THE EFFECT OF FEEDING DIETS MATCHED FOR RATE OF DEGRADATION OF CARBOHYDRATE AND PROTEIN ON MILK PRODUCTION CHARACTERISTICS OF DAIRY COWS.

By

WICLIFF KHUZWAYO ADAMSON TEMBO

B. Agric. Sci., The University of Zambia, 1981
M.Sc., (Animal Sciences) The University of Manitoba, 1987

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Department of *ANIMAL SCIENCES*

The University of British Columbia
Vancouver, Canada

Date *22nd DEC, 1995*

ABSTRACT.

Adequate knowledge of the ruminal degradation characteristics of feedstuffs fed to ruminants is paramount to successful ration formulation using the recently proposed protein rationing systems. In the first of two trials, in situ rumen degradation characteristics of cereal grains with or without steam rolling, roughages and agro-byproducts were evaluated. In vitro starch release of the cereals by the enzyme amyloglucosidase was also investigated.

Steam rolling (SR) significantly reduced the in situ rate of degradation of DM, CP and starch of cereal grains. Compared to unprocessed cereals, in situ rate of degradation of these parameters was significantly lower for corn than for barley or wheat, for both the steam rolled and the unprocessed treatments. However, SR tended to increase the in vitro starch release by amyloglucosidase from cereal grains. In situ degradation characteristics varied significantly ($P < 0.01$) among roughages and agro-byproducts, with alfalfa hay and rye distillers grains having higher rates of degradation. Beet pulp had the highest neutral detergent fiber (NDF) ($P < 0.01$) effective degradability among the agro-byproducts.

In the second trial, twelve lactating dairy cows were used to determine the effect of diets matched for rate of carbohydrate and protein degradation on feed intake, digestibility, rumen and blood components, and the yield and composition of milk. Four diets;

steam-rolled corn-fish meal (SRC-FM), steam-rolled corn-canola meal (SRC-CM), steam-rolled barley-fish meal (SRB-FM) and steam-rolled barley-canola meal (SRB-CM) were all fed with alfalfa hay to the cows four times per day. Feed intake was not influenced by source of carbohydrate or protein (P>0.10), but the digestibility of most nutrients was significantly influenced (P<.10) by source of carbohydrate, being higher on the SRB diets than on the SRC diets.

Total rumen volatile fatty acids and rumen ammonia nitrogen were significantly influenced by source of protein (P<0.10), with most other parameters, including blood parameters, showing significant interactions (P<0.01) between source of carbohydrate and source of protein. Milk production, and the yield of protein, total solids (TS), and solids-not-fat (SNF) were significantly influenced (P<.01) by source of carbohydrate, with the cows consuming SRB diets producing more of the above than those consuming SRC diets. Percent fat and percent SNF were higher and lower respectively on the SRC diets than the SRB diets.

With alfalfa hay as roughage, SRB, when fed in combination with either FM or CM, resulted in more milk production than when SRC was fed with either FM or CM.

Different starch and roughage sources and agro-byproducts degrade at different rates. This variability in degradation characteristics can be exploited in ration formulation in such a way that the provision of energy can be matched to the provision of nitrogen in order to optimize microbial production, maximize performance and minimize protein wastage.

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Dedicated to my family and my own family

My dad and mama used to say,
'Kulimbikila zabwino zili mtsogoro'(nyanja)
which means,
'Stay strong, the goodies are in the future'

GENERAL INTRODUCTION.

The ability of ruminant animals to utilize fibrous feedstuffs has allowed man to maintain these animals and produce meat and milk wholly on roughages. Efficient and economic meat and milk production requires a sufficient supply of nutrients from the rumen and small intestines to optimise production.

In spite of the ability to utilize fibrous feeds and maintain body weight and support moderate production levels, ruminants have limited capacity to consume large amounts to meet their nutrient requirements, particularly cows in early lactation and young growing animals. Good quality roughage can supply energy, protein and other nutrients. However imbalance of these nutrients results in an inadequate or over-supply of some nutrients to the animal. In light of the above facts, supplementation of roughages with concentrates becomes important to correct the imbalances and ensure an adequate supply of nutrients in order to realise the full potential of the animal.

Supplementation with concentrates results in increased dry matter intake (DMI) and supply of nutrients and improved animal performance (Galloway et al., 1993 and Foster et al., 1993).

Species, variety, storage, handling and processing of concentrates are among the factors that determine the quality and ruminal degradation characteristics. Cereal grains contain large amounts of starch and are therefore included in diets as energy

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supplements, while concentrates based on animal and oil-seed byproducts are used as protein supplements.

Concentrate feeds are compounded usually from high energy and protein ingredients which commonly include cereal grains and plant and animal protein sources, respectively. When these materials are consumed they undergo fermentative breakdown in the rumen, releasing energy and nitrogen which are utilized by microbes to build their own cells. A portion of the feed that does not get digested in the rumen plus microbial protein, passes to the small intestine where it is digested by pancreatic and intestinal enzymes. Microbial protein is able to meet protein requirements for most animals at different production stages because of its high quality compared to most feed protein (Storm and Ørskov, 1983). However, increased nutrient demands by high-producing early-lactation dairy cows and young growing beef animals may result in microbial protein not being adequate to meet the animal's requirements for amino acids such as methionine and lysine which are limiting in microbial protein (Storm and Ørskov, 1983, 1984). It has been proposed that providing some of the dietary protein in an undegradable form in the rumen and maximizing microbial protein synthesis through proper carbohydrate and protein ration balancing is the solution to meeting the higher protein requirements for high producing dairy cows and fast young growing beef steers (Nocek and Russell, 1988). Therefore, knowledge of the behavior of carbohydrates and proteins in the rumen becomes important in order to optimise utilization of both energy and protein supplements.

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Carbohydrates include plant material derived from the cell-wall, referred to as structural carbohydrates (SC) and that portion derived from cell-contents referred to as non-structural carbohydrates (NSC) (Van Soest, 1982 and Van Soest, 1986).

Non-structural carbohydrates which include sugars and starches are more soluble than SC which includes all materials related to cell-wall including cellulose, hemicellulose, lignin, silica, and heat damaged protein. Also differences in solubility exist between and within carbohydrate groups. Sugars are more soluble than starches which are more soluble than the complex molecules of cell-walls (Van Soest, 1982 and Van Soest, 1986).

Evaluation of five cereal grains, corn, sorghum, wheat, oats, and barley showed greater in vitro and in situ degradation of barley, wheat and oat starch than to starch from corn and sorghum (Herrera-Saldana et al., 1990b). Similar results in vitro (Malestein et al., 1988, and Cone et al., 1989) and in situ (Fiems et al., 1990; Tamminga et al., 1990, and Malcolm and Kiesling, 1993) have been reported. Processing such as grinding, dry rolling, steam flaking, steam rolling and popping resulted in increased in vitro (Malestein et al., 1988, and Cone et al., 1989) and in situ starch degradation for most grains (Galyean et al., 1981; Theurer, 1986 and Thomas et al., 1988). However other workers reported decreased in situ starch degradation due to steam flaking of corn, wheat and barley (Fiems et al., 1990), steam rolling of barley (Engstrom et al., 1992) and extrusion or expansion of wheat, barley and corn (Arieli et al., 1995). However, degree of gelatinization

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measured in vitro using granular amyloglucosidase enzyme or birefrigence shows that sugar and starch release is improved after steam-flaking (Fiems et al., 1990 and Malcolm and Kiesling, 1993) and steam rolling (Mathison et al., 1991). In vivo studies also support in vitro and in situ findings. Barley starch was more degradable in the rumen than starch from corn; however total digestibility was similar (Spicer et al., 1986; McCarthy et al., 1989; Herrera-Saldana et al., 1990a and Huntington, 1994). Steam rolling and flaking increased in vivo ruminal DM and starch digestibility of grains (Hale, 1973; Galyean et al., 1981 and Theurer, 1986). Steam-rolling also helps to reduce fines and therefore dustness resulting in improved intakes for certain cereal grains such as barley.

Similarly structural carbohydrates, like non-structural carbohydrates, degrade at different rates and to different extents. Varga and Hoover, (1983) reported higher in sacco degradability of NDF for alfalfa hay and clover than for grasses such as orchard grass, while NDF from corn silage was more readily degraded than NDF from legumes and grass hays. Corn cobs, soy hulls and a hay crop silage were lowest in rate of degradation while agro-byproducts were similar or slightly lower than legume and grass hay and agro-byproducts such as wheat bran, brewers grain, beet pulp. Similar results have been observed for legumes and grasses using in vitro (Darcy and Beylea, 1980 and Beylea et al., 1983) and in vivo (Holden et al., 1994) techniques and also other in situ methods (Shaver et al., 1988). Other workers have reported differences in

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the rate of DM and neutral-detergent-fiber (NDF) degradation of a wide range of feedstufs including byproducts (Souvant et al. 1985; Tamminga et al., 1990 and de Smet et al., 1995). These differences in carbohydrate breakdown in the rumen can be exploited in ration formulation so that energy release is consistent and adequate to capture the nitrogen released during fermentation.

Proteins from different sources, like carbohydrates, degrade at different rates in the rumen (Hvelplund, 1985; Tamminga et al, 1990; Herrera-Saldana et al., 1990b; Erasmus et al., 1990, 1994 and Stern et al., 1994). Some physical (eg, mechanical extraction of oil from soybean) and chemical processes (extraction of oil from soybean using hexane) applied during feed or food processing contribute to the decrease in protein degradation in the rumen (Hvelplund, 1985 and Stern et al., 1994). In order to utilize protein efficiently, it is important that nitrogen release is coordinated with presence of sufficient carbohydrate for the capture of nitrogen by bacteria and also to minimize protein wastage (Nocek and Russell, 1988 and Herrera-Saldana et al., 1990a).

In order to accomplish the above, knowledge of ruminal and intestinal behavior of carbohydrates and proteins for feed ingredients is important for proper balancing of the ration to maximize microbial protein production in the rumen and also to provide sufficient total dietary nutrients to meet the animal's nutrient requirements.

The main objectives of this study were;

1. To determine the rate and extent of breakdown of DM, CP, starch and NDF of commonly used cereals, roughages and agro-byproducts using in situ and in vitro methods,

2. To determine the effect of feeding diets matched for rate of carbohydrate and protein degradation on nutrient intake, apparent total tract digestibility, ruminal and blood parameters and milk production characteristics of lactating dairy cows.

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CHAPTER 1.   LITERATURE REVIEW.

1.1. DEGRADATION OF CARBOHYDRATES AND PROTEINS.

1.1.1.   DEGRADATION OF CARBOHYDRATES.

1.1.1.1. General.

Digestion or degradation of carbohydrates decreases as you move from simple sugars, oligosaccharides through pectins and beta-glucans to starch (Van Soest, 1982, 1986). Structural carbohydrates (SC) are less degraded in the rumen than non-structural carbohydrates (NSC). Therefore, nutrient availability in the rumen is dependent on the relationship between non-structural and structural carbohydrates in the feedstuff.

Reasons for differences in degradability of carbohydrates include simplicity/complexity of molecules (simple sugars vs starch), chemical and physical structure of the molecule (inter and intra carbohydrate differences- starch vs NDF and amylose vs amylopectin), physical and chemical association between DM components (lignin/hemicellulose and cellulose, starch/proteins and fats) and source of carbohydrate (legume vs grasses, roughages vs grains, barley vs corn, etc.) (French, 1973; Moran, 1982 and Rooney and Pflugfelder, 1986).

1.1.1.2. Structure of starch.

Starch is a heterogeneous polysaccharide composed of the two polymers, amylose and amylopectin. Amylose is a linear molecule of

900-3000 d-glucopyranose residues linked by α-1,4 bonds. Amylopectin is highly branched polymer, averaging 10^4-10^5 glucose residues and consisting of α-1,4-linked D-glucan chains joined at branch points by α-1,6 bonds (Guilbot and Mercier, 1985; French, 1973; Banks and Muir, 1980 and Williams, 1968). These polymers are deposited within endosperm cells in the semicrystalline granules whose shape (lenticular, polyhedric or spherical), size (1-38μm) and percent content of amylose and amylopectin vary with plant species and cultivar (Guilbot and Mercier, 1985; Banks and Muir, 1980 and Williams, 1968). Starches purified from nonwaxy and heterowaxy cultivars of various grains contain 14-34% amylose. Starches from waxy cultivars have less than 1% amylose. The starch granule is minimally hydrated and is stabilized by inter- and intramolecular hydrogen bonding. Unless the granules are damaged by grain processing, they are resistant to water entry and are not hydrolyzed by all amylases (Guilbot and Mercier, 1985; Williams, 1968, Robyt and Whelan, 1968 and Fogarty and Kelly, 1979).

The distribution of the starch granules within the kernel varies with cereal grain type and cultivar (French, 1973 and Moran, 1982). In brief, the cereal kernel contains three components; 1. the protective outer covering (pericarp), 2. the embryo (germ) and 3. the endosperm. The pericarp and the germ regulate water uptake by the mature kernel. They contain little starch ánd together represent a small percentage of the kernel. Most of the starch is in the endosperm, which can be divided into the the outermost aleurone layer, the peripheral endosperm (subaleurone layer), the

underlying corneous endosperm and innermost, floury endosperm. The aleurone cells do no contain starch granules but do contain autolytic enzymes, amylases and protease inhibitors, water-soluble vitamins, minerals and spherical bodies that contain protein and lipid. The starch granules in the peripheral and corneous endosperm are surrounded by protein storage bodies matrix of the dried endosperm cells. This matrix consists mainly of protein and non-starch carbohydrates and is relatively impervious to water and hydrolytic enzymes. In contrast, the floury endosperm has little cellular structure and the highest density of starch granules. The starch granules are more accessible to enzymatic hydrolysis in this portion of the endosperm (Rooney and Miller, 1982; Seckinger and Wolf, 1973). The proportions of peripheral, corneous and floury endosperm vary among cereal grains. Grain cultivars whose kernels have high proportions of peripheral and corneous endosperm are termed vitreous, corneous or flinty because of their glassy appearance. Kernels containing high proportions of floury endosperm are chalky in appearance and are termed floury, opaque or soft.

Cereal processing is done to aid digestion and to facilitate the mixing of ingredients in the manufacture of compound feeds. Processing is performed to increase the surface area exposed to bacterial and/or enzymatic activity or to change physical or chemical properties.

Cereal processing methods, such as, steam-rolling, steam-flaking, extrusion and expansion, involve hydrothermal and mechanical actions to break down the endosperm structure, exposing

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the starch granules and causing varying degrees of starch granules absorb water, swell and finally release amylose and amylopectin irreversibly from their semicrystalline arrangement (Guilbot and Mercier, 1985; French, 1973 and Banks and Muir, 1980). Steam rolling, in case of barley, is sometimes done to reduce fines, thereby reducing dustiness of the ground grain. If water is applied, the polymers become hydrated, increasing their susceptibility to enzymatic hydrolysis (Guilbot and Mercier, 1985; French, 1973; Banks and Muir, 1980 and Williams, 1968). During processing, the peripheral and corneous regions of the endosperm retain their structure longer than the floury endosperm retain their structure longer than the floury endosperm. Thus, more starch damage and gelatinization occur in the floury endosperm than in the corneous or peripheral endosperm than in the corneous or peripheral endosperm during processing (Rooney and Miller, 1982).

1.1.1.3. In vitro degradation of starch.

Starch is the main component and most abundant of all the NSC and is therefore the major energy source for most animals where cereal grains are available. It is however perplexing to note that it seems to have been protected through crystallinity or some other modification to prevent it from becoming a readily available energy source to animals (Van Soest, 1986).

Differences in in vitro rates of starch degradability using rumen fluid (Malestein et al., 1988; Cone et al., 1989 and Cone and Vlot, 1990) and/or pure enzyme preparations have been reported

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(Malestein et al., 1988; Herrera-Saldana and Huber, 1989; Cone et al., 1989 and Cone and Vlot, 1990).

Malestein et al. (1988), Cone et al. (1989) and Cone and Vlot, (1990) showed a constant ranking in degree of degradability of different starch sources upon 6 h incubation with rumen fluid from cows fed either a hay or hay plus concentrate diet. Unprocessed maize was less degraded than wheat and wheat was less degraded than barley. Steam flaking and popping significantly increased grain degradability. For all samples, starch degradation was higher in cows fed a hay-concentrate than a hay diet alone. This difference was attributed to differences in amylolytic activity of the microflora (Malestein et al., 1988 and Cone et al., 1989). These results are in agreement with those of Herrera-Saldana and Huber, (1989) and Herrera-Saldana et al., 1990b.

1.1.1.4. In situ degradation of starch.

There are limited data regarding in situ rates of starch degradation, in spite of increased interest in starch, and this can be seen from recently published reviews (Nocek and Tamminga, 1991; Hoover and Stokes, 1991; Huntington, 1994 and Stern et al., 1994). Herrera-Saldana et al. (1990b) found that corn, milo and oats had significantly lower rates of in situ starch degradation than wheat or barley, which were similar. Oats showed had the highest rapidly degradable fraction of starch compared to the rest of the cereals. Barley and wheat had similar amounts of starch that were degraded but were higher than corn and milo which were very low. Tamminga

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and et al. (1990) and Hussein et al. (1991a) have published rumen degradation characteristics of starch plus sugars of several concentrate ingredients. Their results confirm the findings of Herrera-Saldana et al., (1990b).

1.1.2. DEGRADATION OF PROTEINS.

1.1.2.1. General.

All animals require nitrogen (N) for muscle tissue, hormone and enzyme synthesis. Nitrogen in feedstuffs for animals is supplied in the form of true proteins and non-protein nitrogen (NPN). In the case of monogastric animals the ultimate end products of protein digestion are peptides and amino-acids, which are subsequently absorbed to provide nourishment. This means that digestion in monogastrics results in end products that are similar in composition to the feed consumed by the animal. In ruminants on the other hand, dietary protein first undergoes fermentation in the rumen releasing ammonia-N, amino-acids and peptides. A small part of these end products is absorbed into the blood system and the major part of it is used by rumen microbes to synthesise their own body proteins. These microbes are washed down to the small intestines together with the unfermented feed where they are digested by pancreatic and intestinal enzymes yielding amino-acids and peptides which are subsequently absorbed. This means that the composition of end products of digestion in ruminants is not similar to the composition of dietary protein because of the substantial changes that the feed undergoes in the rumen. It is

therefore important that feeding of ruminants takes into consideration both feeding for microbial growth and feeding of the animal itself.

Work in vivo, in vitro, and with pure cultures has shown that some amino acids were rapidly removed from culture or rumen fluid while others accumulated (Lewis and Emery, 1962: Chalupa, 1976 and Scheifinger et al., 1976), implying that a preference for certain amino acids exists. Several species of rumen bacteria require specific amino acids for growth (Forsberg, 1978; Jones and Pickard, 1980 and Gomez-Alarcon et al., 1982). Work in vitro with mixed cultures indicated that certain amino acids or groups of amino acids stimulate microbial growth more than others (Maeng et al., 1976). Some bacterial strains require amino acids in peptide form (Pitman and Byrant, 1964 and Pitman et al., 1967), and work in vitro has shown that peptide carbon is more efficiently utilized than amino acid carbon (Wright and Hungate, 1967). Argyle and Baldwin (1989) reported that little bacterial growth occurred with ammonia as the sole N source using in vitro techniques.

While the presence of microbes in the gut has allowed ruminants to utilize fibrous feeds, this has been a challenge to ruminant nutritionists. Monogastric nutritionists are now able to selectively feed for specific dietary requirements for amino-acids without concern that the dietary amino-acids profile will be changed. Because of these differences in the abilities of monogastrics and ruminants to utilize fibrous feeds and proteins (and other feed components) ruminant nutritionists have proposed

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carbohydrate (Goering and Soest, 1970; Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992 and O'Connor et al., 1993) and protein rationing systems (ARC, 1984; NRC 1985; NKJ, 1985; Verite and Peyraund, 1989 and AFRC, 1992) for feed analysis, characterisation and feeding standards.

All systems agree that protein rationing of ruminants requires provision of nitrogen in the form of rumen degradable protein (RDP) and undegradable protein (UDP) to cater for the nitrogen requirements of rumen microbes and the amino-acid requirements of the animal through post-ruminal digestion. In vitro, in situ and in vivo methods are used to determine the degradability and digestion of proteins. Information derived from these methods has been used in the proposed protein rationing systems (NKJ, 1985; Madsen, 1985; NRC, 1989, Verite and Pyraund, 1989 and ARC 1984). This is discussed in detail under section 1.1.2.2.2 of this thesis. In addition, the new protein systems also recognise that microbial protein synthesis requires the presence of a carbon source from carbohydrates in adequate amounts in order to minimize dietary N wastage, maximize microbial protein synthesis and therefore productivity.

Degradability of feed protein is the most intensively as well as extensively researched area of ruminant nutrition when compared to carbohydrates.

1.1.2.2.0.   Characterisation of dietary feed proteins.

1.1.2.2.1.   Nitrogen determination.

Nitrogen (N) determination of feeds is accomplished by the Kjeldahl digestion procedure involving digestion of the material in concentrated sulfuric acid to release the nitrogen. The nitrogen content of the feed is expressed as crude protein by multiplying feed-N by 6.25. The nitrogen content from different natural feeds varies according to the amino-acid profile of the protein. While determination of total N of the feed gives some indication of the quality of a feed, it does not give an indication as to the degree of utilization by the animal.

1.1.2.2.2.   Partitioning of dietary protein.

In order to meet the protein needs of lactating dairy cows, ration formulation systems proposed by NKJ (1985), Madsen (1985), NRC (1989), Verite and Pyraund (1989) and ARC (1984), require partitioning dietary proteins into fractions degraded in the rumen (degradable intake protein, DIP) and those fractions that are resistant to rumen degradation (undegradable intake protein, UIP). A combination of in vitro, in situ and in vivo methods have been used to partition dietary proteins into the different fractions; where;

$$UIP = \frac{duodenal\ N\text{-}microbial\ N}{N\ intake}$$

and

DIP = 1-UIP

and DIP is further broken down to rapidly degradable and slowly degradable-N. Rapidly degradable-N (a) is assumed to be equal to water soluble nitrogen and slowly degradable-N (b) equal DIP minus rapidly degradable-N. Rapidly degradable-N and DIP are estimated from degradability studies with polyster bags using the equation of Ørskov and McDonald (1979);

$$a + b = a + bc/(c+k) \qquad \text{(Equation 1.1)};$$

where a =   water soluble nitrogen (Rapidly degradable-N),

          b =   slowly degradable N,

      $a + b$ =   degradation of dietary N at time infinity,

          c =   fractional rate of degradation of b/h,

and k =   fractional rate of rumen outflow/h

The model also takes care of the totally undigested unavailablle fraction (u) usually given by;

$$u = 100 - (a + b);$$

In vitro methods of measuring rate of protein degradability have been modifications of the Tilley and Terry, (1963) procedure which involves incubation of a feed sample with an inoculum of strained rumen fluid in a centrifuge tube closed with a bunsen valve. This is still a popular method. However, the procedure

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requires rumen cannulated animals. This prompted various modifications. Modifications include use of pure non-bacterial enzymes such as pepsin, pancreatin and pronase and bacterial proteolytic enzymes (Poos et al., 1980a and Krishnamoorthy et al., 1983).

Mathematical treatment of data for in vitro studies is analysed the same way as in situ data.

The development of in vitro continuous culture systems added new advantages over the traditional batch culture systems mentioned above, which are procedurely static. These require the use of rumen cannulated animals to supply inoculum. Solid feed is incubated with rumen fluid in fermentation vessels fitted with agitators and an inlet and outlet to allow movement, feeding, sample collection and also control of liquid and solid turnover rates. Continous cultures have been used successfully to measure feed degradability and to estimate microbial protein synthesis (Hoover et al., 1976 and Hussein et al, 1991a). Czerkawski and Breckenridge (1977) came up with the rumen simulated technique (RUSITEC) to determine degradability of feeds and to estimate microbial protein production.

Measurement of degradability in vivo involves direct measurement of total N flow to the duodenum, microbial N flow to the duodenum and total N intake by use of exogenous and endogenous feed and microbial markers (Mathers and Miller, 1981; McAllan et al., 1988; Owens and Hanson, 1992 and Broderick and Merchen, 1992;).

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Nitrogen degradability can be calculated according to the following equations (McAllan et al., 1988);

N degradability=(Total NAN flow-(MN flow+EN flow)/Total NAN intake) (Equation 1.2);

where;

NAN = Non-ammonia nitrogen

MN = Microbial nitrogen

EN = Endogenous nitrogen

1.1.2.2.3. Methods of estimating post-ruminal digestion of undegradable intake protein (UIP).

The portion of dietary protein that escapes degradation in the rumen goes to the small intestines where some is digested by pancreatic and intestinal enzymes. Part of this protein also escapes digestion and a portion gets fermented in the large intestines, that which is resistant passes on to constitute the undigested-N (unavailable) fraction and is voided. The portion that gets fermented in the large intestine is utilized by microbes. However, because of the limited capacity of the large intestine to absorb nutrients, the benefit to the animal from hind gut fermentation is not very significant. From a productivity point of view it is important that the UIP is highly digestible in the small intestines to maximize the release of amino-acids, which are the ultimate protein forms nutrient required by the animal.

Estimation of the digestion of UIP has been accomplished by use of the mobile nylon bag technique and requires animals with cannulae at the rumen and duodenum (Hvelplund, 1985 and de Boer et al., 1987) or at the rumen only (Varvikko et al., 1983 and Kendall et al., 1991). In this method, rumen-incubated feed samples in polyester mesh bags are recovered from the rumen, washed in the usual way and dried. Some of these bags are analysed for degradable-N and amino-acids and the remaining bags are put back in the intestinal tract through the duodenal cannula and can be recovered either in the ileum or feces. The bags are then washed, dried and analysed for digested-N and amino acids. The portion that has been digested post-ruminally is calculated by difference between what entered at the duodenum and what remained in the bags.

Other workers (Varvikko et al., 1983 and Kendall et al., 1991) using cows with rumen cannula have digested rumen undegraded samples using the pepsin digestion procedure to simulate intestinal digestion.

Though all these methods have been used successfully within their limitations, they all have their own inherent problems. Theoretically, in vivo methods are best since data are collected on the animal itself. However, the increased pressure from animal welfare activists on animal nutritionists not to use animals for research, may mean this method may not be popular in future. This has already resulted in efforts to improve in vitro techniques to simulate digestion in the gut. In vitro techniques are also less expensive.

Presently the amount of dietary protein that escapes degradation in the rumen cannot be measured easily using in vivo techniques. This presents some problems in assessing laboratory methods for predicting degradability. Studies which have attempted to compare in vivo measurements and in vitro estimates of degradability with estimates based on the rate of disappearance of feeds from polyester bags suspended in the rumen, have concluded that the correlation between the methods was poor (Poos et al., 1980b and Krishnamoorthy et al., 1983).

In spite of poor correlation there is already a lot of work in progress and more is needed to establish accurate measurements of in vivo degradability so as to improve the measurement and correlation with in situ data.

1.1.2.2.4. Degradation of protein in the rumen.

Nitrogen in feeds is found in the form of true protein and non-protein nitrogen (NPN). True proteins are complex molecules such as albumins, globulins, prolamins and glutelins composed of amino-acids. Non-protein nitrogen sources includes urea, ammonia-N, biuret, nitrate, nucleic acids, purine derivatives such as uric acid and individual amino acids.

In general terms degradability of nitrogeneous compounds, like carbohydrates, decreases with the complexity of the molecule. This means that NPN is rapidly degraded to ammonia compared to complex molecules such as albumins and globulins and that differences in degradability also exist within different groups of nitrogen sources.

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The term solubility was once used to describe degradability of proteins in the rumen. This is determined by use of a number of solvents and used to rank feeds, although the relative ranking of the feeds varies with the solvent (Crooker et al., 1978 and Williams, 1986). The method assumed that all the soluble proteins were rapidly and completely degraded in the rumen while the insoluble proteins were not. It is, however, now established that chemical bonds rather than solubility are responsible for the resistance to degradation by rumen proteolytic enzymes (Mahadevan et al., 1980). For this reason solubility cannot be equated to degradability. However it has been proposed that water soluble-N should be assumed to be rapidly degradable-N (a) for purposes of protein rationing of ruminants (Williams, 1986).

Degradability of dietary protein in the rumen is an important factor influencing intestinal supply of amino-acids to lactating dairy cows. The rate and extent of protein degradation in the rumen affects microbial protein synthesis and also determines the quantity of undegraded dietary protein that reaches the duodenum. Therefore, as milk yield and the requirements for ruminally degradable protein increase, protein degradation in the rumen becomes an increasingly important factor influencing the amount of amino-acids absorbed from the small intestines.

The extent to which dietary protein is degraded depends on microbial proteolytic activity in the rumen, microbial access to the protein, and ruminal retention time (Waltz and Stern, 1989). Other factors influencing protein degradability include protein

solubility and ruminal pH (Williams, 1986). Protein structure influences accessibility to proteolytic enzymes, thereby affecting degradability of protein in the rumen (Mahadevan et al., 1980 and Opstvedt et al., 1984). Some dietary feed ingredients are naturally resistant to microbial degradation and other constituents may have greater or lower resistance to microbial degradation because of physical and chemical processing (Madsen and Hvelplund 1985; Waltz and Stern, 1989; Khorasani et al., 1989 and Stern et al., 1994).

Compiled nylon bag data from different sources (NRC, 1989 and Stern et al., 1994) indicates that animal protein (fish, blood, meat and bone and hydrolysed feather meal) and protein sources of cereal processing origin are more resistant to ruminal degradation than are conventional plant protein sources such, as canola, soy bean and sun-flower meal. Different sources within each group also degrade at different rates. Ruminal undegradability of animal protein supplements ranged from 48% for fish meal to 82% for blood meal (NRC, 1989). Fish meal sources commonly used in lactating dairy cow rations have undegradability values in the order of 70% for well preserved fish meal and that for rapeseed meals averaging around 30% (Madsen and Hvelplund 1985; de Boer et al., 1987 and Erasmus et al., 1994). Unlike animal proteins there is a diverse supply of plant protein sources that are used as protein supplements in diets of cows. This diversity is even greater when materials that have been treated to reduce ruminal degradability are included along with protein supplements from cereal grain processing (brewers and distillers grains, and gluten meals)

(Madsen and Hvelplund, 1985 and NRC, 1989). For most commonly used plant protein supplements degradability falls around 50%, with a majority being above 50%. Cereal by-product proteins are less degradable than the conventional plant proteins, falling between 40-50% degradability and sometimes lower than some of the proteins of animal origin. Soybean meal was less degradable than canola meal; fish meal was less degradable than meat and bone meal and corn-gluten meal was the least degradable of all meals (de Boer et al., 1987).

Erasmus et al., (1994) were also able to discriminate a group of feedstuffs on the basis of their degradability in the rumen of cows. Animal protein sources (fish meal and blood meal) were less degradable than plant protein sources (soybean, cottonseed, peanut and sunflower meals) with corn gluten being the least. Animal and plant protein sources averaged 23.8 and 56.5%, respectively in nitrogen degradability, while that for corn gluten meal was 18.6%. Among plant protein sources the relative ranking in increasing order of degradability is; cotton seed (42.5%) < soybean (46.2%) < peanut (65.0%) < sunflower (72.1%). Blood meal is the least in rumen degradability when compared to fish meal (18.6 versus 28.3%) while meat meal was similar to soybean meal. The relative ranking inter and intra group of each feedstuff may sometimes change due to further treatments (eg, heat application during food processing) thereby increasing resistance to degradation (Hvelplund 1985; Madsen and Hvelplund 1985; NRC, 1989). Common methods for reducing degradability in the rumen include physical and chemical

treatments. Waltz and Stern, (1989) studied the effect of protection methods on the metabolism of protein from soybean meal on in situ rumen degradation. Results showed that expeller processing and calcium lignosulfonate treatments were most effective in reducing ruminal protein degradation. The order of effectiveness by method was; control < sodium hydroxide < ethanol < propionic acid < calcium lignosulfonate < expleller processing < formaldehyde. Formaldehyde and acetic acid treatment of soybean and rapeseed meal significantly reduced the ruminal degradation of protein (Varvikko et al., 1983 and Khorasani et al., 1989).

Although cereal grains are used mainly as energy sources in diets they do supply a substantial amount of protein and influence metabolism of nitrogen. Herrera-Saldana et al. (1990b) compared in situ protein degradability for corn, milo, wheat, barley and oats. They found significant differences in the rate of degradability of protein of cereal sources and the ranking was as follows in increasing order; milo < corn < oats < barley < wheat. However oats had the highest ruminal availability of protein because of the higher rapidly degradable portion. Similar results have been reported for wheat, barley and corn (Fiems et al., 1990) and for corn and sorghum grain (Erasmus et al., 1994).

1.1.2.2.5.   Digestibility of rumen undegraded protein in the small intestines.

While it is important to have part of the dietary protein escape degradation in the rumen, its value to the animal depends on

its digestibility in the small intestines to release the required amino-acids. Not many studies have measured both in situ ruminal and post-ruminal digestion of protein sources.

Hvelplund, (1985) using the mobile bag technique to measure the digestibility of nitrogen post-ruminally reported significant differences in the digestibility of N and amino-acid-N among various protein supplements. The digestibility of N in the small intestines varied between 63% and 86% and that for amino-acid-N varied between 67% and 87%, respectively. Undegraded rapeseed, fish, and soybean meals averaged 63%, 86% and 81% and 77%, 87% and 87%, for undegraded N and amino-acid-N, respectively. The digestibility of essential amino-acid-N and non-essential-amino-acid-N showed only minor differences. Work using cows confirmed the results obtained with sheep, although only N-digestibility was measured. The disappearance of N from bags averaged 75%, 90% and 96% for undegraded rapeseed, fish and soybean meals, respectively. All feeds tested were above 70% except one fish meal sample which was heat damaged, averaging 11% in post-ruminal digestibility. Post-ruminal N digestion was reported to be higher when bags were recovered from feces than from ileal cannula. The N content and amino-acid composition between the original protein supplement and the rumen undegraded residues showed small differences or variation for the majority of amino-acids (Hvelplund, 1985). However increases were noted for isoleucine, leucine, phenylalanine, threonine, tyrosine and valine with the rest of the amino-acids showing both increases and decreases, which was in agreement with

results from other studies (Hennessy et al., 1987; Varvikko et al., 1983; Hvelplund and Hesselholt, 1987 and De Boer et al., 1987). Ruminal and intestinal digestibility of N for soybean, canola, fish meal and alfalfa hay were 55.1, 44.6; 69.7, 24.0; 28.5, 59.2; and 68.8, 22.2% respectively for the initial and residues respectively at 8 hour rumen incubation time (de Boer et al., 1987). It was shown that protein sources with different rumen degradabilities had different intestinal nitrogen digestibility. Rumen degradability increased with time while intestinal digestibility decreased and both parameters differed among protein sources.

More recent published findings support these earlier findings (Erasmus et al., 1990 and Erasmus et al., 1994). These workers also reported significant differences among feedstuffs in the digestibility of the feed protein, amino-acid profile of undegradable protein and absorbable amino-acid profile. However, the researchers reported that their study also indicated that the amino-acid profile of absorbable protein was much more similar to the profile for the undegraded residues than to the original feed protein.

Differences in intestinal digestibility seem to be related to the degradability in the rumen and also fiber content in the particular protein supplement (Hvelplund, 1985; Hvelplund and Hesselholt, 1987; de Boer et al., 1987 and Erasmus et al., 1994). The higher the rumen degradability the lower was the intestinal digestibility and materials with higher fiber had lower intestinal digestibilities. This is expected because some of the protein that

is ruminally undegradable is bound to cell-walls and that portion passes out as cell-wall bound indigested residue (Hvelplund, 1985 and de Boer et al., 1987)

The importance of the digestibility of undegradable protein after treatment was also demonstrated in the experiments of Hvelplund, (1985) and Erasmus et al., (1994). Hvelplund, (1985) reported decreases in intestinal nitrogen and also amino-acids of undegraded-N when soybean meal was treated with 0.5% formaldehyde when compared to the original soybean meal. Heat damaged fish meal averaged 11% compared to 90% with well preserved fish meal in intestinal digestibility of undegradable protein.

King et al. (1990) and Erasmus et al. (1994) reported reduced intestinal digestibility of blood meal when compared to other feeds with a low degradibility in spite of blood meal delivering more feed-N to the duodenum. This difference was attributed to differences in drying methods used resulting in overprotection of the protein. It is therefore important that processing should not result in overprotection of the protein and that it is important to assess the intestinal digestibility of such material.

Although, most of these experiments came up with valuable data and there is some general agreement among results, usefulness of the data is reduced due to differences in actual values obtained. There is considerable variation among laboratories in measurement of protein utilization and these differences can be accounted for by differences in methods used by each laboratory even under standardized conditions (Beever and Cottrill, 1994).

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1.2. PERFORMANCE STUDIES

1.2.1. MATCHING OF CARBOHYDRATE AND PROTEIN SOURCES VARYING IN RATE OF STARCH AND PROTEIN DEGRADABILITY.

Until a few years ago, relatively little attention was paid to the role of carbohyrates in diets of dairy cattle other than that structural carbohydrates in roughages acted as a source of fiber with important stabilizing properties for rumen fermentation and that cabohydrates in roughages and concentrates were an important energy yielding part of the diet (Baldwin and Koong, 1977). De Visser and Hindle, (1990) reported differences in the ruminal degradation characteristics of NSC like starch and sugars and SC like fiber. Russell and Hespell, (1981) and more recently Henning et al. (1991), observed that optimal microbial protein synthesis results from synchronous utilization of ruminally degraded protein and carbohydrates from dietary ingredients. Protein degradation in the rumen usually exceeds carbohydrate availability and protein wastage occurs (NRC, 1985). On the other hand protein degradation might be too slow to support optimal ruminal digestion of carbohydrates. In both cases, depression in microbial protein synthesis occurs. The principle of nutrient synchronicity is based on the premise that provision of available energy and protein at coordinated rates and in the right proportions should allow microbes to obtain simultaneously ATP, NH_3, AAs and dipeptides (oligopeptides) needed for cell synthesis and result in better utilization of nutrients in the rumen as well as increasing the supply of microbial protein to the small intestine (Oldham, 1984).

Carbohydrate and protein synchrony studies in North America have concentrated on barley, corn and to some extent sorghum as a major NSC sources with fish meal (FM), dried-brewers-grain (DBG), canola meal (CSM), urea (U), or soybean meal (SBM) as protein supplements (DePeters and Taylor, 1985; McCarthy et al., 1989; Casper and Schingoethe 1989; Herrera-Saldana and Huber, 1989; Herrera-Saldana et al., 1990a; Aldrich et al., 1993 and Khorasani et al., 1994). Others have emphasized balancing for structural carbohydrates in the diets (MacGregor et al., 1983).

In Europe where grain production or use as animal feed is not as high as in North America, the concentrate portion of the feed is usually compounded from agro-byproducts such as beet pulp, wheat middlings, hominy, brans, palm-kernel and also processed cereals to mention a few (De Visser and Hindle, 1990).

Johnson, (1976) and Nocek and Russell, (1988) suggested that a combination of rapidly and slowly degraded carbohydrates should support maximum microbial yield. This effect was demonstrated in both in vitro and in situ studies, where increased intake of paper and wheat starch together stimulated microbial yield (Offer, et al., 1978 and NRC, 1985). Oldham (1984) analysed data from different experiments, and found that barley supported higher bacterial yield than corn grain when fed to dairy cows at moderate intakes of diets with 10 or 40% hay. An earlier study by Ørskov et al. (1971) also reported greater microbial protein quantity (DAPA) in abomasal fluid for barley compared to corn with urea as the nitrogen source. In contrast, Spicer et al. (1986), found no

influence of dry rolled sorghum versus dry rolled corn versus steam-flaked barley on microbial yield in steers fed 20% forage diets. Recent studies utilizing diets synchronized for carbohydrate and protein, have produced conflicting results. McCarthy et al. (1989) did not observe any differences in efficiency of microbial protein synthesis (g/kg, organic matter, apparent or truly digested) or total passage of N to the duodenum. Microbial protein synthesis and microbial protein flow to the duodenum was higher for cows fed barley than corn. This was attributed to the higher digestion of organic matter that occurred in the rumen, in spite of low ruminal NH_3-N concentrations. These findings are in agreement with those of Ørskov et al. (1971) and Lee et al. (1986). In contrast, in vivo studies with sheep and continous culture studies by Hussein et al. (1991a,b) indicated that there were no significant differences in bacterial protein synthesis, efficiency, N flow and total AA flow to the small intestines between cows fed barley (B) or corn (C) based diets with SBM or FM as protein supplements. There was however a tendency for higher microbial protein yield on C-SBM than B-SBM and for corn diets than barley. These findings are in agreement with their continous culture findings, although total AAs, essential amino acids (EAAs) and non-essential amino acids (NEAAs) flows were significantly higher for corn or FM than barley or SBM diets. They concluded from these studies that corn or FM has a significant effect on manipulating AAs leaving the rumen.

The above reported results do not agree with those of other workers who have reported significantly higher microbial protein synthesis for barley-cotton-seed meal (B-CSM) diet than barley-dry-brewers-grains(B-DBG) or milo(M-CSM) or M-DBG diets (Herrera-Saldana and Huber, 1989) and barley than corn based diets (Owens and Bergen, 1983). Sniffen and Robinson, (1987) reported higher microbial protein efficiencies for corn than wheat diets. Differences in reported results could be explained by a number of factors, including chemical and physiological (Hoover and Stokes, 1991). Major chemical and physiological modifiers of rumen fermentation are rumen pH and turn-over rate and other nutritionally related characteristics such as level of feed intake, feeding strategies, forage length and quality, and forage:concentrate ratios. Sniffen and Robinson, (1987) noted that, interactions between feed intake, level of production, type of roughage source (legume vs grass), form (hay vs silage) and amount of forage included, all modify the relative abilities of grains to support microbial growth in vivo. Studies dealing with replacement of forage with grain in the diet indicate a decrease in efficiency of microbial protein synthesis when a higher proportion of forage is replaced by grain (Mathers and Miller, 1981 and Owens and Bergen, 1983). In spite of the decreased efficiency, the total microbial-N flow to the duodenum was often increased when grain was added. This was attributed to the increased OM digestion in the rumen which more than off-set the decreased efficiency (Hoover and Stokes, 1991). Differences in type of carbohydrate source may

explain differences in flow of N to the duodenum. These studies suggest that optimum flow of microbial protein and total AAs to the duodenum may be affected by both type and source of carbohydrates and that further studies are needed to identify the combinations that will result in the optimum microbial efficiency and rumen digestibility.

Other workers (MacGregor et al., 1983 and Stokes et al., 1991a,b) have looked at the effect of different ratios of NSC:DIP on milk production. This is because NSC has a major influence on total carbohydrate digestion and DIP affects both carbohydrate digestion and microbial efficiency (Stokes et al., 1991a). Stokes et al. (1991b) investigated the effect of NSC:SC ratio and level of DIP on microbial yield and rumen parameters in lactating dairy cows. Three diets were formulated to provide high, medium, and low levels of DIP and NSC respectively viz 25, 37, and 54% NSC. The protein and carbohydrate digestion and microbial yield were predicted from continuous culture results (Stokes et al., 1991a) to be in the order of diet 1>diet2>diet3 (Stokes et al., 1991b). There were no significant differences between diet 1 and diet 2 in either protein or carbohydrate digestion or microbial yield. Diet 3 resulted in significantly less microbial yield than diet 1 and 2 indicating the low levels of available protein and carbohydrate. This demonstrates the importance of having adequate amounts of NSC and DIP in the diet for microbial growth. It must be noted that diets used in this experiment were formulated to contain similar ratios of available protein and carbohydrate; therefore, no

significant differences in microbial efficiencies were expected inspite of diet 3 having a wider ratio. These results are not in agreement with their earlier studies using the continuous culture technique (Stokes et al., 1991a). In these continuous culture studies, carbohydrate digestion and microbial protein synthesis efficiency responded linearly to the level of DIP within each NSC level. Increasing NSC as a proportion of carbohydrate had a positive effect on total carbohydrate digested and was not related to microbial efficiency. This is supported by in vivo studies involving lactating dairy cows at high intakes (McCarthy et al., 1989 and Herrera-Saldana et al., 1990a).

There is a limited number of studies dealing with lactating cows at high feed intakes, in which information is available to quantitatively assess both microbial yield, efficiency and AAs flow responses to varying dietary NSC, DIP, and total carbohydrate. However, both in vitro and in vivo data are in general agreement concerning the influence of carbohydrate and protein on rumen microbial growth. Non-structural carbohydrate as a proportion of total carbohydrate digested in the rumen seems to be more important. Therefore, as NSC level increases, the concommitant increase in carbohydrate digested will enhance daily microbial protein yield by providing more energy for growth (Hoover and Stokes, 1991).

1.2.2. MILK PRODUCTION.

Several researchers (McCarthy et al., 1989; Casper and Schingoethe, 1989 and Casper et al., 1990) have reported decreased milk production and dry matter intake (DMI) of cows fed barley compared to those fed corn. Others, (DePeters and Taylor, 1985 and Grings et al., 1992) did not observe this response. Nocek and Tamminga, (1991) have recently published on the effect of starch source on milk production. They noted that the magnitude of milk yield response was variable among studies. Changes in milk composition were mainly in fat content. In the studies by McCarthy et al., (1989), milk production was significantly higher for cows fed corn diets than barley. They attributed this increased production to high energy intakes which were used for microbial protein and milk lactose synthesis. Microbial protein synthesis efficiency was not affected by corn or barley diets, in combination with SBM or FM; however protein flow to the duodenum was higher for cows fed barley than corn. If milk production was higher on corn diets, then corn diets were able to provide enough ruminal degradable carbohydrate for microbial synthesis as well as sufficient undegradable protein.

In contrast, Herrera-Saldana and Huber (1989) reported higher milk production on barley based diets than corn. This was attributed to increased DM and starch intakes and also higher microbial protein synthesis (Herrera-Saldana et al., 1990a). It is however argued that the starch content of the barley diets was higher than the other three diets.

European studies (De Visser and Hindle, 1990; De Visser et al., 1991; Tamminga et al., 1991 and De Visser et al., 1992;) have concentrated on replacement of barley by agro-byproducts such as beet pulp. At a certain level of inclusion in the diet, beet pulp has been shown to give similar milk yield to barley. No measurement of microbial yield and amino-acids flow were attempted in these studies.

It appears from the review of literature that more studies are needed dealing with the aspect of carbohydrate and protein source synchronization. In addition not many studies have been done under Canadian conditions. However, interest in carbohydrate and protein synchronization studies is increasing (Sniffen et al., 1992; Russell et al., 1992; O'Connor et al., 1993 and Khorasani et al., 1994)

It was hypothesised that;

1. Non-structural-carbohydrates (starch) from different sources will degrade at different rates,

2. Processing by steam-rolling will increase the rate of starch degradation and release by cereal grains,

3. Cell-wall (NDF) from different roughages and agro-byproducts degrade at different rates,

4. Diets matched for differing rates of carbohydrate and protein degradation will support different levels of milk production.

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CHAPTER 2.   THE EFFECT OF STEAM-ROLLING CORN, BARLEY AND WHEAT ON IN VITRO STARCH RELEASE AND IN SITU DEGRADABILITY OF DRY MATTER, CRUDE PROTEIN AND STARCH.

2.0. ABSTRACT.

Three groups of feedstuffs, cereals, roughages and agro-byproducts were incubated in situ for 2, 3, 6, 12, 24, 36, and 48 h in 2 cows and in 3 periods. The three feed groups were randomly assigned to periods within a cow. Ruminal degradability data was subjected to an iterative procedure using the following equation, $P = a + b(1-e^{(-c(t-lag))})$ for t>lag where; a = rapidly degradable fraction; b = slowly degradable fraction; c = rate constant of b; t = time of incubation; lag = lag time. Statistical analysis was handled separately for each group of feedstuffs. Cereal data were handled as a 3 x 2 factorial analysis with cereal and processing as main effects. Six treatments were involved; unprocessed corn (UPC), barley (UPB), wheat (UPW) and their steam-rolled counterparts, corn (SRC), barley (SRB) and wheat (SRW).

Dry matter, CP and starch disappearance from nytex polyester bags were rapid for all cereals under consideration, though differences existed. About 80% of DM had disappeared by 12 h and started to level off between 12 and 24 h. Starch was most rapidly degraded for all feedstuffs such that by 12 h, at least 80% of corn and 90% of barley and wheat starch had disappeared and all reached a plateau by the 24 h incubation.

Steam rolling resulted in decreasing (P<0.0001) the rate of DM (P<0.0007), CP (P<0.003) and starch (P<0.0091) degradation in the

rumen of cows and the response was not dependent on type of cereal for the three parameters. Average response due to steam rolling for DM, starch and CP was 15.54±0.98 %/h, 22.92±0.98 %/h; 19.26±1.08 %/h, 25.03±1.08 %/h; and 15.08±0.45 %/h, 18.15±0.45 %/h, respectively for the processed and unprocessed grains, respectively.

Type of cereal also significantly affected the rate of DM (0.0371), starch (P<0.0.002) and CP (P<0.0001) degradation of the grains. Corn treatment had lower rate of DM degradation compared to barley (P<0.0137) but not wheat (P>0.0918), while barley and wheat were similar (P<0.1993). Average response to type of cereal was 16.68±0.99, 19.49±0.99 and 21.52±0.99 %/h for corn, wheat and barley, respectively. Rate of starch degradation was significantly lower for corn compared to wheat (P<0.0083) and barley (P<0.0007) and wheat was lower than barley (P<0.0436). Values for rate of starch degradation averaged 15.74±1.32, 22.97±1.32 and 27.73±1.32 %/h for corn, wheat and barley, respectively. For CP, corn had lower rate of CP degradation compared to wheat (P<0.0001) and barley (P<0.0008) while barley was lower than wheat (P<0.0032). Rate of degradation of CP averaged 12.13±0.56, 20.71±0.56, and 16.99±0.56 %/h for corn, wheat and barley, respectively.

In vitro starch release by amyloglucosidase tended to increase with increasing incubation time for all grains. Steam rolling tended to increase in vitro starch release when incubated with amyloglucosidase enzyme at each incubation time for all grains.

Data such as these can be used to rank feeds according to their starch degradability and therefore can be used in carbohydrate and protein synchronization of diets. If steam rolling reduced starch degradation then the process can be used to attenuate the starch degradability of those feeds with high ruminal degradability which would result in negative effects if not matched correctly with a protein source.

2.1. INTRODUCTION.

Carbohydrates are a major source of dietary energy for both livestock and humans and constitute about 60-80% of typical dairy ration (Nocek and Russell, 1988 and Nocek and Tamminga, 1991). They are a large diverse group of simple and complex chemical compounds (Van Soest, 1982 and Van Soest, 1986). Carbohydrates are typically divided into structural carbohydrates (hemi-cellulose, cellulose, pectins) which constituents originate from plant cell-walls, and non-structural carbohydrates (sugars, oligosaccharides, starches) which constituents originate from cell-contents. Structural carbohydrates and their components degrade at lower rates than NSCs; also NSCs within the same group, such as starch, also degrade at different rates. This is determined in part by differences in the physical and chemical structure of different carbohydrates which influence the rate and extent of in vitro rumen digestion and enzymatic (Malestein et al., 1988; Cone et al., 1989 and Cone and Vlot, 1990) and in vitro gas production (Hale, 1970 and Trei et

al., 1970), in situ ruminal (Galyean et al., 1981; Spicer et al., 1986; Theurer, 1986; Herrera-Saldana et al., 1990b and Tamminga et al., 1990) and ruminal in vivo (Huntington, 1994) degradation characteristics.

Malestein et al., (1988), Cone et al., (1989) and Cone and Vlot, 1990) using an in vitro procedure showed a constant ranking in degree of degradability of different starch sources upon 6 h incubation with pure enzymes or rumen fluid from cows fed either a hay or hay plus concentrate diet. Unprocessed maize was less degraded than wheat and wheat was less degraded than barley. Steam-flaking and popping significantly increased the degradability of these grains. Agro-byproducts such as wheat middlings and corn gluten meal were more degradable than their corresponding cereals. For all samples, starch degradation was higher when the feeds were incubated in the rumen of cows fed a hay-concentrate diet than a hay diet alone. These results are in agreement in terms of ranking of the cereals with in situ studies (Herrera-Saldana et al., 1990b; Fiems et al., 1990 and Tamminga et al., 1990).

Herrera-Saldana et al., (1990b) reported that corn, milo and oats had significantly lower rates of starch degradation than wheat or barley. Wheat and barley were similar, with wheat having a higher rate of dry matter and starch degradation. Among all the grains oats had the highest rapidly degradable fraction of starch compared to the rest of the grains. Barley and wheat had similar amounts of rapidly degradable fraction of starch but higher than corn and milo which were very low. Arieli et al. (1995) have

reported a similar ranking of rumen degradation characteristics of dry matter and starch of corn, barley, wheat and sorghum. These differences in starch degradation are due to inherent physical and chemical differences among different grains (French, 1973; Moran, 1982 and Rooney and Pflugfelder, 1986).

Physical and chemical barriers to ruminal digestion can be modified by many processes such as grinding (Galyean et al., 1981 and Fiems et al., 1990), steam flaking (Fiems et al., 1990; Malcolm and Kiesling, 1993), popping (Malestein et al., 1988 and Cone and Vlot, 1990), and steam rolling (Engstrom et al., 1992) which are general livestock feed and human foods processing procedures.

This difference in degradation rates of cereal grains has been cited as being responsible for the differences in microbial protein production when cereals are fed in combination with protein sources of similar or different ruminal degradability (Nocek and Russell, 1988; Herrera-Saldana et al., 1990a; Nocek and Tamminga, 1990 and Hoover and Stokes, 1991) resulting in differences in milk production (McCarthy et al., 1989 and Herrera-Saldana et al., 1990a). In addition, newly proposed protein rationing systems require an adequate and comprehensive description of ruminal and intestinal behavior of carbohydrates and protein from different sources in order to appropriately synchronize protein with carbon release (ARC, 1984; NKJ, 1985; Verite and Peyraund, 1989 and AFRC, 1992). This information is therefore important in formulation of diets, matching rates and extent of ruminal degradation of carbohydrates and protein to maximize microbial protein synthesis.

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The purpose of this experiment was to determine effect of cereal type and steam rolling on DM, starch and CP in situ degradation characteristics and in vitro starch release by amyloglucosidase enzyme.

2.2.0. MATERIALS AND METHODS.

2.2.1. Source and description of feedstuffs and initial handling.

Twelve feedstuffs, consisting of cereals, roughages (corngrass silage-CGrS, orchard grass hay-OGrH and alfalfa hay-ALFH) and agro-byproducts (wheat millrun-WMR, rye distillers grains-RDG and beet pulp-BP) were obtained from the Vancouver area of British Columbia. Cereals; unprocessed corn, barley and wheat and their corresponding steam-rolled counterparts were supplied by East Chilliwack Agricultural Co-operative, Chilliwack, B.C. All cereals were whole grains. The grains were steam rolled at 70°C for 30 minutes under atmospheric pressure and rolling was done using rollers with 5.7 grooves/cm (14 grooves/inch) resulting in flat rolled grains. These feeds were selected because they are commonly used in the diets of ruminant animals and they contribute differently to the energy economy of the animal and therefore a comprehensive study of their degradability in the rumen with respect to carbohydrates is important.

All cereal grains were immediately ground through a 2 mm screen to facilitate sampling and then reduced to 1 mm size using a Wiley Mill, model #3 and Christy and Norris, respectively. All

samples were then dried in a forced air oven at 60°C for 48 h. Residual DM determination was later done on 1.0 g of dried ground samples and this was done at 105°C overnight. The bulk of the samples were packed in 5 kg bags and stored at room temperature for proximate analysis, NDF and starch analysis and also in vitro and in situ studies.

2.2.2.   Cows, diets and nylon bags.

Two dairy cows (average weight = 518 kg) fitted with both rumen (10 cm internal diameter) and duodenal cannulae (Bar Diamond Inc., Parma, Idaho, USA) were used for rumen incubation studies. Cows were tethered in tie stalls and had free access to water. They were offered a TMR twelve times daily using an electrical continuous feeder calibrated to drop feed every 2 h for 17 seconds. This was done to maintain a continuous and even fermentation in the rumen to mimic a continuous type of feeding system that is characteristic of some farms and this has been shown to increase efficiency of microbial protein synthesis under in vitro system (Henning et al., 1991).

The diet was designed in such a way that the majority of the feedstuffs under test were incorporated. This ensures a balance of micro-organisms in the rumen which are responsible for digestion of different kinds of nutrients. The concentrate portion of the diet was a 16% textured commercial dairy feed (40%) (Otter Feed Co-op, Aldergrove, B.C). Corn-grass silage, (50:50), long chopped alfalfa and orchard grass hay made up the roughage portion (60%) of the

diet. Quantity of feed offered per day was calculated at 1.65% body weight and good quality hay alone could have satisfied the nutrient requirements of the cows. Since feedstuffs under investigation were from different sources the estimated intake was divided between roughage and concentrate in the ratio noted above. The cows were given 8.53 kg/d (16% textured commercial dairy feed = 3.41 kg, CGrS = 2.56 kg, ALFH and OGrH = 1.28 kg) DM of a TMR. The ratio of corn-grass silage to hay and that of alfalfa to orchard grass hay was 1:1. Table 1 shows the proportions of ingredients used in the diets fed to the cows. The feed ingredients were pre-weighed and mixed twice weekly and spread on the feed troughs at 1330 and 0130 h. Feeding troughs measured about 2.0 x 0.15 x 0.2m (length x width x height) and were raised about 2m above ground. Conveyor belts wrapped around length-wise and lying on the floor of the feeding troughs were used to drop the feed at timed intervals. On each end of the troughs the belts passed over moving shafts with one side fitted with a motor. The motor was connected to an electronic timer in order to regulate dropping of the feed. At each mixing, all ingredients were sampled separately and stored in plastic bags in a freezer for further processing and chemical analysis. A commercial dairy vitamin-mineral mix was given at 0.2% of the DM intake. The vitamin-mineral mix (Dairy Pride P-20, Van Waters and Rogers Ltd, Abbotsford, B.C., Canada) contained vitamin A, vitamin D, vitamin E, mono ammonium phosphate, sodium selenite, cobalt sulphate, copper oxide, zinc oxide, calcium iodate, manganese oxide, magnesium oxide, molasses, anise flavour #98037 and a

guaranteed analysis of phosphorus 20.0%, iodine 200 mg/kg, cobalt 150 mg/kg, copper 4000 mg/kg, zinc 6000 mg/kg, manganese 2500 mg/kg, magnesium 6.0%, flourine(max) 2000 mg/kg, vitamin A(min) 500000 IU/kg, vitamin D(min) 50000 IU/kg, vitamin E(min) 500 IU/kg, iron 8000 mg/kg and selenium 35mg/kg. Cobalt iodized salt block (Sifto Canada Inc. Mississauga, Ontario) was also available to cows at all times.

At the end of the experiment all feed samples were thawed overnight. Feed (16% textured commercial dairy feed, OGrH, ALFH and CGrS) ingredients were ground through a 2 mm screen to reduce particle size so as to facilitate mixing and sampling using a Wiley Mill (model #3). All samples were then ground through a 1 mm screen using Christy and Norris. Corn-grass silage was first dried at 60°C for 48 h before being ground. All drying at 60°C were done to prevent any possible loss of volatile nitrogen and possible complexing between carbohydrate and protein fractions, which may occur at higher temperature. The samples were thoroughly mixed separately using a Hobart commercial dough mixer and then a subsample taken on which DM analysis was done. The samples were stored in a cooler for chemical analysis (Table 2).

Nylon bags were made from nytex polyester material obtained from Behnsen Graphics (Vancouver, B.C). The bags measured 22x9 cm internal diameter and had an average pore size of 50 ± 2 μm. Glue was first applied as a strip about 0.2 cm from the edges of the fabric leaving one side open of each potential bag and then a double seem was made by stiching leaving the strip of glue in between. The open

side was hemmed and a small nylon string put inside the hem. The bags were put under some weights to hasten sticking together of the bag's sides. The bottom corners of the bags were round so that feed material did not accumulate and compact in the corners.

2.2.3.   Experimental design.

A three period switch-back design was used involving two animals and three groups of feedstuffs (Cochran and Cox, 1969). Each group of the test feed was sequentially incubated once in each cow in two different periods of the three periods. The animals were fed the experimental diet for at least one month before the experimental periods started, to get the animals used to the diet and stabilise the rumen environment.

2.2.4.0.   Incubation procedures.

2.2.4.1.   Rumen incubation.

Five grams of dried ground test feeds samples (cereals- UPC, UPW, UPB, SRC, SRW and SRB; roughages-CGrs, OGrH and ALFH; agro-byproducts-WMR, RDG and BP), were quantitatively weighed into incubation bags (density; 25.3 mg/cm^2) in duplicate for each feed per incubation time to give 2 bags/feed/cow/time. All bags were numerically labelled for identification and then washed, dried for a few hours and put in a dessicator before taking their weights. The bags were tightly secured using the nylon string inside the hem to stop material from coming out of the bags. The bags were then tied to a few common metal rings of about 2.5 cm in diameter. The

rings were themselves then secured to hooks. All the hooks were tied to a single mainline nylon string measuring about 1.0 m. A plastic bottle containing about 300 g of sand was tied to each nylon string to act as a rumen suspension device (RSD). This procedure was done for each incubation time and animal, for the test material under consideration.

Eight incubation times, 0, 2, 3, 6, 12, 24, 36, and 48 h were involved. The bags were inserted into the rumen in reverse order i.e. 48 h bags were placed first, followed by 36 h and down to 2 h incubation. All the bags were then removed from the rumen at once in order to allow for washing of the bags at the same time and also any differences that might be introduced due to differences in exposure to the atmosphere after drying the bags. All batches of bags were wetted by sprinkling lukewarm tap water before being inserted into the rumen to prevent inflation of bags when put in the rumen. Incubations started an hour after the feed had been given. Each batch of bags was pushed in to the liquid strata of the mid-ventral region of the rumen.

After removal from the rumen, all bags were placed into a bucket of very cold tap water to remove excess digesta material adhering to the bags but also to stop fermentation. Four bags per test feed were included in the washing to act as the 0 h disappearance. The zero h bags were washed by immersing the bags in tap water for 15 minutes and then washed together with rumen incubated bags.

Everything was transported to the Animal Science department laboratory and thoroughly washed under running tap water, until the water ran clear. The bags were then spread on perforated aluminium foil and dried in a forced air oven at 60°C for 48 h. The bags were put in the desiccator before being weighed.

The dried incubated samples were composited before being ground through a 1.0 mm screen using a Brinkman micro grinder, and then packed into small polyethylene sample bags and stored at room temperature for CP and starch analysis.

2.2.4.2. Analytical procedures.

Proximate analysis and detergent-fibers (DF's) of the test materials and ingredients of the TMR fed to cows were analysed according to AOAC (1984) and Waldern (1971) and Van Soest et al. (1991), respectively.

Dried incubated composite test samples were analysed for DM, CP and starch. Crude protein was analysed at Pacific Agriculture Research Centre (Agassiz, B.C. Canada) using a Leco Nitrogen Determinator FP-428 (Leco Corporation, St. Joseph, MI). Starch was analysed according to the method of MacRae and Armstrong, (1968), with modifications according to Xiong et al. (1990).

Starch analysis was done by initially gelatinizing samples in a 4.5±0.05 acetate buffer solution (Xiong, et al., 1990) using an autoclave (STERILIZER; Barnstead Still and Sterilizer Co., Boston, Massachusetts, Model # 0745 02131) for 90 min. set at 124°C (MacRae and Armstrong, 1968) followed by incubating with 1 ml

amyloglucosidase (Rhizopus mold) enzyme (Sigma, No. A-7255) in a Controlled Environment Incubator Shaker (New Brunswick Scientific Co., Inc., Edson, N.J., U.S.A) for 16-20 h to release α-linked glucose polymers. The incubated samples were then deproteinized and filtered. An aliquot of the filtrate was used for starch analysis by color development through the copper reduction method. Starch percent (%) was calculated according to MacRae and Armstrong (1968) as shown below;

A.   α-linked glucose polymers = GC x V/100 x 1/W (Equation 2.1);

     a.   α-linked glucose polymers in mg/g,

     b.   GC = glucose concentration in mg/100 ml from standard curve,

     c.   V = volume (dilution to 25 ml) in ml,

     d.   W = sample dry weight in g,

B.   % starch = (α-linked glucose polymers (mg/g))/1,110x100 (Equation 2.2);

2.2.4.3. Treatment of results and statistical analysis.

All starch content analysis of test materials involving ten replications were done in order to validate our modified starch

analysis method. This was done by calculating the mean, range of values, standard deviation (SD), and coefficient of variation (CV).

Disappearance data were fitted through iterative procedures according to the following modified mathematical equation of Ørskov and Macdonald (1979) with a lag phase:

$$p = a + b(1-e^{(-c(t-lag))}) \text{ for } t > lag \quad \text{(Equation 2.3)};$$

where p is the disappearance (%) after t, a is the fraction which disappears rapidly (%), b is the slowly degradable fraction (%), c is the fractional rate of degradation (k_d, %/h) of fraction b, and t is time (h) of incubation. The a, b, c and lag were estimated by an iterative least-square procedure (Appendix 1) using general linear Model (GLM) of the statistcal analysis system (SAS) (1990) package. Effective degradability (EFDEG) was then calculated from the estimates of a, b and c assuming a fractional outflow rate of solids from the rumen (kf) of 5 %/h, because degradability of any nutrient is a function of both digestion and fractional rate of passage of solids. The following equation was used to calculate effective degradability (Appendix 1):

$$EFDEG = a + (((bc)e^{(-c*t-lag)})/(c + kf)e^{(-(c+kf)lag)}$$
(Equation 2.4);

where a, b and c are as defined above.

Degradation characteristics data was statistically analysed as a 3 x 2 factorial experiment (Cochran and Cox, 1969) with cereal and processing as main effects using GLM of SAS package (1990) and LSD was used for mean separation when the interaction was significant.

2.2.4.4. Enzyme in vitro starch release procedure.

The technique was adapted from that of Xiong et al. (1990) and Mathison et al. (1991). Triplicate samples (0.2g) of grain were weighed into 50 ml digestion tubes containing 15 ml of acetate buffer (.2 M, pH 4.50). Amyloglucosidase (Rhizopus mold) enzyme (1 ml) was added to each tube and incubated in an Environmental Controlled Electric Incubator including 3, 6, 12, 24, and 36 h. The reaction was stopped by putting the tubes in a cold ice bath. The samples were then deproteinized by adding 2 mls of 10% $ZnSO_4.H_2O$ followed by 1.0 ml of 0.5% NaOH and then mixed. All treatments were then diluted to 25 ml with deionized water and filtered through a pre-weighed filter paper (WHATMAN # 40). The filtrate was analysed for starch using the starch analysis method as previously described.

2.3.0.   RESULTS AND DISCUSSION.

2.3.1.   General observations.

The chemical composition of corn, wheat and barley and their corresponding steam-rolled counterparts is given in Table 3 and that for starch is given in Table 4. There was very little

variation in DM, OM and EE content among the cereal treatments. Wide variation was observed in CP, NDF, total non-structural carbohydrates (TNC), and ash content and this seem to be related to type of cereal (Table 3). Values for CP, NDF, ash and EE are similar to typical values for corn, barley and wheat reported elsewhere (Herrera-Saldana et al., 1990b; NRC, 1989; Malcolm and Kiesling, 1993).

Starch content also varied according to type of cereal and processing (Table 4). Starch was highest for corn, medium for wheat and least for barley cereals averaging 71.96%, 60.07% and 56.30% for corn, wheat and barley. Wide variation in range, SD and CV were also observed among cereal types. It appears that, the higher the fiber content, the higher was the SD and CV. Herrera Saldana et al. (1990b) and Kartchner and Theurer, (1991) reported similar observations. However, the SD and CV reported were somewhat lower for barley and corn treatments than reported here. Kartchner and Theurer, (1981) reported increased variation among individual estimates of starch as the cellulose content of the material increased. It is possible that it is difficult to achieve thorough mixing of feed ingredients high in fiber content resulting in separation of feed particles making representative sampling difficult (Herrera-Saldana et al., 1990b). Starch values reported in this study are similar to others (Herrera-Saldana et al., 1990b; Huntington, 1994 and de Smet et al., 1995) but different to Malcolm and Kiesling, (1993) who reported much higher values and out of the range reported by Huntington, (1994). Slight increases in starch

content observed (Table 4) due to steam rolling; this agrees with Malcolm and Kiesling, (1993) for corn, wheat and sorghum but not barley and Galyean et al. (1981) for corn, and sorghum. The increase in starch was smaller for corn than wheat and barley.

Variation among replicates in DM, CP and starch in situ disappearance were large for all grains in early incubation times and became smaller by 24 h incubation. The smaller variation in replicates after 24 h incubation would mean that in this study, in situ degradation of DM, CP and starch was influenced by actual feed characteristics and least influenced by other factors such as animal and period (Van der Koelen et al., 1992). Similar observations have been reported by others, although variation started being smaller by 48 h incubation (Van der Koelen et al., 1992 and de Smet et al., 1995). Disappearance of DM and starch were most rapid for all feeds compared to protein disappearance. By 12 h, 80% of DM had disappeared and was starting to level off between 12 and 24 h. Starch was most rapid for all feedstuffs such that by 12 h, between 80% and 90% on average had disappeared from corn, barley and wheat treatments, reaching asymptote by 24 h. Most of the DM in cereal grains is in the form of starch and this can be as high as 75% of DM (Huntington, 1994 and French, 1973). Since DM disappearance paralled that of starch and protein, this is an indication of the significant contribution of starch disappearance to DM disappearance (Varga and Hoover, 1983).

2.3.2.0 Dry Matter degradation characteristics.

2.3.2.1. Rapidly degradable fraction of DM.

Steam rolling significantly (P<0.0012) reduced the rapidly degradable fraction of DM for all grains (39.89±0.58% vs 44.61±0.58 %). Type of cereal also significantly (P<0.0001) affected the rapidly degradable fraction of DM. The rapidly degradable fraction of DM for corn (31.17±0.71%) was significantly lower (P<.0001) than for wheat (49.24±0.71%) and barley (46.33±0.71%) and barley was lower (P<0.0271) than wheat. Similar ranking for unprocessed grains was reported by Herrera-Saldana et al. (1990b) and de Smet et al. (1995) and was also maintained among steam rolled grains in this study (Table 5). The value for UPB (Table 5) is similar to 47.0% reported by Herrera-Saldana et al. (1990b), while UPC and UPW were higher and lower (Table 5) respectively in this study than reported by Herrera-Saldana et al. (1990b), (18.6% and 61.1%, respectively). Values reported by de Smet et al. (1995) were much lower than reported in this study and Herrera-Saldana et al. (1990b). de Smet et al. (1995) used grains ground through a 2.0 mm screen as opposed to 1.0 mm screen used in this study and Herrera-Saldana et al. (1990b) while bag pore size was the same in all the studies. Differences in the quantity of rapidly degradable fraction within an experiment and among experiments may be explained by differences in the solubility of DM components of the different cereal grains and experimental procedural differences, respectively as noted above. Wheat and barley contain more soluble nutrients than corn (Aman and Hesselman, 1984 and Salomonsson et al., 1984). In

contrast to these findings Malcolm and Kiesling, (1993) did not find differences in the rapidly degradable fraction of DM for ground and steam flaked corn, barley and wheat except for a significant decrease for sorghum. In addition there was not much difference in this fraction across cereals which averaged of 24% (Malcolm and Kiesling, 1993).

2.3.2.2. Slowly degradable fraction of DM.

The quantity of the slowly degradable fraction was significant for type of cereal ($P<0.0001$) and approached significance ($P<0.0556$) for steam rolling while interaction was not significant ($P<0.0904$). Steam rolling tended to increase the slowly degradable fraction of DM and this averaged 50.32 ± 0.98% and 47.03 ± 0.98% for the processed and unprocessed group, respectively. The reduction in the rapidly degradable fraction for processed grains seems to be reflected in the increased slowly degradable fraction. This significant reduction in the rapidly degradable fraction of the grains due to steam rolling suggests that some soluble DM was shifted to either the slowly or totally undegradable fraction or both (Chalupa and Sniffen, 1994).

Corn treatments (62.03 ± 1.20%) had siginificantly higher ($P<0.0001$) levels of the slowly degradable fraction when compared to wheat (42.11 ± 1.20%) or barley (41.88 ± 1.20%) which were themselves similar ($P>0.8977$). It was expected that corn with a low rapidly degradable fraction would have a higher slowly degradable fraction than wheat and barley. There is lack of data in literature

for DM, starch and CP slowly degradable fraction. However, Dewhurst et al. (1995) reported a value of 51.1% for wheat grain (15.3% CP); compare with 41.1% (no shown in table 5) for unprocessed wheat grain.

2.3.2.3. Rate of degradation of DM.

The rate of DM disappearance (k_d) for the slowly degradable fraction was also significantly affected by both cereal type (P<0.0371) and steam rolling (P<0.0007) and the effect was not dependent on type of cereal (P>0.1181) (Table 5). For all three cereals, steam rolling significantly (P<0.0007) reduced the rate of DM degradability and these averaged 15.54±0.81 %/h and 22.92±0.81 %/h; an unexpected result. Among the cereals, as expected, corn treatments (16.68±0.99 %/h) had lower rate of DM degradation than barley (P<0.0137) and tended to be lower when compared to wheat (P<0.0918). No significant differences were observed in rate of DM degradation between wheat and barley (P>0.1993). The values for barley and wheat treatments were 21.52±0.99 and 19.49±0.99 %/h, respectively.

Similar results for unprocessed corn versus unprocessed wheat or barley have been found (Herrera-Saldana et al., 1990b; Grings et al., 1992; Fiems et al., 1993; de Smet et al., 1995 and Arieli et al., 1995). That the rates of DMD for barley and wheat in this study are similar (Table 5) was unexpected and in sharp contrast to over whelming evidence that the reverse was true from the above reports. The reason for this discrepancy in our results is not

quite apparent. However, it must be mentioned here that, in spite of wheat numerically having a higher rate of DMD than barley, the rates were statistically the same as reported by Herrera-Saldana et al. (1990b) which is in agreement with our findings (Table 5). It may be speculated that the wheat and barley variety may have had similar properties. Grings et al. (1992) reported values for rate of DMD ranging from 20 to 36 %/h for a barley variety with grain densities averaging from 0.66 kg/L (44 lb/bu) to 0.79 kg/L (53 lb/bu) and Flachowsky et al. (1992) reported values ranging from 5 to 16 %/hr for 12 different varieties of barley. Among the steam rolled cereals corn and barley but not wheat, maintained the same order as for unprocessed grains. It could be possible that steam rolling could have affected SRW more negatively than SRC.

The results that steam rolling reduced the rate of DMD for each grain is in agreement with other previous reports (Fiems et al., 1990; Malcolm and Kiesling, 1993 and Arieli et al., 1995). Engstrom et al. (1992) reported higher (P<0.01) DMD for dry rolled than steam rolled barley at 0, 8 and 24 h of incubation in sacco. In other work, Malcolm and Kiesling, (1993) reported interchanges in ranking of DM disappearance at different incubation times after steam flaking of similar grains including sorghum.

2.3.2.4. Lag time of DM degradation.

Results for lag time of DMD were quite variable (Table 5). The steam rolling effect was not significant (P>0.96) while type of cereal (P<0.0101) and interaction (P<0.0439) were significant. The

interaction occurred because steam rolling reduced the lag time for corn and barley though this was not significant (P>0.4258 and P>0.1131, respectively) but not for wheat which was increased and was significant (P<0.0398). The values for unprocessed grains averaged 1.61±0.25%, 1.40±0.25% and 1.05±0.25% for UPC, UPW and UPB, respectively and the values for processed grains averaged 1.31±0.25%, 2.30±0.25% and 0.41±0.25% for SRC, SRW and SRB, respectively.

2.3.2.5. Effective degradability of DM.

Results for effective degradability of DM indicate that both cereal type (P>0.1681) and interaction (P>0.2550) were not significant, while steam rolling was significant (P<0.0222)(Table 5). Steam rolling decreased the effective degradability of DM for all grains. The average values for processed and unprocessed grains were 75.45±1.12% and 80.29±1.12%, respectively. Arieli et al. (1995) did not find differences in effective degradability of DM for similar grains; untreated, extruded or expanded. The values for these workers averaged over 80% compared to above 70% in this study. Grings et al. (1992) observed similar ranking for barley and corn although effective degradability for corn was around 55% which is much lower than reported here (Table 5), but values for barley were in the same (77.8%, density of 0.79 kg/L) range as reported in this study (Table 5).

2.3.3.0. Starch degradation characteristics.

2.3.3.1. Rapidly degradable fraction of starch.

A summary of the results for starch degradation characteristics is shown in Table 6. Cereal type and steam rolling significantly (P<0.0002 and P<0.0289) affected the quantity of the rapidly degradable fraction of starch and the response to steam rolling was not dependent on the type of cereal (P<0.3741). Steam rolling reduced the level of the rapidly degradable fraction for all grains. Processed and unprocessed grains averaged 44.84±2.16% and 53.58±2.16%, respectively.

Corn treatments had significantly lower level of the rapidly degradable fraction compared to wheat (P<0.0002) and barley (P<0.0001), while wheat and barley were similar (P>0.7417). The average values for corn, wheat and barley were, 28.06±2.65, 59.14±2.65 and 60.43±2.65%, respectively. A similar ranking has been reported by others (Herrera-Saldana et al., 1990b and Tamminga et al., 1990), when UPC was compared to either barley or wheat, but the ranking for barley and wheat in this study is different from the above quoted reports. It must be mentioned here that although reports show a higher value for wheat than barley, Herrera-Saldana et al. (1990b) reported no significant differences in the level of the rapidly degradable fraction of starch. Values for steam rolled grains indicated a significantly lower value for SRC than either barley or wheat (Table 6). The value for UPB reported in this study is similar to that reported by Herrera-Saldana et al. (1990b) and Tamminga et al. (1990), while a higher value for UPC and UPW are

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reported here (Table 6) than elsewhere (Herrera-Saldana et al., 1990b and Tamminga et al., 1990). However the value for UPC reported here (Table 6) is similar to that reported by Grings et al. (1992) for ground corn. Variation in the quantity of the rapidly soluble fraction across experiments may likely be related to differences in washing procedures of zero h bags, and differences among cereals can be explained by inherent physical and chemical differences (French, 1973; Rooney and Pflugfelder, 1986, and Huntington, 1994) of the cereals themselves, resulting in differences in water solubility of the grain (Aman and Hesselman, 1984 and Salomonsson et al., 1984).

2.3.3.2. Slowly degradable fraction of starch.

The quantity of the slowly degradable fraction of starch was significantly affected by both type of cereal (P<0.0001) and processing (P<0.0204) and the response of steam rolling was not dependent on type of cereal (P<0.3684). Steam rolling increased the slowly degradable fraction for all grains, mimicking the result for the rapidly degradable fraction (Table 6). Processed grains averaged 53.38±1.85% compared to 45.18±1.85% for unprocessed grains.

Wheat and barley treatments had similar (P>0.5684) quantity of the slowly degradable fraction and were both lower (P<0.0001) than corn treatment. The values for wheat and barley were 39.62±2.17% and 37.68±2.17%, respectively compared to 70.53±2.17% for corn. Corn starch is more resistant to disintegration in the rumen than

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barley and wheat, resulting in higher quantity of this fraction for corn than wheat and barley. Variation in the quantity of the slowly degradable fraction of starch may in part explain the variation observed in the slowly degradable fraction of DM.

2.3.3.3. Rate of degradation of starch.

The rate of starch degradation for the slowly degradable fraction for all grains is summarized in Table 6. Results indicate that type of cereal ($P<0.002$) and processing ($P<0.0091$) effects were significant and the effect of steam rolling did not depend on type of grain ($P>0.1380$). Steam rolling significantly reduced ($P<0.0091$) the rate of starch degradation for all grains and the processed and unprocessed grains averaged 19.26 ± 1.08 and 25.03 ± 1.08 %/h.

Rate of starch degradtion was significantly lower for corn treatments than for both wheat ($P<0.0083$) and barley ($P<0.0007$) as expected and wheat was lower ($P<0.0436$) than barley. These results, in terms of ranking of the grains, are in agreement with previous reports for rate of degradation of the slowly degradable fraction of starch (Grings et al., 1992; Herrera-Saldana et al., 1990b and Arieli et al., 1995) or the potentially degradable fraction (Tamminga et al., 1990). The ranking of the grains did not change among the unprocessed grains (Table 6). The higher rate of degradation of barley and wheat treatments compared to corn treatments can be explained by inherent differences in the physical and chemical make up of the starch in cereal grains (French, 1973;

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Rooney and Pflugfelder, 1986, and Huntington, 1994) resulting in differences in water solubility of the grains (Aman and Hesselman, 1984 and Salomonsson et al., 1984).

The result that steam rolling decreased the rate of starch degradation in situ conflicts earlier reports (Galyean et al., 1981; Thuerer, 1986 and Thomas et al., 1988) and also data from in vitro studies with pure enzymes and rumen fluid (Cone and Vlot, 1990) and also increased in vitro starch release (Fiems et al., 1990; Mathison et al., 1991 and Malcolm and Kiesling, 1993) and in vivo studies (Thuerer, 1986 and Huntington, 1994). In contrast data that show processing such as steam flaking (Fiems et al., 1990) and steam rolling (Engstrom et al., 1993) and other steam applying processes (Arieli et al., 1995) resulted in reduced rate of starch degradability has previously been reported. Engstrom et al. (1992) reported significantly lower values for steam rolled barley at 0, 8 and 24 h of incubation in sacco in conflict to their findings for glucose release by amyloglucosidase enzyme. They speculated that differences in particle size distribution within each grain, with dry rolled barley having a higher number of small particles than steam rolled barley resulting in more particles disappearing at 0 h incubation from dry rolled barley than steam rolled barley. Malcolm and Kiesling, (1993) reported variable results due to grinding and steam flaking (100°C, 25 minutes, at atmospheric pressure) for these same cereals including sorghum for DMD at different incubation times. Since the greatest effect on DMD is from starch disappearance, by implication it could be concluded

that starch disappearance followed a similar trend. However, their results indicated that temperature at which birefrigence is lost were lower for steam flaked grains than ground grains although the difference was small for corn. In another report for the same cereal grains (Fiems et al., 1990), steam flaking (95-100°C, 30 minutes, at atmospheric pressure) was reported to have consistently reduced DM and CP disappearance at all incubation times. Fiems et al. (1990) inferred from their results that starch disappearance may have been affected in a similar way being in conflict with their gelatinization data which indicated steam flaking increased starch released by amyloglucosidase enzyme. More recently, Arieli et al. (1995) reported a significant reduction in the rate of starch degradation due to expansion (at 125°C) or extrusion (at 115°C) of corn, barley and wheat, although the reduction was not significant for corn and there was no observable change for sorghum. The findings of the above quoted experiments are in agreement with the findings of this experiment inspite of the fact that the steam rolling temperature in this experiment was lower (70°C) than in all of the other experiments, all other conditions being similar.

A number of factors may explain the reduction in starch disappearance due to steam application. Fiems et al. (1990) speculated that retrogradation of gelatinized starch and formation of starch-protein complexes may be responsible for the reduced starch degradability. There is also a possibility that steam rolling may modify the effect of grinding resulting in a steam

rolled grain with a lower fraction of very small particles than dry rolled or ground unprocessed samples, resulting in higher rapidly degradable fraction (Engstrom et al., 1992). In another study, steam rolling at low pressure (atmospheric or 1.4 kg/cm^2) was reported to have decreased starch degradability (Osman, et al., 1970). This is possible to have happened in this experiment since steam rolling was done at atmospheric pressure.

The differences between studies that show significant increase in DM and starch degradability (Galyean et al, 1981 and Thomas et al, 1988) of cereal grains after steam rolling and those in conflict (Fiems et al, 1990, malcolm and Kiesling, 1993, Engstrom et al, 1992 and Arieli et al, 1995) including this report, may explained by the way the two groups treated their test feedstuffs. The former used steam rolled corn and cracked corn that had been retained on a 4 or 2 mm sieve thereby reducing number of fine particles, and the later used grains that had been ground after steam rolling or left unprocessed. Using material that had been ratained on a sieve would tend to reduce the effect of grinding on the zero hour incubation due to differences in number of very small particles for the different grains inspite of the grains having been ground using the same screen size. That grinding of grains through the same screen size results in different particle size distribution (Fiems et al, 1990) would tend to mask the effect of steam rolling.

Dewhurst et al. (1995) have recently questioned the effectiveness of the nylon bag procedure in evaluating concentrates

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which have appreciable levels of water soluble fraction. Certainly more research is required to explore this discrepancy between in sacco and in vitro and in vivo data.

2.3.3.4. Lag time of starch degradation.

Lag time for starch disappearance varied among the grains and was significantly affected by cereal type (P<0.0061) and processing (P<0.0068); however the response to steam rolling was dependent on type of cereal (P<0.001) (Table 6). The interaction occurred because steam rolling significantly reduced the lag time for corn (P<0.0004) and barley (P<0.016) but not for wheat, which was significantly (P<0.0175) increased. Among the unprocessed grains, UPC had the longest time (Table 6) and was significantly different to UPW (P<0.0003) and UPB (P<0.0017), which were similar (P>0.0768). The values were 3.99, 0.91, and 1.79 h for UPC, UPW and UPB, respectively. The longer time on UPC is expected when compared to wheat and barley because corn starch is more resistant to degradation than the other 2, because of differences in physical and chemical make up (French, 1973; Rooney and Pflugfelder, 1986, and Huntington, 1994). Among the processed materials, SRW had the longest lag time when compared to SRC (P<0.0378) and SRB (P<0.0044), and SRC lag time was longer than SRB but this was not significant (P<0.1253). The values averaged 1.16, 2.24 and 0.43 h for corn, wheat and barley, respectively. Differences in lag time among cereals for starch may in part explain the differences in lag time for DMD.

2.3.3.5. Effective degradability of starch.

Results for the effective degradability of starch are shown in Table 6. Cereal type was significant (P<0.0001) while, steam rolling approached significance (P<0.0994) and the interaction was not significant (P>0.1903). Steam rolling tended to reduced the effective degradability of steam rolled grains when compared to the unprocessed grains. Steam rolled grains averaged 83.92±0.75% compared to 85.98±0.75%. Results for wheat and barley agree with Arieli et al. (1995) who also reported reduced effective degradability of starch when these same cereals were subjected to expansion and extrusion although these treatments are different from steam rolling. Although UPC had a faster rate of starch degradation than SRC this did not result in a higher effective degradability than SRC and this could be attributed to the longer lag time observed on UPC.

In terms of effect of cereal type, corn treatment had significantly lower (P<0.0001) effective degradability than wheat and barley, while wheat and barley were similar (P>0.3429) as expected. Corn, wheat and barley treatments averaged 75.21±0.92, 89.15±0.92 and 90.49±0.92% respectively. In spite of corn having the highest available material for the slow degradable fraction, the low rate of degradation in the rumen resulted in lower effective degradability and this explanation is true for both steam rolled and unprocessed grains. This would mean more energy would be available for microbial protein synthesis from barley or wheat than

corn. Differences in effective degradability of starch would partly explain differences observed for DM effective degradability.

2.3.4.0 Protein degradation characteristics.

2.3.4.1. Rapidly degradable fraction of CP.

The summary of results of the protein degradation characteristics for cereal grains is shown in Table 7. Type of cereal, steam rolling and the interaction were significant (P<0.0007, P<0.0001 and P<0.0115, respectively) for the rapidly degradable fraction. Steam rolling significantly reduced the rapidly degradable fraction for all grains but the extent differed among the grains. The decrease was higher in barley grain, lower for corn and least for wheat grain. This agrees with observations for the same grains after extrusion or expansion or steam flaking (Herrera-Saldana et al., 1990b and Arieli et al., 1995). Among unprocessed grains, the rapidly degradable fraction for UPC tended to be lower than UPW (P<0.0536) and UPB (P<0.0002) and UPW was lower when compared to UPB (P<0.0013). This result was the same when SRC was compared to SRW (P<0.0176) or SRB (P<0.0253) which were similar (P>0.7853). Ranking of corn treatment in relation to barley and wheat agrees with previous reports (Fiems et al., 1990; Tamminga et al., 1990; Herrera-Saldana et al., 1990b and Grings et al., 1992). Values for unprocessed and steam rolled grains were; 20.55%, 29.46% and 50.49% for UPC, UPW and UPB respectively and 6.52%, 18.59% and 17.53% for SRC, SRW and SRB respectively (Table 7). Most of the values fall in the same general range as previous reports (Fiems et al., 1990;

Herrera-Saldana et al., 1990b and Tamminga et al., 1990), except for SRC and SRB which were lower and higher respectively than usually reported (Table 7). The decreased level of the rapidly degradable fraction of protein after applying heat may have resulted from formation of resistant complexes between cell wall and soluble proteins. Formation of artifact lignin may increase cell wall content when grains are thermally treated above 65°C (Mathison et al., 1991 and Malcolm and Kiesling, 1993) and it is also possible that resistant complexes were formed between protein and soluble sugars (Fiems et al., 1990). Grains used in this study were steam rolled at 70°C which is higher than 65°C, making it possible for the formation of artifact lignin and complexes of protein and soluble sugars. Differences in solubility of proteins from different cereal sources is related to physical and chemical properties of the material due to species, varietal and processing differences to mention a few (Kakade, 1974; Wall and Paulis, 1975, and Stern et al., 1994). Cereals crops such as barley and wheat though high in glutelins and prolamins like corn, also have a high content of albumins and globulins too. Albumin and globulin protein have a high content of basic and acidic amino-acids making these proteins highly soluble (Kakade, 1974) in water. Glutelins and prolamins are more resistant to disintegration than albumins and globulins (Kakade, 1974; Wall and Paulis, 1975; Stern et al.,1994 and Romagnolo et al., 1994)

2.3.4.2. Slowly degradable fraction of CP.

The slowly degradable fraction for protein was also significantly affected by processing (P<0.0069) and interaction (P<0.0286), while type of cereal effect approached significance (P<0.1058) (Table 7). Steam rolling significantly increased and tended to increase the slowly degradable fraction for barley (P<0.0023) and corn (P<0.088), respectively, but not wheat (P>0.9047). The results for wheat were unexpected. The decreased rapidly degradable fraction resulted in a concomittant increase in the quantity of the the slowly degradable fraction for corn and barley but not wheat (Table 7). The increase in this fraction due to steam rolling may be related to the formation of resistant complexes formed between soluble sugars and proteins, (Fiems et al., 1990 and Mathison et al., 1991). Our results agree with Fiems et al. (1990) who deduced from protein disappearance curves.

Among unprocessed materials, UPW was higher in the slowly degradable fraction when compared to barley (P<0.0047) and tended to be higher than corn (P<0.0576), and UPC tended to be higher (P<0.0883) than barley. Values were 66.63%, 55.08% and 45.06% for wheat, corn and barley (Table 7). Differences in the slowly degradable fraction were also observed for steam rolled grains but differences were not significant (P>0.05). Ranking was SRB, SRW and SRC and their values were 70.07%, 66.02% and 65.12%, respectively (Table 7). Since protein is a component of DM, uit does contribute to the variation observed in the slowly degradable fraction of DM.

2.3.4.3. Rate of degradation of CP.

The rate of degradation for the slowly degradable fraction of protein was significantly affected by type of cereal (P<0.0001) and processing (P<0.003) while interaction was not significant (P<0.0778) (Table 7). Steam rolling decreased the rate of degradation of the slowly degradable fraction of protein for all grains but was only significant for corn (P<0.043) and wheat (P<0.0028). Results for corn and wheat agree with previous reports (Fiems et al., 1990 and Arieli et al., 1995) for the same grains. However extrusion of barley and expansion of sorghum resulted in similar rates of degradation as the control (Arieli et al., 1995).

Among the unprocessed grains, UPW was degraded faster than both UPC (P<0.0001) and UPB (P<0.0017) and UPB was faster than UPC protein (P<0.0009). The rate of degradation averaged 23.43±0.79 %/h, 17.48±0.79 %/h, and 13.55±0.79 %/h, for UPW, UPB and UPC, respectively (Table 7). This ranking was not modified among the steam rolled grains. Values for the rate of degradation were 18.00±0.79 %/h, 16.50±0.79 %/h and 10.70±0.79 %/h for SRW, SRB and SRC, respectively (Table 7). Ranking of the grains for both unprocessed and steam rolled grains agree with previous reports (Fiems et al., 1990; Grings et al., 1992 and Arieli et al., 1995). The value for UPC is somewhat higher than previously reported (Grings et al., 1992) and that estimated by Tamminga et al. (1990) but similar to the 9.0 %/h reported by Arieli et al. (1995). Grings et al. (1992) and Arieli et al. (1995) reported similar values for barley and wheat respectively while Tamminga et al. (1990)

estimated the rate to be around 20 %/h for wheat which is similar to the 23.43 %/h for UPW reported in this study (Table 7). Rates for expanded and extruded grains were much lower (Arieli et al., 1995) than reported here (Table 7) for steam rolled materials. The reduced rate of degradation may be related to formation of resistant complexes such as artifact lignin formed between protein and sugars in presence of heat (Fiems et al., 1990; Malcolm and Kiesling, 1993 and Mathison et al., 1991). Differences in rate of degradation for the 3 grain types is related to differences in the distribution of protein types of these grains (Kakade, 1974; Wall and Paulis, 1975; Romagnolo et al., 1994 and Stern et al., 1994).

2.3.4.4. Lag time of CP degradation.

The lag time of protein degradation was significantly (P<0.0001) affected by cereal type (P<0.0001) and processing (P<0.0003) but the extent of response by the 3 grains was also significant (P<0.0001) (Table 7). The interaction occurred because Steam rolling resulted in reduced (P<0.0291) lag while that for barley and wheat were increased but was only significant for wheat (P<0.0001). The longer lag phase for corn treatments when compared to UPW, SRB and UPB is expected as well as that for wheat and barley comparison, however, the value for SRW was unexpectedly high. Possible formation of protein-carbohydrate resistant complexes as previously speculated would reduce the solubility of heat treated proteins resulting in a longer lag phase.

2.3.4.5. Effective degradability of CP.

A summary of results for the effective degradability of protein are shown in Table 7. Effective degradability of CP was significantly affected by type of cereal (P<0.0001) and processing (P<0.0001) and the interaction was not significant (P>0.05). Steam rolling resulted in a significant reduction in the effective degradability of all grains; corn (P<0.0344) wheat (P<0.0004) and barley (P<0.0031). The average effective degradability of processed and unprocessed grains were 55.72$\pm$1.39% and 72.43%$\pm$1.39%, respectively. This was expected considering that most protein from steam rolled grains would by-pass rumen microbial degradation as indicated by the significantly lowered rate of degradation (Table 7).

For the different cereals, corn treatments had significantly lower quantity of effective degradability than wheat (P<0.0.0001) and barley (P<0.0001) while wheat was lower (P<0.045) than barley. The treatments averaged 47.30$\pm$1.72, 69.41$\pm$1.72 and 75.50$\pm$1.72%. Among the unprocessed grains, corn (UPC) had a significantly lower effective degradability when compared to UPW (P<0.0001) and UPB (P<0.0001) which were similar (P>0.5862) among the unprocessed grains (Table 7). The ranking was the same for steam rolled grain but SRB had a significantly higher (P<0.0241) effective degradability than SRW. The higher rapidly degradable fraction for barley and wheat than corn treatments may explain differences in effective degradability. Most of the corn protein escapes to the small intestines. Similar ranking for corn versus wheat or barley

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was previously reported (Grings et al., 1992 and Arieli et al., 1995). Results for effective degradability by Arieli et al. (1995) are variable with respect to thermal processing. Expansion and extrusion resulted in higher effective degradability for barley, wheat, corn and sorghum which is in conflict with our results. This is interesting because rates for thermally processed materials were lower than unprocessed grains. It is possible that extrusion and expansion may have an effect on other nutrient components compared to those affected by steam rolling. Dry rolled barley at 3 different bushel weights averaged over 70% (Grings et al., 1992) falling in between the values for the 2 barley treatments. Grings et al. (1992) and Arieli et al. (1995) reported a similar value for ground corn, (44%) which also fell between the two corn treatments.

The higher effective degradability of CP for wheat and barley would mean that more nitrogen would be available for microbial protein synthesis in the rumen than from corn.

2.3.5. In vitro starch release.

The results for the release of starch from unprocessed and steam rolled grains are summarised in Table 8. The release of starch increased for all six grains with increasing incubation time. This agrees with previous reports for dry rolled and steam rolled barley grain (Mathison et al., 1991 and Engstrom et al., 1992). Steam rolling increased the release of starch for all the 3 grains, being in agreement with previous reports (Fiems et al., 1990; Mathison et al., 1991; Engstrom et al., 1992 and Malcolm and

Kiesling, 1993) for similar grains. This was expected because amyloglucosidase does not attack ungelatinized starch easily (MacRae and Armstrong, 1968). The improvement in starch release after steam rolling at each incubation time was high for corn than barley and wheat which showed small changes only. The lower degree of gelatinization of barley and wheat when compared to corn therefore, suggests that barley and wheat do not exhibit as much starch gelatinization when subjected to heat as does corn suggesting that barley and wheat starch are more susceptible to enzyme attack than corn starch even before application of steam. This agrees with previous reports for corn, sorghum, barley and wheat (Walker et al., 1970 and Malcolm and Kiesling, 1993), micronized wheat (Aimone and Wagner, 1977) and corn, and wheat (Fiems et al., 1990). It is therefore reasonable to suggest that, steam treatment is more beneficial for grains with low starch degradability than those with high starch degradability.

The increase in starch release due to steam rolling is as a result of gelatinization, which is a measure of the starch granule disruption. Grains from different sources gelatinize at different temperatures and this is related to the physical and chemical structure of the starch source (Moran, 1983 and Rooney and Pflugfelder, 1986). Thermal treatment of grains in the presence of moisture increases swelling of the starch granule resulting in changes in both the chemical and physical structure of starch. This allows for more enzymes to enter the interior of the starch

molecules thereby enhancing enzymatic hydrolysis of starch (French, 1973; Moran, 1982 and Rooney and Pflugfelder, 1986).

Results for starch release (TAble 8) conflict with in sacco data, (Table 6), in which it was observed that steam rolling decreased the rate of DM and starch degradation for all grains. These findings are similar to other previous reports in which such conflict was also reported (Fiems et al., 1990; Engstrom et al., 1992 and Malcolm and Kiesling, 1993). Engstrom et al. (1992) speculated that conflict between in sacco and enzyme starch release data may be related to the fact that, in spite of drying grains to the same moisture content unprocessed material contained more small particles since more DM disappeared from 0 h bags (Engstrom et al., 1992). This is true for our in sacco data (Table 6) which indicates higher 0 h values for unprocessed grains than steam rolled grains. This modifying effect of grinding has already been discussed earlier under section 2.3.3.3. More research is needed to elucidate this conflict. Dewhurst et al. (1995) have recently questioned the efficacy of the nylon bag technique for determination of degradability for concentrates which contain appreciable levels of water soluble materials or small particles which may leave the bag unfermented.

2.4.0.   SUMMARY AND CONCLUSION.

Steam rolling of corn, wheat and barley significantly decreased the rapidly degradable fraction, effective degradability

and rate of degradation for DM, CP and starch but increased the slowly degradable fraction. Values for the rapidly degradable fraction, rate of degradation and effective degradability for DM, CP and starch were lower for corn than wheat and barley. There was no difference in the rate of starch degradation between steam rolled barley and wheat. Corn treatment values were lower than barley and wheat for the slowly degradable fraction of DM, starch and CP.

Steam rolling of corn, barley and wheat did not increase starch degradation in sacco but increased in vitro starch release by amyloglucosidase enzyme. Because of the above conflict and the conflict in the literature regarding thermal processing, it is suggested that more carefully planned research is required to pin point factors which are responsible for the decrease in situ starch degradation associated with thermal processing.

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2.6.0. TABLES.

TABLE 1. Ingredients of the diet consumed by ruminally fistulated cows used for the in situ experiments (DM basis).

Ingredient			
Roughage	60		
Chopped alfalfa hay		15	
Chopped orchard grass hay		15	
Corn-grass silage		30	
Concentrate	40		
Dairy textured feed (16% CP)		40	
Rolled barley			47
Beet pulp			3
Rolled corn			1
Molasses			2
Commercial pelleted protein vitamin-mineral mix[1]			46

[1]Canola meal, Rye distillers grains, meat-meal, feather-meal, wheat millrun, molasses, salt, limestone, vitamin-mineral premix. (A special formulation for the feed company and proportions of the ingredients are confidential).

Table 2. Chemical composition of ingredients used in the diet consumed by ruminally fistulated cows used for in situ study (DM basis).

Nutrient	Ingredient			
	Chopped alfalfa hay	Chopped orchard hay	Corn-grass silage	Dairy textured feed (16 %)
DM	95.23	98.17	97.02	97.54
OM	89.93	93.40	94.06	93.76
CP	19.87	6.77	11.35	15.89
NDF	41.29	61.40	56.92	16.75
ADF	34.58	37.56	33.75	9.23
Starch	4.98	13.71	19.07	45.87
Ash	10.07	6.60	5.94	6.24
Ca	1.54	0.20	0.20	1.22
P	0.24	0.30	0.32	0.27
GE, kcal/g	4.42	4.33	4.83	4.35

Table 3. Chemical composition of cereal grains used in in situ and in vitro experiments (DM basis).

Nutrient	Feedstuffs[1]					
	SRC	UPC	SRB	UPB	SRW	UPW
DM	95.06	95.02	96.06	96.61	93.05	96.70
OM	98.61	98.65	97.11	97.00	98.17	97.97
CP	9.50	8.98	12.43	12.61	15.92	14.85
NDF	9.47	8.37	20.09	19.33	13.68	12.45
TNC[2]	77.54	79.66	61.29	63.52	66.81	66.00
Ash	1.39	1.35	2.89	3.00	1.83	2.03
EE	2.10	1.64	1.30	1.54	1.76	1.65

[1]SRC=steam-rolled corn, UPC=unprocessed corn, SRB=steam-rolled barley, UPB=unprocessed barley, SRW=steam-rolled wheat, UPW=unprocessed wheat.

[2]TNC=Total Non-structural Carbohydrate = DM − (CP + NDF + EE + Ash)

Table 4. Starch content of test feedstuffs and validation of starch analysis method (DM basis).

Feedstuff[1]	No. of reps.	Starch content, % DM	Range of values	S.D.	C.V, %
SRC	10	72.35	67-78	3.57	4.93
UPC	10	71.57	62-79	6.59	9.21
SRW	10	61.08	57-66	3.10	5.06
UPW	10	59.05	55-66	3.14	5.32
SRB	10	58.34	48-69	7.38	12.65
UPB	10	54.26	44-66	6.60	12.17

[1]See Table 3

Table 5. The effect of type of cereal and steam-rolling on in situ dry matter degradation characteristics of corn, barley and wheat incubated in the rumen of dairy cows.

Cereal grains[1]	Degradation characteristics[2,3]			
	a%	b%	K_d%/h	EFDEG%
Cereal type[1]				
Corn	31.17	62.03	16.68	75.42
Wheat	49.24	41.11	19.49	79.33
Barley	46.33	41.88	21.52	78.86
SE[4]	0.71	1.20	0.99	1.37
Process[1]				
SR	39.89	50.32	15.54	75.45
Unprocessed	44.61	47.03	22.92	80.29
SE	0.58	0.98	0.81	1.12
P values[5]				
C	0.0001	0.0001	0.0371	0.1681
P	0.0012	0.0556	0.0007	0.0222
C*P	0.0622	0.0904	0.1181	0.2550

[1]Cereal Type = Corn, wheat, and barley
Process = Steam-rolling (SR) and unprocessed.
[2]a = rapidly degradable fraction,
b = slowly degradable fraction,
k_d = fractional rate of degradation of fraction b,
lag= lag time,
EFDEG = effective degradability at 5 %/h fractional outflow rate.
[3]means in the same column with different letters are significantly different.
[4]SE = standard error(cereal type, n=4 and process, n=6).
[5]Effects;
C = cereal type,
P = processing (steam-rolling)
C*P = interaction.

Table 6. The effect of type of cereal and steam-rolling on in situ starch degradation characteristics of corn, barley and wheat incubated in the rumen of dairy cows.

	Degradation characteristics[2,3]			
	a%	b%	K_d%/h	EFDEG%
Cereal Type[1]				
Corn	28.06	70.53	15.74	75.21
Wheat	59.14	39.62	22.97	89.15
Barley	60.43	37.68	27.73	90.49
SE[4]	2.65	2.17	1.32	0.92
Process[1]				
Processing	44.84	53.38	19.26	83.92
Unprocessed	53.58	45.18	25.03	85.98
SE	2.16	1.85	1.08	0.75
P value[5]				
C	0.0002	0.0001	0.002	0.0001
P	0.0289	0.0204	0.0091	0.0994
C*P	0.3741	0.3684	0.138	0.1903

[1]Cereal Type = Corn, wheat, and barley
Process = steam-rolling (SR) and unprocessed.
[2]a = rapidly degradable fraction,
b = slowly degradable fraction,
k_d = fractional rate of degradation of fraction b,
lag= lag time,
EFDEG = effective degradability at 5 %/h fractional outflow rate.
[3]means in the same column with different letters are significantly different.
[4]SE = standard error(cereal type, n=4 and process, n=6).
[5]Effects;
C = cereal type,
P = processing (steam-rolling)
C*P = interaction.

Table 7. The effect of type of cereal and steam-rolling on in situ crude protein degradation characteristics of corn, barley and wheat incubated in the rumen of dairy cows.

Cereal grains[1]	Degradation Characteristics[2,3]				
	a%	b%	K_d%h	Lag h	EFDEG%
SRC	6.52d	65.12a	10.70	4.02b	42.66
UPC	20.55c	55.08b	13.55	4.96c	51.96
SRW	18.59c	66.02a	18.00	5.86d	57.14
UPW	29.46b	66.63a	23.43	1.00a	81.69
SRB	17.53c	70.07a	16.50	1.52a	67.35
UPB	50.49a	45.06c	17.48	1.10a	83.65
SE[4]	2.63	3.49	0.79	0.23	2.41
P values[5]					
C	0.0007	0.1058	0.0001	0.0001	0.0001
P	0.0001	0.0069	0.003	0.0003	0.0001
C*P	0.0115	0.0286	0.0778	0.0001	0.0524

[1]SRC = steam rolled corn, UPC = unprocessed corn, SRW = steam rolled wheat, UPW = unprocessed wheat, SRB = steam rolled barley UPB = unprocessed barley
[2]a = rapidly degradable fraction,
 b = slowly degradable fraction,
 k_d = fractional rate of degradation of fraction b,
 lag= lag time,
 EFDEG = effective degradability at 5 %/h fractional outflow rate.
[3]means in the same column with different letters are significantly different.
[4]SE = standard error(n=2).
[5]P values;
   C = Cereal type,
   P = processing (steam-rolling)
   C*P = interaction.

Table 8. In vitro starch release (% of DM) by steam rolled and unprocessed cereal grains incubated with amyloglucosidase enzyme.

Incubation time, h.	Cereal Grain[1]					
	SRC	UPC	SRW	UPW	SRB	UPB
3	60.43	48.19	40.33	40.81	48.6	30.26
SD[2]	1.70	1.52	1.19	1.82	1.42	1
6	63.30	58.39	45.68	46.25	53.96	33.2
SD	2.32	1.61	2.85	2.42	1.45	0.57
12	72.72	60.10	53.95	49.19	56.16	33.63
SD	2.04	2.65	2.49	0.78	1.20	0.46
24	75.05	60.91	55.54	52.03	57.63	42.90
SD	0.76	1.82	1.55	1.58	1.55	1.17
36	81.53	64.91	56.06	53.59	57.86	43.33
SD	1.84	1.85	2.08	2.45	2.87	1.90

[1]SRC = steam rolled corn, UPC = unprocessed corn, SRW = steam rolled wheat, UPW = unprocessed wheat, SRB = steam rolled barley UPB = unprocessed barley
[2]SD = standard deviation (n=3).

CHAPTER 3. IN SITU DEGRADABILITY OF DRY MATTER AND NEUTRAL DETERGENT FIBER OF THREE ROUGHAGES AND AGRO-BYPRODUCTS USED AS LIVESTOCK FEEDS.

3.0. ABSTRACT.

Roughages (corn-grass silage-CGrS, orchard grass hay-OGrH and alfalfa hay-ALFH) or agro-byproducts (wheat millrun-WMR, rye distillers grains-RDG and beet pulp-BP) were incubated in the rumen of two dairy cows. Each feed group was incubated in each cow in two periods. Duplicate 5 g samples of the feeds were weighed into nytex polyester bags per incubation time and then incubated in the rumen for, 2, 3, 6, 12, 24, 36, and 48 h. Cows were fed total mixed ration (TMR) every 2 h using a continous feeding system.

Statistical analysis on the degradation characteristics was done separately for roughages and agro-byproducts. A two way analysis of variance was used for data analysis and Duncan multiple range test was used for mean separation and tested for significance at 0.05 level.

For agro-byproducts, the rate of DM and NDF disappearance of RDG was significantly higher (P<0.05) than WMR and BP which were similar (P>0.05). Rate of DM degradation for WMR, BP and RDG averaged 11.21 ± 1.44, 12.27 ± 1.44 and 28.69 ± 1.44 %/h, respectively; NDF, 8.56 ± 1.68, 8.68 ± 1.68 and 19.32 ± 1.68 %/h, respectively. Effective degradability of DM was similar (P>0.05) for RDG and BP (80.75 ± 0.37 and 80.64 ± 0.37%, respectivley) and both were higher (P<0.05) than WMR (67.56 ± 0.37%). However, effective degradability

of NDF was higher for BP than RDG (63.36 ± 0.43 vs $48.04\pm0.43\%$) and WMR, and RDG was higher than ($P<0.05$) WMR (48.04 ± 0.43 vs $33.51\pm0.43\%$).

Significant differences were observed ($P<0.05$) in the rate of degradation of DM and NDF among the three roughages. Rate of DM disappearance was higher ($P<0.05$) for ALFH (15.15 ± 0.51 %/h) than CGrS (6.29 ± 0.51 %/h) and OGrH ($6.58.0\pm0.51$ %/h) which were similar ($P>0.05$). However, the rate of NDF disappearance was similar ($P>0.05$) for ALFH and CGrS but both significantly different ($P<0.05$) to OGrH and values averaged 7.87 ± 0.44, 7.67 ± 0.44 and 6.95 ± 0.44 %/h, respectively. The effective degradability of DM was highest ($P<0.05$) for ALFH ($62.05\pm0.57\%$), medium for OGrH ($43.92\pm0.57\%$) and lowest for CGrS ($40.81\pm0.57\%$). However, the effective degradability of NDF was was similar ($P>0.05$) for OGrH ($28.67\pm0.40\%$) and ALFH ($27.67\pm0.40\%$) which were significantly higher ($P<0.05$) than that of CGrS ($20.96\pm0.40\%$).

Variability in the rate of degradation and effective degradability of DM and NDF can be exploited in diet formulation for matching carbohydrate and protein release in the rumen to promote efficient rumen microbial protein synthesis. A portion of that carbohydrate comes from roughages and agro-byproducts which can avert the negative effects associated with concentrate feeding and can also be a reliable source of slowly degradable carbohydrate.

3.1. INTRODUCTION.

Roughage is a very important component in the diet of dairy cows and other ruminants in general and may constitute 35-100% of the ration DM depending on the stage of production (NRC, 1989). They are traditionally the major source of fiber (Van Soest, 1982 and Beauchemin et al., 1994), however, agro-byproducts with high fiber contents have also been incorporated in diets for a long time and are becoming increasingly important (Sutton et al., 1987; De Visser and Hindle, 1990; De Visser et al., 1991; Swain and Armamento, 1994) complementing traditional roughages or starchy feeds. Fiber content and source in the diet is an important determinant of DMI, gut function and ruminal environment particularly when diets high in starch are fed, with significant impact on milk yield and milk fat (Van Soest, 1982; Nocek and Russell, 1988 and Poore et al., 1993).

Neutral detergent fiber (NDF) has been proposed as an alternative to the crude fiber analysis of the proximate analysis for determining total fiber content of feeds (Goering and Van Soest, 1970) and for formulating diets to maximize DMI and therefore milk production (Mertens, 1983). The concept can be extended further to structural (SC) versus non-structural carbohydrates (NSC). Non-structural carbohydrates in the diet come from grain, high in starch and tend to have the opposite effect to that of fiber on ruminal pH, gut functioning and end products of fermentation and therefore milk fat (Nocek and Russell, 1988).

Fiber and NSC interact in the rumen, impacting on performance of young growing beef animals (Foster et al., 1993 and Galloway et al., 1993) and lactating dairy cows by control of the energy supply for microbial growth (Nocek and Russell, 1988; Herrera-Saldana and Huber, 1989 and Herrera-Saldana et al., 1990a). Structural carbohydrates are digested at a slower rate than NSC (Van Soest, 1982 and Van Soest, 1986).

The value of fiber depends on its quality and this is dependent on many factors among them, plant species, growing conditions, maturity, harvest and storage and preservation methods and physical form at the time of feeding (Van Soest, 1982). These factors affect the release of energy in the rumen required for microbial protein synthesis.

Varga and Hoover, (1983) and Tamminga et al. (1990) have reported major differences among feedstuffs in the rate and extent of breakdown of NDF and an increase in milk production and protein with diets having a faster rate of NDF disappearance.

Legumes have been shown to produce greater live weight gains and milk yields in ruminants than do grasses at similar DM and OM digestibilities (Waldo and Jorgensen, 1981). Diets containing either alfalfa hay, corn silage or bermuda grass hay balanced to 36% NDF resulted in higher DMI and milk yield on alfalfa hay inspite of lower NE of lactation when compared to corn silage and bermuda grass. Similar results have been reported for other roughages (Poore et al., 1993; Holden et al., 1994 and Ruiz et al., 1995). DMI and milk production were higher for alfalfa hay than

orchard grass hay for diets formulated to contain 42% NDF, although the NDF and ADF digestibilities were higher for orchard grass than alfalfa hay (Ruiz et al., 1995). However, Poore et al. (1993) reported no differences in production characteristics for diets containing wheat straw or alfalfa hay at 32% of the diet DM (22% forage NDF) content and balanced for feed NDF and rumen degradable starch but passage rate for solids and liquids were slower for straw than alfalfa hay with no effect on chewing time and NDF digestibility.

These reports suggest that other factors besides percent NDF in the diet affect milk production and the differences in production are a function of forage quality and a proper balance between non-structural carbohydrate and NDF in the diet. Nocek and Russell (1988) reported that milk yield was maximized when the ratio of NSC to NDF was between 0.9 and 1.2. Poore et al. (1993) have proposed that a ratio of 1:1 forage NDF (in diet) to rumen degradable starch will maximize performance by lactating dairy cows.

Knowledge of carbohydrate degradability in the rumen is important in selection of energy sources (carbohydrate) that will match the release of nitrogen (protein) for efficient microbial protein synthesis.

The purpose of this experiment was to determine in situ degradation characteristics of some commonly used roughages (alfalfa hay, orchard grass hay and corn-grass silage) and agro-byproducts (wheat millrun, rye distillers grain and beet pulp).

3.2.0.   MATERIALS AND METHODS.

3.2.1.   Source and description of feedstuffs and initial handling.

Corn-grass silage (CGrS) (50:50), Orchard grass hay (OGrH) and alfalfa hay (ALFH) were obtained from Vancouver area in British Columbia.   The hays were used for lactating dairy cows at the University farm, South campus (University of British Columbia, Dept. of Animal Science) and had been obtained from a private local farmer. Corn-grass silage was originally obtained from Agriculture Canada Research station in Agassiz (B.C). The two silages were ensiled separately and later mixed at 50:50 ratio. The alfalfa hay appeared to have been in mid-bloom and the orchard grass hay appeared to be in full bloom. Wheat millrun (WMR), rye distillers grain (RDG) and beet pulp (BP) (molassed and pelleted), were supplied by East Chilliwack Agricultural Co-operative, Chilliwack, B.C. Characteristically, WMR looked crumbly and shiny small particles of grain and fiber flakes could be seen. Rye distillers grains were granulated and light brownish in color and the BP was molassed and pelleted and of a dark grey colour.

Agro-byproducts, ALFH and OGrH were immediately ground through a 2.0 mm screen using a Wiley Mill (model #3) to facilitate mixing and sampling and then reduced to 1.0 mm size using a Christy and Norris mill. All samples were then dried in a forced air oven at 60°C for 48 h. A second DM analysis was later done on 1.0 g samples at 105°C overnight. The bulk of the samples were packed in polyethylene bags for proximate analysis and NDF analysis. The

samples were stored at room temperature until their use for in situ studies. Corn-grass silage was first dried at 60°C for 48 h and then prepared for use in the same way as agro-byproducts.

3.2.2. Cows, diets and nylon bags.

Details of handling and care of cows, preparation of diets and initial preparation of test samples and incubation procedures for the nylon bag studies have been described in the previous chapter.

3.2.3. Analytical Procedures.

Proximate and fiber analysis methods for feed ingredients have been described in Chapter 2. Dried incubated samples were handled as described in Chapter 2 and NDF was analysed according to Waldern (1971). All chemical analyses were done in duplicate.

3.2.4. Treatment of results and statistical analysis.

Dry matter and NDF disappearance from the nylon bags were calculated as the difference between what was put in and what remained in the bags. Degradation characteristics, rapidly degradable fraction % (a), slowly degradable fraction % (b), lag time h, rate of degradation (k_d) %/h and effective degradability at 5 %/h fractional outflow rate % (EFDEG), were calculated according to the equation of Ørskov and MacDonald (1979). Statistical analysis was done separately for roughages and agro-byproducts. The data were all analysed as a two way analysis according to Cochran

and Cox (1969) using GLM of SAS (1990) and Duncan multiple range test was used for mean separation.

3.3.0.   RESULTS AND DISCUSSION.

3.3.1.   Chemical composition.

Chemical composition of the three agro-byproducts is shown in Table 9. There was not much variability in DM, OM, and ash content of the feeds, averaging 95.09%, 89.10% and 5.99%, respectively. CP, ADF, NDF and hemi-cellulose showed more variation among or between the feeds. RDG was highest in protein content (29.64%) and lowest for BP (10.36%) and intermediate for WMR (18.84%). Neutral detergent fiber was high for RDG and BP averaging 31.85% and 28.36% respectively and WMR was highest (40.38%) which most likely is a reflection of processing. These values are typical of such by-products (NRC, 1989). The protein content of all these materials have been concentrated after the raw material under went processing.

Chemical composition of roughages is shown in Table 9. There was very little difference among feedstuffs in content of DM, OM, ash and EE though CGrS was always much lower in DM and OM compared to the rest of the feeds. ALFH was highest in protein content (19.90%) and lowest for OGrH (6.74%) and intermediate for CGrS (11.26%). Neutral detergent fiber was high for both OGrH and CGrS averaging 61.33% and 56.92%, respectively and ALFH was 41.34% which is indicative of their maturity. Differences in fiber type and cell-content derivatives of feedstuffs such as cellulose, hemi-

cellulose, lignin, fiber-bound nitrogen, pectins and CP, sugars, EE, respectively, give each feed individual characteristics that may contribute to differences in ruminal degradation characteristics (Van Soest, 1982; Buxton and Jorgensen, 1988 and Shaver et al., 1988).

3.3.2.   DM and NDF degradation characteristics of agrobyproducts.

In situ degradation characteristic of DM and NDF for WMR, RDG and BP are shown in Table 10. The DM disappearance of WMR was generally lower at all incubation times compared to RDG and BP. The DM disappearance of RDG was most rapid among the three, levelling off by 12 h, while DM disappearance of BP was still increasing.

The percentage of the rapidly degradable fraction of DM was high for all the feeds (Table 10) and significant differences (P<0.05) were observed among the feeds. More material disappeared initially (P<0.05) from RDG (57.62±0.72%) than BP (52.67±0.72%) and disappearance was least (P<0.05) for WMR (46.60±0.72%).

Wide variation in the slowly degradable fraction was observed for DM. The slowly degradable fraction of RDG was significantly lower than BP (27.78±1.00% vs 42.74±1.00%) but similar to WMR (30.96±1.00%) (Table 10).

The rate of DM degradation of the slowly degradable fraction was significantly higher (P<0.05) for RDG than WMR or BP which were similar (P>0.05). The average rate of DM degradation was 28.69±1.44

%/h for RDG as against 11.21±1.44 %/h and 12.27±1.44 %/h for WMR and BP, respectively (Table 10).

Lag time was similar (P>0.05) for WMR and RDG but both were significantly lower (P<0.05) than BP (Table 10) and lag time for NDF followed a similar trend.

Effective degradability of DM (5%/h fractional outflow rate) was higher (P<0.05) for RDG and BP than that of WMR (Table 10). The values of effective degradability of DM were 80.75±0.37%, 80.64±0.37% and 67.56±0.37% for RDG, BP and WMR, respectively. Comparative data for WMR and RDG with respect to degradation characteristics is scarce. However, because of new interest in BP, data is slowly accumulating (Varga and Hoover, 1983; De Visser and Hindle, 1990 and De Visser et al. 1991 and Swain and Armentano, 1994). A few reports on beet pulp in situ degradation characteristics are in agreement. The 12.27±1.44 %/h rate of DM degradation is similar to 11.40±0.0832 %/h reported by Dewhurst et al. (1995) and 8.7 %/h reported by Swain and Armentano, (1994) for molassed sugar beet feed and dehydrated beet pulp respectively. However, the level of the rapidly degradable fraction and the slowly degradable fraction were both lower than reported by Dewhurst et al. (1995) (52.67±0.72% vs 63.2±0.018%; 42.74±1.00% vs 59.70±0.0187 %) respectively (Table 10). In contrast to the above results, Swain and Armantano, (1994) reported lower and higher values of BP rapidly degradable and slowly degradable fractions (15.3±7.6% and 80.6±7.6% respectively; mean±SD) and Souvant et al.

(1985) reported a 12% value for the rapidly degradable fraction similar to Swain and Armentano, (1994).

Since the chemical composition of BP (molassed pelleted) used in this study was similar to that used by Dewhurst et al. (1995) differences in the rapidly degradable fraction may be related to the quantity of molasses added. Addition of molasses may also explain the higher rapidly degradable fraction values in this study and others (Dewhurst et al., 1995) than those reported by Souvant et al. (1985) and Swain and Armentano, (1994) as molasses would contribute significantly to this fraction. Other reasons could be related to differences in the washing procedure. In our study 0 h disappearance was determined by soaking in water for 15 minutes four bags per feed and then hand washing the bags under tap water together with the ruminally incubated samples, until the tap water became clear, while Dewhurst et al. (1995) soaked the bags in cold water then cold rinse cycle in house-hold laundry machine for 40 minutes and Souvant et al. (1985) only wetted the bags for 30 minutes. In other work the rapidly soluble fraction of DM for dried beet pulp was reported as 6.3% compared to 34.5% for pressed beet pulp (De Visser et al., 1991).

De Visser et al. (1991) speculated that the large difference in the level of the rapidly degradable fraction may be due to swelling of dry particles of beet pulp, increasing particle size and therefore reducing the number of very small particles which could be rinsed out of the bag. This probably never happened in our case since this fraction was reasonably high.

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Differences in DM degradation characteristics may be explained by a number of reasons, including initial source of the byproduct, and processing. All processing methods involved removal of a large portion of the soluble carbohydrate especially RDG. Among the three methods, malting would have more impact on the chemical composition and ruminal degradation characteristics. The protein and fiber content, and rate of protein degradability of RDG are higher and lower respectively than the unprocessed parent rye grain (NRC, 1989). Both protein and fiber will impact the ruminal DM behavior of RDG significantly.

On the other hand, the milling process of wheat resulted in a small increase in CP content compared to an unprocessed wheat, which also shows a three fold increase in crude fiber content after milling process (NRC, 1989) because the process removes most of starchy portion of the grain. Up to 75% of the DM is starch in cereals. The removal of starchy material would reduce the great influence it exerts on DM degradation characteristics. Both starch and protein in wheat are highly degradable (Herrera-Saldana et al., 1990a). However since there is little change in concentration of CP and with probable chemical changes due to processing, the impact of CP on DM degradation would be the same as unprocessed wheat grain. This then would imply that the degradability of fiber would be paramount in influencing DM degradation characteristics.

Pressing of soluble carbohydrates from BP resulted in similar content of CP to unpressed beet-root while that for crude fiber increased two fold to relatively high quantities (NRC, 1989). Like

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WMR, BP DM degradation may be related to the increased fiber content (NRC, 1989).

Malting of cereal grain results in physical and chemical changes due to hydration causing swelling of starch and fiber and also heat of fermentation due to microbial action resulting in some of the protein being bound to fiber. In addition, the drying process has the most significant impact on the degradation of CP in RDG (Wall and Paulis, 1978). Distillers grains have a reduced CP degradability when compared to the parent material because of the reason mentioned in the preceeding statement (NRC, 1989). This may explain the lower rapidly soluble fraction of NDF in RDG when compared to BP though similar to WMR (Table 10). It is unlikely that the lower rapidly degradable soluble fraction of WMR was due to binding of fiber to protein since the process results in less effect on the CP content of wheat. The high levels of the rapidly degradable fraction in BP relative to WMR and RDG is related to the pectin content of the fiber. Beet pulp is high in cell wall content and also high in pectin material which is recovered in NDF (Van Soest, 1982). Pectin belongs to structural carbohydrates but is highly degradable in the rumen, making the fiber of BP highly degradable when compared to other materials of similar fiber content.

In this study, the rate of DM degradation of BP was similar to WMR but significantly lower than RDG (Table 10), while the slowly degradable fraction was higher for BP than RDG and WMR. Effective DM degradability was higher for RDG than both BP and WMR, however

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both RDG and BP were extensively degraded averaging 80% compared to 68% on WMR.

The variation observed in ruminal degradation characteristics of NDF may partly explain the variation in in situ degradation of DM. The rate of NDF degradation paralleled that of DM in this study and the rate of degradation NDF was associated with DM in situ degradation (Varga and Hoover, 1983). Source of material and processing effects are the likely factors that may explain the variation in NDF degradation characteristics.

In spite of the low CP degradability of RDG, the rate of degradability of NDF was still higher than that of WMR and BP which have high and medium CP degradability. This may indicate less effect of CP content on rate of DM degradability. However, CP content would be important in influencing effective degradability. Varga and Hoover, (1983) found no relationship between %CP content and NDF rate of degradation for a diverse group of feedstuffs and a low but positive relationship existed between the extent of NDF degradation and %CP content (r = .46, P<0.03). In this study both DM and NDF rate of degradation for BP were much lower than RDG but similar to WMR, yet the effective degradability was higher than RDG and WMR. This data strengthens previous findings that the amount of NDF degraded is not necessarily related to the rate of degradation (Varga and Hoover, 1983). Of the three byproducts tested, DM and NDF disappearance in RDG was most rapid in reaching an asymptote, WMR was not as rapid but also levelled early when compared to BP. Similar observations for distillers grains and beet pulp and other

feedstuffs from different backgrounds have been reported (Varga and Hoover, 1983).

In situ data on the rate of cell-wall degradation of agro-byproduct feedstuffs such as BP is lacking. Swain and Armentano (1994) reported a rate of 8.0$\pm$2.6 %/h which is similar to the 8.68$\pm$1.68 %/h reported in this study. In contrast, Varga and Hoover, (1983) and De Visser et al. (1992) reported a lower rate of NDF degradation for BP than reported in this study but the value is in the same general area (5.3 %/h vs 8.68 %/h). The differences may be related to variety differences of the beet pulp which may likely have different NDF content between this study and that of Varga and Hoover, (1983). In conflict to our findings for BP and RDG, Varga and Hoover, (1983) reported a slightly lower rate of NDF degradation for distillers (unspecified original source) grains than BP. It is possible that their source of distillers grain was corn. De Visser et al. (1992) reported a lower NDF rate of degradation for maize relative to BP but the BP NDF rate of degradation was lower than for a cereal like barley which falls under similar botanical group with rye.

There is virtually no data on the degradation characteristics for WMR. In this study, WMR was similar to BP in terms of DM and NDF rate of degradation but yielded much lower digested material since most of the digestible portion (starch) has been removed.

3.3.3. DM and NDF degradation characteristics of roughages.

In situ degradation characteristics for the roughages are shown in Table 11. Significant differences (P<0.05) in the degradation characteristics of DM and NDF were observed. The rapidly degradable fraction (a%) and rate of DM degradation, (K_d) were higher (P<0.05) for ALFH than both OGrH and CGrS, which had similar values for these same parameters. The rate of DM degradation of ALFH was 15.15±0.51 %/h and OGrH and CGrS were, 6.58±0.51 and 6.29±0.51 %/h, respectively. Averages for the rapidly degradable fraction were 38.00±1.98%, 24.54±1.98% and 21.62±1.98% for ALFH, OGrH and CGrS, respectively. These values are similar to 36%, 29% and 22% for the same roughages as reported by Mir et al. (1991).

All roughages had significantly different quantities of the slowly degradable fraction (b) of DM and these averaged 42.56±1.55, 38.27±1.55% and 34.19±1.55% OGrH, CGrS and ALFH, respectively. The ranking for the slowly degradable fraction between alfalfa hay and orchard grass was maintained in this study (Table 11) as well as in Mir et al. (1991). The 34% value for alfalfa hay as reported by Mir et al. (1991) is similar to that reported in this study (Table 11) and also Shaver et al. (1988) for a full bloom alfalfa hay; but the orchard grass hay value (53%) was higher than the value of 43% reported here. Differences in the 2 values may be due to differences in maturity between the two orchard grass hays used in the experiments. The more resistant portion of the cell contents as

well as cell-wall content make up a portion of the slowly degradable fraction.

Significant differences were (P<0.05) observed in the lag time (h) among the three roughages. Lag time was longer for OGH (4.33±0.28 h), than for CGrS (2.11±0.28 h) and ALFH (1.37±0.28 h). These results agree with those by Mir et al. (1991) in terms of ranking. Lag time for OGrH but not ALFH was similar to that reported by Mir et al. (1991). A lower lag could be an indication of the presence of a high content of soluble material which can result in both losses from the bag of very small particles as well as that which actually is rapidly degradable in the rumen (Ørskov, et al., 1980).

Values for the rate of DM degradability reported by Mir et al. (1991) were 16.0, 6.0 and 2.0 %/h for alfalfa hay, orchard grass and pure corn silage, respectively. The rates for alfalfa hay and orchard grass hay are similar to those reported in this study (Table 11). The value for silage reported here (Table 11) is higher than that reported by Mir et al. (1991). The silage in this study was a 50:50% mixture of corn and grass silage as opposed to pure corn silage used by Mir et al. (1991). The addition of a grass silage to corn silage increased the rate of DM disappearance in situ.

Values for rapidly degradable fraction averaged 36%, 29% and 22% respectively for ALFH, OGrH and maize silage (Mir et al. 1991) compared to this experiment, 38%, 24.54% and 21.62% for ALFH, OGrH, CGrS (Table 11).

The slowly degraded fraction of DM for ALFH was least among the three, but resulted in significantly higher (P<0.05) effective degradability, than OGrH and CGrS. Averages for effective degradability were 62.05±.57%, 43.92±0.57% and 40.81±0.57% for ALFH, OGrH and CGrS respectively. The high effective degradability of ALFH was the result of the high rate of degradation and rapidly degradation fraction and also lower lag phase when compared to CGrS and OGrH.

NDF degradation characteristics showed differenecs in terms of ranking of the three roughages (Table 11). Alfalfa hay which had the highest rapidly degradable DM, had a lower (P<0.05) rapidly degradable fraction of NDF compared to OGrH and CGrS which were similar to OGrH.

The slowly degradable NDF was higher (P<0.05) for OGrH than ALFH and CGrS, which were also significantly different from each other with ALFH being higher (P<0.05) than CGrS. The average values for slowly degradable fraction and effective degradability were 43.74±1.05%, 33.98±1.05% and 26.66±1.05% and 28.53±.40, 27.67±0.40 and 20.96±0.40% for OGrH, ALFH and CGrS, respectively.

Although the rate of DM degradation for ALFH was 2x more than that for OGrH and CGrS, NDF rate of degradation was similar (P>0.05) to that of CGrS but stil significantly higher than OGrH. The result for ALFH and CGrS when compared to OGrH with respect to rate of NDF degradation are as expected since OGrH was of low quality as indicated by the low and high CP and NDF contents (CP and NDF; 6.74 and 61.33%, respectively). Values for rate of NDF

degradation were 7.87±0.44 %/h, 7.67±0.44 %/h and 6.95±0.44 %/h for ALFH, CGrS and OGrH, respectively.

The lag time for NDF was least (P<0.05) for ALFH (1.57±0.15 h), longest for CGrS (11.30±0.15 h) and longer for OGrH (10.29±0.15 h) (P<0.05). Lower lag time values were reported by Varga and Hoover, (1983) for alfalfa hay and orchard grass hay. Lag time for alfalfa hay and orchard grass hay reported were 4.32 and 0.90 h respectively which were higher and much lower respectively than reported in this study (Table 11). Differences in results reported here and those of Varga and Hoover, (1983) may be explained by differences in maturity of the roughages used.

Results for rate of NDF degradation were similar to those of Varga and Hoover, (1983). Neutral detergent fiber in alfalfa hay was reported to degrade faster than NDF in both orchard grass hay (7.8 vs 5.6 %/h) and pure corn silage averaged 8.2 %/h (Varga and Hoover, 1983). These values are similar to those reported in this study for ALFH and OGrH (Table 11). These findings have been confirmed with in situ (Shaver et al., 1988), in vitro (Mertens and Loften, 1980 and Buxton and Russell, 1988) and in vivo studies (Holden et al., 1994). Cell-walls from alfalfa hay degrades faster than cell walls from orchard grass hay (Buxton and Russell, 1988).

The difference in rapidly degradable fraction of DM in alfalfa hay (Table 11) when compared to other forages may be partly due to the differences in maturity (Shaver et al., 1988). The protein and NDF content of alfalfa hay were 19% and 39%, respectively, which were higher and lower respectively than for OGrH and CGrS. A large

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portion of the rapidly degradable fraction in alfalfa would be high in cell-contents such as proteins, sugars and to a small extent starch which are more readily degradable than the cell-wall. In addition alfalfa hay has broad leaves which tend to be brittle when harvested and dried and will tend to pulverise resulting in very fine particle during grinding. Alfalfa hay is therefore likely to have a large portion of particles which would come out of the bag without necessarily being soluble (Ørskov et al., 1980). On the other hand ALFH had the lowest ($P<0.05$, Table 11) level of the NDF rapidly degradable fraction compared to OGrH and CGrS and the rate of NDF degradation was equal to CGrS but not OGrH. This seems to mean that the high level of the rapidly degradable fraction and rate of DM degradation shown by alfalfa hay is not significantly affected by the solubility and rate of digestion of NDF compared to CGrS and OGrH.

Differences in the rate of NDF digestion in situ can be explained on the basis of the inhibitory effects of lignin on digestion of hemi-cellulose and its negative relationship to digestion of cellulose and hemicellulose (Van Soest, 1982 and Buxton and Russell, 1988). Buxton and Russell, (1988) reported that the apparent inhibition by lignin of cell-wall digestion was 62% greater in grasses than in legumes before maturity. It was observed that the inhibitory effects of lignin were not related to its content. Lignin on a per unit lignin basis was more inhibitory to digestion of grasses than legumes. This is particularly so in immature low-lignin cell walls in which a unit of lignin protects

more carbohydrate than in highly lignified mature cell walls (Smith et al., 1972; Van Soest, 1982 and Buxton and Russell, 1988) and this explains why legumes although with a low content of NDF but high in lignin, digest faster than grasses (Smith et al., 1972 and Buxton and Russell, 1988). In vitro rate of cellulose digestion was higher for delignified orchard grass (Darcy and Beylea, 1980) and alfalfa hay than intact hays (Beylea et al., 1983).

This may also in part explain the lower lag phase of NDF observed on alfalfa hay than CGrS and OGrH (Table 11) which are graminae in origin. Inherent species differences between legumes and grasses in chemical and physical cell-wall constituents and or removal of cell-wall proteins, cell-wall alteration by grinding and hydration all contribute to variation in lag times (Darcy and Beylea, 1980; Shaver et al., 1988 and Buxton and Russell, 1988).

3.4.0.   SUMMARY AND CONCLUSION.

The rate of DM and NDF degradation was higher for RDG than BP and WMR. RDG and BP had significantly higher levels of highly soluble fraction though different, when compared to WMR. The slowly degradable fraction was consistently higher for BP DM and NDF than RDG and WMR. Though effective degradability of DM for RDG and BP were different they were both extensively degradable compared to WMR. Beet pulp had the highest effective degradability for NDF. Lag times for DM and NDF were higher for BP than WMR and RDG.

The level of highly degradable fraction, rate of degradation and effective degradability of DM were significantly higher for ALFH than CGrS and OGrH while the rate of NDF degradation of ALFH was similar to CGrS but significantly higher than OGrH. However, in spite of similar rate of NDF degradation, the amount digested in OGrH and ALFH was significantly higher CGrS; longer NDF lag times were noted for CGrS and OGrH relative to ALFH.

Variation in the degradation characteristics of DM and NDF such as shown by roughages and agro-byproducts can be exploited in ration formulation for ruminants (Mertens, 1983). Efficient microbial growth requires sufficient and sustained release of nutrients in the rumen. Alfalfa hay, OGrH and CGrS have been used as roughages in combination taking advantage of this variability. The in situ ruminal behavior of byproducts is less well known, but all indications are that they show wide variation (Varga and Hoover, 1983; Souvant et al., 1985 and Dewhurst et al., 1995). From

this study BP in combination with either RDG or WMR would be best; taking advantage both of the rate of degradation and effective degradability.

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3.6.0.   TABLES.

Table 9.   Chemical composition of agro-byproducts and roughages used in in situ experiment (DM basis).

				Nutrient					
Feedstuff[1]	DM	OM	CP	ADF	NDF	HCell	Ash	EE	TNC
WMR	94.77	94.16	18.84	14.30	40.38	26.08	5.84	2.51	33.09
RDG	93.35	95.54	29.64	12.83	31.85	19.02	4.46	2.56	31.49
BP	97.14	92.33	10.36	18.18	28.36	10.18	7.67	0.43	53.18
ALFH	95.23	91.57	19.90	34.58	41.34	6.76	8.43	1.28	29.05
OGrH	98.17	93.54	6.74	37.56	61.33	23.77	6.46	1.44	24.03
CGrS	97.02	92.44	11.26	33.75	56.92	23.17	7.56	1.33	22.93

[1]WMR = wheat millrun, RDG = rye distillers grains, BP = beet pulp, ALFH = alfalfa hay, OGrH = orchard grass hay and CGrS = corn-grass silage

[2]TNC=Total non-structural carbohydrate = DM − (CP + NDF + EE + Ash)

Table 10. In situ degradation characteristics of dry matter and neutral detergent fiber of wheat millrun, rye distillers grain and beet pulp[1].

Degradation	Agro-byproducts[3]			
Characteristics[2]	WMR	RDG	BP	SE[4]
DM				
a (%)	46.60c	57.62a	52.67b	0.72
b (%)	30.96b	27.78b	42.74a	1.00
k_d(%/h)	11.21b	27.69a	12.27b	1.44
lag (h)	0.26b	0.33b	1.61a	0.48
EFDEG (%)				
0.05 %/h	67.56b	80.75a	80.64a	0.37
NDF				
a (%)	7.65b	8.89b	27.68a	1.97
b (%)	42.09c	50.24b	61.83a	1.86
k_d(%)	8.56b	19.32a	8.68b	1.68
lag (h)	0.24b	0.35b	1.91a	0.41
EFDEG (%)				
0.05 %/h	33.51c	48.04b	63.36a	0.43

[1]WMR = Wheat millrun, RDG = rye distillers grain, BP = beet pulp.
[2]a = rapidly degradable fraction,
b = slowly degradable fraction,
k_d = fractional rate of degradation of fraction b,
lag= lag time,
EFDEG = effective degradability at 5 %/h fractional outflow rate.
[3]Means in the same row with different letters are significantly different (P<0.05).
[4]SE = standard error (n=2)

Table 11. In situ degradation characteristics of dry matter and neutral detergent fiber of corn-grass silage, orchard grass hay and alfalfa hay[1].

Degradation Characteristics[2]	roughage[3]			
	CGrS	OGrH	ALFH	SE[4]
DM				
a (%)	21.62b	24.54b	38.00a	1.98
b (%)	38.27b	42.56a	34.19c	1.55
k_d(%/h)	6.29b	6.58b	15.15a	0.51
lag (h)	2.11b	4.33a	1.37b	0.28
EFDEG (%)	40.81c	43.92b	62.05a	0.57
NDF				
a (%)	11.79a	13.32a	8.50b	0.74
b (%)	26.66c	43.74a	33.98b	1.05
k_d(%/h)	7.67ab	6.95b	7.87a	0.44
lag (h)	11.30a	10.29b	1.57c	0.15
EFDEG (%)	20.96b	28.53a	27.67a	0.40

[1]CGrS = corn-grass silage, OGrH = orchard grass hay, ALFH = alfalfa hay.
[2]a = rapidly degradable fraction,
 b = slowly degradable fraction,
 k_d = fractional rate of degradation of fraction b,
 lag= lag time,
 EFDEG = effective degradability at 5 %/h fractional outflow rate.
[3]Means in the same row with different letters are significantly different (P<0.05).
[4]SE = standard error (n=2)

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CHAPTER 4.   THE EFFECT OF DIETS MATCHED FOR RATE OF DEGRADATION OF CARBOHYDRATE AND PROTEIN ON MILK PRODUCTION CHARACTERISTICS OF DAIRY COWS.

4.0. ABSTRACT.

Twelve lactating multiparous Holstein cows averaging 150 d (40-291 d) postpartum, were randomly assigned to one of four concentrate diets; steam-rolled corn-fish meal (SRC-FM), steam-rolled corn-canola meal (SRC-CM), steam-rolled barley-fish meal (SRB-FM) or steam-rolled barley-canola meal (SRB-CM), in a three period/four treatments switch-back design. Concentrate diets were fed at a 50:50 ratio with alfalfa hay (ALFH) and the total feed per day was allocated according to body weight, milk production and butter-fat as per NRC, (1989) standards. Each period lasted for 28 days split into a 14 d adjustment, 7 d intake and 7 d digestibility and metabolism sections. Cows were first kept in the free stall section of the barn for the first 14 d to adjust to the diet. Six cows were then moved to the stanchion section of the barn for intake studies for 7d and then moved back to the free stall barn. The remaining 6 cows were then moved to the stanchion section of the barn and only 4 were used for a 7 d digestibility and metabolism study. A computerized feeding system was used for concentrate and ALFH was fed 4x/day in the free-stall barn and feeding for both concentrate and hay changed to 4x/day separately and individually for each cow when moved to the stanchion barn. Feed intake, digestibility and milk production (MP) for the last 5 days of each period were considered for statistical analysis.

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Milking of cows was 2x/day (0330 and 1530 h) and samples for composition analyses were collected on 2 consecutive days.

Actual daily DMI and DMI (%B.Wt.), were not affected by (P>0.05) either source of carbohydrate or protein in the diet and averaged; 23.74, 23.77, 23.84, and 23.54 kg/cow/d; 3.63, 3.65, 3.65, and 3.61 %BWt.; for SRC-FM, SRC-CM, SRB-FM, and SRB-CM, respectively. Starch intake approached significance (P<0.11) for protein source while NDF and hemi-cellulose, and ADF intake were higher for SRB than SRC (P<0.05) and for CM than FM (P<0.05), respectively.

Barley based diets promoted higher actual milk yields and efficiency of feed utilization (MP:DMI) than corn diets (P<0.01): 25.76, 25.07, 27.59, and 27.40 kg/d: 1.07, 1.04, 1.14, and 1.16, for SRC-FM, SRC-CM, SRB-FM and SRB-CM, respectively. Significant differences (P<0.05) were detected in percent fat and solids-not-fat; 2.99 and 9.05 for barley; and 3.54 and 8.69 for corn. In addition feeding barley based diets resulted in higher yield of total solids, SNF and protein than corn diets. DM, OM, starch, CP, NDF and hemi-cellulose digestibility were significantly higher (P<0.05) for the barley diets than corn. These data showed a beneficial effect for actual milk production, efficiency of feed utilization, DMD and OMD, starch and fiber digestibility when diet was matched for high rumen starch and protein availability and also when diet with high rumen starch availability was fed with protein source of moderate rumen protein availability

4.1. INTRODUCTION.

Ruminants, unlike mono-gastric animals, derive their protein needs from protein of microbial origin synthesised in the rumen and that portion of dietary protein that escapes rumen degradation. Whilst microbial protein supply is often sufficient to meet protein needs (Van Soest, 1982), this is not true for high producing dairy cows and young growing steers (ARC, 1980 and NRC, 1989). This is also true for energy needs (NRC, 1989). It has been suggested that the increased needs for protein by high producing cows and fast growing steers can be met by providing part of the dietary protein in a form which is undegradable in the rumen but available in the small intestines, thus increasing amino-acid (AA) supplied to the small intestines (ARC, 1980 and NRC, 1989). Feeding this supplemental protein is one of the most expensive but most important aspects of dairy cattle nutrition. Therefore, it would be prudent to maximize rumen microbial protein synthesis to increase AA supply to the small intestines and maximize the efficiency of utilizing ruminal undegradable protein. The most critical nutrient components to optimize the efficiency of microbial protein synthesis are energy (ATP), a carbon (C) source and a nitrogen source (N) (Sniffen et al., 1983; Nocek and Russell, 1988). Efficiency of microbial protein synthesis, however, requires that both C and N be available within the same time frame and in proportionate amounts (Nocek and Russell, 1988; Herrera-Saldana et al., 1990b; Nocek and Tamminga, 1991 and Hoover and Stokes, 1991).

Starches and proteins from different sources have been found to degrade at different rates (Spicer et al., 1986; Casper and Schingoethe, 1989; Malestein et al., 1988 and Herrera-Saldana et al., 1990b).

Several researchers (Casper and Schingoethe, 1989; McCarthy et al., 1989 and Casper et al., 1990) have reported decreased milk production and dry matter intake (DMI) of cows fed barley compared to those fed corn. Others, (DePeters et al., 1985 and Grings et al., 1992) did not observe this response. Nocek and Tamminga, (1991) have recently published data from different experiments on the effect of starch source on milk production. They noted that the magnitude of milk yield response was variable among studies. Changes in milk composition were mainly in fat content. In the studies by McCarthy et al. (1989), milk production was significantly higher for cows fed corn diets than barley diets. They attributed this increased production to a high energy intake which was used for microbial protein synthesis and milk lactose synthesis. Efficiency of microbial protein synthesis was not affected by corn or barley diets, in combination with SBM or FM; however protein flow to the duodenum was higher for cows fed barley than corn. If milk production was higher on corn diets, then corn diets were able to provide enough ruminal degradable carbohydrate for microbial synthesis but also an adequate quantity of quality undegradable protein.

In contrast, Herrera-Saldana and Huber, (1989) reported higher milk production on barley based diets than corn. This was

attributed to increased DM and starch intakes and also higher microbial protein synthesis (Herrera-Saldana and Huber, 1989 and Herrera-Saldana et al., 1990a). However, starch intakes were confounded with the fact that starch content on barley diets was higher than on the other three diets (Herrera-Saldana et al., 1990a).

It is theorized that diets appropriately matched for differing rates of carbohydrate and protein degradation will support higher milk production, especially on diets matched for high rumen availabilities when compared with diets unmatched in rumen availabilities or low in rumen availabilities of carbohydrate and protein.

The main objective of the experiment was to determine the effect of feeding diets matched for different rates of carbohydrate and protein degradation on nutrient intake, apparent total tract digestibility, ruminal and blood parameters and milk production characteristics of lactating dairy cows.

4.2.0.   MATERIALS AND METHODS.

4.2.1.   Diets.

Four complete diets were formulated at 50:50 (concentrate:roughage) ratio. Steam-rolled barley (SRB) and steam-rolled corn (SRC) served as sources of highly and slowly degradable carbohydrate respectively, in combination with either canola meal (CM) or fish meal (FM) as sources of highly and slowly degradable protein, respectively. The feed ingredients were chosen because

there are commonly used in dairy cattle rations and also for their wide differences in the rate of starch (Table 6) and protein degradation (Madsen, 1985). All the ingredients were prepared at Agriculture Canada Research Station Feedmill (Agassiz, BC). The barley and corn grain were steam-rolled at approximately 75 °C (pressure, 15 Psi). The grains used in this experiment and those used in the chapter 2 for nylon bag studies are from different sources. Both FM and CM had been ground and a binder added before pelleting and feeding. All diets were formulated to contain 16% CP and 1.7 Mcal/kg, net energy of lactation (NE_L) of DM on average. Alfalfa hay was the roughage portion of the diet. Ingredient composition, chemical composition of the major dietary ingredients and calculated chemical composition of the diets are shown tables 12, 13 and 14 respectively.

4.2.2. Cow management and experimental design.

Twelve multiparous lactating Holstein, 150 d (40-291 d) postpartum with average milk production of 29 d (19-45 kg/d) cows were used in a three period-switch-back design (Lucas, 1956). A four treatment- three period sequence was chosen (Appendix 2). The treatments were assigned to numbers (1-4) which were then used for randomization. The cows were themselves randomly assigned to the sequences separately for each period. Weight of cows was taken before the start of the experiment and at the end of each experimental period. Water and cobalt iodized salt block were available at all times. The cows were initially housed in the free

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stall section of the barn during the adjustment period days and alternate groups of 6 cows were then moved to the stanchion section of the barn for either intake or digestibility and metabolism studies for 5 days.

4.2.3.   Nylon bag studies.

Nylon bag studies, as outlined in chapter 2, were done for several feed ingredients (SRC, SRB, FM, CM and ALFH). The cows were individually fed a standard concentrate (3.0 kg/d-16% dairy textured feed) and roughage diet (5.5 kg/d-60% Alfalfa hay and 40 % grass hay) four times/day. The bags used in the study measured 10x5 cm internal diameter and had an average pore size of 52 ± 2 μm. The edges were heat sealed leaving one width side open. The incubation times involved were 0, 2, 4, 8, 12, 18, 24, 36, and 48 h.

Feed samples were ground through a 2.0 mm screen using a Wiley Mill (model #3). Two-three grams of dried test material were quantitatively weighed into incubation bags ($40-60mg/cm^2$) for each incubation time. The bags were tightly secured using ordinary office rubber bands to stop material from coming out of the bags. The bags were then put in big polyester mesh bags measuring 25x40 cm with a pore-size of 3 mm to allow rumen fluid go in and out.

The small incubation nylon bags were removed from the big bags and washed in a washing machine 4-5 times after filling the machine with water and agitated for about 5 minutes/time. The washed bags were dried in a forced air oven at 55°C till constant weight. Four

bags per test feed were included in the washing to act as zero hour disappearance after initially washing them in water at 39°C for 30 minutes and then washed together with ruminally incubated bags.

The dried duplicate incubated samples were composited for each cow during grinding through a 0.5 mm screen using a Brinkman micro grinder, and stored under room temperature for chemical analysis.

Zero hour and rumen incubated samples for SRC and SRB were analysed for DM and starch while FM and CM were analysed for DM and CP. The alfalfa hay was analysed for DM, CP and NDF.

The rumen degradation characteristics of cereals and protein supplements were analysed separately using t-test (Cochran and Cox, 1969) according to GLM of the Statistical Analysis Institute (SAS, 1990).

4.2.4.   Nutrient intake and apparent total tract digestibility.

The cows were individually fed concentrates with a computer controlled grain feeder while in the free stall barn and the amount of feed consumed was computer recorded. The feed was allocated to each cow according to body weight, actual milk production and butter fat percentage at the start of each period. Alfalfa hay was fed ad libitum from common feed bunks for all cows and was fed four times per day at 0800, 1330, 2000 and 0130 h. Concentrates were sampled every other day and hay was sampled every day. A sample of weigh-back was taken daily during the experimental period.

After a 10 d adjustment to the diet, six cows were transferred to the stanchion barn where they were individually secured and fed

ad-libitum for 3 days of the experimental stage to establish individual intakes. Intake was measured for 7 days and then the cows were moved back to the free stall barn. Appropriate allotments (according to body weight, milk production level and butter fat) of cereal and a protein supplement were weighed and mixed before being offered, separate from hay. Hay was fed ad-libitum and intake recorded. The cows were fed four times per day as previously mentioned for hay. After 7 days of intake measurement, cows were taken back to the free stall barn and the remaining six were moved to the stanchion barn for digestibility and metabolism studies for the last 7 days of each period. These cows were fed close to their maximum intake level. This was achieved by establishing maximum intake within 2 to 3 days. Digestibility and metabolic studies were done in the last 5 days of each period. One cow from each dietary treatment was randomly chosen for digestibility and metabolism studies. Weigh back samples were taken daily for each cow while in the stanchion barn. One cow from the digestibility group was removed due to an injury to the legs and was replaced by another from the same group. The total number of cows used for feed intake and milk production characteristics data was 11.

Continuous feeding of cows was adopted to mimic farm computerised feeding conditions and ensure a continuous supply of energy and nitrogen to the rumen which has been shown to increase efficiency of bacterial growth in vitro (Henning et al., 1991).

The total fecal collection procedure was used for digestibility studies. Wooden boxes were placed behind each cow as

fecal collecting vessels. Urine cups, fastened with a harness to each cow, allowed for separation of urine from feces. The urine was directed into buckets using vacuum cleaner hose. Feces for each cow were weighed daily, thoroughly mixed and about 2-3kg sample was kept for further processing and analysis. The samples were stored in a freezer. At the end of the experiment, the samples were thawed, mixed thoroughly using a commercial dough mixer for each cow and period. A sub-sample for chemical analysis was taken on which DM, OM and nutrient analyses were performed according to methods previously mentioned.

At the end of each experimental period, grain, protein supplements and hay feed samples were composited and subsampled. Alfalfa hay samples including weigh-backs were first chopped in a shredder-grinder (Mighty Mac Compost Shredder grinder, Amerind Mackissic, Parker Ford. PA) with a 2.5 cm screen to reduce particle size and therefore facilitate subsampling. Concentrate mix and hay weigh-back from the stanchion barn feeding were composited separately for each cow and period. An amount sufficient for the required chemical analyses and nylon bag studies was dried in a forced air-oven at 60°C for 48 h before being ground using a 1.0 mm screen. Duplicate ground samples were composited and thoroughly mixed for each feed or weigh-back, for each animal and each period before being subsampled and packed in polyethylene sample bags. All samples were stored at room temperature for appropriate chemical analyses.

4.2.5.   Analytical procedures.

Methods for chemical analysis of feed, weigh-back and fecal samples are as described in Chapter 2. Weigh-back samples were analysed for all nutrients except GE, EE, Ca and P. Calcium (Ca), and phosphorus (P) were analysed according to the methods of Heckman (1967) and Parkinson and Allen, (1975). Feed, weigh-back and fecal data were used to calculate voluntary feed and nutrient intake and total apparent digestibility.

NDF for concentrate and weigh-back was analysed by combining the Ankom filter bag technique (FTB) (Komarek, 1993) and the NDF procedure according to Waldern, (1971). Samples (0.35g) were weighed into pre-weighed Ankom made Nylon bags (5cm x 5cm). The mouths of the bags were sown (double seam) using a house-hold sewing machine to prevent material from getting out of the bags and then weighed. The bags were refluxed for an hour in a beaker containing the required amount of NDF solution (35ml/bag). After one hour the bags were washed in an excess amount of hot water. All bags were dried in a forced air oven at 105°C overnight, desiccated and then weighed. All chemical analyses were done in duplicate. Feed intake and apparent digestibility was calculated according to the following formulae:

Voluntary intake/day = quantity of feed given - quantity of weigh-back (Equation 4.2);.

Digestibility Coefficient = ((IN - FN)/IN)*100 (Equation 4.3);

where, IN = Intake (nutrient),

       FN = fecal (nutrient).

4.2.6. Rate of passage.

Liquid and particulate matter flow rates were measured using cobalt-ethylenediamine tetraacetic acid (Co-EDTA) and chromium mordanted fiber, respectively.

Co-EDTA was prepared according to Uden et al (1980) and administered as a single dose on the first day of fecal collection. 37.5g of Co-EDTA (5g of Co) was first dissolved in 1 liter of deionized water and flushed down into the rumen using a Rheinhard oral tube. About 2 liters of water was flushed down the tube following marker administration in order to make sure that all of the marker went into the animal.

Chromium-mordanted fiber was also prepared according to Uden et al. (1980). A small amount of feed was mixed with 100g (3g Cr) of Cr-mordanted fiber. In addition, a small amount of molasses (Blackstrap Molasses, product of West Indies, Croby Molasses Co.ltd, ST.Johns NB, Canada) was added and mixed to improve fiber acceptability. The animals were observed for any refusals. Only one cow showed reluctance to consume all the marker mixture. The left-over marker was weighed and a sample stored for Cr analysis. Fecal collection for marker estimation started 12 h after marker administration and there after, at three hour intervals up to 72 h post dosing after which a 6 h interval was followed for a further

52 h. Fecal samples were taken as grab samples. Sampled feces were scraped into a collecting bucket or to one of the sides of the fecal collection box or a plastic cover was put on top of the old feces to avoid mixing with the new ones. Samples were put in plastic bags and stored in a freezer. At the end of the experiment the samples were thawed and dried at 60°C for 48 h and ground through a 1.0 mm screen using a Wiley mill. The samples were stored at room temperature for marker analyses.

Samples for fecal cobalt concentration were prepared by ashing 0.5 g of fecal material at 500°C overnight. Five ml of 4 N HCl was added after the samples had cooled. The mixture was allowed to sit for 30 minutes at room temperature before diluting with 15 ml deionized water and subsequently centrifuging at 10,000 x g for 10 minutes. Cobalt absorption was read using an air-acetylene flame with a Perken Elmer Atomic Absorption Spectrophotometer (Model 4000 Perken-Elmer Corporation Norwalk, CT) (Christian and Feldman, 1970). It was read at 241 nm wavelength.

Chromium samples were prepared by weighing 0.5 g of fecal material into pre-weighed 50 ml erlynmeyer flask. Thirty mls of 4 M HNO_3 was added and samples were left to sit for 4 hours at room temperature. The samples were then heated to 75°C for 12 h, cooled and the gross weight taken so as to determine the amount of remaining solution.

After that the samples were centrifuged at 12,000 x g for 10 minutes. The supernatant was decanted into test-tubes and read directly. Appropriate dilutions for samples with a reading higher

than the highest standard were made with deionized water. The Cr concentration was determined using atomic absorption spectroscopy (Christian and Feldman, 1970 and Fenton and Fenton, 1979) as for Co analysis and read at 357.7 nm wavelength.

The rate of passage was calculated as the rate of decline in the natural logarithm of cobalt or chromium concentration in the feces after peak concentration. It was assumed that one defecation occurred midpoint in the interval between collections as proposed by Faichney, (1980)

4.2.7. Blood Sampling.

Blood samples were taken on the last day of each experimental period before the after-noon feeding and 2.5 h after feeding from the four cows on the metabolism study. The blood was collected in 10 ml heparinized tubes from the coccygeal vein. It was immediately centrifuged at 2000 x g for 10 minutes. The serum was decanted into small vials, stored in a freezer and later analysed for blood-urea-nitrogen (BUN) and blood glucose (BG) using Kodak Ektachem DT slides (Clinical Products Division, Eastman Kodak Co., Rochester, NY).

4.2.8. Rumen sampling.

Rumen fluid was collected on the last day at the same time as blood sampling. Samples were collected just before the after-noon feeding and 2.5 h there after. A rubber tube perforated on one end was used to collect the fluid after applying vacuum using a vacuum

pump. A Reinhard pipe was first placed into the throat of the animal before the rubber tubing was pushed into the rumen. The pH of the fluid was immediately measured using a pH meter. The samples were stored in a freezer at -20°C.

Before analysis the rumen samples were thawed at room temperature and centrifuged at 27,000 g for 10 minutes at 4°C (McCarthy et al., 1989). Ten ml of the supernatant was treated with 2 ml of 25% metaphosphoric acid. The supernatant was used for rumen-ammonia-nitrogen (rumen NH_3-N) analysis according to Chaney and Marbach, (1962) using a Technicon Autoanalyser II (as a manifold and proportioning pump) according to the method of Wall and Gehrke, (1975). The rumen NH_3-N was analysed directly without pre-wet digestion. Volatile fatty acids (VFA's) were analysed according to Erwin et al. (1961).

4.2.9.   Milk production and composition.

All cows on the trial were milked twice daily starting at 0330 and 1530 h and milk weight was recorded for each cow. Milk samples from both a.m. and p.m. milkings were taken for each cow on 2 consecutive days in the last 5 days of each period. A potassium dichromate pill, a preservative, was added to each sample tube at the time of collecting the samples. The morning and after-noon samples were immediately composited for each cow and each day in each period. The samples were frozen and later analysed for milk protein, fat, total-solids (TS) and solids-not-fat (SNF). Milk fat and protein were analysed at the Dairy Herd Improvement Services

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laboratory (Abbotsford, BC). Total solids (TS) were determined by a regular DM determination (AOAC, 1984). A 10 ml sample of a well-mixed milk sample was oven dried in an aluminium pan at 100°C for 24 h. Solids-not-Fat (SNF) was calculated by the difference between TS and fat content. Yields of the above milk components were calculated for the last 5 days of each period by averaging the content values for the two milk sampling days. Milk production values were used to calculate 3.5% fat-corrected-milk (3.5% FCM) and solids-corrected milk (SCM) (Tyrrell and Reid, 1965), yield of fat and protein and milk poduction gross efficiencies. The gross efficiency was calulated as the ratio of milk production (actual or 3.5% FCM) to dry matter or organic matter intake.

3.5%FCM=(0.4255xlbs milk)+[16.425x(%fat/100)xlbs milk) (Equation 4.4);

SCM=(12.3xlbs fat)+(6.56x lbs SNF)-(0.0752xM) (Equation 4.5);

4.2.10. Statistical analysis.

Intake, digestibility, blood, ruminal and milk characteristics data were subjected to analysis of variance using the General Linear Model procedure (SAS Institute, Cary, NC, 1990). The statistical model used to handle switch-back designs using the SAS package (Sanders and Gaynor, 1987) and is shown below;

$Y_{jkl} = \mu + Cow_j + b_jP_k + Period_k + Trt_l + E_{jkl}$ (Equation 4.6);

Where:

Y_{jkl} = observed response of the jth cow in the kth period receiving the lth treatment,

μ = overall mean,

Cow_j = effect of the jth individual cow,

b_j = partial regression coefficient of the response variable on period for the jth cow,

P_k = k^{th} period,

$Period_k$ = (class variable) effect of the kth period (estimates environment period effect throughout the study,

Trt_l = effect of the lth treatment;

E_{jkl} = random error associated with the jkl^{th} observation (estimated from pooling of higher order interaction involving period, treatment, and cow, which is consistent with the error term components described by Lucas, (1956).

The $b_j P_k$ term was omitted when analysing for digestibility, ruminal and blood data.

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A two way analysis of variance was used to analyse the data and orthogonal contrasts (pre-planned comparison) were used to compare the effect of carbohydrate and protein source and whether there was an interaction between the two according to Cochran and Cox, (1969). Simple co-variance analysis was used to handle ruminal and blood data according to Cochran and Cox (1969). The before feeding observation (0 h) was used as a covariate to the 2.5 h post feeding observation. Values for VFAs of one cow on BFM in period (0 h) were very low and was therefore not considered in the analysis. Least significant difference was used for the interaction for all data.

4.3.0. RESULTS AND DISCUSSION.

4.3.1. In situ Trial.

Tables 15a and 15b show the rumen degradation characteristics of feed ingredients used in the milk production trial. Note that comparisons were made on a within source of carbohydrate or protein basis. Alfalfa hay was not included in the statistical analysis (Table 15a). It is however important to mention that values for the rate of degradation of DM and NDF including extent of degradation of DM for alfalfa hay are similar to those recently reported by Alhadrami and Huber, (1992) and Beauchemin et al. (1994) for alfalfa hay of similar chemical composition in CP, ADF and NDF. The rapidly degradable NDF fraction reported (Table 15a) is similar to that previously reported for alfalfa hay with ADF content of 38% but the rapidly degradable DM fraction was higher than that

reported by Alhadhrami and Huber, (1992). The values for rapidly degradable fraction and rate of degradation of DM for alfalfa hay are also consistent with those reported in Table 11. Mir et al. (1991) have reported DM degradation characteristics for alfalfa hay (not identified) as 36%, 34%, 16 %/h and 2 h for rapidly and potentially degradable DM, rate of degradation and lag time for DM, being inconsistent with our values (Table 15a). However, the effective degradability of DM reported here (Table 15a) was similar to that reported by Mir et al. (1991) at a fractional outflow rate of 5 %/h. The most likely reason for this is that the hays were of different maturity.

Cereal (SRC and SRB) degradation characteristics are shown in Table 15a. Except for a lack of significance (P>0.05) of lag and slowly degradable fraction of DM and starch, all degradation characteristics were significantly higher (P<0.05) for SRB than SRC (Table 15a). Most of these degradation characteristics are consistent with other findings (Herrera-Saldana et al., 1990b; Tamminga et al., 1990; Hussein et al., 1991a and Grings et al., 1992). Values for degradation rates of DM and starch were similar to those reported by Herrera-Saldana et al. (1990b) and Grings et al. (1992) for corn. Values for these characteristics were higher for barley in our case than reported by these workers. Effective degradability at an outflow rate of 9.0 %/h for DM reported in this study, falls within the range of values reported by Grings et al. (1992) for both corn and barley at a rate of passage of 8.0 %/h.

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However effective degradability for starch was somewhat lower in our case than that reported by Grings et al. (1992).

The significantly higher (P<0.05) values of DM degradation characteristics of SRB than SRC would suggest a high digestibility of OM as a result of higher ruminal nutrient degradability such as CP (Table 15a). Differences in nutrient degradation characteristics between barley and corn can be attributed to differences in the type of starches and protein (Kakade 1974; Huntington, 1994; Romagnolo et al., 1994 and Stern et al., 1994) and neutral detergent fiber degradation rate has been reported to be higher for barley than corn in spite of corn having had a higher soluble fraction (De Visser et al., 1992). The starch in barley is mainly of a floury waxy type and has a higher content of amylopectins than corn starch (French, 1973; Rooney and Pflugfelder, 1986 and Huntington, 1994). In general, waxy type of starches (high content of amylopectin) easily swell in heated water, thereby allowing for an easy enzymatic attack resulting in faster rates of in vitro or in vivo or in situ digestion than non-waxy starches (Huntington, 1994). In addition barley has a higher content of rapidly soluble material (DM) than corn (Table 15; Herrera-Saldana et al., 1990b and Grings et al., 1992) due to the high content of simple carbohydrates and nitrogen (Aman and Hesselman, 1984).

Proteins in barley, wheat and corn are mainly prolamins and glutelins which resist rumen degradation but only barley and wheat have substantial amounts of albumins and globulins which are highly soluble. Corn on the other hand has trace amounts of albumins and

contains low amounts of globulins when compared to barley and wheat (Kakade, 1974; Wall and Paulis, 1978; Wilson et al., 1981; Spicer et al., 1986 and Romagnolo et al., 1994). These differences in quantity of types of proteins accounts for differences in degradability of proteins of cereals which contributes to the variation observed in DM degradation characteristcs.

Differences in degradation characteristics of barley and corn in different experiments are likely to be a reflection of differences among starch, variety, location, year, grain density, processing, climatic conditions and agronomic practices (Grings et al., 1992; Flachowsky et al., 1992; Engstrom et al., 1992 and Huntington, 1994) but also methodology, which is responsible for differences in degradation characteristics between SRC and SRB used for the lactating dairy cows trial and the in situ studies of cereals in Chapter 2. Differences in quantity of rapidly degradable fraction in Table 5 and 6 compared to Table 15a for barley and corn can be explained by differences in the methods for determination of this fraction as described in materials and methods of Chapters 2 and 4. The higher quantity of rapidly degradable fraction for SRB and SRC grains in table 15a compared to table 5 and table 6, may also partly explain the lower quantity of slowly degradable fraction in Table 15a than Table 5 and 6. However, inspite of the higher quantity of the rapidly degradable fraction of DM or starch in Table 15a than in Table 5 and 6, that did not translate into higher rates of degradation of the two parameters. The differences in the rate of DM and Starch degradation could be related to some

differences in size of the bags, quantity of sample in the bags, washing procedures of the bags, and also frequency of feeding while quantity of feed and pore size of the bags remained constant as described Chapters 2 and 4.

Degradation characteristics of protein sources used as feed ingredients are shown in Table 15b. Except for the rapidly degradable soluble fraction for DM and CP, all parameters were significantly higher for CM than FM (P<0.05), being in agreement with earlier reports (Hvelplund, 1985; NRC, 1989; Hussein et al., 1991a and Khorasani et al., 1994). Why the rapidly soluble fraction (DM and CP) and lag (CP) for FM is higher (P<0.05) and lower (P<0.05) respectively than that for CM is unknown and the result was unexpected.

Differences in degradation characteristics of CM and FM can be attributed to differences in types of proteins found in these supplements and also external artificially modifying processes such as application of heat, pelleting and oil extraction method. Oil crops such as CM contain albumins and globulins which have a high content of basic and acidic amino-acids and these proteins are highly soluble (Kakade, 1974). Fish meal on the other hand generally resists degradation, its ruminal degradability is reduced by heating during the drying process. Heat during drying of FM protein has been shown to induce formation of S-S cross-linking from sulfhydryl oxidation (Opstvedt et al., 1984) resulting in increased numbers of disulfide bonds and decreased ruminal proteolysis of FM protein (Chen et al., 1987).

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Differences in degradation characteristics as found in this experiment and many others, have a significant impact on the site and extent of digestion, ruminal and blood parameters, supply of nutrients to the small intestine and subsequent metabolism and animal performance.

4.3.2.0.   Intake.

4.3.2.1.   Effect of carbohydrate source.

Source of carbohydrate did not affect (P>.10) the consumption of DM, OM, CP and starch (Table 16). Total intakes of ADF and NDF were also not affected by carbohydrate source (Table 16). Dry matter intakes as actual total and percent body weight averaged 23.72 kg/cow/day and 3.64% respectively for the four diets being similar to intakes reported by McCarthy et al. (1989) for similar diets. Our findings in this experiment differ from others, Casper and Schingoethe. (1989), McCarthy et al. (1989) and Casper et al. (1990) who found that cows consumed less of barley-based diets than corn based diets with alfalfa hay and corn silage as roughage and fed in combination with sources of protein with different degradability rates. Grings et al (1992) and DePeters and Taylor, (1985) reported no differences for cows in mid-lactation while Khorasani et al. (1994) reported a significant interaction between carbohydrate and protein source for total DM intake with cows on corn-based diets consuming more than those on barley diets when fed with a highly degradable source of protein.

Total intake of NDF (P<0.006) and hemi-cellulose (P<0.0001), concentrate NDF and hemi-cellulose intakes were all significantly (P<0.01) affected by cereal type (Table 16). Cows fed SRB concentrate consumed in excess of 2x the amount of NDF and hemi-cellulose consumed by cows fed SRC based concentrate. Total intake of ADF tended to be higher (P<0.13) on SRB than SRC (Table 16).

The differences between SRB and SRC in intake of fiber material may be explained on the basis of differences in chemical composition with barley grain and barley based diets being higher in fiber than corn (Table 13 and 14) since total DM intakes were similar among diets (Table 16). The NDF and hemi-cellulose content (Table 13) of SRB (29.71 and 23.14%, respectively.) were about 2x more than that of SRC (14.68 and 10.94%, respectively) while the same parameters averaged 36.09% and 13.37% for SRB based diets being higher than corn based diets which averaged 29.06% and 7.19% (Table 14). These findings are different from those of McCarthy et al. (1989) who reported no differences while Grings et al. (1992) indicated that cows on a corn diet consumed more NDF than cows on barley. There is a possibility that fiber digestion could have been depressed on barley diets in the experiment of Grings et al. (1992) due to low ruminal pH resulting from higher ruminal degradability of barley starch than corn thereby affecting cellulolytic activity of bacteria. They did not measure pH in their experiment. Terry et al. (1969) indicated that optiomal pH for cellulolytic activity of bacteria in the rumen is about 6.8 and ruminal fiber digestion is

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decreased as pH of the rumen fluid declines particularly if below 6.0 (Stewart, 1977).

Protein and starch intake were not significantly affected (P>0.05) by source of carbohydrate (Table 16). Total protein and starch intake in this experiment averaged 4.17 and 7.27 kg/cow/day respectively.

4.3.2.2. Effect of protein source.

Dry matter, OM, CP, NDF and hemi-cellulose intakes were not significantly affected by (P>0.10) protein source (Table 16). Cows on CM consumed more (P<0.10) ADF than on FM (Table 16). Since the DM intakes were similar among diets this result may in part be explained by the high ADF content of SRB and CM compared to corn (Table 13) let alone FM which contains no botanical fiber. This result is different from that of McCarthy et al. (1989) who showed no significant differences in ADF intake due to protein source.

Overall, the results of intake reported here are similar to McCarthy et al. (1989) in which source of carbohydrate rather than protein had a major influence on most changes in nutrient intake (Table 16).

4.3.3.0. Dry matter, organic matter and nutrient digestibility.
4.3.3.1. Effect of carbohydrate source.

Dry matter and organic matter intakes of cows during the digestibility trial were not significantly (P>0.05) affected by carbohydrate source (Table 17) and these averaged 21.85 and 20.52

kg/cow/day for all diets respectively and is in agreement with Table 16, although the actual values are lower (Table 17) than in Table 16.

Apparent digestibilities for DM, OM, CP, starch, NDF and hemi-cellulose were significantly (P<0.10) higher on the SRB diets than the SRC based diets (Table 17) being in agreement with the results reported by Herrera-Saldana et al. (1990b) for all parameters except fibers using barley and milo based diets.

There were no statistical differences (P>0.10) in total tract apparent digestibility of ADF by cows consuming either SRB or SRC based diets (Table 17). The results reported in this experiment for DM and OM intake and ADF digestibility are different from the results reported by DePeters and Taylor, (1985) and McCarthy et al. (1989), for dairy cows and Spicer et al. (1986) for growing steers but agrees with McCarthy et al. (1989) for total tract apparent starch and protein digestibility (Table 17). More starch and protein were digested on SRB than SRC based diets.

DePeters and Taylor, (1985) and McCarthy et al. (1989) reported no significant difference in total tract digestibilities of DM and OM in spite of finding significant differences in apparent total tract digestibilities of starch (barley higher than corn), NDF (corn higher than barley) and protein (barley higher than corn).

In our studies the significantly higher digestibilities of starch, CP, NDF and hemi-cellulose of SRB based diets over SRC

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based diets was also manifested in the higher DM and OM digestibilities (Table 17).

The higher protein digestibility on SRB diets than SRC diets can be explained in part by the fact that protein in both barley and CM is highly degradable while corn and FM are less degradable in the rumen (Herrera-Saldana et al. 1990a,b).

The results for starch digestibility in all experiments testify to the finding that barley starch is more degradable than that of corn (Table 15;, Herrera-Saldana et al., 1990a,b and Grings et al., 1992). About 80% of barley starch is digested in the rumen compared to about 50% of corn with the reverse being true for post-ruminal digestion in which about 40% of corn is digested compared to about 20% of barley (McCarthy et al., 1989). This has implication on milk production with respect to glucose and VFA's provision to the animal.

4.3.3.2. Effect of source of protein.

Apparent digestibilities for all parameters were not significantly affected (P>0.10) by protein source (Table 17). The slightly elevated starch and protein apparent digestibilities in FM diets when compared to CM diets may be related to higher (P<0.07) rate of passage of particulate matter on CM diets than FM based diets (Table 17). These results agree with those reported by McCarthy et al. (1989) and Herrera-Saldana et al. (1990b) for all nutrients except NDF. Source of carbohydrate rather than protein

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source was the predominant factor affecting total tract digestibilities of nutrients.

4.3.4.0. Ruminal VFAs, NH_3-N and pH.

In general, the rapid and extensive ruminal degradation of starch and protein on all diets and also fiber on barley based diets resulted in fairly high concentrations of total volatile fatty acids (VFAs) in the ruminal fluid especially when CM based diets were fed (Table 18). Rumen fluid pH was not significantly affected by the source of carbohydrate or protein ($P>0.05$) and averaged 7.0, close to 6.8 and above 6.0 considered to be optimal for cellulolytic bacteria activity (Terry et al., 1969) and depression of fiber digestibility (Stewart, 1977) respectively. The lowest pH was 6.20 on SRC-FM which also had the lowest concentration of total VFAs, why this is so is not clear. Since these pH values were close to 6.8 and above 6.0 and that rate of passage for solids and liquid were similar among diets, the low fiber digestibility (Table 17) observed on SRC diets may be related to some other unknown factors. Low pH values were responsible for low fiber digestibility on all diets but also when barley diets were compared to corn (McCarthy et al., 1989)

In this study protein source significantly affected ($P<0.03$) the total concentration of ruminal VFAs with CM based diets being higher (78.43 versus 72.80 mM/l) than FM based diets (Table 18). These results are in agreement with those reported by Herrera-saldana and Huber, (1989) for cotton seed meal versus dry brewers

grain, Hussein et al. (1991b) for soybean meal versus FM and also Aldrich et al. (1993) for CM/SBM versus blood meal. Total VFAs concentration was shown to increase linearly as degradable intake protein increased in continuous cultures (Stokes et al., 1991a). Others have reported no significant differences (Casper and Schingoethe, 1989 and Khorasani et al., 1994) while McCarthy et al. (1989) reported significant carbohydrate and protein effects as well as interaction effects for similar protein sources.

Source of carbohydrate had no significant (P>0.05) effect on total VFA concentration (Table 18), in agreement with the results of Herrara-saldana and Huber, (1989), Hussein et al. (1991a,b) and Aldrich et al. (1993).

There was a significant interaction (P<0.05) between source of carbohydrate and protein in concentration of acetate, butyrate, valerate and also acetate:propionate (Table 18). The interaction in acetate concentration occurred because when CM replaced FM on corn diets more acetate was produced than when CM replaced FM on barley diets. It was expected that more acetate will be produced on barley based diets than corn based diets considering the high fiber digestibility on barley diets. There was however tendency towards higher acetate levels on barley diets than on corn diets but this was an insignificant small increase. Khorasani et al. (1994) reported no significant differences in acetate concentration inspite of the fact that diets with high starch degradability had higher content of fiber than diets with low starch degradability.

Propionate was significantly affected by both source of carbohydrate (P<0.0001) and protein (P<0.0001). Cows consuming barley diets had higher acetate concentration than those consuming corn diets (17.44 vs 15.23%). The higher molar percent of propionate on barley based diets than corn diets is consistent with high starch fermentation of barley in the rumen (Table 15a). The high propionate concentration on barley diets may partly explain the higher milk production on these diets than corn diets (Table 19). Propionate is glucogenic and must have resulted in higher glucose production which went in lactose production; Lactose is the main milk carbohydrate. The high propionate concentration on barley diets also translated into lower milk fat percentage (Table 19) which is supported by the lower A:P ratios on barley diets than corn diets (Table 18). Herrera-Saldana et al. (1990a) also reported low A:P ratios which resulted in low milk fat percentages (Herrera-Saldana and Huber, 1989). The data for propionate is in agreement with Khorasani et al (1994) who reported significant effects for both source of carbohydrate and protein but did not find any differences in the A:P ratio and milk fat percentages. McCarthy et al (1989) reported significant interaction for acetate and propionate concentration and the A:P ratios, while Aldrich et al (1993) reported no significant differences in acetate and propionate concentration but A:P ratios were significant for both source of carbohydrate and protein.

Butyrate molar percent was not affected by either source of carbohydrate or protein but interaction was significant (P<0.03).

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(Table 18). The interaction in butyrate concentration occurred because more butyrate was produced when CM replaced FM on barley diets than when CM replaced FM on corn diets. Other workers reported no differences (Herrera-Saldana and Huber, 1989; McCarthy et al., 1989, and Khorasani et al., 1994) in concentration of butyrate while others have reported significant carbohydrate source effect (Casper and Schingoethe, 1989 and Aldrich et al., 1993) with diets of low starch degradation being higher than diets of high starch degradability. Although McCarthy et al. (1989) and Herrera-Saldana and Huber (1989) reported no differences in butyrate concentration, there was however a tendency toward high butyrate concentration on diets with carbohydrate source of slow starch degradability. There was tendency toward higher butyrate concentration on corn diets than barley in this experiment but this increase was not significant.

Isobutyrate and isovalerate molar percentages were significantly affected (P<0.01) by source of carbohydrate and protein (Table 18). In both cases corn based diets resulted in higher molar percentages than barley based diets (1.7 vs 0.59 molar %, isobutyrate; 1.90 vs 0.9 molar %, isovalerate). Isovalerate results agree with those reported for dairy cows for similar diets (Casper and Schingoethe, 1989) and sheep (Hussein et al., 1991b). In contrast Aldrich et al. (1993) reported higher concentration of isovalerate for diets containing highly degradable non-structural carbohydrate (NSC) than those containing less degradable NSC. This difference may be explained by differences in the source of NSC. In

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this study and many others (Casper and Schingoethe, 1989 and McCarthy et al., 1989) corn and barley were the less and highly degradable carbohydrate source respectively while Aldrich et al., (1993) used ear corn and high moisture shelled corn for the same. Other workers (McCarthy et al., 1989, and Khorasani et al., 1994) reported no differences in concentration of isovalerate. As for isobutyrate, reports are conflicting. Casper and Schingoethe, (1989), Aldrich et al. (1993) and Khorasani et al. (1994) have reported no carbohydrate effect. The higher molar percentage of isobutyrate and isovalerate on corn based diets than on barley based diets may be related to the higher levels of valine and leucine as pecursors of isobutyrate and isovalerate (Harwood and Canale-Parola, 1981), respectively. More valine and leucine reached the duodenum on corn diets than barley (McCarthy et al., 1989), and corn contains about the same amount as barley while leucine is about twice as high in corn than barley (Grings et al., 1992).

Molar percentages for isobutyrate and isovalerate were higher for CM based diets than FM (Table 18) and these were 0.93 vs 0.81 and 1.65 vs 1.16 molar %, respectively. Results for isobutyrate are consistent with those of Aldrich et al. (1993) for lactating dairy cows and Hussein et al. (1991b) for sheep. Khorasani et al. (1994) also reported a protein effect but in their results indicated high concentration of isobutyrate for slowly degradable protein source diet. Isovalerate was shown to be higher on SBM than FM diets fed to sheep (Hussein et al., 1991b) and lactating dairy cows (McCarthy et al., 1989) inspite of the differences not being statistically

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significant. The higher isobutyrate and isovalerate on CM based diets than corn reflects the higher (P<0.05) ruminal CP degradation in the rumen because isobutyrate and isovalerate are derived from the deamination of branched chain amino-acids, valine and leucine respectively (Harwood and Canale-Parola, 1981).

Rumen NH_3-N concentrations were significantly (P<0.05) affected by protein but not by carbohydrate source (Table 18). Cows consuming CM based diets produced more rumen NH_3-N than those on FM based diets (8.5 vs 4.7 mg/dl), suggesting greater ruminal fermentability of protein in CM compared to FM (Table 15) (Herrera-Saldana et al., 1990a,b and Hussein et al., 1991a,b). This supports the findings and proposal by Erdman et al. (1986) that, the amount of NH_3-N in the rumen and fermentability of protein are strongly linked. Similar results were also shown with soybean meal versus FM with corn or barley using sheep (Hussein et al., 1991b) and dairy cows (Zerbini et al., 1988 and McCarthy et al., 1989), cotton seed meal versus dry-brewers grains with barley or milo (Herrera-Saldana and Huber, 1989) and soybean meal versus urea with corn or barley (Casper and Schingoethe, (1989) and more recently Khorasani et al. (1994) for dairy cows utilizing diets almost similar to the diets used in this experiment.

Rumen NH_3-N concentration for the CM diets was above 5 mg/dl while that for FM was close to 5 mg/dl. Satter and Slyter, (1974) found from in vitro studies that 5 mg/dl of rumen NH_3-N was required for optimal microbial growth. It is unlikely in this study that the low fiber digestibility on SRC-CM diets is related to rumen NH_3-N

concentration since this was adequate and that SRB-FM with a concentration close to 5mg/dl had quite high fiber digestibility. It may be speculated that energy on the SRC-CM diet could have been limiting development and proliferation of bacteria.

Reported values for rumen NH_3-N concentrations in the literature for similar diets range from 8.6-16 mg/dl (Casper and Schingoethe, 1989), 18-20.5 mg/dl (Hussein et al., 1991a) 10.2-16.4 mg/dl (Herrera-Saldana and Huber, 1989) 8.9-14.8 mg/dl (Aldrich et al., 1993), 11.97-13.57 mg/dl (Khorasani et al., 1994) and lowest being 1.39-3.54 mg/dl (McCarthy et al., 1989) for cattle and 18-20.5 mg/dl (Hussein et al., 1991b) for sheep. Khorasani et al. (1994) have also indicated a minimum value of about 4 mg/dl for slowly degradable starch and slowly degradable protein diet.

The low NH_3-N concentration on SRC-FM and SRB-FM may not just be due to the degradability of both SRC and FM but also to the synchronicity and asynchronicity respectively of the diets. On both diets the release of carbohydrate is able to contend with the release of nitrogen from FM. The rate of starch degradation in corn is about 2x more than the CP in FM and corn itself (Table 15a,b and Hussein et al., 1991b) and for SRB-FM combination, rate of starch degradation in barley is 5x more than its own CP and almost equal to the rate of release of protein in FM (Table 15a,b and Hussein et al., 1991b). This then would suggest a higher fixation of NH_3-N by α-keto-acids provided from carbohydrate sources at a rate adequate to contend with the release of nitrogen (Mahadevan et al., 1982). Aldrich et al. (1993) has published data supporting the above

observation. Cows on a low rumen available non-structural carbohydrate/low rumen available protein showed lower rumen NH_3-N concentration compared to the converse dietary combinations.

It is important to note that the rumen results should be interpreted with caution because of the possibility of salivary contamination because it was sampled once/cow/period and a stomach tube was used (Erdman et al., 1982).

It must be borne in mind that, measured concentrations in the rumen are a function of production and utilization by rumen microbes and this may in part explain the differences in rumen parameters within an experiment but also among experiments.

Results for blood parameters are also shown in Table 18. Carbohydrate ($P < 0.05$) and protein ($P < 0.05$) source including interactions were significant ($P < 0.005$) for blood-urea-N (BUN). Cows on SRB diets had lower blood urea-nitrogen (BUN) than SRC based diets (19.41 vs 20.92 mg/dl), and cows had more BUN on CM based diets than FM based diets (20.62 vs 19.71, mg/dl). The result for protein source is as expected, resulting from the significantly higher production of NH_3-N in the rumen (Table 18), when CM was fed than FM. The interaction occurred because, when FM replaced CM on SRC diets resulted in higher levels of BUN than CM. This was unexpected considering that SRC-FM combination gave lower rumen NH_3-N (Table 18).

The higher BUN on the SRB-CM than SRB-FM diets was possibly a result of the high rumen NH_3-N concentation as well as the high protein degradability in the rumen of both SRB and CM (Table 15a,b)

since the BUN was lower on SRC-CM diets (Table 18). These finding are in agreement with those of Casper and Schingoethe, (1989) for barley with SBM or urea as a protein supplement.

In contrast Herrera-Saldana and Huber, (1989) were unable to show significant differences in BUN between cotton-seed meal and dry brewers grain for barley or corn diets, and Aldrich et al., (1993) between high ruminal available and low available protein with high available non-structural or low available non-structural carbohydrate diets. McCarthy et al., (1989) and Herrera-Saldana and Huber, (1989) reported only a carbohydrate effect as also reported in this study. The result that FM resulted in higher BUN than CM on SRC diets conflicts with the findings of Herrara-Saldana and Huber, (1989), Casper and Schingoethe, (1989), Aldrich et al. (1993) and Stokes et al. (1991a,b) who reported no significant difference for similar diets (i.e. low rumen available carbohydrate in combination with either high or low rumen available protein). It is however of interest to note that this study and all others were able to show high rumen NH_3-N for high rumen available protein and low rumen available protein on low rumen available non-structural carbohydrate diets. Veen et al. (1988) also reported similar observations. This then suggests that factors other than ruminal NH_3-N level affect BUN. Feeding of slowly degradable protein increases intestinal amino-acids which are subsquently absorbed. It is possible that the high BUN on such diets could be resulting from ammonia released in the liver through deamination and gluconeogenesis from amino-acids (Veen et al., 1988). The most

susceptible amino-acids to gluconeogenesis are alanine, glutamic acid, serine and aspartic acid (Lindsay, 1982). Although blood amino acids were not measured in this experiment, diets (FM vs CM) with significantly low rumen NH_3-N had BUN levels in the expected range compared to those with high rumen NH_3-N but also their blood glucose levels were high (Table 18). It is possible that cows on SRC-FM would want to compensate for the short-fall in rumen NH_3-N and blood glucose through deamination and gluconeogenesis in order to support or maintain optimal milk synthesis, inspite of SRC starch being less degradable in the rumen. This seems to be evident from SRB-FM diets with the lowest rumen NH_3-N, and the unexpected normal level of BUN showed the highest blood glucose (Table 18). The SRB and FM diets would result in low levels of intestinal glucose compared to SRC-FM but a high level of intestinal amino-acids, microbial protein and undegradable protein.

The higher BUN and high glucogenic amino-acids on slowly degradable protein diets in comparison with highly degradable protein may be seen as an indication of gluconeogenesis (Veen et al., 1988). The results for blood glucose showed a significant carbohydrate source effect but also a significant interaction (P<0.01).

4.3.5.0   Rate of passage.

Results for rate of passage of solids and liquid data are shown in Table 17. Source of carbohydrate did not influence the rate of passage of either solids or liquids. This is agrees with

results for intake (Table 16 and 17), which shows that the source of carbohydrate did not influence dry matter intakes. However, DM and nutrient digestibilities were influenced by source of carbohydrate with barley based diets being digested more than corn based diets. If intake and rate of passage of solids of the diets was similar among diets, the higher digestibility of DM, OM and nutrients observed on barley based diets than corn based diets could be attributed to the higher rumen digestion of barley than corn (Table 15a) in addition to a better rumen environment for proliferation and development of microorganisms necessary for digestion. Increased rate of digesta passage from the rumen has been shown to increase feed intake (Baumgardt, 1970), decrease ruminal digestion and decrease total tract digestibility (Harrison et al. 1975; Mertens, 1977). Values for solid and liquid rate of passage were 5.64, 6.05, 5.43 and 8.63 %/h and those for liquid rate of passage were 11.81, 13.44, 10.42 and 10.71 %/h for SRC-FM, SRC-CM, SRB-FM and SRB-CM diets, respectively. The values for solids rate of passage are similar to those reported by MacGregor et al (1983).

Source of protein significantly affected the rate of passage for solids but not liquids (Table 17). Cows consuming CM based diets had higher rate of passage for solids than those cows consuming FM based diets. Rate of passage for solids averaged 7.34 %/h for CM compared to 5.54 %/h for FM based diets. This is expected considering the fact that CM is more digested in the rumen than FM (Table 15b). However, the higher rate of passage for solids

for CM diets than FM diets is not supported by increased feed intake (Table 16 and 17) but a small depression in DM, OM, and nutrient digestibilities was observed though this was not significant.

4.3.6.0. Milk yield and composition.

Milk yield but not 3.5% FCM and SCM was significantly affected by source of carbohydrate (Table 19). Cows consuming SRB based diets produced on average 2.08 kg/day more milk (P<0.01) than cows consuming SRC based diets. When milk yield was corrected for fat and solids, the significant differences disappeared. Since total DM and OM intakes did not show any influences of source of carbohydrate or protein (Table 16, 17), the increase in actual milk production by cows on SRB based diets may be explained by higher DM and OM digestibility resulting from high nutrient constituent digestibilities (Table 17). This should have resulted in a greater supply of digested nutrients for milk synthesis, and possibly increased microbial mass in the rumen and thus providing additional protein and energy, with the extra energy going into body stores (Table 19). Yield (passage to duodenum) and efficiency of bacterial synthesis was reported to be higher for diets matched for high rates of both NSC and protein degradation (McCarthy et al., 1989; Herrera-Saldana et al., 1990b and Aldrich et al., 1993). On the other hand, flow of ammonia-non-microbial N, (McCarthy et al., 1989 and Aldrich et al., 1993) and starch were reported to be higher on corn based diets than barley. In the present trial most apparent

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nutrient digestibilities were influenced by carbohydrate rather than by protein source and were higher for barley than corn based diets irrespective of protein source. This positive effect of barley would result in a high supply of nutrients for both the animal and also development and prolifereation of rumen bacteria. Microbial growth has been shown to be influenced more by the fermentation of carbohydrate (Nocek and Russell et al., 1988 and Argyle and Baldwin, 1989) than protein.

Rumen bacterial growth on barley diets was also probably influenced by the high provision of peptides and amino-acids or both because of the higher ruminal fermentation of CM and also protein in general on these diets than corn diets (Argyle and Baldwin, 1989).

Although starch and non-ammonia non-microbial N were most likely higher on corn based diets than barley it is possible that these materials were not available or less digested in the small intestine and passed to the cecum where they were fermented but unavailable for absorption (McCarthy et al., 1989). Response to the increased provision of non-ammonia-non-microbial protein is also dependent on whether the animals were in negative energy balance (Marsden, 1985). These two factors may probably explain in part differences in milk production results found when barley and corn are compared.

These results agree with those of Herrera-Saldana and Huber, (1989) but are in conflict with those of Casper et al. (1989, 1990), who reported higher milk production for corn based diets

compared to barley diets. In contrast to the above, DePeters and Taylor, (1985), Grings et al. (1992) and Khorasani et al. (1994) and Aldrich et al. (1993) reported no differences in actual milk production when corn or barley and when diets high or low in rapidly degradable carbohydrate were fed to lactating cows.

Milk fat and SNF percentages were significantly affected by carbohydrate source (Table 19). Cows consuming SRC diets had higher milk fat concentrations (P<0.06) but lower SNF (P<0.06) than SRB diets. Fat concentration is negatively correlated to milk production but also high starch digestibility can decrease milk fat concentration (Ørskov, 1986 and Macgregor et al, 1983). However, the reduced milk fat concentration observed for barley based diets (Table 19) is not consistent with the high fiber content (Table 14) and high fiber digestibility (Table 17) but also lack of significance among the diets in acetate concentration (Table 18) observed between barley and corn based diets. Diversion of nutrients away from milk fat synthesis towards body energy deposition occurred and this is indicated by increased body weight gains on SRB diets since 3.5% FCM and SCM were similar among diets (Table 19). Although not statistically significant, on average, cows on barley based diets tended to gain weight more than cows consuming corn based diets (Table 19). MacGregor et al, (1983) also observed reduced fat percentage and milk energy secretion with increased milk yield but no change in 4% FCM on diets high in TNC compared with diets low in TNC. It must be remembered that the reduced concentration of milk fat and elevated yields of milk,

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protein SNF and increased body weight gain (Table 19) are consistent with increased glucogenic energy supply from the readily fermentable carbohydrate of barley diets (Table 15a) and high total tract digestibility of nutrients (Table 17). This is also suppoted by the higher propionate production and also the lower A:P ratios (Table 18), resulting in low milk fat percentage (Table 19) on barley based diets than corn based diets. Carbohydrate source had no influence on protein (%) and total solids (%) ($P>0.05$). McCarthy et al. (1989) and Khorasani et al. (1994) and Grings et al. (1992) reported no differences in fat and protein concentration for corn and barley based diets. Herrera-Saldana and Huber, (1989) reported higher fat concentration for milo based diets than barley which is in agreement with our findings although corn instead of milo was used as a carbohydrate source of low starch degradability.

Yield of protein, total solids and SNF were all significantly affected by carbohydrate source (Table 19). Cows consuming SRB based diets produced on average 0.1, 0.2 and 0.3 kg/day more protein, total solids and SNF ($P<0.02$., $P<0.002$ and $P<0.01$, respectively) than did cows consuming SRC diets. No significant differences ($P<0.05$) were shown in the case of fat yield although this tended to be higher for cows consuming SRC diets. Aldrich et al. (1993) and Khorasani et al. (1994) reported data that fat yield was significantly higher for cows consuming diets high in slowly degradable carbohydrate than those receiving diets low in highly degradable carbohydrate in contrast to other researchers who reported no differences (Herrera-Saldana and Huber, 1989; McCarthy

et al. 1989, and Grings et al. 1992). The data for protein yields are in agreement with those of Oliveira et al. (1993) and Chen et al. (1994) for steam flaked sorghum versus dry rolled sorghum but in conflict with results from McCarthy et al. (1989) who showed higher protein yields for corn based diets than barley based diets. Our findings for protein are consistent with the suggestion that increased fermentability of carbohydrate results in increased milk protein (DePeters and Cant, 1991). The higher milk protein on such diets could have resulted from increased casein rather than true protein, NPN or whey protein. Khorasani et al. (1994) reported significantly higher casein concentration both as a percent of milk production and milk protein for barley diets than corn. However as noted by DePeters and Cant, (1991) changes in milk casein result in opposite changes to whey protein; the net effect being very small changes in total milk protein (0.1 kg difference in this study). In contrast to all these studies, Herrera-Saldana and Huber, (1989), Grings et al. (1992), Aldrich et al. (1993) and Khorasani et al. (1994), did not find any difference in protein yield.

Data on SNF in this experiement are constistent with those of Oliviera et al. (1994) and Chen et al. (1994) but different from McCarthy et al. (1989) who reported higher SNF yields for cows on corn than barley. Casper and Schingoethe, (1989) on the other hand reported no differences for similar diets. There are only a few studies in which total solids were measured, however, Casper and Schingoethe, (1989) and DePeters and Taylor, (1985) showed no differences for corn and barley diets which is not consistent with

the findings in this experiment. Higher total solids for the SRB diets than the SRC diets was a result of the increased milk protein and SNF since fat yield was lower for these diets. Although lactose was not measured in this experiment, the data on total solids and SNF would suggest that significantly higher lactose yield for the SRB diets than the SRC diets. This is consistent with higher blood glucose levels for the SRB diets than the SRC diets (Table 18) and is supported by the higher propionate production on these diets (Table 18). Hardwick et al. (1961) indicated that lactose is a major regulator of the volume of milk produced by mammary glands. Although experiments which reported significant differences in milk production including this experiment did not measure milk lactose (Herrera-Saldana and Huber, 1989; Casper and Schingoethe, 1989 and McCarthy et al., 1989) and those that reported no differences in milk production found no differences in lactose concentration and yields, this does not declare this speculation invalid.

Protein source in this experiment did not affect yield of milk, FCM (3.5%), SCM, fat, protein, total solids, SNF and milk composition of the above mentioned parameters (Table 19), consistent with the findings of McCarthy et al. (1989) on all parameters but not Khorasani et al. (1994) for protein yield and fat percent, Casper and Schingoethe, (1989) for protein, SNF and total solids concentration and Aldrich et al. (1993) for protein concentration.

Efficiencies for DM and OM conversion to milk indicated a significant carbohydrate source effect for milk production and DM

and OM intake but not for FCM (3.5%) (Table 19). Cows on the SRB diets had higher efficiencies than cows on the SRC diets (1.15 versus 1.06; 1.23 versus 1.13, respectively). Since intake of DM and OM were similar (Table 16 and 17), these efficiency values are consistent with the high digestibility of DM, OM and the nutrients on SRB diets than SRC diets (Table 17). Herrera-Saldana and Huber, (1989) however found no differences in efficiency of DM conversion to milk. They attributed their findings to more protein and starch from milo diets escaping degradation in the rumen and therefore being available in the small intestines for enzymatic digestion off-setting the lower total tract digestibility. In this experiment it is possible that the lower efficiencies are related to uncaptured rumen NH_3-N on the SRC-CM diet and that the undegraded starch and protein SRC-FM did not have much time to be degraded in the small intestine and absorbed although rate of passage for solids was significantly affected (P<0.07) by protein source (Table 17).

No significant differences (P<0.05) were observed for protein source influence on all efficiencies (Table 19).

4.4.0.   SUMMARY AND CONCLUSIONS.

Matching carbohydrate and protein sources differing in the rate of carbohydrate and protein degradation showed beneficial effects for the following characteristics and was dominated by the effect of source carbohydrate;

Starch intake tended to be higher for the FM than the CM diets while barley based diets had higher starch and fiber intakes than corn.

Barley based diets had higher DM, OM, starch, CP, NDF, and hemi-cellulose digestibility than corn based diets.

Milk production, efficiency of feed utilization and milk protein yield were higher on barley based diets than corn based diets irrespective of differences in protein rate of degradability for the protein sources.

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4.6.0   TABLES.

Table 12. Ingredients composition of concentrates fed to lactating
dairy cows as a percentage of the dry matter[1].

	D I E T S			
ITEM	SRC-FM	SRC-CM	SRB-FM	SRB-CM
Steam rolled corn (SRC)	89.95	81.75	.....	.....
Steam rolled barley (SRB)	.....	.....	91.09	84.55
Fish meal (FM)	8.06	.....	7.12	.....
Canola meal (CM)	.....	15.15	.....	13.51
Limestone	.....	1.09	.....	0.15
Salt	0.99	1.10	0.85	0.90
Vitamin-mineral mix[2]	0.99	1.10	0.93	0.90

[1]Concentrates: SRC-FM, steam-rolled corn-fish meal; SRC-CM, steam-
rolled corn-canola meal; SRB-FM, steam-rolled barley-fish meal and
SRB-CM, steam-rolled barley-canola meal.
[2]Phosphorus 20.0%, iodine 200 mg/kg, cobalt 150 mg/kg, copper 4000
mg/kg, zinc 6000 mg/kg, manganese 2500 mg/kg, magnesium 6.0%,
flourine(max) 2000 mg/kg, vitamin A(min) 500000 IU/kg, vitamin D
(min) 50000 IU/kg, vitamin E (min) 500IU/kg, iron 8000 mg/kg, and
selenium 35mg/kg.

Table 13. Nutrient analysis of major dietary ingredients fed to lactating dairy cows[1].

Item	ALFH	SRC	SRB	FM	CM
DM%	89.37	95.01	94.64	96.07	96.04
% OF DM					
OM	91.34	97.81	98.39	74.64	88.66
CP	17.39	9.02	10.29	56.82	33.54
Starch	3.82	74.80	67.10	–	10.66
NDF	44.89	14.68	29.71	7.08	26.65
ADF	39.95	3.74	6.57	2.31	17.71
H/CELL	4.94	10.94	23.14	4.77	9.20
GE Kcal/g	4.43	4.43	4.36	4.35	4.35
EE	2.34	4.03	1.69	8.34	4.62
Ash	8.66	2.19	1.61	25.36	11.34
Ca	1.50	0.02	0.07	5.70	0.65
P	0.18	0.34	0.31	3.55	2.63

[1]ALFH = alfalfa hay, SRC = steam-rolled corn, SRB = steam-rolled barley, FM = fish meal, CM = canola meal

Table 14. Chemical analysis of diets fed to lactating dairy cows[12].

Item	SRC-FM	SRC-CM	SRB-FM	SRB-CM
DM%	95.69	96.07	95.62	96.34
% OF DM				
OM	88.77	91.30	92.97	93.51
CP	16.15	16.13	15.56	15.12
Starch	31.18	33.63	32.15	33.65
NDF	29.32	28.80	36.13	36.05
ADF	22.28	21.47	23.04	22.42
H/CELL	7.04	7.33	13.09	13.65
NE1, Mcal/kg[3]	1.53	1.61	1.58	1.60
Ash	5.46	5.92	5.16	5.50
Ca	1.03	1.37	1.01	0.76
P	0.38	0.50	0.37	0.42

[1]SRC-FM = steam-rolled corn-fish meal, SRC-CM = steam-rolled corn-canola meal, SRB-FM = steam-rolled barley-fish meal, SRB-CM = steam-rolled barley-canola meal.
[2]Concentrate plus alfalfa hay
[3]estimated from NRC (1989)

Table 15a. In situ disappearance of dry matter, starch and neutral detergent fiber in cows of alfalfa hay and cereal ingredients used in rations for lactating dairy cows[12].

Degradation Characteristics[3]	ALFH[5]	SRC	SE[4]	SRB	SE	P<0.05
DM						
a (%)	43.90±0.43	41.38	0.27	52.42	0.86	0.0066
b (%)	35.16±1.17	36.32	2.40	39.09	0.68	0.3842
k_d(%/h)	6.32±0.02	6.42	0.34	12.24	0.98	0.0301
Lag (h)	0.00±0.00	0.26	0.26	0.00	0.00	0.4226
EFDEG[4] (%)						
0.05	63.54±0.11	61.50	0.87	80.14	0.27	0.0024
0.09	58.69±0.27	56.13	0.60	74.13	0.30	0.0013
Starch						
a (%)		44.83	1.77	36.31	2.09	0.0397
b (%)		54.10	2.35	55.87	1.87	0.6155
k_d(%/h)		5.88	0.11	15.26	1.34	0.0200
Lag (h)		1.75	1.46	0.00	0.00	0.3526
EFDEG[4] (%)						
0.05		71.79	1.57	78.35	0.24	0.0440
0.09		63.38	1.63	71.42	0.24	0.0397
NDF[6]						
a(%)	8.02±.10	ND[7]		ND		
k_d(%/h)	6.29±.07					

[1]ALFH = alfalfa hay, SRC = steam-rolled corn, SRB = steam-rolled barley.
[2]Means in the same row within cereal effect are significantly different (P<0.05).
[3]a = rapidly degradable fraction,
 b = slowly degradable fraction,
 k_d = fractional rate of degradation of fraction b,
 lag= lag time,
 EFDEG = effective degradability at 5%/h and 9%/h fractional outflow rate.
[4]SE = standard error (n=2)
[5]Mean±standard deviation (n=4).
[6]Estimated as slope of the regression of the natural log of percentage degradability vs time.
[7]Not determined.

Table 15b. In situ disappearance of dry matter and crude protein in cows of FM and CM ingredients used in rations for lactating dairy cows[12].

Degradation Characteristics[3]	FM	SE[4]	CM	SE	P<0.05
DM					
a (%)	52.72	0.05	43.16	1.37	0.0199
b (%)	15.46	2.18	44.42	2.10	0.0108
k_d(%/h	4.33	0.70	8.34	2.27	0.0336
Lag (h)	0.00	0.00	0.00	0.00	0.4226
EFDEG[5] (%)					
0.05	59.76	0.32	70.57	2.84	0.0233
0.09	57.64	0.10	64.26	2.69	0.0432
CP					
a(%)	48.16	0.12	36.15	2.96	0.0259
b(%)	23.73	3.94	56.90	4.43	0.0305
k_d(%/h)	3.02	0.44	8.06	2.14	0.0458
Lag (h)	0.00	0.00	1.18	1.18	0.4226
EFDEG[5] (%)					
0.05	57.25	0.63	69.36	2.97	0.0370
0.09	54.26	0.28	60.85	2.91	0.0421

[1]FM = fish meal, CM = canola meal.
[2]Means in the same row within protein effect are significantly different (P<0.05).
[3]a = rapidly degradable fraction,
 b = slowly degradable fraction,
 k_d = fractional rate of degradation of fraction b,
 lag= lag time,
 EFDEG = effective degradability at 5%/h and 9%/h fractional
        outflow rate.
[4]Standard error (n=2).
[5]EFDEG = Effective degradability.

Table 16. Least square means for dry matter, organic matter and nutrient intakes of lactating cows receiving SRC or SRB with either FM or CM during the intake study.

| | DIETS[1,2] | | | | Main effects and interaction[3] | |
| | SRC | | SRB | | | |
ITEM	FM	CM	FM	CM	C	P
DMI, kg/d						
TOTAL	23.74±.30	23.77±.30	23.84±.36	23.54±.34	NS[4]	NS
CONC.	11.20±.67	10.30±.63	11.35±.73	10.51±.71	NS	NS
HAY	12.53±.62	13.47±.62	12.49±.73	13.03±.70	NS	NS
%Bwt	3.63±.05	3.65±.05	3.65±.06	3.61±.05	NS	NS
OMI, kg/d						
TOTAL	22.19±.29	22.29±.29	22.41±.33	22.20±.32	NS	NS
CONC	10.74±.61	10.00±.61	11.00±.71	10.30±.69	NS	NS
HAY	11.45±.57	12.28±.57	11.41±.66	11.89±.64	NS	NS
Nutrients.						
CP, kg/d						
Conc	1.57±.12	1.41±.12	1.68±.14	1.55±.13	NS	NS
Hay,	2.47±.12	2.81±.12	2.54±.14	2.65±.13	NS	NS
Total	4.03±.09	4.22±.09	4.22±.11	4.21±.10	NS	NS
Starch, kg/d						
Conc	7.45±.39	6.62±.39	6.96±.45	6.16±.44	NS	.12
Total	7.91±.36	7.12±.36	7.41±.42	6.65±.41	NS	.11
ADF, kg/d						
Hay	4.44±.34	5.27±.34	4.85±.39	5.56±.38	NS	.09
Total	4.85±.33	5.91±.33	5.53±.39	6.47±.38	.13	.04
NDF, kg/d						
Conc	1.30±.16	1.28±.16	2.93±.18	2.53±.18	.0001	NS
Hay	5.57±.29	5.99±.29	5.55±.34	5.79±.33	NS	NS
Total	6.86±.28	7.28±.28	8.18±.33	8.32±.32	.006	NS
H/CELL, kg/d						
Conc	0.71±.07	0.78±.07	1.86±.09	1.91±.08	.0001	NS
Hay	0.59±.03	0.64±.03	0.58±.04	0.61±.04	NS	NS
Total	1.31±.06	1.42±.06	2.44±.07	2.52±.06	.0001	NS

[1]SRC = steam-rolled corn, SRB = steam-rolled barley, FM = fish meal, CM = canola meal.
[2]Mean±se (SRC diets, BFM and CCM, n=9, 7 and 8, respectively).
[3]The interaction of source of carbohydrate and source of protein were not significantly differently (P<0.10).
[4]NS = not significant (P>0.10).

Table 17. Least square means of dry matter and organic matter intakes, total apparent nutrient digestibilities and rate of passage for lactating cows fed either SRC or SRB with either FM or CM during the digestibility trial.

ITEM	DIETS[1,2] SRC FM	SRC CM	SRB FM	SRB CM	Main effects[3] SE[4]	C	P
Intake, kg/d							
DM	21.97	21.72	21.75	21.94	0.64	NS[5]	NS
OM	20.60	20.34	20.43	20.70	0.68	NS	NS
Digestibilities							
DM	68.79	67.16	75.47	74.39	2.20	.07	NS
OM	71.10	69.22	77.92	75.62	2.01	.07	NS
CP	75.01	71.71	78.64	77.23	1.27	.05	NS
Starch	92.13	89.50	96.64	95.82	1.52	.06	NS
ADF	44.64	44.53	51.62	56.29	5.46	NS	NS
NDF	39.83	35.96	53.87	57.62	4.74	.05	NS
H-CE	48.20b	27.91c	55.22a	65.22a	5.42	.04	NS
ROP[6], %/h							
Solid phase	5.64	6.05	5.43	8.63	.52	NS	.07
Liquid phase	11.81	13.44	10.42	10.71	.58	NS	NS

[1]SRC = steam-rolled corn, SRB = steam-rolled barley, FM = fish meal, CM = canola meal.
[2]Means in the same row with different letters are significantly different P<0.10.
[3]The interaction between source of carbohydrate and source of protein significant for hemi-cellulose (P<0.0962).
[4]SE-Standard error (n=3).
[5]NS-not significant (P>0.10).
[6]ROP-rate of passge.

Table 18. Least squares means of changes in ruminal volatile fatty acid, pH, ammonia-N, blood glucose and blood urea-N concentrations for cows fed SRC or SRB with either FM or CM[1]

ITEM	SRC		SRB		Main effects and interaction[2]		
	FM	CM	FM	CM	C	P	CXP
VFA[4,5]							
Molar %							
Acetate(A)	64.72±1.32b	68.32±1.19a	69.45±1.41a	65.04±1.22b	NS[3]	NS	.02
Propionate(P)	16.39±0.42b	14.06±0.42c	17.89±0.45a	17.80±0.44a	.0001	0.0001	NS
Butyrate(B)	13.85±0.56a	12.72±0.53bc	11.97±0.52c	13.33±0.54ab	NS	NS	.03
Isobutyrate	1.10±0.04	1.20±0.04	0.52±0.04	0.65±0.04	.0001	.004	NS
Valerate	1.30±0.02b	1.53±0.03a	1.34±0.03b	1.30±0.03b	.009	.001	.002
Isovalerate	1.64±0.09	2.17±0.07	0.67±0.08	1.12±0.07	.0001	.0001	NS
A:P	3.96±0.37b	4.85±0.35a	3.87±0.36b	3.68±0.34b	.0001	NS	.001
Total,mM/L	72.22±2.04	75.43±2.46	73.38±2.38	81.43±2.54	NS	.03	NS
pH	6.20	7.05	7.25	7.30	NS	NS	NS
NH3-N, mg/dl	5.35	8.63	4.02	8.34	NS	.05	NS
BUN, mg/dl	22.59a	19.25b	16.82c	21.99a	.05	.05	.005
BG, mg/dl	63.95c	75.29b	85.32a	72.77b	.01	NS	.01

[1]Means in the same row with different letters are significantly different (P<.10).
[2]The interaction between source of carbohydrate and source of protein was not significant (P<.10).
[3]NS = not significant (P>.10).
[4]VFAs = mean±se (SRC diets and CCM=3, BFM=2)
[5]se = .29, .18, .29 and .60 (pH, NH3N, BUN and BG, respectively. n=3)

Table 19. Least square means for milk production, yield components, milk composition, gross efficiencies and body weight change for cows fed SRC or SRB with either FM or CM.

| | DIETS[1] | | | | Main effects and interaction[2] | |
| | SRC | | SRB | | | |
ITEM	FM	CM	FM	CM	C	P
Yield, kg/d						
Milk	25.76±0.58	25.07±0.58	27.59±0.68	27.40±0.65	.01	NS[3]
3.5% FCM	25.01±0.99	26.51±0.99	25.88±1.16	25.22±1.12	NS	NS
SCM	23.94±0.45	24.56±0.45	24.99±0.53	24.78±0.51	NS	NS
Fat	0.91±.061	0.95±.061	0.87±.71	0.85±.068	NS	NS
Protein	0.85±.024	0.82±.024	0.92±.029	0.91±.028	.02	NS
T/solids	3.17±.038	3.18±.038	3.40±.045	3.36±.043	.0016	NS
SNF	2.27±.080	2.21±.080	2.51±.094	2.55±.091	.0116	NS
Composition, %						
Fat	3.32±.23	3.76±.23	3.04±.26	2.93±.25	.06	NS
Protein	3.30±.05	3.23±.05	3.37±.05	3.29±.05	NS	NS
T/solids	12.05±.19	12.40±.19	12.00±.22	12.07±.21	NS	NS
SNF	8.74±.15	8.64±.15	8.96±.17	9.14±.17	.06	NS
Gross efficiency						
Milk:DMI	1.07±.018	1.04±.018	1.14±.021	1.16±.02	.002	NS
FCM:DMI	1.07±.051	1.09±.051	1.06±.059	1.07±.057	NS	NS
Milk:OMI	1.15±.019	1.11±.019	1.22±.022	1.23±.021	.002	NS
FCM:OMI	1.15±.055	1.17±.055	1.13±.065	1.14±.062	NS	NS
Body weight						
change Kg/28 d	+5.63±11	-7.99±11	+6.91±13	+10.98±12.9	NS	NS

[1]Mean±se (SRC diets, BFM and CCM, n=9, 7 and 8, respectively).
[2]The interaction between carbohydrate source and protein source was not significant (P>0.10).
[3]NS = P>0.10.

5.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS.

Roughages will continue to be the basic and important portion of the diet of ruminant animals for meat and milk production. However supplementation with cereals and protein sources for energy and nitrogen provision for efficient microbial protein synthesis is paramount to efficient and economic production of meat and milk. Careful selection of energy and protein sources according to their rate of digestion in the rumen is important for provision of energy for the capture of nitrogen by microbes.

Knowledge of the behavior of feed components in the gastrointestinal tract is accomplished by use of in vitro, in situ and in vivo methods. Essentially the first two mimic what happens in vivo. However, this may be impossible to achieve as neither the in vitro nor the in situ estimates are the same as found by in vivo systems.

In this study, steam rolling of cereal grains increased the in vitro release of starch by amyloglucosidase. However in situ studies showed that steam rolling of cereals resulted in a decreased rate of DM and starch degradation which was in conflict with many published in vivo data and the few in situ studies that have been reported. Studies in which it was concluded that steam rolling increased starch degradation, researchers used grains that had been retained on a screen of known size, thereby removing differences in particle size distribution among the processed and unprocessed grains while in this study and others which are in conflict, grains used had been ground without further sieving.

The in situ procedure was also used to determine degradation characteristics of agro-byproducts. NDF from RDG degrades much faster than that of BP and WMR but BP has the highest ruminal availability.

As for steam rolling of cereals and certain other concentrate feeds of agro-byproduct nature, high in pectic material, the in situ method may not be suitable for the determination of the degradation of certain feed components.

More research is required to pin point factors which are responsible for the reduced DM and starch degradation in situ, possibly products of mallaird reaction and retrogradation reactions and also the general in situ technique.

In addition more research is required to determine degradation characteristics of feed components especially agro-byproducts which are becoming increasingly important in North America.

From in situ, in vitro and milk production studies, it was concluded that;

1.   starch in barley and wheat degrade much faster than corn,

2.   steam rolling of corn, wheat and barley decreases starch degradation in situ,

3.   steam rolling of corn, wheat and barley increases in vitro starch release by amyloglucosidase enzyme,

4.   NDF from alfalfa hay degrades faster than that from corn -grass silage and orchard grass hay,

5. NDF from rye distillers grains degrades faster than that from beet pulp and wheat mill run, with beet pulp having the highest effective degradability.

6. From the milk production trial, it can be concluded that diets matched for high ruminal availability of both carbohydrate and protein and also diets high in ruminal availability of carbohydrate but fed with a protein source of moderate nitrogen availaibility will result in increased milk production with alfalfa hay as a roughage. This agrees with our in situ studies when barley was compared to corn and when canola meal was compared to fish meal for ruminal availabilities. Certainly further research is required to confirm these findings.

Variability in degradation characteristics of carbohydates and proteins of cereals, protein supplements, roughages and agro-byproducts can be exploited in ration formulation to achieve a balance between the adequate provision of energy and nitrogen for efficient microbial protein and provision of some of these nutrients through lower tract digestion.

6.0 APPENDICES.

APPENDIX 1. SAS program used to calculate degradation characteristics for feeds using the modified equation of Ørskov and MacDonald, (1979).

```
  options ps=59 ls=80 nocenter;
    *JOHN HALL-AG CANADA - ØRSKOV EQUATIONS WITH LAG PHASE
SOLUTION;
    OPTIONS PAGESIZE=90;
    TITLE 'Dry matter Agrobyproducts';
    FILENAME SASDATA 'b:insabsas.prn';
    DATA DMD ;
    INFILE SASDATA MISSOVER;
    INPUT Sample Trt Cow T DMD;
    RUN;
    PROC SORT;
    BY trt cow;
    PROC NLIN  ITER=50 METHOD=MARQUARDT;
    BY trt cow;
    PARMS A=50 B=40 C=.04 .05 LAG=0,2,4;
       BOUNDS LAG>=0;
     IF LAG<0.0 THEN DO;
     LAG = 0.0;
     END;
     IF T<LAG THEN DO ;
     MODEL DMD = A;
     DER.A = 1. ;
     DER.B = 0. ;
     DER.C = 0. ;
     DER.LAG = 0. ;
    END ;
    ELSE DO ;
    MODEL DMD = A + B*(1.-EXP(-C*(T-LAG))) ;
    DER.A = 1. ;
    DER.B = (1.-EXP(-C*(T-LAG))) ;
    DER.C = B*(T-LAG)*EXP(-C*(T-LAG)) ;
    DER.LAG = -B*C*EXP(-C*(T-LAG)) ;
    END ;
    OUTPUT OUT=B PREDICTED=YHAT RESIDUAL=YRES PARMS=A B C LAG;
    PROC PRINT DATA=B noobs;
    data baba;
    set WORK.B;
    file tembo;
    put TRT 6 COW 9 T 13-14 DMD 20-24 YHAT 26-32
    YRES 34-41 A 43-49 B 51-57 C 59-65 LAG 67-73;
    run;
    PROC PLOT ;
     BY trt;
```

```
    OPTIONS PAGESIZE=25;

    PLOT DMD*T='0' YHAT*T='P' / OVERLAY ;

    RUN;
    DATA SUM(DROP= YHAT YRES ) ;
    OPTIONS PAGESIZE=90;
  *CALCULATING   EFFECTIVE DEGRADABILITY;
    SET B;
    IF T < 48 THEN DELETE;
    IF T > 48 THEN DELETE;
    *THE CALCULATED CONSTANTS ARE THE SAME FOR EACH INCUBATION
TIME
      THIS STATEMENT DELETES ALL BUT ONE TIME;
      TO=LAG;
    Kf=.05;
      *Kf IS THE FRACTIONAL RATE OF PASSAGE;
        EFFDGRD=A+(((B*C)*EXP(C*TO))/(C+Kf))*EXP(-(C+Kf)*TO);
    PUT trt A B C LAG Kf EFFDGRD;
    RUN;
    PROC PRINT ;
    RUN;
options ps=59 ls=80 nocenter;
data degrade;

    infile 'c:\sas\tembo';
    input sample trt cow T dmd yhat yres a b c lag;
  ***if period = '0' then delete;
run;
proc glm;
class sample trt cow T;
model a b c lag yres=trt cow;
means trt/tukey;
lsmeans trt/stderr pdiff ;
run;

proc glm;
class trt cow T;
model dmd yhat yres=trt cow;
means trt/tukey;
lsmeans trt/stderr pdiff;
run;
```

APPENDIX 2. Schematic representation of the allocation of diets for a 4 treatment/3 period switch back design used for the dairy cow trial[1]

Cow ID[23]	Period		
	1	2	3
8707	BFM	CCM	BFM
8802	CFM	BCM	CFM
8810	CCM	CFM	CCM
8817	BCM	CFM	BCM
8819	CFM	CCM	CFM
8821	BCM	BFM	BCM
8902	CCM	BCM	CCM
8908	CFM	BFM	CFM
8909	BFM	CFM	BFM
8913	BFM	BCM	BFM
8918	BCM	CCM	BCM
8920	CCM	BFM	CCM

[1]CFM = steam-rolled corn-fish meal,
 CCM = steam-rolled corn-canola meal,
 BFM = steam-rolled barley-fish meal,
 BCM = steam-rolled barley-canola meal.
 (4 treatments-complete design with blocks disregarded- Lucas, 1956)
[2]Cows # 8707, 8802, 8810 and 8821 were used for metabolism study.
[3]Cow # 8913 = removed from trial after spraying hind legs.