bran (Peterson 1992). When the oat hull is removed all minerals with the exception of chromium increase in concentration because there is very little mineral associated with the hull. Owen et al. (1977) conducted a study of two cultivars grown in five seasons at 16 different locations in Saskatchewan. The authors observed mean macro mineral contents of Ca 0.057 ± 0.011, P 0.37 ± 0.06, K 0.44 ± 0.06, and Mg 0.14 ± 0.02% and trace mineral contents of Fe 92 ± 32, Zn 42 ± 12, Mn 42 ± 7, and Cu 7 ± 3 ppm.

Peterson (1993) stated that oat contains little or no vitamins C, A and D. The B vitamins, thiamin (6.7 mg/kg), riboflavin (1.1 mg/kg), niacin (8.0 mg/kg), vitamin B6 (2.1 mg/kg), pantothenate (11.8 mg/kg), folate (1.04 mg/kg), and biotin (0.13 mg/kg), are present in sufficient concentrations to make useful dietary contributions (Lockhart and Hurt 1986). Tocols, which contribute to vitamin E activity, are present as part of the total lipid of oat. In oat, α-tocotrienol is the major fraction, making 40% of the tocols, while α-tocopherol contributes 18% (Peterson 1993).

2.1.3.2 The Oat Hull

Crosbie et al. (1985) reported that the proportion of hull in whole oat grain ranges from 20 to 30% and varies depending on environment and genetic factors. The structural composition of the hull is radically different from the groat. The hull is very fibrous in nature and is composed primarily of structural carbohydrates and other cell wall material (Welch 1995). Hemicellulose and cellulose along with gums, pectins, and mucilages are carbohydrates that comprise hull fibre. Lignin is composed of substituted phenylpropane units linked in a complex three-dimensional array (Welch 1995). Hemicellulose, cellulose, and lignin are water insoluble, whereas the other fibre components, gums, pectins, and mucilages, are more hydrophilic and are classified as soluble. The distinction between these two fractions has important implications on physiological function.

Frølich and Nyman (1988) observed glucose and xylose (50 and 38% of total) as the major monosaccharides in the insoluble oat hull fibre. Other monosaccharides found in minor amounts were uronic acids, arabinose and galactose. Crosbie et al. (1985) analyzed 75 machine separated oat hull samples of seven varieties from up to 16 sites and found a lignin content of 0.8 to 7.6%. Frølich and Nyman (1988) reported oat hulls with a high lignin content of 20%. Thompson (2001) analyzed the hulls of ten different varieties of oat for ash, crude protein (CP), NDF, ADF, and acid detergent lignin (ADL) content and *in vitro* dry matter disappearance (IVDMD). The hulls were variable in ash (4.7 to 7.3%) and ADL (1.3 to 7.7%) content. However, the samples were similar in NDF (79.9 to 88.2%), ADF (42.5 to 49.6%), and CP (2.3 to 4.5%) content. An inverse relationship between the lignin content of oat hulls and their IVDMD was observed by Thompson (2001). In this study the variety AC Assiniboia had the lowest ADL content of 1.3% and the highest IVDMD of 68.2%. Conversely, the variety Triple Crown with the highest ADL content of 7.7% had the lowest IVDMD at 33.1%. Other researchers have also reported an inverse relationship between lignin content and digestibility of feeds (Crosbie et al. 1985; Garleb et al. 1991; Jung et al. 1997).

Oat hulls have low levels of starch, water-soluble carbohydrate, protein, and oil. UK samples containing diverse genotypes and cultivars contained 0.3 to 1.8% starch, 0.2 to 0.8% water-soluble carbohydrate, 0.09 to 0.47% oil, and 2.0 to 4.9% protein (Welch et al. 1983). Similarly, work by Birkelo and Lounsbery (1991) found CP in oat hulls to vary from 3.4 to 8.8%. These same authors also observed 56.9 to 61.4% NDF content in oat hulls, which was lower than the observations made by Thompson (2001).

2.1.3.3 The Oat Groat

Soluble nutrients of oat grain are found mainly in the groat. Welch (1995) states that carbohydrate is the major, but highly variable, groat constituent. Much of the variation can be attributed to analytical methods. Protein and oil content of groat are considered to be consistent across samples. The whole oat grain generally has lower protein and oil content than the groat. This is due to the diluting effect of the highly fibrous hull. The fibre content of the groat is substantially lower than that of the hull. The major carbohydrates contained in the groat are storage carbohydrates, chiefly starches and some sugars. Oat groat is ideal for feeding to monogastric animals, particularly for piglet and poultry diets. Hull-less oat incubated *in situ* had a significantly higher soluble fraction (46.4%) and effective degradability (86.8%) when compared to hulled oat and barley (Mustafa et al. 1998). When fed to dairy cattle, hull-less oat showed similar production characteristics to corn and could replace corn in the diet (Petit and Alary 1999). However, these same authors reported that when fed to ruminants, hull-less oat, as a result of decreased ruminal fibre digestion, had decreased dry matter intake compared to cereals with hulls.

Although it is widely recognized that the oat groat has superior nutritional qualities when compared to other cereal grains, its use has not become wide spread for an assortment of reasons. For instance, dehulling is costly and not available to all animal producers. Additional processing is not practical when cheaper more accessible feeds exist. Breeding of naked (hull-less) oat has had limited success due to agronomic defects in the genetic stock and inadequate techniques for harvesting, cleaning, storing, grading, processing, and marketing (Schrickel et al. 1992). In spite of these obstacles, improved naked oat cultivars are being developed. In the meantime, it may be more practical to improve the whole oat grain, particularly in areas pertaining to ruminant nutrition where the fibrous hull has application.

2.2 Oat Grain as a Feed

In comparison to feeding ruminants, oat grain displays a depression in digestibility when fed to monogastrics. However, the bulk fibre content of oat grain can limit the amount of energy and soluble nutrients a ruminant can consume before its satiety level is reached. In monogastrics, the fibrous hull dilutes the energy content of oat and impairs digestion. This is a disadvantage in comparison to other cereal grains like corn and wheat.

If the hull is not removed, oat grain is ground or pulverized before use in balanced poultry diets. The use of oat groats represents a good feed grain option for both broilers and laying hens. Similarly, grinding or pelleting of oat is desirable for swine as whole oat grain is unpalatable (Schrickel et al. 1992). The use of oat groats in swine diets has been an accepted practice for a number of years. Groats are a good grain for swine diets because they improve protein and amino acid content, reducing the need for supplemental protein.

The feeding of oat grain to monogastrics presents some nutritional hurdles because it is high in phytic acid and β-glucans. Phytic acid is an organic compound that is a chelate of phosphorous, making it unavailable for digestion in non-ruminants. Additional phosphorous or enzymes (phytase) are added to monogastric diets to make phosphorous more available. Because of mixed linkages, β-D-glucan gums in oat present problems in young chicks and early weaned piglets. The gums apparently reduce feed efficiency by interacting with microorganisms in the alimentary tract and reduce the absorption of essential nutrients (Schrickel et al. 1992). This author reported that the gums have been successfully destroyed or modified with the use of enzyme (β-glucanase) treatment, autoclaving, the addition of antibiotics, or gamma irradiation.

Oat grain sets the standard for cereal grains fed to horses. In general, oat grain is highly palatable, digestible, and a good source of nutrients for horses. Other grains create a dense pack in the digestive tract, impairing digestion. There is concern regarding high intake of other grains which cause colic in horses. Oat groats have been used in racing horse rations, but they are not necessary for recreational horses. Both the racing and recreational horse markets stimulate much of the worldwide demand for high-quality oat.

2.2.1 Oat Grain in Ruminant Production

The majority of oat that enters the feed market is utilized in ruminant production systems. But in relation to other cereals, oat is not the predominant grain fed to ruminants. Because of this, very little research has been conducted on oat grain in ruminant production. Corn and barley grain are the grains of choice, especially in feeding programs designed for growing and fattening cattle. These grains are competitively priced, more digestible than oat, and provide a greater amount of energy per unit of dry matter. In Canada, oat grain has been phased out of the dairy industry and replaced by barley. Studies have shown oat grain is comparable to other cereal grains at maintaining high milk yields in dairy cattle (Tommervik and Waldern 1969; Moran 1986). Genetic selection and improved practices have led to increased dry matter intake of dairy cattle and increased milk production. These advancements have created greater disparity regarding the capacity of feedstuffs to provide adequate nutrients for the dairy cow. For this reason, oat grain and its high fibre hull, has been discounted as a high energy feed for ruminants.

Oat has become a traditional feed for small ruminants, especially as a supplement to pasture. In Australia, oat grain often supplements grazing systems for growing or fattening wethers, or for flushing ewes at lambing time. Contrary to this, sheep production in Canada has steadily decreased to the point where the industry cannot consume the feed oat that is available. Cattle, being larger in mass and number, are the more logical target industry for oat grain.

Creep feeding programs based on oat have been successfully employed with young beef and dairy cattle. Schingoethe et al. (1982) observed similar weight gains in Holstein calves that were supplemented pelleted diets containing oat or corn. No differences were observed in the first five weeks when calves were fed 3.6 kg per day of whole milk supplemented with pellet. Nor were there any differences in weight gain from 5 to 12 weeks when calves were fed the pellets *ad libitum*.

2.2.1.1 Processing Oat Grain

The small size of the reticulo-omasal orifice in sheep can prevent the ruminal outflow of whole grains. Calves, like sheep, have a small reticulo-omasal orifice but have been successfully fed whole oat grain up to the age of four months. Australian researchers (Kimberley 1976; McDonald and Hamilton 1980) fed hay supplemented with whole oat grain to cattle between the ages of 6 and 24 months and observed no benefit to processing oat before feeding. Mature cattle have a large reticulo-omasal orifice so whole oat grain may require processing before feeding. Nordin and Campling

(1976) reported an improvement from whole oat (52%) to rolled oat (83%) in apparent organic matter digestibility in cattle. In contrast, Ørskov et al. (1974) observed no change in apparent organic matter digestibility of whole oat (70%) versus ground/pelleted oat (68%) in sheep. Chestnutt (1992) recovered large quantities (20%) of unprocessed barley from the feces of sheep, thus supporting the need for processing. Regardless, Cuddeford (1995) and Rowe et al. (2001) suggest that oat does not need to be processed before being fed to sheep.

Feed density plays a role in the need for processing of oat. Processing of feeds decreases their density, which increases their rumen retention and potentially increases fermentation time. Similarly, feeds with high densities are fermented less in the rumen because they flow out faster. In contrast, Zinn (1993) observed a 7.2% decrease in the net energy (NE) in beef cattle when oat was processed finely (density = 0.17 kg/L) as compared to coarsely (0.33 kg/L). This report had no explanation for the decreased NE of finely processed oat but stated that similar results were observed using finely processed corn. The accuracy of NE calculation may have had an impact on the values observed by Zinn (1993).

The need to process oat grain before feeding to cattle remains a controversy. An Australian study by Toland (1976) observed only 5% of total dry matter intake of whole oat was voided in the feces, whereas dry rolling only made a small improvement in organic matter digestibility. Cuddeford (1995) cited another Australian journal by Toland (1978), stating that rumination accounted for 66 and 44% of the total breakdown of whole light and heavy oat as opposed to 27 and 17% for whole soft and hard wheat. The additional rumination in oat fed cattle may explain why researchers are finding increased digestibility of whole oat in comparison to other unprocessed cereal grains. Contrary to this, another Australian study found dairy cows excreted 24% of whole oat grain when fed 3.5 or 7.0 kg dry matter of oat daily as a supplement to pasture (Valentine and Bartsch 1989). This study observed no difference in production parameters when the grain was fed whole or hammermilled. Moran (1986) conducted a dairy production trial comparing whole and rolled oat and observed no significant difference in dry matter intake (DMI) or milk production.

2.2.1.2 Feeding Oat Grain to Dairy Cattle

In the early part of the twentieth century, oat grain was the main grain used in Canadian dairies. As the century progressed, oat grain was phased out of dairy diets and replaced by barley grain. For this reason, very few studies have been conducted on oat grain fed to dairy cattle. Most studies have focused on comparing oat to other cereal grains in complete rations (Fisher and Logan 1969; Tommervik and Waldern 1969; Moran 1983; Moran 1986; Martin and Thomas 1987) or as supplements to pasture grazing (Moate et al. 1984; Valentine and Bartsch 1989). More recent studies have been conducted on oat with respect to protein content (Schingoethe et al. 1982), naked oat (Petit and Alary 1999), and fat level (Ekern et al. 2003), but these studies are few. Because of the limited material, there is very little available information on the production characteristics of dairy cows that are fed oat grain.

In an Australian study by Moran (1986), wheat, barley, and oat were compared as a cereal source for Fresian-crossbred cows (69 d post-partum, 500 kg live weight). Three grain based diets of 60% rolled cereal grain, 17% oat silage, 17% lucerne hay, and 6% protein/mineral supplement were fed, *ad libitum*, for three weeks. Milk production was measured over the last seven days (Table 2.2). Moran (1986) observed no difference ($P<0.05$) in milk yield of cows fed diets containing barley, wheat, or oat. The milk fat (MF) yield of oat fed cows was significantly higher and, as a result, fat-corrected milk (FCM) yield was also significantly higher. The concentration of milk protein (MP) was significantly lower in oat fed cows. Moran (1986) concluded that when coarsely rolled oat was offered at 60% total dry matter (DM) to cows yielding 25 kg FCM per day, oat was superior to wheat and barley as a cereal grain source. It may be more likely that at grain levels of 60% the oat diet was providing more fermentable NDF. This may be the reason that FCM yield and MF yield was highest in oat fed cattle, even though DMI were not different.

Tommervik and Waldern (1969) reported similar ($P<0.05$) yields of FCM with diets containing wheat, barley, oat, sorghum, or maize at 47% total DM, MF and MP yields were not significantly different either. Although not significant when compared to all other grains, MF concentration was highest and MP concentration was lowest in oat fed cows. The study by Fisher and Logan (1969) compared rations based on corn or oat grain when fed to dairy cows. The corn diet yielded more milk and had a higher MP concentration. However, cows in this trial consumed significantly more corn concentrate than oat concentrate. Due to the recent advances in dairy production where animals are larger, have greater DMI, and produce more milk, these studies have limited application in today's Canadian dairy herds.

A study conducted by Ekern et al. (2003) at the Agricultural University of Norway (Ås, Norway) evaluated high-fat oat in concentrate for dairy cows. The experiment was conducted as two trials (Table 2.3). Experiment one was conducted in

Table 2.2 Effect of cereal source on productivity (kg/head/day) of dairy cows

Variable	Diet			SEM
	Barley	Wheat	Oat	
Dry Matter Intake	16.89	18.10	17.69	1.06
Milk Yield	22.9	24.0	25.1	0.7
FCM	24.6b	24.9b	27.6a	0.7
Milk Fat Yield	1.03b	1.01b	1.18a	0.04
Milk Protein Yield	0.80b	0.89a	0.78b	0.03
Milk Fat (%)	4.54	4.19	4.72	0.19
Milk Protein (%)	3.52a	3.84a	3.12b	0.11

Values on the same line with same letter do not differ (P>0.05)
Modified from Moran (1986)

Table 2.3 Milk production characteristics (kg/head/day) of dairy cows consuming concentrates based on different cereal grains

	Experiment 1			Experiment 2		
Variable	Barley	Oat	SEM	Oat	High-Fat Oat	SEM
Dry Matter Intake	18.59	18.84	--	21.09	21.47	--
Concentrate	8.79	10.13	--	10.55	10.77	0.35
Grass Silage	7.90	7.10	--	10.08	10.24	0.12
Milk Yield	23.6b	26.2a	0.37	33.5b	34.7a	0.21
ECM[1]	24.2	24.8	0.46	31.7b	32.9a	0.30
Milk Fat Yield	0.97	0.92	0.023	1.24	1.29	0.018
Milk Protein Yield	0.81b	0.87a	0.015	1.05b	1.09a	0.008
Milk Fat (%)	4.17a	3.53b	0.054	3.71	3.71	0.043
Milk Protein (%)	3.47a	3.35b	0.020	3.16	3.14	0.021

Values on the same line with same letter do not differ (P>0.05)
Modified from Ekern et al. (2003)
Experiment 1 conducted in 1991
Experiment 2 conducted in 1997
[1]energy-corrected milk (Sjaunja et al. 1990)

1991 and compared barley concentrate to oat concentrate in a 2 x 2 change over design. The concentrates for experiment one differed only in the use of the experimental grains. Both grains made up 77.5% of DM in their respective concentrate. Experiment two was carried out in 1997 and used the same 2 x 2 crossover design to compare regular oat concentrate to high-fat oat concentrate. The concentrates in this experiment contained 65% of either regular oat or high-fat oat. In contrast to experiment one, the concentrates in experiment two were adjusted to equal the level of amino acids apparently absorbed in the intestine (AAT) according to Madsen et al. (1995). Daily allowances for concentrates were fixed at 13 and 11 Feed Unit milk (FEm), according to Ekern (1991), for adult cows and heifers. Silage was restricted with small amounts of beet roots and ammonia-treated straw in experiment one and with hay in experiment two.

The first experiment conducted by Ekern et al. (2003) showed significantly higher milk yield from oat fed cows as compared to barley fed. MF and MP concentrations were lower in oat fed cattle. The energy-corrected milk (ECM) yields were not different when diets were compared. Although not statistically analyzed, the DMI of diets were similar. The intake of barley concentrate was 8.79 kg per day while oat was 10.13 kg per day. This difference may have affected milk production in this experiment.

In the second experiment Ekern et al. (2003) managed to feed the dairy concentrates at similar levels. However, there were some discrepancies in protein levels in the concentrates. The authors admitted that they were unsure of the effect of the higher protein concentration in the high-fat oat concentrate. The high-fat oat fed cows yielded significantly more milk, ECM and MP than the regular oat. Although there is some question regarding the cause of differences in milk in the study by Ekern et al. (2003), the theory of a high-fat oat providing more energy for milk production remains sound.

2.3 Oat Nutrients in Dairy Production

2.3.1 Energy Requirements of Lactating Cows

The energy requirements of dairy cattle for maintenance and milk production are expressed in net energy for lactation (NE_L) units (Mcal per kg feed DM). The single energy unit (NE_L) is used for both maintenance and milk production by National Research Council (2001) because metabolizable energy is used at the same efficiencies for maintenance and milk production (Moe and Tyrell 1972). National Research Council (2001) has set the maintenance requirement for NE_L of mature dairy cows in dry-lot or free stall systems at 0.080 Mcal per kg $BW^{0.75}$. The net energy for lactation (NE_L) as defined by National Research Council (2001) is the energy contained in the milk produced. When individual components are measured directly, NE_L concentration in milk is calculated:

$$NE_L = 0.0929 \times Fat\ \% + 0.0547 \times Crude\ Protein\ \% + 0.0395 \times Lactose\ \% \qquad (2.2)$$

The dairy cow meets its requirements for NE_L through dietary energy and/or the mobilization of body stores. Dietary energy derived from different feeds can be expressed as total digestible nutrient (TDN). Different feeds and diets will have different TDN based on their nutrient compositions. National Research Council (2001) estimates TDN using the equation:

$$TDN\ (\%) = tdNFC + tdCP + (tdFA \times 2.25) + tdNDF - 7 \qquad (2.3)$$

Where *tdNFC* is truly digestible non-fibre carbohydrate, *tdCP* is truly digestible crude protein, *tdFA* is truly digestible fatty acid, and *tdNDF* is truly digestible neutral detergent fibre. Once TDN is determined, NE_L for a specific feed or diet can be calculated using the Weiss et al. (1992) equation for NE_L:

$$NE_L\ (Mcal/kg) = (TDN \times 0.0245) - 0.12 \quad (2.4)$$

As determined by National Research Council (2001), oat grain has a TDN of 78.5% and a corresponding NE_L of 1.80 Mcal per kg (Table 2.1). In comparison to other cereal grains that are available in western Canada, oat is not considered to be equal in dietary energy. The higher fibre content of oat causes it to have a reduced TDN.

2.3.2 Carbohydrates

The major source of energy in diets that are fed to dairy cattle is carbohydrates, which normally comprise 60 to 70% of the total diet (National Research Council 2001). Carbohydrates serve several functions in ruminants. First, they provide the rumen microbes and host animal with energy. Second, certain types of carbohydrate maintain the health and function of the gastrointestinal tract. In general, carbohydrates are classified as either nonstructural or structural. Nonstructural carbohydrates are primarily found in plant cells while structural carbohydrates comprise cell wall material. Also associated with the cell wall is lignin.

2.3.2.1 Nonstructural Carbohydrates

Nonstructural carbohydrates are those carbohydrates that are not included in the cell wall matrix and are not recovered in NDF. They are comprised of sugars, starches, organic acids, and other reserve carbohydrates such as fructans. Cereal grains normally provide the bulk of nonstructural carbohydrates present in dairy rations. In western Canada barley is the grain that is largely used as a cereal source, although corn, wheat, and oat have also been used.

Nonstructural carbohydrates can be classified as water-soluble or water-insoluble. Monosaccharides (glucose and fructose) and disaccharides (sucrose and lactose) are water-soluble nonstructural carbohydrates and are rapidly fermented in the rumen. Larger polysaccharides like galactans and β-glucan gums (found in the bran of oat) are water-insoluble nonstructural carbohydrates. Although pectins are associated with the cell wall, they are almost completely digested in the rumen.

In cereal grains, the major storage carbohydrate is starch. The amylose content of oat starch is 17.5 to 33.6% (Welch 1995). Depending on the source, processing, and other factors, the ruminal degradation of starch can be 40 to over 90% (National Research Council 2001). Herrera-Saldana et al. (1990) stated that over 90% of the starch in oat grain is soluble and almost 100% of oat starch disappears *in situ* within 4 hours of incubation.

The optimal nonstructural carbohydrate concentration of lactating dairy cow diets is not well defined. For the prevention of acidosis and other metabolic problems, Nocek (1997) suggests a maximum of 30 to 40% nonstructural carbohydrates in the ration dry matter. National Research Council (2001) relates the optimal nonstructural carbohydrate in diets of high producing dairy cows to 5 factors: 1) the effects of rapidly degradable starch on ruminal digestion of fibre; 2) the amount of nonstructural carbohydrate replacing NDF in the diet, affecting volatile fatty acid production, rumination, and saliva production; 3) site of starch digestion; 4) dry matter intake and physiological status of the animal; and 5) processing or conservation methods used to alter extent and rate of nonstructural carbohydrate digestion.

The total starch level, rate, and extent of ruminal degradation have an impact on the amount of carbohydrate that can be added to a diet. The variability of starch fermentation rate depends on grain source and amount of grain processing. The degradability of starch in five common grains has been ranked as follows: oat > wheat > barley > corn > sorghum (Herrera-Saldana et al. 1990). In the case of high producing dairy cows, high dry matter intakes cause a faster rate of passage that may negate the ruminal digestibility of a processed or highly soluble starch.

2.3.2.2 Structural Carbohydrates

The most common measures of fibre used in feed analysis are crude fibre, neutral detergent fibre, and acid detergent fibre. The method that best separates structural from nonstructural carbohydrates in plants is neutral detergent fibre. Neutral detergent fibre measures hemicellulose, cellulose, and lignin, whereas acid detergent fibre does not include hemicellulose. Since crude fibre does not quantitatively recover hemicellulose or lignin, recent studies have considered it outdated.

The concentration of NDF in feeds or diets is negatively correlated with energy concentration. However, the proportions of hemicellulose, cellulose, and lignin in NDF are variable between and within feed sources. Due to the complex composition of NDF, feeds or diets with the same NDF concentration do not necessarily have the same available energy. For example, oat can have an NDF concentration of 35 to 40%, similar to immature alfalfa hay. Because of the complex nature of NDF and the associative affects of other nutrients and their physical form, these two feeds are most likely to react differently to ruminal fermentation, despite similar NDF concentrations.

Ruminal pH is correlated to the concentration of NDF present in diets. This is because NDF generally ferments slower and is less digestible than nonstructural carbohydrates. The reason for this is two fold. NDF fermentation results in less acid production and the majority of NDF sources are forages that promote extra chewing and rumination, providing saliva production for greater buffering capacity (National Research Council 2001). National Research Council (2001) also describes a relationship between the total NDF in the diet and the percentage that comes from forage and non-forage sources. The relationship is dependent on the type of feeds used and has not been quantified for all feeds. In practice, as forage NDF decreases, the total amount of NDF in the diet needs to increase. This means that a greater proportion of NDF must come from a non-forage source like cereal grains. Oat grain provides a substantial amount of NDF for this purpose. However, with increasing NDF concentration, the non-fibre carbohydrate (NFC) concentration of the diet decreases, lowering the total energy contained within the diet.

Non-forage fibre sources generally have large proportions of potentially degradable NDF, small particle size, and high specific gravity. Also, non-forage fibre sources have similar or faster passage rates and similar or slower NDF digestion rates as compared to those of forages (National Research Council 2001). Because of this, non-forage NDF sources are significantly less effective at maintaining milk fat percentage than are forages (Clark and Armentano 1997). When considering the dietary concentration of NDF, other qualitative adjustments must be considered, including: source of starch, forage particle size, amount of effective fibre, dietary buffer supplementation, and feeding method.

2.3.2.3 Lignin

It is widely known that lignin reduces the degradation of plant material by rumen microbes. The nature, distribution, and overall effect of lignin negatively influences nutrient availability of plant-derived feeds. Van Soest (1994) described lignin as the most significant factor limiting the availability of plant cell wall material to animal herbivores and anaerobic digestive systems. The type and concentration of lignin in feed varies from source to source. Most forage plants are either grasses or legumes. It has become apparent that grass lignins are different in having many ester linkages that are largely absent in legumes (Van Soest 1994).

Chemically, lignin is comprised of substituted phenylpropane units linked in a complex three-dimensional array. Lignin is derived from the polymerization of cinnamic acids or their corresponding alcohols (Van Soest 1994). Lignin found in legumes tends to be the conventional polymerized alcohol type. Ferulic and *p*-coumaric acids tend to be more important in grasses. Although these compounds are not considered lignin, it is possible they are precursors of lignin in grasses.

The formation of free-radicals is required for the polymerization of phenylpropanoid monomers. These principal free-radical forms (Figure 2.4) arise from reaction with oxygen or peroxide. Ultraviolet light as well as peroxidases can induce

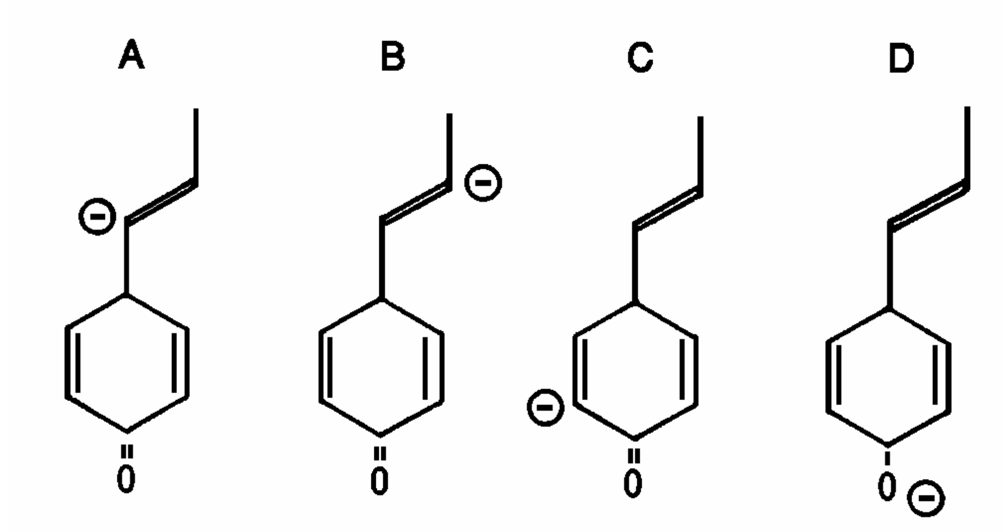

Figure 2.4 Free radical structures believed to be intermediates in lignin polymerization. A-C are quinone methides formed by loss of a proton at the indicated position. D is the radical formed by loss of a proton at the hydroxyl position. Note that formula C is not possible with a syringyl component because the postion is blocked by a methoxyl group (Modified from Van Soest 1994).

dimerization and polymerization of these free radicals. These polymerization products have a condensed structure containing primarily carbon-to-carbon (at the indicated sites in Figure 2.4) and ether linkages between phenylpropanoids in a three-dimensional array.

True lignin is difficult to quantify. The chemical analysis of lignin depends on the characterizable chemicals that can be extracted and separated. The precise compounds that comprise lignin are insoluble and cannot be extracted without destruction. Acid detergent lignin (ADL) is not only a measure of true lignin, but includes non-lignin components contained in a net non-carbohydrate fraction of dietary fibre. From a nutritional perspective, the greatest relevance of lignin may be as a measurement of indigestible residues, which contribute to a dietary source of indigestible bulk referred to as ADL.

2.3.3 Energy Value of Fats

The foremost reason for providing fat in dairy cow diets is to increase the energy density of the diet. The amount of NE_L that fat can provide is primarily a function of the long-chain fatty acid content and digestibility. Fatty acid digestibility is often influenced by dry matter intake, volume of fat consumed, and degree of unsaturation. The degree of unsaturation of fatty acids is most important when considering lipid digestion and absorption in ruminants. After hydrolyzation of esterfied fatty acids, mainly triglycerides, unsaturated fatty acids are hydrogenated by ruminal microorganisms. The primary products resulting from hydrogenation of fatty acids in the rumen are C18:0 and various isomers of C18:1. National Research Council (2001) estimates that 85 to 90% of the fatty acids leaving the rumen are free fatty acids, while approximately 10 to 15% are microbial phospholipids.

Although fats contain approximately 2.25 more energy per unit than carbohydrates or protein, they can impede digestion in the rumen. Jenkins (1993) stated that increasing the degree of unsaturation not only decreases the digestibility of fatty acids, but also increases the possibility that ruminal fermentation will be adversely affected. When the microbial capacity to saturate fatty acids is exceeded, unsaturated fatty acids will accumulate and obstruct fermentation. The results of impaired ruminal digestion are reductions in dry matter intake, milk fat percentage, and ruminal fibre digestion. This scenario may come about when feeding oat because oleic and linoleic acids contribute upwards of 80% of the total fatty acid in oat (de le Roche et al. 1977).

National Research Council (2001) states that when feeding lipids the primary determining factor affecting ruminal fermentation is the rate at which unsaturated fatty acids are released from feeds. Fatty acids that are released slowly from the feed to the ruminal fluid may have a lesser effect on fermentation. Knapp et al. (1991) observed minimal effects on rumen fermentation in dairy cattle when feeding polyunsaturated oils in the form of whole-seed soybeans. Oat is unique among cereal grains in that the majority of lipids are found in the endosperm (Peterson 1992). In most other cereals, the lipid fraction is concentrated in the germ and in the bran milling fractions. Youngs et al. (1977) observed 38.2% lipid in oat bran and 53.3% in the starchy endosperm. Because of its association with the endosperm, it may be possible that oat lipid has a slow release in rumen fluid, regulating the amount of lipid hydrolysis over time.

2.3.4 Protein and Amino Acids

Crude protein in feed is generally estimated from a measure of total nitrogen content. It is assumed that, on average, feedstuffs contain 16 g of nitrogen per 100 g of protein. However, because all nitrogen is measured, this calculated estimate does not only contain protein nitrogen, but other endogenous sources of nitrogen referred to as non-protein nitrogen.

When considering protein quality, it is the individual amino acids and their proportions in relation to one another that determine the overall nutritive value of the protein. Nutritionally, this concept is considerably more applicable in monogastric animals that can absorb intact feed amino acids. Because of ruminal fermentation in ruminants, much of the protein consumed by the animal is degraded into ammonia and carbon chains. From the substrate available in the rumen, the ruminal microorganisms will synthesize amino acids for their own proteins (National Research Council 2001). This microbial crude protein contributes the largest proportion of protein available to the host ruminant. Other proteins available to the host include ruminally undegraded feed protein (RUP) and, to a lesser extent, endogenous crude protein.

Microbial proteins account for 35 to 66% of the intestinal amino acids in dairy cows (Clark et al. 1992). Considered to be a consistent, high quality source of absorbable amino acids, microbial protein has an apparent intestinal digestibility of about 85% (Schwab 1996). The second major source of absorbed amino acids in dairy cattle is RUP. Schwab (1996) explains that there seems to be little difference between the essential amino acid composition of most intact feeds and the RUP fraction of the same feed.

Rulquin and Verite (1993) list lysine and methionine as the two major limiting amino acids in ruminants. In dairy cattle lysine and methionine are co-limiting, as responses are higher when they are both supplemented. Schwab (1996) explained that content of milk protein is more responsive than milk yield to supplemental lysine and methionine, particularly in mid to late lactation cows. The milk protein fraction most affected is casein, and its response is independent of milk yield. However, greater protein responses are observed when lysine and methionine are supplied together rather than independent of each other. Rulquin and Verite (1993) recommend amino acid levels of 7.3% lysine and 2.5% methionine of absorbable protein to achieve optimal response in milking cows.

Oat protein has quality amino acid profile compared to other cereals and the decline in its protein quality at higher protein levels is less marked (Welch 1995). Globulins are the primary storage protein in oat, accounting for up to 75% of the total proteins (Peterson 1992). With the exception of rice, the predominant proteins in other cereal grains are prolamins. For this reason, the concentrations of some amino acids in oat are notably different than those in other grains (Table 2.4). Globulins contain less glutamic acid and proline but more lysine than do prolamins. Thus, oat is lower in glutamic acid and proline and higher in lysine compared to other cereal grains. Lysine is important because it is considered one of the most limiting amino acids in animal nutrition.

Table 2.4 Amino acid content of barley and oat grains (% of CP, DM basis)

Amino Acid	Barley[1]	Oat[1]	Oat[2]	Hulled Oat[3] Gerald	Hulled Oat[3] Image	Naked Oat[3] Kynon	Naked Oat[3] Pendragon
Alanine	--	--	5.1	4.6	4.7	4.4	4.3
Arginine	4.3	5.9	7.7	6.6	6.8	6.6	6.7
Aspartic acid	--	--	9.1	8.7	8.8	8.0	8.3
Cystine	1.8	1.7	2.0	3.1	3.2	3.0	3.1
Glutamic acid	--	--	22.0	18.0	17.2	17.5	17.9
Glycine	3.2	3.9	4.7	5.1	5.1	4.8	4.7
Histidine	2.1	1.6	2.6	2.3	2.3	2.1	2.4
Isoleucine	3.8	3.7	4.0	3.7	3.8	3.6	3.5
Leucine	6.2	6.8	7.7	7.5	7.3	7.0	7.4
Lysine	3.3	3.3	4.6	4.7	4.7	4.2	4.5
Methionine	1.3	1.4	2.3	1.3	1.3	1.2	1.2
Phenylalanine	4.9	4.4	5.7	5.4	5.4	5.1	5.2
Proline	--	--	3.6	4.8	4.8	4.4	4.2
Serine	3.6	3.9	4.1	4.9	4.9	4.4	4.4
Threonine	3.1	3.9	3.0	3.6	3.6	3.3	3.5
Valine	4.7	4.7	5.7	6.2	6.0	6.3	5.9

[1]National Research Council (1982)
[2]Peterson (1976)
[3]Givens et al. (2004)

2.4 Objectives of Thesis

Few studies have evaluated oat grain as a dairy feed. It has been shown that oat grain in dairy rations can support milk production of 25 kg per day. Oat grain has also been shown to maintain or raise MF and lower MP content. The current average daily production of milk in Canadian Holstein dairy cattle is approximately 30 kg per day. Because of this, it is doubtful that historic observations on oat grain and other cereals will be valid in today's Canadian dairy rations. With this in mind, the Crop Development Centre has developed low-lignin hull, high-oil groat (LLH-HOG) oat. It is hypothesized that the low lignin and high oil content of LLH-HOG oat will improve digestibility and energy content when fed to dairy cattle, such that it is better than regular oat and comparable or superior to barley. The combination of low lignin hull and high oil groat in LLH-HOG oat will result in a nutritionally superior grain for ruminants when compared to Derby oat and nutritionally similar compared to CDC Dolly barley.

The objectives of this study were:

(1) to determine the nutritional characteristics of three cereal grains, LLH-HOG oat, Derby oat, and CDC Dolly barley,

(2) to evaluate total tract digestibility of LLH-HOG oat and CDC Dolly barley,

(3) to evaluate *in situ* and *in vitro* rumen degradability of LLH-HOG oat compared to CDC Dolly barley, and

(4) to determine the nutritional impact of LLH-HOG oat and Derby oat when replacing CDC Dolly barley in high production, lactating dairy cow rations.

3.0 OAT GRAIN DIGESTIBILITY AND RUMEN DEGRADABILITY

3.1 Introduction

Oat (*Avena sativa*) grain is a cereal crop commonly grown in western Canada. In 2003/04 Canadian producers grew a total of 3.7 million tonnes of oat, of which 1.6 million were exported, 0.14 million processed as human food, 0.17 million used as seed, and another 1.6 million were classified as feed, waste and dockage (Canada Grains Council 2006). In agricultural practices oat is a suitable feed for use in ruminant diets. Much of the oat that does not enter other sectors can be used on farm as feed. Oat is not considered a high energy grain, making it less competitive as a feed source compared to other cereals such as barley. For this reason, the Crop Development Centre has developed a new type of oat with characteristics intended to improve its digestibility and energy content in ruminants. The notable nutritional characteristics of this oat are a hull that is low in ADL and a groat that is high in EE. These qualities observed in LLH-HOG (low-lignin hull, high-oil groat) oat are intended to improve animal performance.

3.2 Materials and Methods

3.2.1 Grain Samples

The objective of this study was to determine the chemical composition, total tract digestibility in sheep, and ruminal degradability of 01-499-04 LLH-HOG oat. This research was conducted by contrasting 01-499-04 LLH-HOG oat to other grains commonly used as ruminant feeds in western Canada. CDC Dolly barley grain and Derby oat grain were chosen to represent conventional grains.

3.2.1.1 CDC Dolly Barley

CDC Dolly, a two-row barley, was developed at the Crop Development Centre. Registered and released in 1994, CDC Dolly was selected to represent conventional barley grain for this project. The sample of CDC Dolly used in all trials and analysis in this project was grown in 2003 in the Foam Lake Rural Municipality No. 276 (land location: SW-3-30-12-W2) on an Oxbow association soil type with a loam surface texture.

3.2.1.2 Derby Oat

In 1988 the Crop Development Centre oat research and development program registered and released Derby oat. Derby oat was selected for this project as a conventional oat grain. The sample of Derby oat used in all trials and analysis in this project was grown in Aberdeen Rural Municipality No. 373.

3.2.1.3 LLH-HOG Oat

The Crop Development Centre developed 01-499-04, a breeding line of LLH-HOG (low-lignin hull, high-oil groat) oat. LLH-HOG oat was developed with a low acid detergent lignin (ADL) hull content compared to normal oat. LLH-HOG oat was also developed with high groat fat (oil) content. The 01-499-04 LLH-HOG oat grain used in this project was grown in 2003 at the University of Saskatchewan, Saskatoon, Corman Park Rural Municipalty No. 344 (land location: NE-2-37-5-W3). The oat was grown on a Bradwell association soil type with a loam to clay loam surface texture.

The 01-499-04 sample had a high percentage of thin grain kernels. Prior to use in all experiments it was cleaned using a wind and screen grain cleaner, which removes thin grain and chaff based on shape and density. Cleaning removed 15.7% of the grain sample by weight. All experimental results were based on the remaining cleaned sample of 01-499-04 LLH-HOG oat.

3.2.2 Chemical Analysis of Grains

Grain samples were analyzed following the Cornell Net Carbohydrate and Protein System (CNCPS) based on the Association of Official Analytical Chemists (1990) for dry matter (DM: method 930.15), Kjeldahl nitrogen (CP: method 984.13) using a Kjeltec 1030 auto analyzer, ether extract (EE: method 920.39), acid detergent fibre (ADF: method 973.18) and acid detergent lignin (ADL: method 973.18). The procedure of Van Soest et al. (1991) was used to determine neutral detergent fibre (NDF) using sodium sulfite and heat stable amylase (ANKOM Technology Corporation 1997). For determination of NDF, ADF, and ADL, an ANKOM Fiber Analyzer (ANKOM Technology Corporation 1997) was used. Soluble crude protein (SCP) was determined according to the procedure described by Roe et al. (1990). Neutral detergent insoluble crude protein (NDICP), acid detergent insoluble crude protein (ADICP), and non-protein nitrogen (NPN) were determined according to the procedure of Licitra et al. (1996). An Oxygen Bomb Calorimeter (Parr Instrument Company, Moline, Ill) was used to determine gross energy (GE) by the procedure of Rossini (1956). The procedure for minerals as described by Zasoski and Burau (1977) was used to determine calcium (Ca) and phosphorus (P). Amino acid analysis was conducted following the procedure of Llames and Fontaine (1994). The performic acid oxidation with acid hydrolysis-sodium metabisulfite method was used to oxidize cystine and methionine to cysteic acid and methionine sulfone, respectively.

3.2.3 Physical Analysis of Oat Grains

Test weight (TW) of the oat samples was measured using an Ohaus 0.5 litre measure, a Cox funnel to standardize the pouring rate, and a striker to level the contents of the container (Canadian Grain Commission 2005). TW was measured in kilograms per hectoliter, without reference to moisture content. Kernel plumpness was measured using a 50 g sample. The sample was placed on a 5.5/64 inches slotted screen that was stacked on a 5.0/64 inches screen and a bottom pan. The apparatus was then strapped into a rotary shaker that was run for four minutes. Plumpness was measured as the percentage of kernels remaining above the top sieve (5.5/64 inches). A Laboratory Dehuller Model LH 5095 (Codema Inc., Eden Prairie, MN) was used to determine the percent groat for oat samples. Thousand kernel weights were determined by counting out 200 kernels, weighing them, and then multiplying the total weight by five.

In addition to wet-chemistry analysis, near-infrared transmission (NIT) spectroscopy was used to determine the oil and crude protein content of the oat samples. The NIT spectroscopy was carried out using a NRISystems Model 5000 (Foss NIRSystems Inc., Silver Springs, MD).

3.2.3 Digestibility and Voluntary Intake by Sheep

A randomized block design using Suffolk wethers compared the digestibility of 01-499-04 LLH-HOG oat to CDC Dolly barley. Seven diets were randomly allocated to twenty-one sheep in two periods. The 01-499-04 LLH-HOG oat grain and CDC Dolly barley grain were fed with barley silage to construct diets containing 50, 75, and 90% grain (DM basis). A seventh diet containing only barley silage was used as the control. The twenty-one wethers had a mean weight of 47.4 ± 5.5 kg and were used to determine apparent digestibility of DM, CP, EE, NDF, ADF, and GE. Sheep were stratified based on bodyweight and then randomly allocated to one of the seven diets, such that three animals were fed the same diet at one time. Animals were housed in the Livestock Research Barn at the University of Saskatchewan (Saskatoon, SK) and were cared for according to the guidelines of the Canadian Council on Animal Care (1993).

The barley silage used in the trial was collected daily from a concrete tower silo located at the University of Saskatchewan. CDC Dolly barley and 01-499-04 LLH-HOG oat were rolled using a Roskamp Huller Rollermill Model J (CPM Roskamp Champion, Waterloo, IA).

3.2.3.1 Adaptation and Feeding of Sheep

The digestibility trial consisted of a 14 d period of adaptation, a 7 d voluntary intake period, followed by an 8 d restricted intake period with sample collection on the last 5 d. During the adaptation period all groups, excluding the silage control group, were fed a diet that consisted of 1/3 silage, 1/3 hay, and 1/3 of the corresponding concentrate (as fed) in the target diet. At this time sheep were group housed in one of seven pens depending on their target diet. Groups that were assigned to 25:75 forage:concentrate ratio (DM) diets had 14 d of 3-step adaptation with a minimum of two days on each diet. Similarly, groups targeted for 10:90 forage:concentrate ratio (DM) diets had 14 d of 6-step adaptation with a minimum of two days on each diet. With the completion of the adaptation period the animals were placed in individual metabolic crates for the remaining two periods.

Sheep were fed at 0700 and 1600 h throughout the trial. During the restricted intake period, animals were restricted to 90% of their voluntary intake. If the 90% restricted intake value exceeded 2.8% of BW as DM, then the restriction value was set at 2.8% of BW as DM. Ten g 1:1 sheep mineral (Appendix A) and 10 g cobalt iodized salt (Appendix A) were added to diets on alternating days throughout the trial. Fresh water was available *ad libitum* throughout the trial.

3.2.3.2 Sample Collection, Analysis, and Calculations

Sheep were fitted for fecal collection bags at the beginning of the voluntary intake period (14 d on feed). At 0700 h during the last 5 d of restricted intake, total fecal samples were collected into individual pre-weighed, brown paper bags. After collection, these bags were placed in a forced air oven at 55 ^{o}C and dried for 72 h. Fecal dry matter was recorded and then samples were ground through a 1mm screen using a Christy & Norris mill. Samples collected over the 5 d were composited proportionately to their DM weight, resulting in one sample for each individual animal. Samples were stored in 150 ml vials at room temperature until chemical analysis was performed. Feed samples were collected during the 5 d restricted intake period. Feed and fecal samples were analyzed for DM, CP, EE, NDF, ADF, ADL, and GE as described in section 3.2.2.

Apparent digestibility (%) using the total collection method was calculated using the following equations:

$$\textbf{Dry Matter Digestibility (\%)} = \frac{\textbf{(DM intake – Fecal DM output) x 100}}{\textbf{DM intake}} \quad (3.1)$$

$$\textbf{Nutrient Digestibility (\%)} = \frac{\textbf{(Nutrient intake – Fecal nutrient output) x 100}}{\textbf{Nutrient intake}} \quad (3.2)$$

3.2.4 *In Situ* Studies

A non-lactating Holstein cow fitted with a flexible rumen fistula was used to determine the rumen degradability of 01-499-04 LLH-HOG oat, Derby oat, and CDC Dolly barley. The cow was fed a 50:50 forage to concentrate (DM basis) TMR at 1.2% of BW. The ration was fed twice daily in equal portions at 0800 and 1600 h. This ration was chosen to represent the rumen environment and characteristics of a lactating dairy cow. Fresh water was available *ad libitum* throughout the experiment. The cow was housed in the Stone Barn at the University of Saskatchewan (Saskatoon, SK) and cared for according to recommendations of the Canadian Council on Animal Care (1993).

Oat and barley grain samples were ground through a 2 mm screen in a table top Reutsch grinder. Five grams of each ground sample were weighed into dacron bags (8cm x 20cm) with an average pore size of 45µm. Rumen incubations were performed using a staged in and all out procedure. Incubation times were 48, 36, 24, 12, 8, 4, and 0 h. To allow for appropriate residue for analysis, a greater number of bags were inserted for the longer incubation times. Each grain was incubated in four bags at 48 h, three bags at each 36, 24, and 12 hour, two bags at 8 h, and one bag at 4 and 0 h (Appendix A). This procedure was repeated in three separate incubation periods (n=3).

After incubation of the bags, they were hand washed under cold water until the wash water became clear. The washed bags were then dried in a forced air oven at 55 °C for 48 h. Each sample residue was then ground through a 1 mm screen in a table top Reutsch grinder. Grain residues for each time were composited. The grains and their residue from each composite sample were analyzed for DM, NDF, and CP content. The ruminal DM, CP, and NDF disappearance data was then used to estimate ruminal kinetic parameters using the equation of Ørskov and McDonald (1979) with an incorporated lag time (McDonald 1981):

$$P = a + b\,[1 - e^{-c}\ (t - L)] \qquad (3.5)$$

Where *P* is ruminal disappearance at time *t* (h); *e* is the base of the natural log; *a* is the (%) soluble fraction of the dry matter or nutrient (CP and NDF); *b* is the (%) potentially degradable fraction of the dry matter or nutrient; and *c* is the rate constant at which the *b* fraction is degraded (%/h). *L* (h) is the lag period, which is more useful in the incubation of forages and other highly fibrous feeds.

Ørskov and McDonald (1979) developed an equation that predicts the effective degradability of specific nutrients. This equation was used on the ruminal DM, CP, and NDF disappearance data. The equation is as follows:

$$ED = a + \frac{b \times c}{c + (Kp^{-1} - d)^{-1}} \qquad (3.6)$$

Where *ED* is effective degradability of a nutrient; *a*, *b*, *c*, and *d* are as defined above; and *Kp* is the outflow rate of feed particles from the rumen (%/h). It was assumed that the outflow rate was six percent per hour.

3.2.5 *In Vitro* Studies

The Ankom Technology (2005) procedure was used to evaluate the *in vitro* degradability of 01-499-04 LLH-HOG oat, Derby oat, and CDC Dolly barley grain. Grain samples were ground through a 2 mm screen in a table top Reutsch grinder. Samples of 0.25 g were weighed into each of five Ankom Filter Bags for each incubation time (48, 30, and 24 h). For standardization, two blank, three alfalfa, and three wheat straw filled Ankom Filter bags were also included at each incubation time. Samples were then incubated for 48, 30, and 24 h in a Daisy *II* Incubator (Ankom Technology 2005) and then analyzed for DM and NDF as described in 3.2.2. From this data the DM and NDF *in vitro* degradability were calculated. Rumen inoculum for this procedure was collected from a non-lactating Holstein cow fitted with a flexible rumen fistula. This cow was fed a 50:50 forage to concentrate TMR (1.2% of BW, DM basis) fed twice daily in equal portions at 0800 and 1600 h. This experimental procedure was repeated three times (n=3).

3.2.6 Statistical Analysis for Digestibility of Grains

Data were analyzed using regression analysis in the mixed model procedure of Statistical Analytical System (SAS Institute, Inc., 1999). Level effects were evaluated with linear, quadratic, and cubic contrasts prior to fitting appropriate equations.

3.2.7 Statistical Analysis for Degradability of Grains

A one-way analysis of variance was used to analyze the data collected from the *in situ* incubation of the three grains in three blocks (replicates) using one animal. Data were fitted to the Ørskov and McDonald (1979) equation in order to determine degradation rate, lag time, soluble fraction, degradable fraction, undegradable fraction, and effective degradability. For each grain these data were analyzed as a one-way analysis using the mixed model procedure of SAS Institute, Inc. (1999) with block as a fixed effect. The mixed model procedure of SAS Institute, Inc. (1999) was used to contrast the means of the *in vitro* incubation of grains using a one-way analysis. Three grains were incubated in three blocks (replicates) in the Daisy *II* Incubator (Ankom Technology, 2005). Significant differences were declared when $P<0.05$.

3.3 Results and Discussion

3.3.1 Chemical Composition of Cereal Grains

The Derby and 01-499-04 LLH-HOG oat were similar in some nutrient composition aspects (Table 3.1), while CDC Dolly barley had a notably different nutrient profile. The ADL and structural carbohydrate, NDF and ADF, contents were variable from grain to grain. Derby oat had NDF, ADF, and ADL contents of 39.2, 24.0, and 2.6%, content of these nutrients in CDC Dolly barley were 28.6, 15.3, and 0.7% respectively. Numerically, 01-499-04 LLH-HOG oat had intermediate NDF (38.0%), ADF (22.3%), and ADL (1.1%) as compared to the other grains. Even though the fibre content of 01-499-04 LLH-HOG oat was close to that of Derby oat, its ADL content was less than half that of Derby oat. The difference in ADL content was a direct result of the low-lignin hull of 01-499-04 LLH-HOG oat. The NDF and ADF concentrations in both oat samples were higher than the average concentration reported by National Research Council (2001). Moe et al. (1973), Rowe and Crosbie (1988), and Herrera-Saldana et al. (1990) observed NDF and ADF values of 31.7 and 13.6%, 30.0 and 14.4%, and 24.0 and 16.5%, respectively. All of those values are approximately 25% lower than the NDF and

Table 3.1 Nutrient composition of experimental cereal grains (% of DM)

Nutrient	CDC Dolly Barley	Derby Oat	LLH-HOG Oat
Dry Matter	90.1	92.7	92.1
Crude Protein	13.8	13.7	15.3
Ether Extract	2.6	5.4	6.5
NDF	28.6	39.2	38.0
ADF	15.3	24.0	22.3
ADL	0.7	2.6	1.1
NDICP (%CP)	17.6	9.7	8.0
ADICP (%CP)	1.1	1.9	1.3
SCP (%CP)	23.4	23.1	22.7
NPN (%CP)	8.6	15.0	7.3
Ash[1]	2.9	3.3	3.3
Calcium	0.16	0.09	0.13
Phosphorus	0.27	0.34	0.43
GE (Kcal/kg)	4532	4649	4714
tdNFC[2]	55.6	40.5	38.9
tdCP[2]	13.7	13.6	15.2
tdFA[2]	1.6	4.4	5.5
tdNDF[2]	17.4	22.0	24.2
(1x)TDN[3]	83.3	79.0	83.6
NE_L[4] (Mcal/kg)	1.92	1.82	1.93

[1]average for grains as expressed by National Research Council (2001)
[2]National Research Council (2001)
[3]calculated using equation 2.3
[4]calculated using equation 2.4

ADF content of the oat used in this study. CDC Dolly barley also had a higher fibre content than reported by National Research Council (2001). This author reported a mean NDF content for barley of 20.8% and ADF of 7.2%. The fibre contents of all grains were affected by the dry growing season of 2003. It is common for cereals to have greater fibre content when produced under dry growing conditions. Some of the characteristics observed in drought exposed oat are increase hull percentage and decreased test weight (TW) and plumpness (Sandhu and Horton 1977). The percent of groat in Derby oat and 01-499-04 LLH-HOG oat (Table 3.2) were 61.3 and 62.0% respectively, resulting in hull contents of 38.7 and 38.0%. These values were greater than the 20 to 30% range of hull percentage reported by Crosbie et al. (1985). The TW and plumpness (>5.5/64 inch sieve) for Derby oat were 48.3 kg/hl and 44.4%. The same measurements for 01-499-04 LLH-HOG oat were 45.9 kg/hl and 32.2%.

The 01-499-04 LLH-HOG oat contained 15.3% CP, exceeding the CP of the other two grains by more than 1.5 percentage units. The CP content of both oat samples was greater than the average content reported by other authors (Herrera-Saldana et al. 1990; National Research Council, 2001). In addition to having an effect on fibre, dry growing conditions have been shown to increased oat protein content (Forsberg and Reeves 1995). The measure of CP using NIT spectroscopy for Derby oat was 16.9% and for 01-499-04 LLH-HOG oat it was 18.4% (Table 3.2).

Both Derby and 01-499-04 LLH-HOG oat had EE contents more than twice that of CDC Dolly barley. The 01-499-04 LLH-HOG oat had the highest EE content at 6.5%, while Derby oat had an EE content of 5.4%. The 01-499-04 LLH-HOG oat was selected to contain more lipid than conventional oat, and displayed this quality when compared to

Table 3.2 Whole grain characteristics of Derby oat and LLH-HOG oat

Variable	Derby Oat	LLH-HOG Oat
Test Weight (kg/hl)	48.3	45.9
Thousand Kernel Weight (g)	35.2	31.2
Plump (% >5.5/64 inches)	44.4	32.2
Plump (% >5.0/64 inches)	84.4	74.1
Groat[1] (%)	61.3	62.0
Oil[2] (%)	6.7	7.7
Protein[2] (%)	16.9	18.4

[1]Codema laboratory dehuller
[2]near-infrared transmission spectroscopy

Derby oat. Past reports have observed greater lipid content than these in a number of oat varieties. Sahasrabudhe (1979) observed 4.6 to 11.7% lipid in six varieties of whole oat grain, while de la Roche et al. (1977) observed similar values of 4.5 to 10.3% lipid in nine varieties of whole oat grain. In total, these two authors observed a total of eight varieties of oat that had greater lipid content than 01-499-05 LLH-HOG oat. The 01-4990-04 LLH-HOG oat had a high EE content that translated into a higher caloric value per unit weight than either of the other two grains.

The GE content of Derby oat and 01-499-04 LLH-HOG oat were 4649 and 4714 Kcal per kg, respectively, while the gross energy of CDC Dolly barley was 4532 Kcal per kg. The high EE and low ADL content of 01-499-04 LLH-HOG oat also had a direct effect on percent total digestible nutrient (TDN). The 01-499-04 LLH-HOG oat had a calculated TDN (formula in 2.3.1) of 83.6% while Derby oat had a TDN of 79.0%. The TDN value calculated for CDC Dolly barley was 83.3%. Although the percent TDN obtained for Derby oat and CDC Dolly barley had similar values to assessments of oat and barley grain reported by National Research Council (2001), the percent TDN obtained for 01-499-04 LLH-HOG oat was not. National Research Council (2001) gave a TDN of 78.5% for oat grain and 82.7% for barley grain. Using the same National Research Council (2001) calculations, 01-499-04 LLH-HOG oat had a greater TDN than the other two grains in this study. The TDN equation (National Research Council 2001) is a function of several feed nutrients. TDN has a positive correlation with nutrients such as non-fibre carbohydrates (NFC), EE, and CP, while it is negatively correlated to NDICP, ADICP, and ADL. These relationships worked in favor of 01-499-04 LLH-HOG oat because of its particular nutrient profile. The 01-499-04 LLH-HOG oat had greater

CP and EE content compared to the other two grains and had lower NDICP, ADICP, and ADL concentrations than Derby oat. Even though CDC Dolly barley had lower ADICP, and ADL content, its NDICP content was numerically twice that of 01-499-04 LLH-HOG oat. NE_L, calculated from TDN (formula in 2.3.1), ranged from 1.82 to 1.93 Mcal per kg for the three grains. The NE_L values calculated for the grains showed the same trend as TDN because the equation used for calculating NE_L (Weiss et al. 1992) is a direct function of TDN.

3.3.2 Physical Characteristics of Oat Grains

The 01-499-04 LLH-HOG oat had a lower test weight (TW) than Derby oat (Table 3.2). According to the Canadian Grain Commission (2005) oat must have a minimum TW of 56.0 kg/hl to be graded as No. 1 Canada Western (CW), 53.0 kg/hl for No. 2 CW, 51.0 kg/hl for No. 3 CW, and 48.0 kg/hl for No. 4 CW. With respect to this grading scheme, the sample of 01-499-04 LLH-HOG oat used would have been graded as lightweight. Concurrently, 01-499-04 LLH-HOG oat had a lower thousand kernel weight than Derby oat. Percent plump, measured with a 5.0/64 inch sieve, was 74.1% for 01-499-04 LLH-HOG oat and 84.4% for Derby oat. The groat percentage for both 01-499-04 LLH-HOG and Derby oat were similar, 62.0 and 61.3% respectively. Near-infrared transmission estimates for oil and protein were higher than the results found using wet-chemistry. However, the comparative ranking of these measures remained similar despite the different methods. The substandard physical characteristics observed in both oat grains were attributed to the dry growing season in 2003.

3.3.3 Amino Acid Content of Barley and Oat Grain

The most abundant amino acid in CDC Dolly barley, Derby oat, and 01-499-04 LLH-HOG oat was glutamic acid, accounting for approximately 20% of the protein in all three grains (Table 3.3). Both oat types had similar amino acid profiles, and they were similar to values reported by other authors (Table 2.4). As a percent of CP, only cysteic acid, a measure of cystine, differed by more than 10% between 01-499-04 LLH-HOG and Derby oat. There also was a 10% difference in isoleucine and phenylalanine when measured as a percent of DM. With the exception of glutamic acid and proline, CDC Dolly barley had lower concentrations of analyzed amino acids, as percent DM and percent CP, than the oat samples. The proline content of CDC Dolly barley was almost twice that of either oat. Bruckental et al. (1991) reported that increasing proline supply in dairy cattle increased milk fat yield.

Recommendations made by Rulquin and Verite (1993) for percentage of metabolizable protein supply of the total essential amino acids (EAA) were 15.0 and 5.1% for lysine and methionine, respectively. This observation was supported by Schwab (1996) who affirmed that to achieve maximum content and yield of milk protein, lysine and methionine should make up 15 and 5% or more of metabolizable EAA in duodenal digesta. Analysis of tryptophan was not done in this study, hence National Research Council (1982) values for tryptophan in barley (0.17% of DM) and oat (0.17% of DM) were used to calculate lysine and methionine as a percent of the total EAA. CDC Dolly barley contained 9.8% lysine and 4.6% methionine, Derby oat contained 10.5% lysine and 4.4% methionine, and 01-499-04 LLH-HOG oat contained 10.5% lysine and 4.3%

Table 3.3 Amino acid content of experimental grain samples

	CDC Dolly Barley		Derby Oat		LLH-HOG Oat	
Amino Acid	%DM	% of CP	%DM	% of CP	%DM	% of CP
Alanine	0.503	3.64	0.633	4.62	0.672	4.39
Arginine	0.616	4.46	0.835	6.09	0.911	5.95
Aspartic acid	0.767	5.56	1.126	8.22	1.191	7.78
Cysteic acid[1]	0.275	1.99	0.404	2.95	0.383	2.50
Glutamic acid	2.921	21.17	2.72	19.85	2.955	19.31
Glycine	0.492	3.57	0.65	4.74	0.673	4.40
Histidine	0.268	1.94	0.289	2.11	0.312	2.04
Isoleucine	0.389	2.82	0.444	3.24	0.496	3.24
Leucine	0.819	5.93	0.952	6.95	1.028	6.72
Lysine	0.435	3.15	0.543	3.96	0.581	3.80
Methionine	0.205	1.49	0.224	1.64	0.238	1.56
Phenylalanine	0.546	3.96	0.616	4.50	0.700	4.58
Proline	1.232	8.93	0.689	5.03	0.736	4.81
Serine	0.565	4.09	0.662	4.83	0.708	4.63
Threonine	0.435	3.15	0.465	3.39	0.498	3.25
Valine	0.538	3.90	0.621	4.53	0.666	4.35

[1]measure of cystine

methionine. Even though they constitute only a portion of the amino acids present, the cereal grains in this study fall below the recommended dietary amino acid concentrations for lysine and methionine.

3.3.4 Intake of Diets by Sheep

The intake of diets containing CDC Dolly barley ranged from 2.57 to 2.75% of BW by individual (Appendix A). The 01-499-04 LLH-HOG oat diets had intakes ranging from 1.93 to 2.03% of BW. These data points were fitted to linear equations (Figure 3.1). National Research Council (1985) predicts 50 kg finishing sheep should have a dry matter intake of 3.2% of BW. Although the CDC Dolly barley containing diets approached this level, the 01-499-04 LLH-HOG oat diets resulted in only two thirds the predicted level. Linear regression indicated that the intake of sheep increased linearly when barley but not oat levels of the diet increased (Figure 3.1). The intakes used for the regression analysis were determined at 90% of voluntary intake. This was done to ensure intake of entire diets.

3.3.5 Total Collection Digestibility Determination

There has been some debate as to the applicability to cattle of digestibility data obtained with sheep. Schneider and Flatt (1975) stated that significant differences between cattle and sheep digestion exist. Moreover, the direction and magnitude of these differences may be a function of the feed and of the nutrient involved. Roughages and silage tend to be more digestible by cattle than by sheep, while sheep tend to digest concentrates better than cattle. Unfortunately, the discrepancy between species fails to

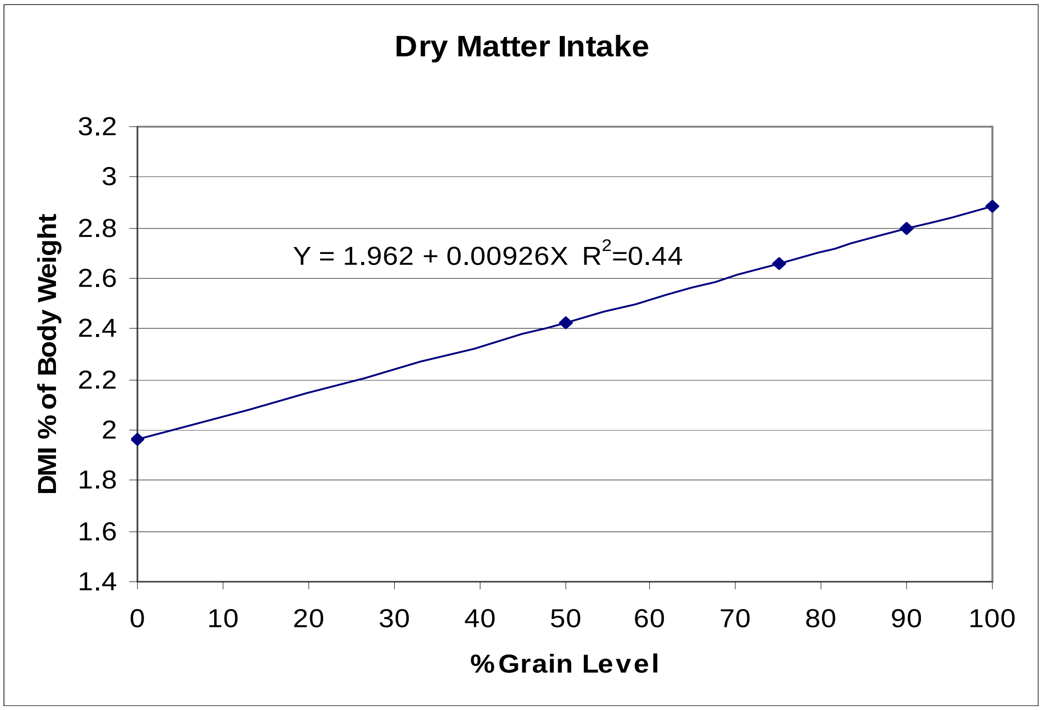

Figure 3.1 Dry matter intake of sheep diets containing CDC Dolly barley (Total collection method)

show a definitive pattern (Schneider and Flatt 1975). At times, particularly for digestion trials, it may be advantageous to use one species over the other. Sheep are small and easy to handle and eat less experimental ration, making them a favorite animal for digestion trials. Sampling and handling feces is convenient with sheep because of the drier form and lower volume. The cost per individual animal and of feed, equipment, and the ease of conducting digestion trials is undoubtedly in favor of sheep. Regardless of the differences, the primary purpose of conducting digestibility experiments is to compare two different feeds rather than provide feed data to be used for a specific species. This trial compared the digestibility of 01-499-04 LLH-HOG oat to that of CDC Dolly barley.

The apparent digestibility of DM was 65.4% for the silage diets (Appendix A). The DM apparent digestibility of diets increased linearly as the content of grain increased in sheep diets (Figure 3.2). Using linear regression, DM apparent digestibility was estimated at 79.1% for CDC Dolly barley and 74.0% for 01-499-04 LLH-HOG oat at a feeding level of 100% (Appendix A). The regression estimates of DM apparent digestibility of CDC Dolly barley and 01-499-04 LLH-HOG oat, fed at 100%, were significantly different ($P<0.05$).

The NDF apparent digestibility of silage diets was 54.0% (Appendix A). The data for NDF apparent digestibility of diets containing CDC Dolly barley or 01-499-04 LLH-HOG oat were fitted to quadratic curves (Table 3.4). The apparent digestibility of ADF for both grains was found to be unchanged with increasing concentrate level. Apparent digestibility of CP for 01-499-04 LLH-HOG oat increased linearly as grain content increased. However, apparent digestibility of CP for CDC Dolly barley was found to be quadratic and increased as grain content increased (Table 3.5). Regression estimates for

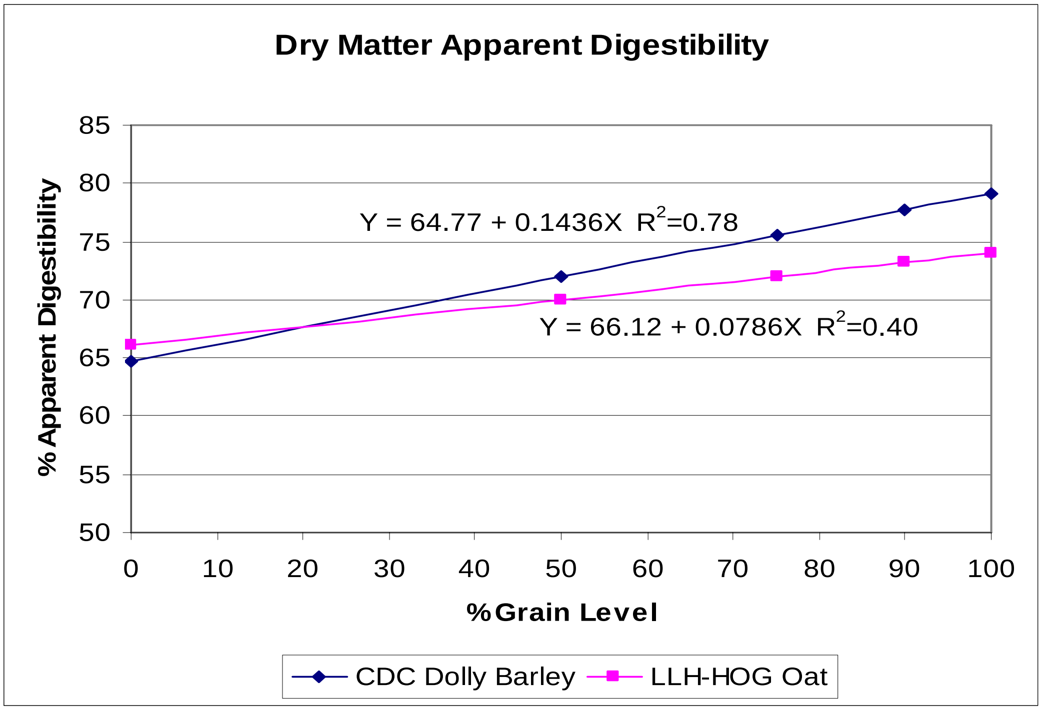

Figure 3.2 Dry matter apparent digestibility of sheep diets containing CDC Dolly barley or LLH-HOG oat (Total collection method)

Table 3.4 Nutrient apparent digestibility regression equations of sheep diets containing CDC Dolly barley or LLH-HOG oat (Total collection method)

	Y Intercept		X		X^2			
Y	Est.	SE	Est.	SE	Est.	SE	R^2	P-value
Dry Matter Intake (% of BW; 90% ad libitum)								
CDC Dolly Barley	1.962	0.134	0.00926	0.00216	--	--	0.44	<0.001
LLH-HOG Oat	1.916	0.134	0.00069	0.00215	--	--	0.00	0.633
Dry Matter Apparent Digestibility (%)								
CDC Dolly Barley	64.77	1.142	0.1436	0.01845	--	--	0.78	<0.001
LLH-HOG Oat	66.12	1.140	0.0786	0.01837	--	--	0.40	<0.001
NDF Apparent Digestibility (%)								
CDC Dolly Barley	54.04	2.485	-0.316	0.1345	0.0033	0.00151	0.20	0.025
LLH-HOG Oat	54.22	2.485	0.236	0.1344	-0.0030	0.00150	0.19	0.045
ADF Apparent Digestibility (%)								
CDC Dolly Barley	42.50	3.045	-0.0217	0.04921	--	--	0.01	0.708
LLH-HOG Oat	45.36	3.040	-0.0766	0.04900	--	--	0.12	0.104

Table 3.5 Nutrient apparent digestibility regression equations of sheep diets containing CDC Dolly barley or LLH-HOG oat (Total collection method)

	Y Intercept		X		X^2			
Y	Est.	SE	Est.	SE	Est.	SE	R^2	P-value
Crude Protein Apparent Digestibility (%)								
CDC Dolly Barley	67.96	1.388	-0.0984	0.07510	0.0018	0.00084	0.29	0.040
LLH-HOG Oat	68.40	1.328	0.0710	0.02141	--	--	0.42	<0.001
Ether Extract Apparent Digestibility (%)								
CDC Dolly Barley	68.28	1.839	0.0831	0.02872	--	--	0.25	0.007
LLH-HOG Oat	69.77	1.836	0.1956	0.02959	--	--	0.68	<0.001
Digestible Energy (Kcal/kg)								
CDC Dolly Barley	2739	50.9	8.43	0.823	--	--	0.87	<0.001
LLH-HOG Oat	2808	50.8	7.42	0.819	--	--	0.74	<0.001

apparent digestibility of CP, 75.7% for CDC Dolly barley and 75.5% for 01-499-04 LLH-HOG oat, were similar when extrapolated to 100% (Appendix A). EE apparent digestibility was linear for both grains (Figure 3.3), and the percent digestibility of diets containing 01-499-04 LLH-HOG oat were higher than those containing CDC Dolly barley (Table 3.4). Palmquist (1991) stated that true digestibility of fat in dairy cattle decreases linearly as fat content increases, and that fatty acid digestibility does not change among fat sources. The reason for apparent digestibility of fat to be greater in high-fat diets than low-fat diets may be a result of the additional oat grain fat diluting endogenous fecal fat. When regressed to 100% grain, 01-499-04 LLH-HOG oat was predicted to have 89.3% EE apparent digestibility while CDC Dolly barley was predicted to have 76.6%. The DE was different ($P<0.05$) between the two grains at a level of 50% but was not different at higher grain concentrations (Appendix A). The DE regressions for both grains were linear with an R^2 value of 0.74 for 01-499-04 LLH-HOG oat and 0.87 for CDC Dolly barley (Figure 3.4). When regressed to 100% grain, 01-499-04 LLH-HOG oat and CDC Dolly barley had numerically similar DE. The 01-499-04 LLH-HOG oat was predicted to have DE of 3550 Kcal per kg and CDC Dolly barley was predicted to have 3582 Kcal per kg of DE. These results were closer in value to each other than the 3470 Kcal per kg DE for oat and 3640 Kcal per kg DE for barley reported by National Research Council (2001).

There has been little work comparing digestibility of oat and barley grain. However, a study conducted by Rowe and Crosbie (1988) compared the digestibility in sheep of two oat samples differing in lignin content. The diets consisted of 100% grain,

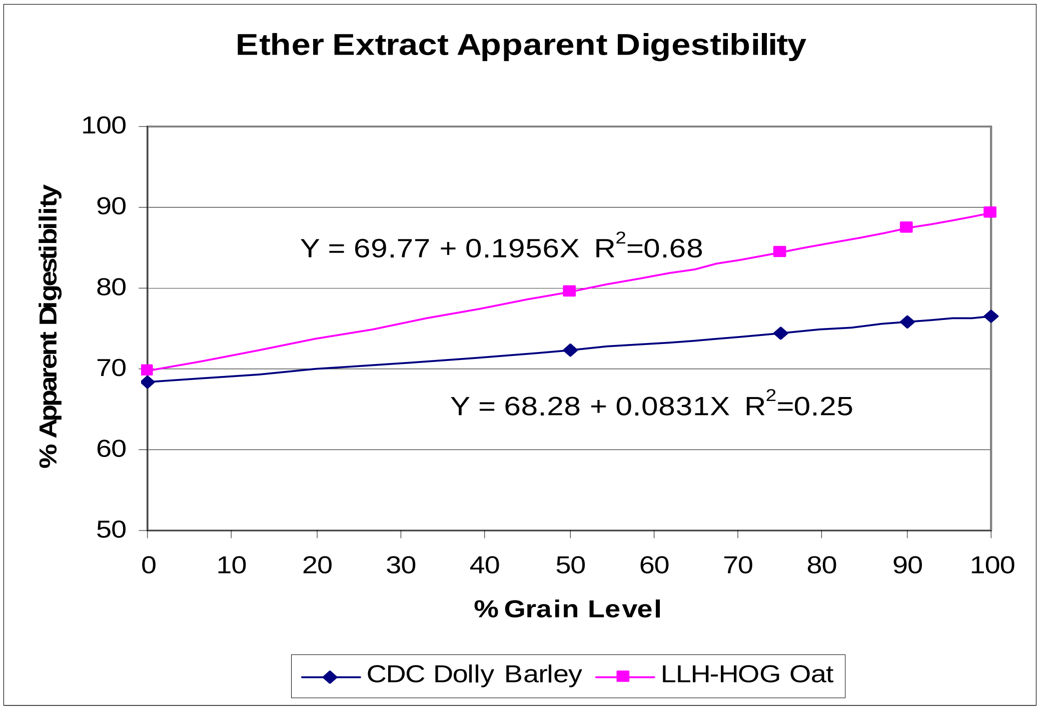

Figure 3.3 Ether extract apparent digestibility of sheep diets containing CDC Dolly barley or LLH-HOG oat (Total collection method)

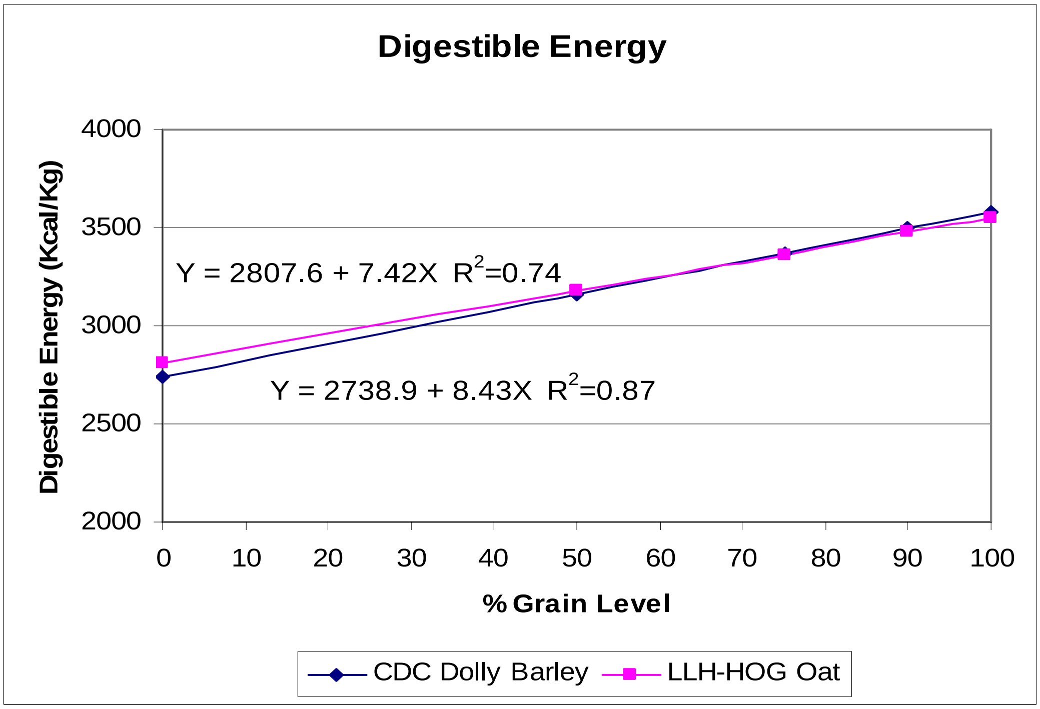

Figure 3.4 Digestible energy of sheep diets containing CDC Dolly barley or LLH-HOG oat (Total collection method)

either low-lignin (0.8%) Murray oat or high-lignin (2.3%) Mortlock oat. The apparent digestibility of DM, organic matter, NDF, and ADF were all significantly greater ($P<0.01$) for the low-lignin Murray oat. Rowe and Crosbie (1988) also observed higher ($P<0.01$) digestible energy in low-lignin Murray oat (3728 Kcal per kg) than the higher-lignin Mortlock oat (3346 Kcal per kg). It was apparent that lower levels of lignin in oat improved their digestibility in ruminants. The current study showed that the apparent digestibility in ruminants of 01-499-04 LLH-HOG oat was comparable to that of CDC Dolly barley.

3.3.6 Ruminal Degradability Evaluation

Rumen *in situ* degradation characteristics of DM, CP, and NDF of 01-499-04 LLH-HOG oat, Derby oat, and CDC Dolly barley were determined (Table 3.6) and the *in vitro* degradability of DM and NDF at three different incubation times was determined for the same samples. The Ørskov and McDonald (1979) equation with the integrated lag time (McDonald 1981) was used to derive degradation curves of DM, NDF, and CP for grains incubated *in situ*. The passage rate (*Kp*) for all *in situ* calculations was assumed at six percent per hour.

3.3.6.1 Dry Matter Degradability

The DM degradation rates of the grains were not different ($P<0.05$), even though CDC Dolly barley had a DM degradation rate of more than twice that of either oat (Table 3.6). Mustafa et al. (1998) did find a difference in the DM degradation rates of barley and oat. These authors observed DM degradation rates of 35.0 and 36.5% per hour in two types of oat, which were greater ($P<0.05$) than the 28.4% per hour observed for barley. In

Table 3.6 Dry matter (DM), crude protein (CP), and neutral detergent fibre (NDF) degradation characteristics of barley and oat when incubated *in situ*

Variable	Grain			SEM	P-value
	CDC Dolly Barley	Derby Oat	LLH-HOG Oat		
Dry Matter					
Kd[1] (%/hr)	26.5	14.9	11.3	3.29	0.066
T0[2] (hr)	0.0	0.0	0.0	-	-
Soluble *A* (%)	38.2b	56.9a	55.8a	0.80	<0.001
Degradable *B* (%)	47.9a	15.9b	20.7b	1.23	<0.001
Undegradable *C* (%)	13.9c	27.2a	23.5b	0.88	0.001
ED[3] (%)	77.0a	68.0b	68.9b	0.39	<0.001
Crude Protein					
Kd[1] (%/hr)	17.7	23.7	33.2	5.47	0.245
T0[2] (hr)	0.5	0.0	0.0	0.31	0.444
Soluble *A* (%)	24.5b	72.9a	71.0a	2.73	<0.001
Degradable *B* (%)	67.8a	21.1b	22.5b	2.54	<0.001
Undegradable *C* (%)	7.7	6.0	6.6	0.78	0.397
ED[3] (%)	74.9b	89.8a	90.0a	0.59	<0.001
Neutral Detergent Fibre					
Kd[1] (%/hr)	10.3ab	12.2a	8.4b	0.67	0.039
T0[2] (hr)	0.0	0.0	0.0	-	-
Soluble *A* (%)	0.0	0.0	0.0	-	-
Degradable *B* (%)	58.7a	36.0c	47.4b	2.07	0.004
Undegradable *C* (%)	41.3c	64.0a	52.6b	2.07	0.004
ED[3] (%)	36.7a	24.0c	26.6b	0.59	<0.001

Passage rate (*Kp*) was assumed six percent per hour
[1]degradation rate
[2]lag time
[3]effective degradability

contrast, even though the DM degradation rates in the current study were not different, the oat samples tended to have a lower DM degradation rate than the barley (Figure 3.5). Similarly, Sauvant et al. (1985); Herrera-Saldana et al. (1990); and Prestløkken (1999) observed numerically higher DM degradation rates in barley (11.6, 8.46, and 40.1% per hour) than oat (10.0, 3.44, and 21.9% per hour).

Much of the variation between the degradation rates in the cited studies was attributed to differences in sample grind size, amount of sample incubated, bag pore size, animal species, and animal diet. Mustafa et al. (1998) used a grind size of 3 mm, with 7 g of sample per bag, having average pore sizes of 41 µm. These authors incubated the samples in one non-lactating Holstein cow consuming a 50% concentrate diet. Savant et al. (1985) used nine non-lactating Alpine goats fed 33% concentrate diets. Three grams of sample ground through a 1 mm screen were weighed into bags with pore sizes between 5 and 10 µm. Herrera-Saldana et al. (1990) used 6 g with the same grind size, but used bags with an average pore size of 50 µm. These authors incubated samples in six crossbred beef steers consuming diets of 60% concentrate. Prestløkken (1999) used three non-lactating dairy cows consuming diets of 30% concentrate. Samples were ground at 1.6 mm and 2 g were incubated in bags with an average pore size of 36 µm.

In the present study CDC Dolly barley had significantly lower DM soluble (*A*) and undegradable (*C*) fractions than either oat. As a result, the degradable (*B*) fraction of CDC Dolly barley was significantly greater than in either oat. Mustafa et al. (1998) reported DM *A* fractions in oat of 43.6 and 44.1% and *B* fractions of 21.6 and 28.1%. They also reported a lower DM *A* fraction (24.9%) and higher *B* fraction (57.3%) in barley. Values this report and reported by Prestløkken (1999) were similar to the current

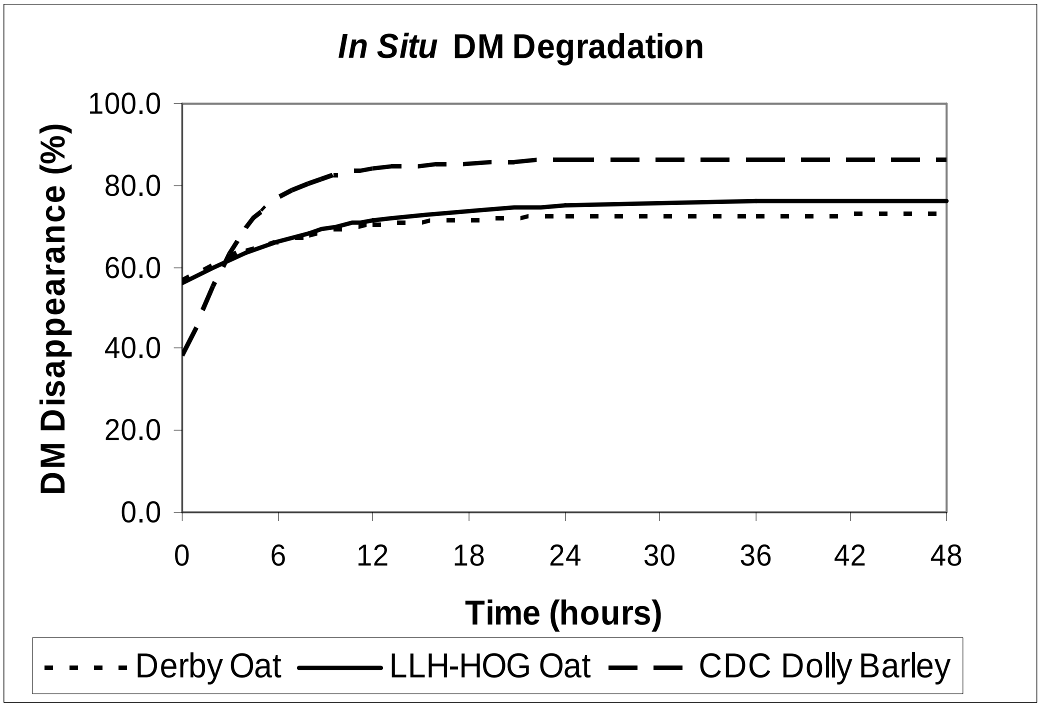

Figure 3.5 Dry matter (DM) degradation rates of barley and oat when incubated *in-situ*

study. Although it can be agreed that oat has a higher *A* fraction, it was apparent that the *C* fraction of oat was also higher than that of barley. Derby oat and 01-499-04 LLH-HOG oat differed only ($P<0.05$) in their *C* fractions, where 01-499-04 LLH-HOG oat had the lower of the two. The small CDC Dolly barley *C* fraction resulted in the highest dry matter effective degradability (ED) of 77.0% ($P<0.05$). The 01-499-04 LLH-HOG oat had an ED of 68.9% and was not different from the ED of Derby oat, which was 68.0%. Mustafa et al. (1998) reported similar findings where barley had an ED of 73.7%, which was greater than the ED of two oat varieties (Calibre and AC Mustang; 68.8 and 62.9%).

3.3.6.2 Crude Protein Degradability

The soluble crude protein content in Derby and 01-499-04 LLH-HOG oat were similar ($P>0.05$). Both had significantly higher *A* fractions and significantly lower *B* fractions than CDC Dolly barley (Table 3.6). Other authors have reported significantly higher *A* fractions in oat versus barley (Herrera-Saldana et al. 1990; Mustafa et al. 1998; Prestløkken 1999). However, none of these studies observed as large a difference between oat and barley as found in the current study, where the soluble *A* fraction of both oat grains were almost three times more than CDC Dolly barley. The CP degradation rates of the three grains were not different. However, it was apparent that oat CP shows greater solubility than does CDC Dolly barley over the first 24 hour of rumen incubation (Figure 3.6). Mustafa et al. (1998) observed faster degradation rates in oat than in barley, and while not significant this was also the trend in the current study. The *C* fraction of the grains was also found to be similar. Even though it was not significantly different, CDC Dolly barley was the only grain with a lag time (TO). The solubility of the CP in oat translated into significantly higher CP ED over CDC Dolly barley. CDC Dolly barley had

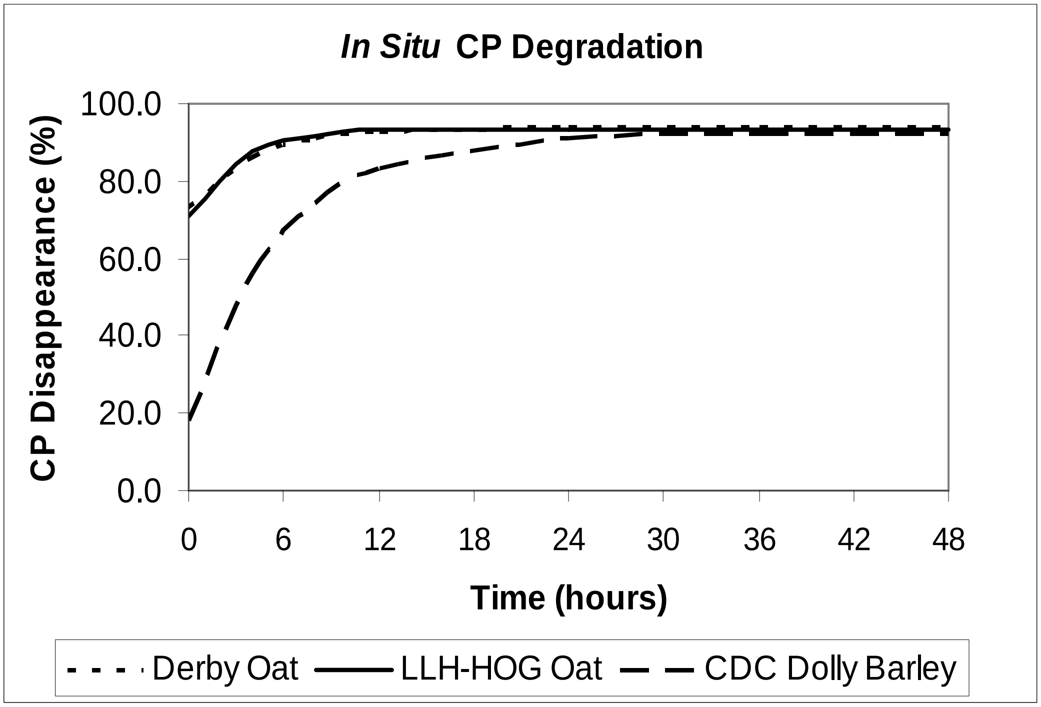

Figure 3.6 Crude protein (CP) degradation rates of barley and oat when incubated *in-situ*

a CP ED of 74.9% while Derby oat was 89.8% and 01-499-04 LLH-HOG oat was 90.0%. Mustafa et al. (1998) found barley CP to have a similar ED (85.0%) to that of Calibre oat (85.3%) and greater than AC Mustang oat (82.9%). The oat grains used in the current study showed advantages over barley in total ruminally available protein, but disadvantages in providing ruminally undegraded feed protein (RUP).

3.3.6.3 Neutral Detergent Fibre Degradability

Derby oat had a significantly higher ($P<0.05$) NDF degradation rate than the 01-499-04 LLH-HOG oat (Table 3.6) and the NDF degradation rate of CDC Dolly barley was intermediate. Thompson (2001) observed similar NDF degradation rates (1.3 and 1.3% per hour) in the hulls of two oat types, Calibre and AC Assiniboia, that differed in ADL content (5.4 and 1.3%). However, Mustafa et al. (1998) observed different NDF degradation rates (4.3 and 11.2% per hour) in two oat grains, AC Mustang and Calibre, with similar ADL contents (7.7 and 7.6%). Calibre oat, as reported by Mustafa et al. (1998), had a higher NDF degradation rate than barley (3.7% per hour), while AC Mustang did not.

In the studies of Mustafa et al. (1998) and Thompson (2001) it was apparent that ADL content had little effect on the degradation rate of the NDF *B* fraction in oat. However, it was possible that ADL content affected the amount of *C* fraction in oat NDF which in turn affected the amount of *B* fraction. In the cited studies and current study, the oat with the greater ADL content had a larger *C* fraction than its respective counterpart. In the instance of Mustafa et al. (1998) both oat varieties had ADL contents greater than 7% and had *C* fractions greater than 70%. Thompson (2001) reported that Calibre, with 5.4% ADL, contained 56.8% *C* fraction, while AC Assiniboia, with 1.3% ADL, had 9.2%

C fraction. Similarly, in the current study Derby oat with 2.6% ADL and 01-499-04 LLH-HOG oat with 1.1% ADL had *C* fractions of 64.0 and 52.6%, respectively. The inverse is true for the NDF *B* fraction in all scenarios, the higher the ADL content the lower the *B* fraction. Even though the NDF degradation rate of Derby oat was greater than that of 01-499-04 LLH-HOG oat, 01-499-04 LLH-HOG oat had more degradable NDF over 48 hours (Figure 3.7). This was because of a lower ADL content resulting in a larger *B* fraction.

The smaller *C* fraction in 01-499-04 LLH-HOG oat offset its slower degraded *B* fraction, which made its overall NDF disappearance greater than that of Derby oat after approximately six hours (Figure 3.7). The NDF composition of oat had a longer-term, positive effect on the degradability of oat in the rumen. The NDF *B* fraction of 01-499-04 LLH-HOG oat was higher ($P<0.05$) than Derby oat (47.4% versus 36.0%), but was lower ($P<0.05$) than CDC Dolly barley (58.7%). The *C* fractions of the grains were different, with CDC Dolly barley having the lowest (41.3%) and Derby oat the highest (64.0%).

The 36.7% NDF ED of CDC Dolly barley was the highest of the three grains, mostly as a result of its larger *B* fraction. The NDF ED of 01-499-04 LLH-HOG oat (26.6%), although not as high as CDC Dolly barley, was significantly greater than that of Derby oat (24.0%). Mustafa et al. (1998) observed similar findings in which barley NDF had an ED greater than oat.

3.3.7 *In Vitro* versus *In Situ*

In vitro DM degradation of grains appeared to plateau after 30 h and NDF degradation did not increase after 24 h (Table 3.7). Although the *in vitro* data could not be statistically analyzed using the Ørskov and McDonald (1979) equation, it showed

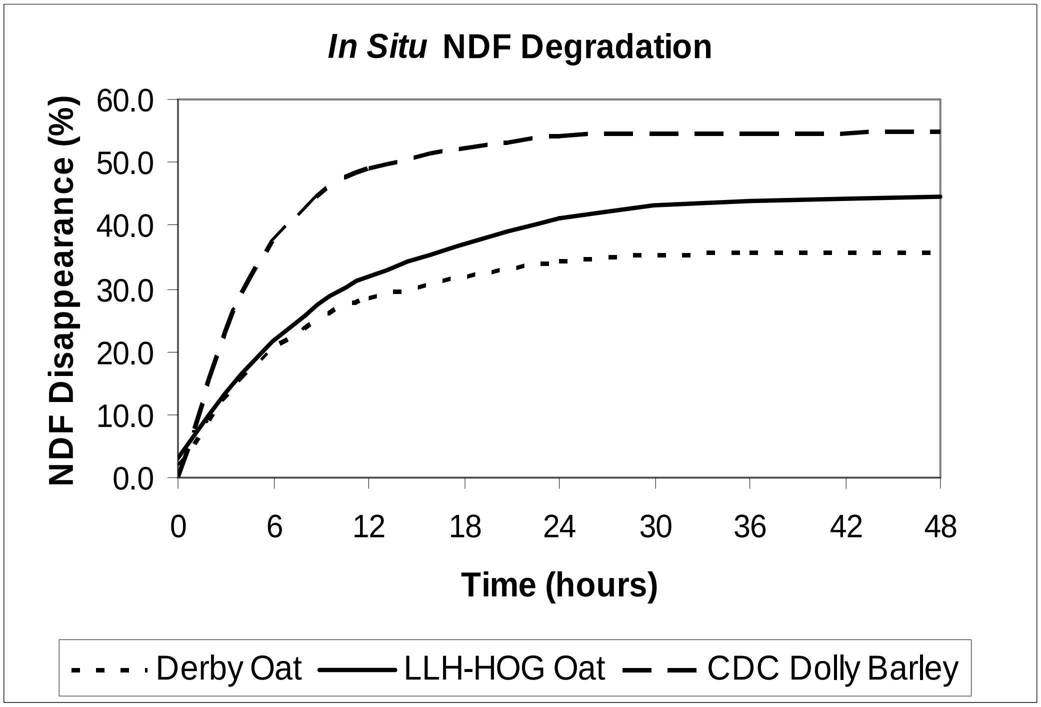

Figure 3.7 Neutral detergent fibre (NDF) degradation rates of barley and oat when incubated *in-situ*

Table 3.7 Mean *in vitro* dry matter and neutral detergent fibre disappearance (%)

	Grain				
Time (hour)	CDC Dolly Barley	Derby Oat	LLH-HOG Oat	SEM	P-value
Dry Matter					
24	69.8a	58.2b	55.9b	0.99	<0.001
30	80.7a	64.0b	65.2b	1.02	<0.001
48	83.9a	66.9b	67.6b	1.14	<0.001
Neutral Detergent Fibre					
24	69.9a	39.4b	44.3b	2.07	<0.001
30	69.0a	41.4c	51.5b	2.73	<0.001
48	65.2a	37.7c	49.8b	2.33	<0.001

Numbers followed by different letters in the same row are different (P<0.05) similar trends to the *in situ* studies. The *in vitro* DM degradation of 01-499-04 LLH-HOG and Derby oat were not different ($P<0.05$) at any time, but both were significantly lower than CDC Dolly barley. The *in vitro* NDF degradation was highest in CDC Dolly barley ($P<0.05$). Derby oat NDF degradation was the lowest ($P<0.05$) at all times except at 24 h where it was similar to 01-499-04 LLH-HOG oat. Even though the degradation of 01-499-04 LLH-HOG oat NDF was lower than that of CDC Dolly barley, the amount of degradable NDF was virtually the same. When considering the NDF concentrations of these grains (Table 3.1) coupled with their degradation after 48 h, the amount of CDC Dolly barley NDF degraded was 18.6% of total DM and 18.9% of 01-499-04 LLH-HOG oat total DM. The degradable NDF present in Derby oat was 14.8% of the total DM. The *in vitro* incubation of cereal grains resulted in similar estimates as determined by *in situ* incubation. Using the *in situ* data, the percentage of DM in the form of potentially degradable NDF was 14.1% in Derby oat, 16.8% in CDC Dolly barley and 18.0% in 01-499-04 LLH-HOG oat.

National Research Council (2001) states the maximum amount of NDF in dairy diets is dictated by the NE_L requirement of the cow, the minimum amount of NFC required for good ruminal fermentation, and the potential negative effects of high NDF on DMI. NDF in feed is negatively correlated with energy content, however not all measures of NDF can be considered equal. Because of the varying proportions of hemicellulose, cellulose, and lignin, two feeds of similar NDF values may not have similar NE_L. This was observed between 01-499-04 LLH-HOG oat and Derby oat. Despite having similar NDF concentrations, 01-499-04 LLH-HOG had a greater NDF degradability than that of Derby oat, thus providing more NE_L. The most prominent cause of this difference was the lower ADL content of 01-499-04 LLH-HOG oat when compared to Derby oat.

3.4 Conclusions

The results of this study indicate that the 01-499-04 LLH-HOG oat has similar nutritional characteristics to CDC Dolly barley and improved nutritional properties compared to Derby oat. Although the sample of 01-499-04 LLH-HOG oat had poor physical properties due to the growing season, it did excel in several important aspects. As expected, the NDF, ADF, and EE content of the oat grains were greater than that of the barley. In fact, 01-499-04 LLH-HOG oat and Derby oat had higher than previously reported values of NDF and ADF for oat (Moe et al. 1973; Rowe and Crosbie 1988; Herrera-Saldana et al. 1990; National Research Council 2001). The intended differences in lower ADL content and higher EE content for 01-499-04 LLH-HOG oat versus Derby oat were confirmed. The result was a high GE and higher TDN and NE_L values for 01-499-04 LLH-HOG oat versus to Derby oat and other reported values for oat. Despite having substantial EE content, 01-499-04 LLH-HOG oat had an EE content lower than some values previously reported (de la Roche et al. 1977; Sahasrabudhe 1979). The major difference between grains in amino acid content was in percent proline. CDC Dolly barley protein contained more proline than either oat, indicating that as dairy feed CDC Dolly barley may support higher milk fat yields (Bruckental et al. 1991). It was apparent that all of the experimental grains could not provide the appropriate recommended balance of lysine and methionine for lactating dairy cattle, as determined by Rulquin and Verite (1993). As such, these amino acids would need to be provided from another source.

The nutrient composition and characteristics of 01-499-04 LLH-HOG oat greatly influenced its digestibility characteristics. When fed to sheep, 01-499-04 LLH-HOG oat showed similar digestibility to CDC Dolly barley. The apparent DM digestibility of 01-499-04 LLH-HOG oat was lower than that of CDC Dolly barley. Nevertheless, the high GE content of 01-499-04 LLH-HOG oat translated into DE similar to CDC Dolly barley. Unfortunately, the DMI of 01-499-04 LLH-HOG oat diets by sheep were considerably lower than the intake of CDC Dolly barley diets. The cause of the lower intake is not clear but it is possible that it is related to the greater fibre content of oat. Depression of feed intake could be achieved through the accumulation of slowly digested fibre in the rumen, leading to gut fill, which limits intake. If this is the situation, added processing may increase the intake of this oat in sheep. Increased lipid in ruminant diets has been shown to impede fibre digestion. It also is possible that with increasing grain the lipid content of rations increased to the point where fibre digestion was decreased. This may have caused the accumulation of fibre in the rumen, depressing intake.

The 01-499-04 LLH-HOG oat *in situ* incubations displayed greater NDF degradability over 24 hours than Derby oat. This property of 01-499-04 LLH-HOG oat was a direct result of its low ADL content in comparison to conventional oat grains. ADL impedes the digestion of nutrients associated with it. Thus, lower ADL content improves the digestibility of the associated nutrients, particularly of the associated structural carbohydrates. Even though the ruminal degradation of 01-499-04 LLH-HOG oat NDF was improved, it remained lower than the ruminal degradability of NDF in CDC Dolly barley. Despite this, the amount of degradable NDF in 01-499-04 LLH-HOG oat was the same as that of CDC Dolly barley after 48 hours of *in vitro* incubation. The improved NDF degradability had little effect on the total DM ruminal degradability of 01-499-04 LLH-HOG oat in comparison to Derby oat.

One clear difference between barley and oat was the solubility of protein. The 01-499-04 LLH-HOG oat and Derby oat had greater protein solubility than CDC Dolly barley. A rapidly soluble protein may not provide by-pass protein in the form of ruminal undegradable protein, but if rumen outflow becomes fast enough, rapidly soluble protein may contribute to by-pass protein. The soluble protein in oat may be considered disadvantageous if enough fermentable carbohydrate is not supplied. Matching these two nutrients in supply and fermentation rate can optimize microbial protein synthesis, while other scenarios would be energy inefficient. Despite the rapid solubility of oat CP, the results observed in the *in situ* trial did not translate into a substantial advantage in apparent digestibility of CP compared to CDC Dolly barley. Although not enough incubation times were used for the fitting of the Ørskov and McDonald (1979) equation in the *in vitro* study, the use of the Daisy *II* Incubator (Ankom Technology 2005) supported the findings of the *in situ* trial.

4.0 OAT GRAIN IN DAIRY TOTAL MIXED RATIONS

4.1 Introduction

In the early part of the twentieth century, oat was the foremost grain used in Canadian dairy herds. This trend continued into the mid 1900s. However, as time progressed recommendations for the use of barley in milk production were becoming more prominent (Morrison 1957). By the twenty-first century, barley had all but replaced oat as the feed grain for dairy cattle. Dairy rations can include a wide array and mixture of feedstuffs. Some nutrient-rich feeds find a niche in dairy feeding, while others, such as barley, are used as a result of their nutrient composition. Oat forages commonly are used in dairy rations while oat grains are considered less desirable in dairy concentrate. This led to the question: can oat grain be a viable option as an energy source in lactating dairy cow rations? To answer this question the Crop Development Centre developed a new type of oat. The concept of LLH-HOG (low-lignin hull, high-oil groat) oat as exemplified by breeding line 01-499-04 was developed with the intent of improving feeding value for ruminants. The goal of this study was to determine the nutritional impact of 01-499-04 LLH-HOG oat grain or Derby oat grain when replacing CDC Dolly barley in high production, lactating dairy cow rations.

4.2 Materials and Methods

4.2.1 Trial Design

Nine lactating Holsteins, six multiparous and three primiparous (80 ± 25 d in milk), were assigned to one of three dietary treatments in a triple replicate three x three Latin square design production trial. This design was used to compare dry matter intake (DMI), bodyweight (BW) change, milk yield, milk composition, rumination characteristics, and TMR nutrient digestibility using acid insoluble ash (AIA) (Jackman 2001), of diets containing 01-499-04 LLH-HOG oat, Derby oat, or CDC Dolly barley. The mean BW of the cows at the start of the trial was 651 ± 80 kg. Cows were housed at the University of Saskatchewan Dairy Barn, Saskatoon, SK. All cows received appropriate care according to the guidelines of the Canadian Council on Animal Care (1993).

4.2.2 Rations and Feeding Management

Total mixed rations (TMR) with a 49:51 forage to concentrate ratio (DM basis) were fed *ad libitum* at 0800 and 1600 h daily. TMR intakes were targeted at an average of 4.6% daily orts (as fed). Each diet was fed for 28 d, with the first 7 d for diet adaptation. Dietary treatments included one of three concentrates, CDC Dolly barley, Derby oat, or 01-499-04 LLH-HOG oat. Each TMR contained 31 to 33% grain on a dry matter basis (Table 4.1). All rations were formulated to meet minimum National Research Council (2001) requirements for nutrients. Cows were housed and fed in individual tie stalls (1.2 by 2.2 m). Fresh water was available *ad libitum* to each cow. Cows were milked twice daily, beginning at 0400 and again at 1500 h.

4.2.3 Milk Samples, Analysis, and Calculations

DMI and daily milk yield were recorded on the last 10 d of each period. Cows were weighed on the last 3 d of each period. In order to test blood urea, blood samples were taken from the tail vein, 2 hour post-feeding, on each of the last 2 d of each period. Milk samples were collected from morning (0400 h) and evening (1600 h) milking on days 26 to 28 of each period. After pooling morning and evening samples, they were

Table 4.1 Dairy production trial diet ingredients (% of DM)

	Diet		
Ingredient	CDC Dolly Barley	Derby Oat	LLH-HOG Oat
Alfalfa Hay	12.7	12.7	12.7
Barley Silage	36.3	36.3	36.3
CDC Dolly Barley	31.1	--	--
Derby Oat	--	31.6	--
LLH-HOG Oat	--	--	33.3
Canola Meal	6.62	6.36	5.49
Soybean Meal	6.62	6.36	5.49
Corn Gluten Meal	2.04	2.04	2.04
Canola Oil	0.76	0.76	0.76
Molasses	0.79	0.79	0.79
Salt (Co-I)	0.32	0.32	0.32
Sodium Bicarb	0.32	0.32	0.32
Dynamate[1]	0.12	0.12	0.12
Limestone	0.57	0.57	0.57
Min-Vit Premix[2]	1.70	1.70	1.70

[1]contained 22% S, 18% K and 11% Mg. (International Mineral and Chemical Corp., Mundelein, IL)

[2]contained 16.1% Ca, 8.5% P, 10.4% Cl, 6.3% Na, 3.3% Mn, 1.8% K, 1% S and 1050 mg Fe, 2100 mg Zn, 1500 mg Mn, 533 mg Cu, 45 mg I, 12 mg Se, 15 mg Co, 333,333 IU vitamin A, 60,000 IU vitamin D3 and 1000 IU vitamin E per kg.

stored at 4 °C until analyzed. Samples were analyzed (Association of Official Analytical Chemists 1990) in duplicate for total solids (TS; method 925.23), milk fat using the Babcock procedure (MF; method 989.04), milk protein using the Kjeldahl procedure (MP; method 984.13), and lactose (ML; method 972.16) using infrared spectroscopy (O-Scan 605, Foss Foods, Denmark). Somatic cell count (SCC) was measured using a Fossomatic 360 (Foss Foods, Denmark). Milk urea nitrogen (MUN) was measured using a Beckman analyzer (Beckman instruments, CA). Blood urea nitrogen (BUN) was measured using enzymatic/kinetic UV assay absorbance in a Roche/Hitachi analyzer (Roche Diagnostics, Laval, QU). Feed samples were analyzed for dry matter (DM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), and gross energy (GE) as described in section 3.2.2. Feed samples were also analyzed for acid insoluble ash (AIA) using the procedure of Vogtmann et al. (1975).

Apparent digestibility (%) using the indicator method was calculated using the following equations:

$$\text{Dry Matter Digestibility (\%)} = 100 - \frac{\text{\% indicator in feed}}{\text{\% indicator in feces}} \times 100 \qquad (4.1)$$

$$\text{Nutrient Digestibility (\%)} = 100 - \frac{\text{\% indicator in feed} \times \text{\% nutrient in feces}}{\text{\% indicator in feces} \times \text{\% nutrient in feed}} \times 100 \qquad (4.2)$$

Fat-corrected milk (3.5% FCM, kg) was calculated using the equation (Bath 1985):

$$\text{3.5\% FCM} = (0.432 \times \text{milk yield}) + (16.23 \times \text{fat yield}) \qquad (4.3)$$

Over the final 48 hours of each period, the cows were observed every five minutes and were categorized as eating, ruminating, lying, or standing for that five minute period. These observations were then used to calculate the total time eating, ruminating, lying, chewing, and the eating rate (grams per minute).

4.2.4 Digestibility of Dairy Total Mixed Rations

Fecal samples were collected from each cow at 1800 h on each of the last 3 d of each period. Approximately 800 g of sample were collected, as rectal grab samples, into individual aluminum pans. After collection, sample weights were recorded and samples were frozen and stored at -20 ^{o}C. On trial completion, all samples were placed in a forced air oven at 55 ^{o}C and dried for 72 hours. Fecal DM was recorded and samples were ground through a 1mm screen using a Christy & Norris mill. Samples collected from individual animals over each period were composited to create one sample for each animal per period. Samples were stored in 150 ml vials at room temperature until chemical analysis was performed.

TMR samples were collected on days of fecal collections. Feed and fecal samples were analyzed for DM, CP, EE, NDF, ADF, and GE as described in 3.2.2 and AIA as described in 4.2.3. Apparent digestibility using the indicator method was calculated using the formulas described in 4.2.3.

4.2.5 Dairy Concentrate Palatability and Preference Test

On completion of the dairy production trial a palatability and preference test (Paterson 1996) was conducted using CDC Dolly barley and 01-499-04 LLH-HOG oat concentrates. This experiment was conducted using the same nine Holsteins as in the production trial. The amount of concentrate offered per feeding was 1050 g. Concentrates were offered for five minutes each, with a five minute interval between offerings. The feed remaining after five minutes was weighed and recorded. This procedure was carried out before TMR was fed at 0800 and 1600 hour for seven consecutive days. The order of concentrate presentation was alternated such that the same concentrate was not offered first on consecutive days.

4.2.6 Statistical Analysis for Milk Production Trial

Data were analyzed as a triple replicated three x three Latin square design with the mixed model procedure of SAS Institute, Inc. (1999). Animal and period were the blocking factors for the trial. Animal and period were treated as random and fixed, respectively. Means were separated based on least significant difference after a protected *F*-test. Significant differences were declared when $P<0.05$.

4.2.7 Statistical Analysis for Preference Test

Data were analyzed by a *t*-test using the mixed model procedure of SAS Institute, Inc. (1999). Using an *F*-test, means and their standard deviations were separated based on least significant difference. Significant differences were declared when $P<0.05$.

4.3 Results and Discussion

4.3.1 Impact of Grains on Milk Yield and Composition

The compositions of samples taken from the TMR were similar in most aspects including CP and GE content (Table 4.2). Although the GE content of the grains showed a large range, in the total ration GE was unaffected. The NDF content of the oat TMR were numerically higher than that of the barley TMR. The percentage of NDF in the oat

Table 4.2 Nutrient levels calculated from analysis of TMR forage and concentrate offered in the Dairy Production Trial (% of DM)

	Diet[1]		
Nutrient (%)	CDC Dolly Barley	Derby Oat	LLH-HOG Oat
Crude Protein	18.7	18.7	19.1
Ether Extract	2.5	3.7	4.2
NDF	31.5	37.3	36.7
ADF	19.0	22.9	21.2
GE (Kcal/kg)	4501	4554	4526
Calcium	0.83	0.83	0.82
Phosphorus	0.46	0.45	0.44
Acid Insoluble Ash	1.96	2.34	2.06

[1]ingredients are found in Table 4.1

rations were attributed to the higher NDF content of the oat grains. National Research Council (2001) reported that NDF concentrations greater than 32% of TMR DM might limit DMI in cows producing approximately 40 or greater kg/d of milk.

Actual and 3.5% FCM yields were not different ($P<0.05$) from cows fed TMR containing CDC Dolly barley, Derby oat, or 01-499-04 LLH-HOG oat (Table 4.3). There was a trend ($P=0.09$) for higher milk yields from cows fed rations containing 01-499-04 LLH-HOG oat. Other studies have shown good results using oat, Tommervik and Waldern (1969) observed no differences in milk yield from cows fed rations containing oat, barley, wheat, corn or milo. Moran (1986) also found no difference in milk yield from cows fed rations containing oat, barley or wheat. A study measuring the fatty acid content of MF from cows fed barley, oat, barley treated with acidified-formalin reagent, or oat treated with acidified-formalin reagent diets revealed no difference in milk yield (Martin and Thomas 1987). Studies comparing oat to lupin as supplements for cows on pasture also observed no difference in milk production (Moate et al. 1984; Valentine and Bartsch, 1989). A study by Fisher and Logan (1969) did show higher solids-corrected milk (SCM) yield (Tyrrell and Reid 1965) in cows fed rations with corn versus oat. It is important to note that these authors reported that less ($P<0.05$) oat concentrate (11.11 kg per day) was consumed by cows compared to corn concentrate (14.16 kg per day), perhaps limiting milk yields of oat fed cows. A study by Petit and Alary (1999) observed no difference in milk yield between cows fed corn or naked oat. In the findings of Moran (1986) daily DMI of wheat, barley, and oat rations were not different but oat rations had the highest FCM yield.

Table 4.3 Results of the Dairy Production Trial

Variable	Diet[1] CDC Dolly Barley	Derby Oat	LLH-HOG Oat	SEM	P-value
Milk Yield (kg/day)	40.0	39.3	42.1	1.74	0.086
Milk Fat (%)	3.45	3.29	3.19	0.135	0.196
Milk Fat (kg/day)	1.37	1.28	1.34	0.069	0.335
3.5% FCM (kg/day)	39.5	37.8	39.9	1.70	0.220
Milk Protein (%)	3.33a	3.16b	3.06c	0.077	<0.001
Milk Protein (kg/day)	1.32	1.23	1.29	0.052	0.080
Total Solids (%)	12.5a	12.2b	12.0b	0.15	0.010
Lactose (%)	4.54	4.51	4.58	0.087	0.100
SCC (x1000/ml)	112	127	100	55.6	0.147
Milk Urea (mmol/L)	6.76b	7.51a	7.04ab	0.301	0.012
Blood Urea (mmol/L)	8.34	9.13	8.61	0.358	0.061
Silage/hay DMI (kg/day)	13.4	13.5	13.2	0.50	0.562
Concentrate DMI (kg/day)	12.3	12.6	12.6	0.46	0.612
Total DMI (kg/day)	25.8	26.1	25.8	0.95	0.799
DMI Standard Deviation	1.01	1.06	1.22	0.136	0.377
DMI/100kg FCM (kg)	66.0	68.9	65.1	3.24	0.079
BW Change (kg/day)	0.38	0.56	0.38	0.156	0.632
Eating (min/24hr)	243b	269a	267a	9.2	0.045
Ruminating (min/24hr)	500	531	527	28.3	0.344
Laying (min/24hr)	745	751	785	50.5	0.565
Total Chewing (min/24hr)	743	800	794	31.8	0.085
Eating Rate (g/min)	107	97	97	3.5	0.057

[1]formulations found in Table 1

It should be noted that with the exception of Petit and Alary (1999), all of the previously mentioned studies mean milk yields did not exceed 28 kg per day. Milk yields in the current study were in excess of 39 kg per day, with the 01-499-04 LLH-HOG oat ration yielding 42.1 kg per day. Again, with the exception of the report by Petit and Alary (1999), the mean DMI of rations, where reported, did not exceed 18.1 kg per day. Tommervick and Waldern (1969) reported oat as having TDN of 79.5%. Using the equation for NE_L by Weiss et al. (1992) the NE_L in Mcal per kg for oat grain would be 1.83, comparable to the 1.82 Mcal per kg calculated for Derby oat in this study. The DMI of the rations in the current study did not differ ($P<0.05$), ranging from 25.8 to 26.1 kg per day (approximately 4.0% DMI as a percent of BW). The study conducted by Tommervick and Waldern (1969) reported DMI between 16.5 and 17.1 kg per day (approximately 3.2% DMI as percent of BW). With NE_L ranging from 1.83 to 2.07 Mcal per kg in five different grains, Tommervick and Waldern (1969) may have experienced differences in milk yield if animals were consuming rations at amounts similar to the current study.

Ekern et al. (2003) observed significantly higher milk production in cattle fed oat versus barley grain. The oat diet also resulted in a significantly higher daily MP yield, but produced lower ($P<0.05$) concentrations of MF and MP. Ekern et al. (2003) also compared regular oat to a high-fat oat, and reported that high-fat oat fed cows yielded more ($P<0.05$) milk, MP, and MF. Unfortunately, the authors were unsure if their findings were due to differences in fat or differences in protein content of the rations. Although not different, the current study did show a trend ($P=0.09$) for 01-499-04 LLH-HOG oat rations to yield more milk than Derby oat rations. Unlike the study by Ekern et al. (2003), 01-499-04 LLH-HOG oat failed to result in higher MP. In fact, 01-499-04 LLH-HOG oat resulted in significantly lower milk MP percentage with no difference in MF yield or concentration.

MF percentage and yield were not different among diets. Moran (1986) observed no difference in MF percentage of oat fed cows compared to wheat and barley though there was a higher MF yield from oat fed cows. Tommervick and Waldern (1969) did not report any differences in MF content in addition to MF yield of cows fed rations with oat, barley, wheat, or corn. Similarly, Fisher and Logan (1969) did not observe differences in MF percentage of oat or corn fed cows even though SCM yield was different.

MP percentage was significantly different among all three TMR, but was not different when measured as total yield (kg per day). Other studies (Logan and Fisher 1969; Moran 1986) showed no difference in MP yield between barley and oat, although in all cases oat resulted in lower MP yield and percentage when differences were observed from other grains (Logan and Fisher 1969; Tommervik and Waldern 1969; Moran 1986; Valentine and Bartsch 1989; Ekern et al. 2003). The percentage of TS in milk was higher ($P<0.05$) in cows fed TMR containing CDC Dolly barley. The differences were attributed to the lower MP percentages observed in oat fed cows. Observations of solids-not-fat in other studies showed similar trends to the TS observations made in the current study (Fisher and Logan 1969; Tommervik and Waldern 1969). MUN was significantly different in cows fed TMR containing Derby oat or CDC Dolly barley. BUN was not affected ($P<0.05$) by grain type but did show a trend ($P=0.06$) towards higher concentrations in cows fed Derby oat rations.

4.3.2 Feed Intake and Bodyweight

DMI, BW change, and DMI as a percentage of 100 kg 3.5% FCM yield were not different ($P<0.05$) between diets (Table 4.3). Fisher and Logan (1969) observed greater ($P<0.05$) concentrate intake in cows fed corn based rations compared to oat based rations. The results of this study were different from the findings of Tommervik and Waldern (1969) where concentrate intake was greater in oat fed cows than for corn fed animals. All cows in the current study averaged DMI greater than 25 kg per head per day. A trend was found ($P=0.08$) in which DMI/100 kg FCM of 01-499-04 LLH-HOG oat TMR fed cows required less DM (65.1 kg) to yield 100 kg of FCM than Derby oat fed cows. Cows gained similar weight on all diets showing that all diets supplied excess energy for milk production at the reported levels. Although the TMR analysis (Table 4.2) showed similar gross energy content in the three rations, it was apparent that the 01-499-04 LLH-HOG oat and CDC Dolly barley rations supplied more DE for lactation than the Derby oat ration.

4.3.3 Dietary Consumption and Feeding Behavior

Cows spent less time ($P<0.05$) eating TMR containing CDC Dolly barley than diets containing oat (Table 4.3). Rumination time, time spent laying, chewing time, and eating rate were not affected ($P<0.05$) by diet type. Total chewing time was numerically lowest ($P=0.09$) in cattle fed CDC Dolly barley TMR. Eating rate also trended ($P=0.06$) to more rapid consumption of the CDC Dolly barley ration. Ruminal acidity is inversely related to the concentration of NDF because NDF ferments slower and is less digestible than NFC (National Research Council 2001). Depending on the physical structure, NDF may also promote chewing and saliva production, improving rumen buffering capacity. It is possible to theorize that the oat rations, because of their greater NDF content and their trend (P=0.09) towards greater total chewing time, provide better rumen buffering than barley based rations. However, ruminal pH measurements were not taken.

4.3.4 Dairy Concentrate Palatability and Preference

When offered concentrate containing CDC Dolly barley or 01-499-04 LLH-HOG oat dairy cattle showed no preference (P>0.05). Dairy cattle ate 1909 g per day of CDC Dolly barley and 1872 g per day of 01-499-04 LLH-HOG oat when offered 2100 g of concentrate daily (Table 4.4). Rowe at al. (2001) observed lower intakes by sheep and cattle of low-lignin Murray oat compared to high-lignin Mortlock oat. In contrast, an earlier study by Rowe and Crosbie (1988) found no difference in intake of the same two oat varieties by sheep. In the dairy production study when oat grain was mixed into TMR, the lignin content of the oat had no effect on dry matter intake by dairy cattle (Table 4.3). The standard deviations of intakes by cows were also compared and were not found different (P<0.05).

4.3.5 Digestibility Determination

Apparent DM digestibility of Derby oat TMR was lower (P<0.05) than the other diets in the dairy production trial (Table 4.5). The apparent DM digestibility of the 01-499-04 LLH-HOG oat ration was not different than that of the CDC Dolly barley ration. Similar trends were observed in the sheep digestibility trial. Using the regression equations (Table 3.4 and Table 3.5) a comparison could be made between the dairy TMR and the 50% forage and 50% grain, sheep rations. Numerically CDC Dolly barley rations had lower CP, EE, and NDF apparent digestibility in both digestibility trials. DM apparent digestibility was greater in CDC Dolly barley rations in both experiments. TMR

Table 4.4 Observed results of the concentrate palatability and preference test

	Concentrate			
	CDC Dolly Barley[1]	LLH-HOG Oat[1]	SEM	P-value
Diet Consumed (g/serving)	1909	1872	54.8	0.600
Standard Deviation	211	132	--	0.159

[1]the amount of each grain offered in a day was 2100 g (1050 g in both the morning and evening)

Table 4.5 Nutrient digestibility of TMR by lactating dairy cows

Digestibility (%)	Diet[1]			SEM	P-value
	CDC Dolly Barley	Derby Oat	LLH-HOG Oat		
Dry Matter	70.7a	63.7b	68.6a	1.20	0.001
Crude Protein	77.0	76.9	78.4	1.00	0.314
Ether Extract	74.5b	83.3a	84.4a	1.22	<0.001
NDF	37.9ab	32.2b	42.9a	2.67	0.022
ADF	15.9	15.4	18.6	3.49	0.704
Gross Energy	72.5a	66.8b	70.8a	1.88	0.004
DE (kcal/kg)	3262a	3040b	3206a	53.9	<0.001

[1]ingredients are in Table 4.1

containing either CDC Dolly barley or 01-499-04 LLH-HOG oat were not significantly different in DE. In the sheep trial, similar rations (50% grain, 50% forage) only differed by 18.5 Kcal per kg. The Derby oat TMR had the lowest DE ($P<0.05$). When comparing the DE of the Derby oat ration to that of 01-499-04 LLH-HOG oat ration, 01-499-04 LLH-HOG oat showed an advantage. Both the high-oil and low ADL content of 01-499-04 LLH-HOG oat contributed to improve DE. Greater oil content contributed to the overall energy content while lower ADL improved the overall digestibility of the oat and thus of the ration.

The EE apparent digestibilities of 01-499-04 LLH-HOG oat and Derby oat rations were significantly greater than the CDC Dolly barley ration. The difference is an effect of added fat increasing apparent digestibility of EE because of the dilution of endogenous fecal fat and non-fatty acid ether-soluble material in the basal diet (Palmquist, 1991). CP and ADF apparent digestibility were not different ($P<0.05$) between diets. Oat NDF made up only a portion of the total NDF in the TMR, approximately 33.2 to 34.5%, but had an obvious impact on the apparent digestibility of the rations. NDF apparent digestibility was different ($P<0.05$) between Derby oat (32.2%) and 01-499-04 LLH-HOG oat (42.9%) rations. The low ADL content of 01-499-40 LLH-HOG oat had a positive effect on digestibility making the NDF in the dairy TMR more digestible compared to conventional Derby oat.

4.4 Conclusions

Dairy cows fed 01-499-04 LLH-HOG oat containing TMR yielded as much milk as cows fed CDC Dolly barley TMR. Feeding 01-499-04 LLH-HOG oat TMR also yielded similar MF and MP but had a significantly lower MP concentration than cows fed the CDC Dolly barley TMR. Very few studies have been conducted on oat grain in dairy rations, but those reviewed support the findings of the current study. Although the NDF concentrations of the oat TMR were greater than that of the CDC Dolly barley TMR, DMI by dairy cows were not different. Dairy cattle also showed no preference when consuming concentrates that contained CDC Dolly barley or 01-499-04 LLH-HOG oat. The 01-499-04 LLH-HOG oat did show improved production compared to Derby oat with a trend to yielding more milk (P=0.09) and MP (P=0.08) from dairy cows fed these oat. The DMI required to yield 100 kg of FCM also trended (P=0.08) lower in cows fed 01-499-04 LLH-HOG oat rations as compared to those fed Derby oat. For this reason it is appropriate to conclude that 01-499-04 LLH-HOG oat, when included in dairy TMR, supplied more energy for the support of high milk yields than did conventional oat grain.

Cows spent more time consuming oat containing TMR than they did barley TMR. Based on NDF concentration and total amount of time cows spent chewing, oat rations may have caused greater saliva production in dairy cows. For this reason it is possible that oat based TMR may have higher ruminal buffering capacity than the barley based TMR.

The apparent digestibility of DM and NDF, and the DE content of 01-499-04 LLH-HOG oat TMR in dairy cows were significantly greater than that for Derby oat TMR. These characteristics of 01-499-04 LLH-HOG oat TMR were also similar to that of CDC Dolly barley TMR. The low-lignin and high-oil characteristics of 01-499-04 LLH-HOG oat made its nutritional qualities in dairy cattle superior to conventional oat and similar, if not better, than barley. The low ADL content of 01-499-04 LLH-HOG oat improved apparent digestibility of NDF and DM, and in combination with the high-oil content, the low-lignin content of 01-499-04 LLH-HOG oat also improved the digestible energy value of this oat breeding line.

5.0 GENERAL DISCUSSION

The 01-499-04 LLH-HOG oat was similar to Derby oat in nutrient composition, with the exception of EE, ADL, and CP content. The 01-499-04 LLH-HOG oat had higher EE, lower ADL, and higher CP, translating into more GE and a greater DM and NDF digestibility. All grains evaluated, including CDC Dolly barley, had unusually high NDF concentrations as compared to published values. For this reason the grain samples from the present study may not have been fully representative of commercial grain of the same type. The 2003 growing season was relatively hot and dry, suggesting that in a normal season these grains may have had lower NDF contents. Other side effects experienced because of the 2003 season included lower than typical TW and plumpness in the oat samples. Although 01-499-04 LLH-HOG oat was a high-oil oat, its lipid content was not as high as some other high-oil oat. The calculated TDN concentration and NE_L content of 01-499-04 LLH-HOG oat were higher than those of the regular oat and similar to barley.

The DMI of oat diets were significantly lower than barley diets fed to sheep. Palatability and/or NDF related rumen fill may have caused the decreased intake. The depressed digestibility of NDF, leading to rumen fill, may have been a result of the high lipid levels in oat upsetting fibre digestibility. Contrary to the digestibility trial, DMI of dairy TMR containing oat or barley were not different. Dairy cows showed no preference when consuming concentrate containing either 01-499-04 LLH-HOG oat or CDC Dolly barley. The species difference for oat preference of cattle and sheep may be a function of the size of the reticulo-omasal orifice, which is larger in cattle. Rolled oat in dairy TMR can be fed to dairy cattle without negative preference or palatability effects.

When fed to sheep, 01-499-04 LLH-HOG oat had similar apparent digestible energy content to CDC Dolly barley. Also, the DE content of 01-499-04 LLH-HOG oat TMR was similar to that of CDC Dolly barley TMR. Because there was no DMI difference by dairy cows the TMR were supplying the same total DE. High producing dairy cattle were able to maintain body weight when fed any of the three TMR. The apparent digestibility of DM, NDF and the DE content of 01-499-04 LLH-HOG oat TMR in dairy cows were similar to CDC Dolly barley TMR and greater than Derby oat TMR.

Because of its lower ADL content, 01-499-04 LLH-HOG oat displayed greater NDF degradability over 24 hours than Derby oat in the *in situ* trial. The NDF degradability of 01-499-04 LLH-HOG oat was improved but remained lower than CDC Dolly barley. Regardless of its lower ADL content, 01-499-04 LLH-HOG oat did not have different ruminal DM degradability than Derby oat. Nevertheless, as previously noted, 01-499-04 LLH-HOG oat TMR had a higher DM digestibility than Derby oat TMR. The NDF content of oat TMR was greater than that of barley TMR. Despite this and the noted differences in the grains, all TMR in the dairy trial were close in GE. Even so, the higher EE and lower ADL of 01-499-04 LLH-HOG oat provided more DE and digestible NDF to lactating dairy cows than Derby oat. It is apparent that the digestibility of 01-499-04 LLH-HOG oat TMR was greater than that of Derby oat TMR and similar to CDC Dolly barley TMR.

Cows fed 01-499-04 LLH-HOG oat TMR yielded as much milk as those fed CDC Dolly barley TMR. This is significant since the experimental TMR contained around one third oat or barley grain. MF and MP yields were also similar, however MP concentration was significantly lower in cows fed 01-499-04 LLH-HOG oat. The amount of 01-499-04

LLH-HOG oat TMR required to yield 100 kg FCM trended (P=0.08) lower than the amount of Derby oat TMR required. When fed to dairy cattle, 01-499-04 LLH-HOG oat showed improved production characteristics versus Derby oat because of its improved digestibility and greater energy content. In addition, 01-499-04 LLH-HOG oat showed similar production characteristics to that of CDC Dolly barley.

There are many special considerations when feeding oat to dairy cattle. It is possible that the higher NDF concentration and greater amount of time spent chewing oat TMR may have caused a greater capacity for rumen buffering. The high NDF content of oat may also allow it to substitute a portion of the forage NDF in dairy TMR. This would be advantageous when considering 01-499-04 LLH-HOG oat because it has similar nutritional value to that of barley and would thus provide more energy if it could be fed at a higher concentration. Another special consideration of oat is its CP solubility. Oat CP was more soluble than that of barley. The carbohydrate fermentation of oat diets would have to match protein fermentation in the rumen to maximize microbial protein and prevent energy inefficiency. Oat has a high CP content and because of this it will provide some of the supplemental protein. Additional RUP may need to be supplemented because of oat’s highly solubility CP.

From the results of this study it was apparent that, because of its low ADL and high EE content, 01-499-04 LLH-HOG oat was more satisfactory for milk production than Derby oat and was similar to CDC Dolly barley. The 01-499-04 LLH-HOG oat, as described in this study, would be an excellent cereal grain for feeding lactating dairy cows in western Canadian dairies.

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Appendix A

Table 1 Nutrient composition of experimental grains (performed by Dairy One, Ithaca, NY, USA)

	CDC Dolly Barley	Derby Oat	LLH-HOG Oat
Energy			
DE (Mcal/kg)	3.63	3.84	3.80
NEL 3X (Mcal/kg)	1.86	1.90	1.95
TDN 1X	82	86.5	85
Horse TDN	83.5	80.5	79.5
Feed Fractions			
CP	12.9	14.1	16.6
SCP%CP	31	25	26
Fat	2.4	6.1	6.9
Starch	47.4	47.4	41.0
Sugar	4.0	3.2	3.1
NDF	20.7	21.3	26.9
ADF	7.3	9.6	10.1
NFC	63.1	56.5	47.3
NSC	51.5	50.5	44.2
NDIN	2.1	1.2	1.3
ADIN	0.2	0.3	0.4
Ash	3.00	3.30	3.16
Lignin	2.4	1.8	2.2
Minerals			
Calcium	0.14	0.09	0.11
Phosphorus	0.30	0.35	0.50
Magnesium	0.13	0.16	0.18
Chloride Ion	0.18	0.18	0.23
Potassium	0.59	0.55	0.62
Sodium	0.023	0.029	0.023
Sulfur	0.17	0.21	0.22
Copper (PPM)	5	7	11
Iron (PPM)	102	204	175
Manganese (PPM)	16	41	36
Zinc (PPM)	29	21	31
Molybdenum (PPM)	1.2	1.5	2.1

Table 2 Mean dry matter intake and nutrient apparent digestibility for diets offered during digestibility trial (Total collection method)

	Grain Source			
Level[1] (% DM)	CDC Dolly Barley	LLH-HOG Oat	SEM[2]	P-value
Dry Matter Intake (% of BW; 90% ad libitum)				
0	1.86	1.86	0.145	1.000
50	2.57	2.03	0.145	0.013
75	2.75	1.93	0.145	<0.001
90	2.58	1.97	0.145	0.004
100[3]	**2.89**	**1.99**	--	--
Dry Matter Apparent Digestibility (%)				
0	65.3	65.3	1.57	1.000
50	70.7	71.8	1.57	0.515
75	73.9	70.5	1.57	0.044
90	79.0	73.1	1.57	<0.001
100[3]	**79.1**	**74.0**	--	--
NDF Apparent Digestibility (%)				
0	54.0	54.0	2.45	1.000
50	46.5	59.5	2.45	<0.001
75	47.3	53.2	2.45	0.097
90	52.5	52.0	2.45	0.893
100[3]	**54.9**	**47.4**	--	--
ADF Apparent Digestibility (%)				
0	44.3	44.3	3.19	1.000
50	39.2	44.6	3.19	0.238
75	36.1	37.1	3.19	0.817
90	45.9	39.2	3.19	0.142
100[3]	**40.3**	**37.7**	--	--

[1]indicates amount of grain (CDC Dolly barley or LLH-HOG oat) in diet
[2]pooled SEM
[3]values calculated using equations in Table 3.5

Table 3 Mean nutrient apparent digestibility for diets offered during digestibility trial (Total collection method)

	Grain Source			
Level[1] (% DM)	CDC Dolly Barley	LLH-HOG Oat	SEM[2]	P-value
Crude Protein Apparent Digestibility (%)				
0	67.8	67.8	1.24	1.000
50	67.8	72.6	1.24	0.009
75	69.0	73.0	1.24	0.027
90	73.8	74.6	1.24	0.629
100[3]	**75.7**	**75.5**	--	--
Ether Extract Apparent Digestibility (%)				
0	68.2	68.2	1.72	1.000
50	72.7	81.1	1.72	0.001
75	72.8	84.2	1.72	<0.001
90	76.7	85.6	1.72	<0.001
100[3]	**76.6**	**89.3**	--	--
Digestible Energy (Kcal/Kg)				
0	2754	2754	49.9	1.000
50	3116	3271	49.9	0.034
75	3294	3303	49.9	0.894
90	3544	3439	49.9	0.146
100[3]	**3582**	**3550**	--	--

[1]indicates amount of grain (CDC Dolly barley or LLH-HOG oat) in diet
[2]pooled SEM
[3]values calculated using equations in Table 3.5

Table 4 Mean nutrient apparent digestibility for diets offered during digestibility trial (Indicator method)

Level[1] (% DM)	Grain Source		SEM[2]	P-value
	CDC Dolly Barley	LLH-HOG Oat		
Dry Matter Intake (% of BW; 90% ad libitum)				
0	1.86	1.86	0.151	1.000
50	2.57	2.12	0.151	0.045
75	2.73	1.93	0.151	0.001
90	2.54	1.97	0.151	0.012
Dry Matter Apparent Digestibility (%)				
0	62.6	62.6	1.74	1.000
50	65.0	71.2	1.74	0.018
75	67.8	68.9	1.74	0.641
90	70.2	72.1	1.74	0.446
NDF Apparent Digestibility (%)				
0	52.6	52.6	3.29	1.000
50	37.7	60.4	3.29	<0.001
75	37.8	52.9	3.29	0.002
90	35.6	52.3	3.29	0.001
ADF Apparent Digestibility (%)				
0	42.8	42.8	4.43	1.000
50	29.4	45.9	4.43	0.014
75	24.7	36.5	4.43	0.070
90	26.3	39.4	4.43	0.046

[1]indicates amount of grain (CDC Dolly barley or LLH-HOG oat) in diet
[2]pooled SEM
[3]values calculated using equations in Table 3.5

Table 5 Mean nutrient apparent digestibility for diets offered during digestibility trial (Indicator method)

	Grain Source			
Level[1] (% DM)	CDC Dolly Barley	LLH-HOG Oat	SEM[2]	P-value
Crude Protein Apparent Digestibility (%)				
0	66.7	66.7	1.98	1.000
50	62.5	72.7	1.98	0.001
75	62.1	72.6	1.98	<0.001
90	63.2	74.8	1.98	<0.001
Ether Extract Apparent Digestibility (%)				
0	66.9	66.9	2.52	1.000
50	67.7	81.5	2.52	<0.001
75	66.5	84.0	2.52	<0.001
90	62.8	85.7	2.52	<0.001
Digestible Energy (Kcal/Kg)				
0	2708	2708	75.4	1.000
50	2904	3294	75.4	0.001
75	3050	3294	75.4	0.030
90	3165	3445	75.4	0.014

[1]indicates amount of grain (CDC Dolly barley or LLH-HOG oat) in diet
[2]pooled SEM
[3]values calculated using equations in Table 3.5

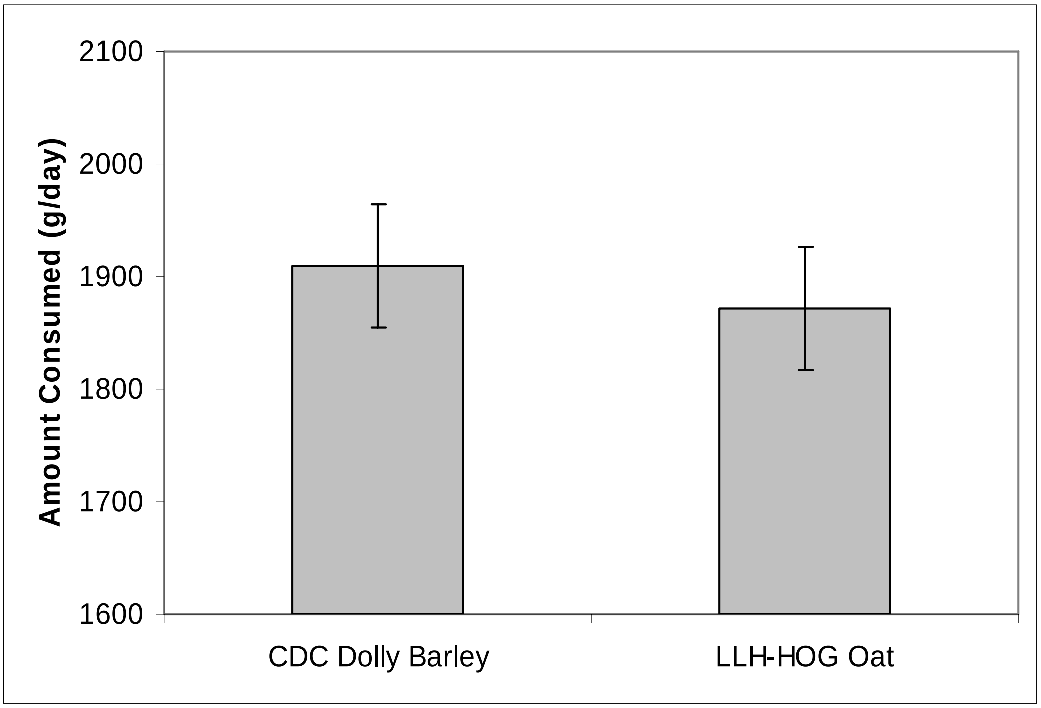

Figure 1 Mean concentrate consumed per day and SEM during the preference test. The amount of each grain offered in a day was 2100 g (1050 g in both the morning and evening).

Table 6 Incubation schedule for *in situ* analysis

Incubation Time (hour)	Day	Number of Bags per Sample	Time of bag placement
48	1	4	8pm
36	2	3	8am
24	2	3	8pm
12	3	3	8am
8	3	2	12pm
4	3	1	4pm
0	3	1	Extract & Wash - 8pm

Table 7 Mineral and vitamin content of 1:1 sheep mineral.

Variable	Guaranteed Analysis	Amount
Calcium (%)	Act.	16.0
Phosphorus (%)	Act.	16.0
Sodium[1] (%)	Act.	4.0
Zinc (ppm)	Act.	1,660
Iodine (ppm)	Act.	25
Iron (ppm)	Act.	4,000
Manganese (ppm)	Act.	800
Cobalt (ppm)	Act.	14
Flourine (ppm)	Max.	3,000
Vitamin A (IU/kg)	Min.	202,400
Vitamin D_3 (IU/kg)	Min.	33,300
Vitamin E (IU/kg)	Min.	400

*contains added selenium at 7 ppm
[1]equivelant to approximately 10.0% salt

Table 8 Mineral content of cobalt iodized salt.

Variable	Guaranteed Analysis	Amount
Sodium (%)	Act.	38.5
Iodine (ppm)	Act.	150
Cobalt (ppm)	Act.	100
Salt (%)	Min.	97