COMPARISON OF STRATEGICALLY BLENDED BY-PRODUCT FEED PELLETS ON PERFORMANCE, RUMEN FERMENTATION AND NUTRIENT DIGESTIBILITY OF GROWING CATTLE

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ABSTRACT

Beef producers are looking to alternative feed sources due to competition for starch sources among ethanol and livestock producers and with human food needs. Limited research is available on blended by-product feeds as alternative sources of starch and protein for backgrounding cattle. Three trials were conducted to evaluate the performance and effect on rumen fermentation and nutrient digestibility in growing cattle fed blended by-product pellets (BP). Pellets were based on by-products from the oilseed and grain sectors and were formulated to be isonitrogenous (17.0% CP) and isocaloric (1.92 and 1.28 Mcal kg^{-1} NE_m and NE_g, respectively). In Trial 1, four pellets were evaluated. The pellets were formulated to be either high starch (HS 45% DM basis) or high fat (HF 8.8% DM basis) and either low or high in soluble protein (LSP 27% of CP; HSP 37% of CP DM basis). In Trial 2, only the two HF pellets were evaluated. In Trial 1, 300 cross-bred steers (320 ± 21.6 kg, mean ± SD) were randomly assigned to one of 25 pens and fed one of 5 diets in a completely randomized block design. The control diet consisted of 46.9% forage and 53.1% barley-based concentrate. The four treatment diets consisted of 48.4% forage and 51.6% BP (DM basis). All diets were formulated to 1.63 and 1.02 Mcal kg^{-1} NE_m and NE_g, respectively (DM basis). In Trial 2, 180 cross-bred steers (326 ± 20.3 kg, mean ± SD) were randomly assigned to one of 15 pens with each pen randomly assigned to one of three treatments in a completely randomized design. Treatments included a control diet consisted of 54.3% forage and 45.7% barley-based concentrate and the two HF BP treatment diets which consisted of 55.6% forage and 43.4% of one of the two HF BP used in Trial 1 (DM basis). In Trial 1, no ($P>0.05$) effect of treatment was observed on ADG, however, DMI was reduced ($P<0.01$) with the HS treatment relative to the control and HF treatment. No significant differences ($P=0.16$) were observed in DMI between steers fed the control and HF BP diets. Gain:feed (G:F) was the poorest ($P<0.01$) for the HF diets. In Trial 2, ADG was lower ($P=0.04$) and DMI was higher ($P=0.04$) for HF BP (Control vs. HF), therefore cattle fed the control diet had superior feed efficiency ($P<0.01$). Dietary NE_g content (Mcal kg^{-1} DM) as calculated from animal performance was 7.5 and 8.3% lower ($P<0.01$) for cattle fed the HF diets relative to the control cattle in Trial 1 and 2, respectively. Trial 3 used 5 crossbred heifers (631 ± 31 kg, mean ± SD) in a Latin square design. Diets were the same as that used in Trial 1. Heifers fed HF BP had higher ($P=0.05$) mean pH values than those fed the control diet and trended ($P=0.07$) to have higher mean pH than those fed the HS BP. Feeding HF BP caused a decrease ($P<0.05$) in

propionate concentration, without affecting acetate or total VFA concentration. Rumen ammonia-N levels and digestibility of CP was highest ($P<0.05$) for HS, intermediate for HF, and the lowest for the control. Feeding HF BP relative to both the control and HS diets reduced ($P<0.05$) GE, DE and EE digestibility. Total nitrogen excretion (% of total N excretion) was not affected ($P>0.05$) by treatment. Feed costs per kg of gain were reduced by feeding HF BP due to cost of ingredients and relative excellent cattle performance. These results indicate that BP are a viable and economic alternative for supplementing energy and protein in backgrounding diets with no adverse effects on rumen fermentation. Moreover, feeding BP does not increase the potential of having nutrient excretion issues in the environment.

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DEDICATION

I dedicate this thesis to my family, Susana and Oscar Zenobi and Maria Manuela and Ricardo Tribulo for their support and for inspiring in me to share my desire to spread knowledge and passion about agriculture with others. Finally, for the most important person in my life, my wife, Paula. Your love and support give me inspiration, motivation, and courage. I could not have done it without you!

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LIST OF ABREVIATIONS

%	Percent
µg	Micrograms
µM	Micrometers
ADF	Acid detergent fiber
Ammonia-N	Ammonia nitrogen
ANOVA	Analysis of the variance
BW	Body weight
Ca	Calcium
CP	Crude protein
d	Day
DDGS	Dried distillers grains with solubles
DE	Digestible Energy
DM	Dry matter
DMI	Dry matter intake
EE	Ether extract (Fat)
g	Grams
GE	Gross Energy
h	Hour
HF HSP	High fat, high soluble crude protein
HF LSP	High fat, low soluble crude protein
HS HSP	High starch, high soluble crude protein
HS LSP	High starch, low soluble crude protein
kg	Kilogram
l. dorsi	*Longissmus dorsi*
mg	Milligrams
ml	Millilitres
mm	Millimetre
mn	Nanometers
N	Nitrogen
NDF	Neutral detergent fiber
NDF	Neutral detergent fiber
NE_g	Net energy gain
NE_m	Net energy maintenance
^oC	Celsius degrees
OM	Organic Matter
P	Phosphorus
RDP	Ruminal degradable protein
RUP	Ruminal undegradable protein

SAS	Statistical analysis system
SD	Standard deviation
SE	Standard error
SEM	Standard error of the mean
US	Ultrasound
USA	United States of America
VFA	Volatile fatty acid
VI	Voluntary Intake
wt	Weight

1 GENERAL INTRODUCTION

Currently, environmental policies and regulations are causing farmers to rethink their traditional way of production and move toward more productive, profitable and sustainable management systems. Expansion of the value added processing of the cereal grain and oil seed processing sectors such as ethanol production, canola crushing, grain cleaning, and oat processing have all created a large supply of by-products at competitive prices. These by-products have unique nutritional characteristics particularly in terms of fiber, protein and mineral content, either as a result of their inherent nature or due to industrial processing. Their unique nutrient content and availability make many of these by-products attractive feed sources for the cattle producer.

However, several questions remain unanswered regarding their feeding value. Many of the by-products from industrial processing of the grain and oil seed sectors have been studied individually and a good understanding of their uses and shortfalls is known. For example, dry and wet distiller grains with solubles have a high energy value due to fat content and high bypass protein content (Mustafa et al., 2000; Beliveau and McKinnon, 2008). Distiller's by-products are also high in specific minerals such as phosphorus (McKinnon and Walker, 2008) and sulphur (Corrigan et al., 2009). Walter et al. (2010) concluded that barley grain in finishing diets could be replaced by wheat and corn dried distillers grains with solubles (DDGS) at levels up to 40% of the total diet without affecting performance and meat quality. However, this study revealed that graded levels of wheat or corn DDGS in finishing diets greatly increased urinary and fecal N and P excretions, respectively. Yang et al. (2012) showed that blood urea nitrogen was higher in steers fed wheat DDGS compared to a barley-based diet. Similar results were reported by Brake et al. (2010) with corn DDGS and Li et al. (2011). Likewise, McKinnon and Walker, (2008) concluded that ADG and feed efficiency were improved by replacing barley grain with wheat DDGS at levels up to 50% of DM in backgrounding diets. However the CP level reached 21% of DM. Feeding of N at levels higher than the requirement for growth results in an increase in urinary N excretion (Hristov et al., 2011) generating higher ammonia (NH_3-N) emissions (Todd et al., 2006). Therefore, issues associated with excretion of nitrogen and phosphorous such as run-off from manure, additional release of ammonia into the atmosphere, atmospheric fine particulate matter formation (Hristov et al., 2011) and difficulty to manage the

nitrogen:phosphorus ratios of manure when applied to crop land (Erickson et al. 1999) are current challenges when DDGS are included in rations at levels before mentioned.

Canola screenings is another co-product commonly used as a supplement in cattle rations. Pylot et al. (1999), evaluated performance and rumen function of steers fed graded levels of canola screenings in combination with barley grain. Conclusions of this study were that addition of canola screenings improved apparent digestibility of DM, CP, and fatty acids. Moreover, it was reported that DM digestibility and DMI were not affected by feeding fat up to 10% of DM when canola screenings were processed (Pylot et al., 2000a). Canola screenings are a good source of both energy and protein for backgrounding cattle but lack sufficient energy for finishing cattle (Pylot et al. 2000b).

Mustafa et al. (1998) showed that peas are a very good source of soluble starch and protein, which results in rapid fermentation of both nutrients in the rumen. However, suboptimal rumen fermentation and reduced microbial protein synthesis are both associated with asynchrony of ruminal available energy and protein (Nocek and Russell, 1988; Casper et al., 1999). Pea and oat hulls trend to be high in fiber (Mustafa et al., 1998; Thompson et al., 2000). However, the availability of that fiber to rumen microbes differs between the two by-products with pea fiber being more degradable. Grain screenings are also good source of energy and protein leading to similar performance of backgrounding cattle relative to animals fed a barley-based ration when formulated to meet requirements for a targeted gain (Marx, 1999).

While these studies have been useful in categorizing and defining the nutritional value of each by-product studied, they failed to achieve optimal utilization of nutrients contained in each product. Currently, as a result of competitive pricing, many of these by-products are used as alternative energy and/or protein sources to cereal grains in cattle rations. However, their use is more a reflection of price rather than nutritional value. In such situations it is not unrealistic to over feed specific nutrients such as protein or phosphorus leading to potential environmental concerns.

This past research shows that no by-product by itself is the ultimate solution for use as a sole supplement for backgrounding or finishing cattle. Each by-product has shortfalls that could be improved by combining ingredients and manufacturing a blended feed that has targeted nutritional characteristics. Therefore, there is opportunity to strategically blend combinations of specific by-product feeds to develop feed products that are targeted at the specific needs of

different classes of beef cattle (i.e. backgrounding calves and finishing cattle). This can be accomplished by focusing on optimizing energy and protein available in rumen, improving fiber digestion, and/or increasing by-pass energy and/or protein in order to maximize metabolizable energy and protein supply.

The objective of the following literature review is to provide an overview of the literature on rumen digestive physiology and its microbial ecology and on the composition and feeding value of by-product feeds as well as their use as feedstuffs for ruminant animals.

2 LITERATURE REVIEW

2.1 Rumen Digestive Physiology and its Microbial Ecology

Ruminants are able to use fibrous feeds as sources of nutrients due to microbial fermentation which takes place in the reticulum rumen (McDonald et al., 2002).The microorganisms have a highly specified symbiotic relationship, amongst themselves and with the host (Church, 1988). The reticulum rumen forms a chamber that maintains an appropriate environment for anaerobic fermentation. The pH, moisture, ionic strength, and oxidative-reduction conditions in the reticulum rumen are maintained in a range compatible for the growth of suitable microbes (Cunningham, 1997).

The bacteria, protozoa and fungi responsible for fermentation consist of a vast variety of microbial species dispersed mainly in the rumen contents (fluid and solid fractions) (McAllister et al., 1990). The interplay among these microorganisms is extremely complex, with the waste products of one microbial species serving as substrate for another (Cunningham, 1997).The ruminal microbial population can be modified by several factors, one of the most important being diet formulation. In order to provide a ruminal environment that maximizes microbial protein synthesis and animal growth, balanced diets have to be fed that consider the requirements of both the animal and the ruminal microorganisms (Cunningham, 1997). The major end products of the fermentation of carbohydrate are volatile fatty acids (VFA) which consist mainly of acetic, propionic, and butyric acids (Cunningham, 1997). Branched chain VFA's (i.e. valerate, isobutyrate, and isovalerate) are primarily derived from fermentation of branched-chain AA (Allison, 1970). Volatile fatty acids are absorbed through the rumen wall into the blood stream and are transported to body tissues and are the major energy source for ruminants. Ruminants obtain 50 to 70 percent of their energy from the VFA produced in the rumen (Cunningham, 1997). It is important to bear in mind that the type of VFA produced in the rumen is directly associated with diet composition. For instance, high-forage diets result in an acetic/propionic/butyric acid concentration ratio of 70:20:10, while 60:30:10 is typically the VFA concentration ratio for animals eating high-grain diets (Cunningham, 1997). A large part of the dietary protein is also fermented in the rumen, which forces ruminant animals to depend on microbial protein to meet their own protein needs. Ruminants obtain 50 to 80 percent of their metabolizable protein requirements from microbial protein synthesis (Storm and Ørskov, 1983).

Rapid microbial growth and efficient protein utilization occur when energy and protein availability in the reticulum rumen are synchronized.

2.2 Ruminal Microbial Ecosystem

After feed is ingested and reaches the reticulum rumen, it is a short matter of time before feed particles are colonized by ruminal microorganisms (Craig et al., 1987). This process is suggested to occur within 5 min after feed reaches the rumen (Bonhomme, 1990). Czerkawski and Cheng (1988) divided ruminal microbes into three different populations based on their relative proximity to feed particles. A major distinction divides microbes loosely (liquid phase) and firmly (solid phase) attached to cell walls of feed particles (McAllister et al., 1990). Microbes found in the liquid phase rely on soluble carbohydrates and protein as nutrients. This group represents approximately 25 percent of the microbial mass and plays a crucial function in initiating the break down of cell walls of recently ingested feed (McAllister et al., 1990).

The microbes associated with the solid phase are attached to feed particles. They digest insoluble polysaccharides such as starch and fiber as well as less soluble protein. Several authors found higher endoglucanase, amylase, protease, hemicellulose and cellulase activities in these microbes relative to the microbial population in the rumen fluid (Minato et al. 1966; Brock et al. 1982; Williams and Strachan, 1981). Forsberg and Lam (1977) and Craig et al. (1987) observed that the rumen bacterial population attached to the feed particles explained 70 to 80% of the total microbial mass in the rumen and they are responsible for most of the fermentation activity in the rumen (McAllister et al., 1994). The third and last rumen bacteria population represents 5 percent of the microbes and are attached to the rumen epithelium or to protozoa (McAllister et al., 1994).

The physical link between bacteria and feed in the rumen is by a fibrous polysaccharide glycocalyx. This link serves two main functions: it acts as a canal to transport enzymes and substrate; and it serves as a protective film to stabilize and prevent enzymes from deactivation (Cheng et al., 1981; Lappin-Scott et al., 1992). Diet formulation has a large impact on the number and relative proportions of the different organisms found in the rumen. Special consideration is given when making changes in ruminant diets. Shifts from diets high in cell wall carbohydrate (forage) to diets high in readily fermentable carbohydrate (grains) have a dramatic influence on the microbial population due to changes in ruminal pH (Van Soest, 1994). For

instance, cellulolytic bacteria whose main substrate is fiber are most active at a pH of 6.2 to 6.8. Their numbers can be reduced when the pH drops below a threshold of 6.0 (Van Soest, 1994). Amylolytic bacteria on the other hand are capable of fermenting starch in a pH range of 5.0 to 7.0 (Van Soest, 1994). Under pH 5.5, protozoa are diminished in number. Thus, normal feeding practices should maintain a pH range between 5.8 and 6.4. Rumen pH is one of the most variable factors that influence the microbial population and therefore the levels of volatile fatty acids produced (Russell and Rychlik, 2001; Aschenbach et al., 2011).

2.2.1 The Microbes Responsible for Rumen Fermentation

2.2.1.1 The Bacteria

The bacterial population responsible for fermentation is vast. It has been reported that ruminal contents contains 10^9 to 10^{10} bacteria per ml (Hoover and Miller, 1991; McDonald et al., 2002). Most are obligate anaerobes, although facultative bacteria are present in the rumen as well (Hungate, 1966). Rumen bacteria are essential for the transformation of complex carbohydrates (CHO) into simple sugars, driving the process of fermentation and subsequently VFA production. To accomplish this task, fermentation end products of one microbial species are often used as a substrate for another species. A clear example of this synergism is Ruminococcus albus and Bacteroides ruminicola. R. albus has cellulotytic activity, being able to digest cellulose but it cannot digest protein (Qi et al., 2009). However, B. ruminicola is the opposite. When rumen environment conditions are suitable for growth of both species, R. albus provides the end products of cellulose digestion such as hexose which is used as an energy source for B. ruminicola. The former provides ammonia and branch-chain fatty acids to R. albus for protein synthesis (Qi et al., 2009). Bacteria can be classified according to their shape, size, and structure. They can also be grouped according to the type of substrate specificity fermented (Table 2.1). These bacteria are able to degrade and utilize a broad list of substrates such as cellulose, hemicellulose, starch, sugars, protein, and lipids. Usually, one species of bacteria is able to degrade and ferment more than one substrate.

Table 2.1: Grouping of rumen bacteria according to the type of substrate fermented.

Major Cellulolytic Species	**Major Lipid-utilizing Species**
Bacteroides succinogenes	Anaerovibrio lipolytica
Ruminococcus flavefaciens	Butyrivibrio fibrisolvens
Ruminococcus albus	Treponema bryantii
Butyrivibrio fibrisolvens	Eubacterium sp.
	Fusocillus sp.
Major Pectinolytic Species	Micrococcus sp.
Butyrivibrio fibrisolvens	
Bacteroides ruminicola	**Major Hemicellulolytic Species**
Lachnospira multiparus	Butyrivibrio fibrisolvens
Succinivibrio dextrinosolvens	Bacteroides ruminicola
Treponema bryantii	Ruminococcus sp.
Streptococcus bovis	
	Major Amylolytic Species
Major Ureolytic Species	Bacteroides amylophilus
Succinivibrio dextrinosolvens	Streptococcus bovis
Selenomonas sp.	Succinimonas amylolytica
Bacteroides ruminicola	Bacteroides ruminicola
Ruminococcus bromii	
Butyrivibrio sp.	**Major Methane-producing Species**
Treponema sp.	Methanobrevibacter ruminantium
	Methanobacterium formicicum
Major Sugar-utilizing Species	Methanomicrobium mobile
Treponema bryantii	
Lactobacillus vitulinus	**Major Acid-utilizing Species**
Lactobacillus ruminus	Megasphaera elsdenii
	Selenomonas ruminantium
Major Proteolytic Species	
Bacteroides amylophilus	**Major Ammonia-producing Species**
Bacteroides ruminicola	Bacteroides ruminicola
Butyrivibrio fibrisolvens	Megasphera elsdenii
Streptococcus bovis	Selenomonas ruminantium

Source: Church, D. C. ed. The Ruminant Animal: Digestive Physiology and Nutrition. Englewood Cliffs, N.J.: Prentice Hall, 1988.

2.2.1.2 The Protozoa

There is also a large population of protozoa present in the rumen fluid (10^5 to 10^6 per ml) (Hoover and Miller, 1991). Their numbers are influenced by feeding practices. Thus different types of diets seem to encourage different protozoal genera. Even though their numbers are smaller than that of bacteria, they can account for up to 50% of the total rumen microbial mass (McDonald et al., 2002). This is due to their relative larger size compared with bacteria. Over 25 genera and 100 species of protozoa have been identified (Qi et al., 2009). Protozoa are anaerobic and most of them are ciliated and can be grouped into the genus Isotricha or Entodinium (Hobson and Stewart, 1997; McDonald et al., 2002). Even though protozoa are found in the rumen fluid, they can also be found attached to feed particles. Protozoa engulf large numbers of rumen bacteria reducing their numbers (Hobson and Stewart, 1997). Ruminants can survive under complete defaunation (Hoover and Miller, 1991). Defaunation studies have shown both a positive and a negative role for rumen protozoa. On the one hand it is claimed that protozoa play a significant role in fiber digestion in the rumen accounting for up to one third of total fiber digestion (Qi et al., 2009). Another potential benefit of protozoa in the total ecological picture of the rumen is that they are capable of engulfing large particles of starch, storing them and thus protecting the starch particles from bacteria degradation (Hobson and Stewart, 1997). This may reduce the potential for acidosis on high grain diets. Thus, starch particles have different fates. They can be fermented by rumen bacteria, digested by protozoa, become available when protozoa die or be washed-out from rumen to the lower tract. Different from ruminal bacteria, ruminal protozoa require preformed amino acids since they are not able to utilize NH_3-N as a source of N for protein synthesis. Ruminal protozoa degrade dietary, bacteria and endogenous proteins elevating ruminal NH_3-N levels. Consequently, defaunation (i.e., removal of ruminal protozoa), is associated with lower ruminal NH_3-N levels (Jouany, 1996). Through this role, protozoa play a role in recycling N in the rumen. On the other hand, protozoa play a crucial role in methane production due to a symbiotic relationship between protozoa and ruminal methanogens. Protozoa produce hydrogen that methanogens need in order to reduce CO_2 to methane (Qi et al., 2009). For a numbers of years there has been an interest in developing technologies that can eliminate or alter the protozoa population with the intent of reducing methane production and/or improving ruminal protein metabolism.

2.2.1.3 The Fungi

Aerobic fungi have long been identified to be normal inhabitants of the rumen (Lund, 1974; Clarke and DiMenna, 1961). Orpin (1984) identified anaerobic fungi as common inhabitants of the rumen and stated their role in plant cell wall degradation. Today, six genera of ruminal fungi have been identified (Qi et al., 2009). Cellulases, hemicellulases, and xylanases are produced at high levels by rumen fungi (Akin and Rigsby, 1990). Anaerobic fungi are able to colonize and break down the lignin-containing plant tissues better than bacteria (Akin and Rigsby, 1990). For instance, a superior cellulose-digesting capacity of some fungi of the geneus *Neocallimastix* relative to cellulotytic bacteria like *F. succinogenes* and *R. flavefaciens* has been documented (Qi et al., 2009). However, when *R. flavefaciens* and *Neocallimastix* where grown in a mixed culture, an antagonist relationship was observed which affected cellulose-digesting capability (Qi et al., 2009). Other evidence supports the fact that rumen fungi have a greater capability to colonize lignin-containing tissues and to degrade cell wall components of plants (Bauchop, 1979). Thus, rumen fungi are found more often with forage than cereal grain based diets (Bauchop, 1981). It is believed that this ability to colonize lignin-containing tissue and to degrade the cell wall is due to fungi-produced rhizoids which allow fungi to penetrate highly lignified plant tissues (Qi et al., 2009). In addition, this activity allows other cellulolytic organisms to penetrate deeper into plant tissues. All of this activity makes rumen fungi interesting for a continuing research focus on maximizing the value of low quality fibrous feeds in ruminant diets.

2.3 Rumen Digestion and Nutrition

2.3.1 Carbohydrates

The major sources of carbohydrates (CHO) in ruminant diets are fibrous feeds which contain cellulose and hemicellulose and cereal grains rich in starch. These two types of CHO are referred to as structural and non-structural, respectively (Nocek and Russell, 1988; Van Soest, 1994). Regardless of their classification, carbohydrates are fermented in the reticulum rumen to release glucose. Glucose and other sugars are absorbed and metabolized by bacteria, generating energy for microbial growth and maintenance (Cunningham, 1997). The end-products of this metabolism are VFA, which once absorbed across the rumen wall provide up to 80% of the energy needed of by the animal (Ishler et al., 1996).

The structural CHO are one of the main constitutes of the cell wall that provide support for the plant. The cell-wall of plants consists of cellulose, hemicellulose, pectin, and lignin (Van Soest, 1994). Cellulose has a strength-giving role, whereas hemicellulose, pectin, and lignin cement the cellulose together. Except for lignin, all these cell-wall components are carbohydrates (Cunningham, 1997). Cellulose is composed of linear chains of glucose monomers joined by β1-4 glycosidic linkages (Van Soest, 1994). The importance of these structures resides in that mammals do not have the enzymatic system to hydrolyze this type of link (McDonald et al., 2002). Therefore, in order to digest cellulose, ruminants depend on microorganisms that reside in the rumen. Ruminal microbes hydrolyze cellulose through the cellulase enzymatic system (Cunningham, 1997). Hemicellulose, however, is a branched polymer of sugars. Different from cellulose, hemicellulose is a heterogeneous combination of glucose, xylans, glucans, mannans and arabinogalactans (Grenet and Besle, 1991). In addition, hemicellulose is closely associated with lignin; hence it is less soluble than celullose in the rumen (Van Soest, 1994). The non-carbohydrate polymer, lignin is indigestible and reduces cell-wall carbohydrate digestibility (Traxler et al., 1998). Therefore, this cell-wall component is the main limiting factor for the availability of plant cell-wall material for microbial digestion (Van Soest, 1994). Ruminal microorganisms that ferment structural CHO grow slowly and predominantly utilize ammonia as a N source for protein synthesis (Bach et al., 2005).

The non-structural carbohydrates are present in the seeds, leaves and stems, i.e. they are usually not included in the cell-wall matrix (Van Soest, 1994). Pectins, monosaccharides, disaccharides, olisaccharides and some polysaccharides belong to the water-soluble carbohydrate fraction (Allen, 1997). One of the most common non-structural CHO is starch, which represents 56 - 80% of grain weight (Huntington, 1997). Starch is a polysaccharide composed of amylose and amylopectin (Huntington, 1997). Amylose is a linear molecule of glucose joined by α1-4 glycosidic linkages. Amylopectin is a large, highly branched polymer of glucose. Glucose units are linked linearly with α1-4 glycosidic bonds (Van Soest, 1994). Branching takes place with α1-6 bonds. Both types of linkages are hydrolyzed by amylase enzymes that are present in both mammals and microbes (McDonald et al., 2002). Special mention is needed for corn and sorghum grains in which starch granules are embedded in a protein matrix that prevents bacteria from a rapid attachment and penetration (McAllister and Cheng, 1996). This may influence digestion rate of these cereal grains in the rumen (Okine and Kennelly, 1994). Consequently, any

disruption in the physical structure of either the outer layers or the protein matrix can affect microbial attachment and penetration (McAllister and Cheng, 1996) enhancing feed efficiency for a given feed (McAllister et al., 1994). However, rapid starch degradation represents a risk for rumen disturbances such as acidosis (Ørskov, 1986; McAllister and Cheng, 1996). Ruminal microorganisms that ferment starch grow rapidly and utilize either ammonia or amino acids as N sources for protein synthesis (Bach et al., 2005).

2.3.2 Protein

Metabolic activity of the three major groups of microorganisms in the rumen: bacteria, protozoa, and fungi are responsible for protein metabolism in the rumen (Bach et al., 2005). Ruminant N inputs can be divided into N in the diet, N recycled, and endogenous N (Church, 1988). NRC (2001) classifies dietary protein as rumen degradable protein (RDP), and rumen undegradable protein (RUP). Rumen-degradable protein provides most of the nitrogen needed for microbial protein synthesis. Nolan and Dobos (2005) and Bach et al. (2005) mentioned factors that could potentially affect ruminal protein degradation, the most important being protein solubility, availability of fermented CHO, and the rumen microbial population. Moreover, RDP can be classified as true protein and NPN (non-protein nitrogen). True protein is degraded to peptides and amino acids and eventually deaminated into ammonia or incorporated into microbial protein. Non-protein N used by microbes is N found in ammonia, amino acids, and small peptides (Bach et al., 2005). Ammonia serves as a N source for bacterial amino acid synthesis. It is estimated that approximately 80% of the rumen bacteria can grow with ammonia as their sole source of nitrogen (Bryant and Robinson, 1963). Excess ammonia is mostly absorbed from the rumen into the blood stream, but small amounts may pass into the lower digestive tract and are absorbed.

Fermentation of rumen available energy is crucial to couple uptake of ammonia by microbes to build microbial crude protein. Rumen protein metabolism can be divided in protein degradation and microbial protein synthesis (Bach et al., 2005). The goal is to maximize microbial protein synthesis and capture of RDP, leading to a decrease in N losses and an increase of essential amino acids to the lower gut of the host (Tamminga, 1996; Bach et al., 2005).

Nitrogen leaving the rumen (outputs) can be divided into ammonia-N, RUP, endogenous N, and microbial protein (Bach et al., 2005). The microbial protein that reaches the small intestine is the single major supply of amino acids to the host ruminant (Storm and Ørskov,

1983). It accounts for 50 to 100% of metabolizable protein requirements (Schwab, 1995; NRC, 1996). The amino acid composition of RUP reaching the lower tract, is similar to that of the original protein present in the diet (Nolan and Dobos, 2005). Its biological value depends on source of RUP (NRC, 2001). Protein absorbed across the small intestine is called metabolizable protein, and consists of microbial protein, absorbable RUP and endogenous protein (NRC, 1996, 2001). Fecal protein is that which is not digested (RUP and/or microbial protein) in the rumen and small intestine plus microbial protein synthesis and endogenous protein produced after this point (Nolan and Dobos, 2005).

2.3.3 Lipid

Plant lipids are classified as structural and storage lipids. Structural lipids are located in protective surface layers of leaves (waxes) or in membranes (phospholipids, glycolipids). Storage lipids however are mainly in seeds (triglycerides) (Tamminga, 1996). There are several lipid categories. One of the most fundamental of biological lipids is fatty acids that are used to build more structurally complex lipids. Fatty acids consist of carbon chains, typically between four and 24 carbons long (Hunt and Groff, 1990), and can be saturated or unsaturated. Although lipids are modified in the rumen, they provide little nutritional value to ruminal microorganisms (Harfoot, 1978). Moreover, around 87% of fatty acid intake is recovered at the duodenum suggesting that dietary fatty acids may be absorbed and metabolized to a limited extent by ruminal epithelial cells along with minimal fatty acid absorption into blood and degradation by microbes (Jenkins, 1993). However, through the *de-novo* lipid synthesis, ruminal microbes can cause a net gain of fatty acids across the rumen (Jenkins, 1994).

Ruminal lipid metabolism is a step-wise process involving hydrolysis and bio-hydrogenation. Hydrolysis is a required step for bio-hydrogenation of unsaturated fatty acids (Jenkins, 1994). It consists of breaking down lipids to release free fatty acids and glycerol (Harfoot and Hazlewood, 1988). Glycerol liberated during hydrolysis is rapidly fermented by bacteria to VFA (propionate and butyrate); while saturated free fatty acids undergo bio-hydrogenation.

The first step of bio-hydrogenation is an isomerization carried out by hydrogenases. This process allows the reduction of fatty acids according to different pathways described by Harfoot and Hazlewood (1988). The end product of bio-hydrogenation is stearic acid. However, when

large amounts of unsaturated fatty acids are available, bio-hydrogenation generally stops before this final step and intermediate isomers of those fatty acids (*cis* and *trans*) are found in the rumen fluid (Harfoot et al., 1973).

2.4 Synchronizing Protein and Energy Fermentation to Optimize Microbial Crude Protein Synthesis

Nitrogen in urine and feces can be seen as an indicator of inefficiency of N utilization (Castillo et al., 2001; Van Soest, 1994). Excess of nitrogen in ruminant diets is the main reason for losses of N in urine. It is also suggested that unbalanced amino acid supply and asynchrony between rates of release of carbohydrate and RDP in the rumen can led to N losses. Van Soest (1994) and Castillo (2001) stated that fecal N is relatively constant relative to DM intake (7.5 and 6 g N/kg DMI, respectively). Although the amount of fecal N can be modified to some extent, it is not a primary strategy to reduce N losses. Research has focused on reducing urinary N excretion (Castillo et al., 2001; Monteils et al., 2002) which at the same time may help to improve microbial protein synthesis and thereby animal performance.

Balancing the supply of fermentable carbohydrate with RDP in an appropriate ration and synchronising the rate of degradation of energy and protein in the rumen has been suggested as a mechanism for maximizing the capture of RDP and optimizing microbial growth rate and efficiency in ruminants (Sinclair et al., 1993). When rumen fermentation of energy and protein are synchronized, there is a coupling of energy (ATP) production with that of ammonia-N release (Bach et al., 2005). Under this condition, capture of ammonia-N in the rumen for microbial protein synthesis is increased, augmenting microbial protein outflow to the duodenum, and enhancing animal performance. However, when asynchrony between carbohydrate and protein degradation occurs, excess ammonia-N is absorbed through the rumen wall into the blood stream, and converted into urea in the liver as energy is lost as heat. Urea is then partially excreted as urinary-N, with the rest recycled to the rumen. Also, there can be a decrease in microbial protein reaching the small intestine (Nocek and Russell, 1988; Nocek, 1997).

In summary, N losses may be diminished by maximizing microbial protein synthesis and capture of RDP. In order to achieve this reduction, synchronization of the fermentation of energy and protein in the rumen is essential.

2.5 Cornell Net Carbohydrate and Protein System (CNCPS)

The Cornell Net Carbohydrate and Protein System (CNCPS; (Fox et al., 1992; Russell et al., 1992; O'Connor et al., 1993; Pitt et al., 1996; Fox et al., 2004) is a nutritional evaluation program developed to evaluate requirements, feed utilization, animal performance and nutrient excretion for ruminants based on research and knowledge on feed composition, feed digestion, feed passage and physiological status (Fox et al. 2004). The CNCPS is a combination of dynamic and static approaches to model both ruminal and whole-body metabolism in the animal. Several updates to the CNCPS have been published (Tylutki et al., 2008; Van Amburgh et al., 2008; Van Amburgh et al., 2009). The CNCPS model has different sub-models for maintenance, growth, lactation, rumen fermentation, nutrient excretion, etc. However, the rumen sub-model is one of the most dynamic parts of the CNCPS. Competition between rate of degradation and rate of passage of different fractions in feeds are crucial elements of this sub-model. As a consequence, the model predicts variable amounts of both carbohydrate and protein fractions degraded in the rumen.

Sniffen et al. (1992) described the original feed composition sub-model. Protein and carbohydrate pools were partitioned into fractions, each of them having a different rate of degradation. Protein was portioned into three fractions: PA, PB, PC. Non-protein nitrogen (PA), is buffer soluble protein consisting of ammonia, peptides and amino acids. True protein (PB) is divided into three sub-fractions based on inherent rate of degradation. The PB1 fraction is represented by buffer soluble protein which is rapidly degraded in the rumen (Kd = 120 - 400% h^{-1}) while the PB2 fraction is made up of protein not bound to NDF that is insoluble in buffer but soluble in neutral detergent solution. While some PB2 is intermediately fermented in the rumen (Kd = 3 - 16% h^{-1}), some escapes to the small intestine. PB3 consists of protein insoluble in neutral detergent but soluble in acid detergent solution. The PB3 fraction is associated with the cell wall, thus it is slowly degraded in the rumen (Kd = 0.06 - 0.55% h^{-1}) and part of it escapes to the small intestine. A major factor influencing the extent of rumen degradation of the PB2 and PB3 fractions is rumen particle passage rate. Unavailable protein (PC) represents protein insoluble in acid detergent solution and it is considered unavailable to the ruminant. PC is made up of protein associated with lignin, tannin-protein complexes, and Maillard products (Krishnamoorthy et al., 1982).

In the CNCPS, carbohydrate is divided into four fractions: CA, CB1, CB2, and CC. Fraction CA contains sugars and organic acids that are water soluble and rapidly fermented (Kd = 200 - 350% h^{-1}). Fraction CB1 consists of starch and pectins that are intermediately degraded in the rumen (Kd = 20 - 50% h^{-1}). Fraction CB2 represents fiber carbohydrates (FC) that are available and slowly degraded (Kd = 2 - 10% h^{-1}). Fraction CC is undegradable, and is associated with lignin and resistant starch.

2.6 Environmental Impact of Overfeeding Nitrogen in Feedlot Animals

Environment pollution due to nitrogen (N) and phosphorus (P) excretion from cattle generates a major concern in the public media. There is no question that overfeeding of N and P increases total excretion of these nutrients. Feedlots, where there is a high number of animals in a relative small area are one of the biggest concerns due to challenges in terms of manure management and ammonia volatilization. If proper manure handling is not practiced, overfeeding of nutrients can be a significant problem, particularly if nutrient levels accumulate in the soil and contaminate water sources through leaching or surface runoff.

In typical feedlot diets 80% to 90% of the total N intake is excreted (Satter et al., 2002). Depending on the nature of the diet, N excreted can be divided in fecal and urinary nitrogen. Urinary-N can account for almost 50 to 75% and fecal-N for 25 to 50% of total excreted N (Giger-Reverdin et al., 1991). Satter et al. (2002) cited that in common grain-based diets fed in the finishing period, urinary-N accounts for 75% or more of excreted N. However, special circumstances can modify the route of N excretion. When fermentable carbohydrates reach the lower tract, their fermentation causes a change in the route of excretion to 50% fecal-N and 50% urinary-N (Giger-Reverdin et al., 1991; Bierman et al., 1999).

Feeding nitrogen over an animal's requirement increases nitrogen excretion causing a potential increase in ammonia volatilization from manure (Spiehs et al., 2002) and a potential environmental problem and waste of nutrient. Contrary, decreasing N intake has also been shown to reduce volatilization of N emissions from manure (Korevaar, 1992). Also, volatilization of N deceases manure nutrient value relative to fertilizers (James et al., 1999). However, manure N is less susceptible to be volatilized (Satter et al., 2002). Thus, any management practice that can diminish urinary N would have more environmental impact. Thus, evidence has shown that lower CP level in the diet decreases fecal and urinary N excretion, but has a greater impact in

decreasing the urine N (Satter et al., 2002). It is worth noting that both reducing CP intake and synchronizing the fermentation of energy and protein in the rumen is crucial to reducing N excretion in ruminant animals.

This review of rumen microbial fermentation was provided to set the stage for the following discussion of by-products feeds. As indicated previously, the expansion of the value added processing of cereal grains and oil seeds has created a large supply of by-products at competitive prices. The inclusion of these by-products in ruminant diets is common. At the present, by-products are typically used in isolation as a replacement for cereal grains or forages, a practice which has been shown to be less than ideal in terms of optimizing their nutritional values. It is important to bear in mind that these by-products have unique nutritional characteristics that need to be considered when incorporating them in diets. A balanced diet would lead to improved animal performance, optimized nutrient utilization and a reduced environmental impact. Therefore, strategic blending of by-product feeds that vary in rumen available energy and protein content can be accomplished to meet metabolizable energy and protein requirements of cattle and minimize over feeding of nutrients such as protein. In order to develop strategically blended feed pellets it is imperative to know the advantages and limitations of each by-product. The following discussion reviews the literature on selected by-products available in western Canada.

2.7 Major by-products available, nutritional profiles and research in isolation.

2.7.1 Dried Distillers Grains with Solubles (DDGS)

Distillers grains (DG) are a by-product of the ethanol distillation process of cereal grains to produce ethanol. Cereal grains such as corn, sorghum (USA), and wheat (Canada), or a mixture of two or more grains may be used to produce ethanol (Stock et al., 1999). Briefly, the process involves grinding, cooking, liquefaction, saccharification and fermentation of the cereal grain used (Bothast and Schlicher, 2005). The end products of fuel ethanol production are alcohol, carbon dioxide and distillers grains (Spiehs et al., 2002). As a result of ethanol production, a variety of by-products are available for livestock feeding including wet DG, dry DG, thin stillage, condensed distillers solubles, wet DG with solubles and dry DG with solubles (Liu, 2011). Dried distillers grains with solubles (DDGS) are the most common form of DG available in North America. Dried distillers grains with solubles are dense and have high dry

matter content, facilitating transport ease and storage life relative to WDG or WDGS (Stock et al., 1999). In the United States and eastern Canada the ethanol industry relies on corn as feedstock due to supply, price and high ethanol yield versus other cereal grains. Wheat is an important crop in western Canada, where all new and existing grain ethanol plants use wheat as a feedstock (Liu, 2011). Livestock producers in western Canada have access to both corn and wheat as well as blended DDGS due to importation of USA DDGS to Canada.

There are two common types of DG. Wet distillers grains (WDGS) contain primarily unfermented grain residues (protein, fiber, fat and up to 70% moisture); while DDGS is WDGS that have been dried with the concentrated thin stillage to 10-12 per cent moisture. In this thesis, only DDGS will be reviewed.

Dry distiller grain with solubles has been used for animal feeding for over a century. The nutritional composition of DDGS reflects the nutrient content of the cereal grain fermented after removal of starch (Schingoethe, 2006). Chemical composition of corn, wheat and triticale DDGS relative to original grains is given in Table 2.2.

Table 2.2: Chemical composition of corn, wheat and triticale DDGS relative to original grains

	Corn		Wheat		Triticale	
Item	Grain[z]	DDGS[y]	Grain[z]	DDGS[w]	Grain[v]	DDGS[x]
DM (%)	90	88.9	90.2	93.8	90	89.3
Crude protein	9.8	31.8	14.2	39.3	17.6	30.7
Crude fat	4.1	13.7	2.34	5	1.7	5.4
Acid detergent fiber	3.3	11.5	4.2	11	8	13.7
Neutral detergent fiber	10.8	43.8	11.8	48.1	15	29.6
Starch	75	5.5	70	2	-	5.9
Calcium	0.03	0.07	0.05	0.18	0.06	0.07
Phosphorus	0.32	0.89	0.44	0.91	0.33	0.78

Data sourced from: [z] NRC, 1996; [y]Walter et al. 2010; [w]Nuez-Ortin and Yu 2009; [x]McKeown et al. 2009 and Wierenga et al. 2006; [v]Shaver, 2005.

Examining the chemical composition of DDGS, it is evident that relative to the original grain, the starch content is significantly reduced; while fiber, fat, protein, and mineral concentrations increase approximately three fold (Mustafa et al., 1998; Klopfenstein et al., 2008). Initially DDGS were used as a protein source for cattle (Klopfenstein et al. 1978), but

more recently they have also been used as an energy source for replacing corn or barley grain in ruminant diets (Ham et al., 1994; Gibb et al., 2008; McKinnon and Walker, 2008; Yang et al., 2012).

Fat is an important component of DDGS, as fat contributes significantly to the energy value of DDGS as lipids contain approximately 2.25 times more energy than carbohydrates (Van Soest, 1994). When comparing corn to wheat DDGS, corn DDGS has a higher fat level (10.9 ± 0.85) than wheat DDGS (4.6 ± 0.07) (Spiehs et al., 2002; Gibb et al., 2008). In contrast, wheat DDGS has a higher protein content than corn DDGS (31.8 vs. 39.3; (Nuez Ortín and Yu, 2009; Walter et al., 2010). Dry distillers grains with solubles are an excellent source of ruminally undegradable protein (RUP) and methionine (Firkins et al., 1985; Kleinschmit et al., 2007), but they are poor in lysine which may limit milk production (Kleinschmit et al., 2007). The amino acid composition of wheat grain and wheat DDGS is superior to that of corn and sorghum (Liu, 2011). Wheat DDGS has a higher lysine and lower RUP content than corn DDGS (Mustafa et al., 2000).

Fiber is the major constituent in DDGS, this fiber is readily digestible, but it may lack effective NDF due to small particle size (Beliveau and McKinnon, 2008). It has been reported that the peNDF of wheat DDGS is less than <10% (Beliveau and McKinnon, 2009), a value below the 22% effective fiber level recommended for dairy rations (Mertens, 1997). It has been reported that even though NDF (30.3 vs. 31.2%) does not vary much between wheat or corn DDGS, ADF values (21.2 vs. 14.6%) are notably higher for wheat than corn DDGS (Widyaratne and Zijlstra, 2007).

The mineral content of corn DDGS has been reported as highly variable (Spiehs et al., 2002). Generally, corn and wheat DDGS are low in Ca (0.06 and 0.15), but high in P (0.89 and 1.07) and S (0.51 and 0.48) (Spiehs et al., 2002; Gibb et al., 2008).

Lately, due to large supply and competitive pricing, DDGS have been used at higher inclusion rates as a replacement for grains in feedlot rations (Klopfenstein et al., 2008). When DDGS are fed at levels higher than 15% of the diet, this by-product serves as both a source of energy and protein (Klopfenstein et al., 2008). Several studies have been published regarding feeding value of corn, wheat and triticale DDGS (Ham et al., 1994; Buckner et al., 2007; Beliveau and McKinnon, 2008; Gibb et al., 2008; Beliveau and McKinnon, 2009; Leupp et al., 2009a; Leupp et al., 2009b; Spiehs and Varel, 2009; Walter et al., 2010; Wierenga et al., 2010).

The nutritional characteristics and feeding value of corn DDGS have been well documented (Klopfenstein et al., 2008; Schingoethe et al., 2009). Regarding corn DDGS, Ham et al. (1994) conducted a trial to assess the feeding value of corn DDGS relative to dry-rolled corn (control). They found that animals fed 40% corn DDGS gained faster and more efficiently (9.5%) than cattle fed the control diet, concluding that corn DDGS (1.87 Mcal Kg^{-1} DM) had 1.20 times more energy than corn grain. It was suggested that this was due to higher lipid, metabolizable protein, and fermentable fiber fractions (Larson et al., 1993; Ham et al., 1994). More recently, Bickner et al. (2007) reported a quadratic trend for final BW and ADG when cattle were fed increasing levels of corn DDGS up to 40%, in a corn-based finishing diet. Although there was no effect of increasing levels of DDGS on DMI and gain efficiency, the optimum G:F was observed with 20% inclusion. A meta-analysis carried out by Klopfenstein et al. (2007) would suggest that maximum ADG is reached with between 20 and 30% DDGS; and the highest G:F efficiency is achieved between 10 to 20% DDGS. This meta-analysis also produced clear evidence that corn DDGS has greater feeding value than dry rolled corn.

With regard to wheat DDGS McKinnon and Walker (2008) observed that ADG and gain efficiency were improved by replacing barley grain with wheat DDGS at levels up to 50% of DM in backgrounding diets. Moreover, Beliveau and McKinnon (2008) replaced barley grain in a finishing diet with wheat DDGS at levels up to 23% (DM basis) with no effects on animal performance, concluding that wheat DDGS would have similar NE_g values to barley grain. Another study was conducted to assess if wheat DDGS can be fed as a source of both energy and fiber in feedlot finishing diets. A control diet of 15% barley silage and 85% barley-based concentrate was compared with three diets formulated by gradually substituting barley grain and silage so that the final diet consisted of 65% barley-based concentrate, 35% wheat DDGS and no silage (Yang et al., 2012). Results showed that in spite of lower DMI observed when steers were fed increasing levels of wheat DDGS, barley grain and silage can be replaced by wheat DDGS without negatively affecting growth performance and carcass characteristics (Yang et al., 2012). Published data indicate that wheat DDGS can be included in finishing cattle diets in levels between 10 and 20% with equal energy value to that of barley grain (Beliveau and McKinnon, 2008; Gibb et al., 2008). Few studies have compared the feeding value of wheat and corn DDGS in parallel. Walter et al. (2010) reported lower NE_g for wheat DDGS than corn DDGS. These values reported that inclusion of 40% corn DDGS in a barley-based diet, resulted in a NE_g value

of 1.58 MCal kg^{-1}, while the inclusion of 40% wheat DDGS resulted in a NE_g value of 1.26 MCal kg^{-1} (Walter et al., 2010). Relative to corn DDGS, wheat DDGS has a lower lipid content, which is one of the factors that reduced its energy value (Al-Suwaiegh et al., 2002). In the work of Walter et al. (2010) gain:feed ratio and NE_g had a different response for the two DDGS. No difference in gain:feed and calculated NE_g of the diet was observed for wheat DDGS, however, both parameters improved when steers were fed increasing levels of corn DDGS. The authors concluded that both wheat and corn DDGS can be fed at levels up to 20% (DM basis) without negatively affecting performance, while corn DDGS could be fed at levels up to 40% (DM basis) resulting in enhanced performance.

Holtshausen et al. (2011) also evaluated performance, rumen fermentation and ruminal pH profile of backgrounding cattle fed corn silage in combination with barley grain, corn or wheat DDGS. Diets were composed of 55% corn silage, 5% supplement, and 40% barley grain or one of the two DDGS. Results showed that animals fed the corn or wheat DDGS diets had greater final BW than heifers fed the control diet. Heifers on the wheat or corn DDGS diets trended to have a greater ADG but significantly lower DMI compared with heifers on the barley grain diet. Gain to feed ratio was not different, even though numerically higher for DDGS diets than heifers fed the barley diet. Rumen fermentation parameters were not different for heifers fed the barley and wheat DDGS diets. Holtshausen et al. (2011) concluded that both types of DDGS can be fed as alternatives to barley grain in growing cattle fed a corn silage-based diet.

Although animal performance is equal or superior when barley grain is replaced by either wheat or corn DDGS (Walter et al., 2010; Holtshausen et al., 2011), their use can have environmental consequences. These authors compared the inclusion of either wheat or corn DDGS in finishing diets to evaluate total nitrogen and phosphorus excretion (Walter et al., 2011). It was found that graded levels of wheat or corn DDGS in finishing diets greatly increased urinary and fecal N and P excretion (Walter et al., 2011). In agreement with this finding, Brake et al. (2010) reported a greater urea excretion in urine and feces for corn DDGS than for steers fed a control diet.

A positive relationship between total N intake and endogenous urea-N production has been reported (Kennedy and Milligan, 1980). This result highlights the fact that overfeeding of N causes an increase in urinary N excretion (Hristov et al., 2011; Todd et al., 2006). This can result in higher ammonia (NH_3-N) emissions due to volatilization of urea (Todd et al., 2006). Other

issues associated with excretion of nitrogen and phosphorous from animal waste include run-off from manure and an increase in atmospheric fine particulate matter (Hristov et al., 2011). Also there is difficulty to manage the nitrogen:phosphorus ratio of manure in crop land (Erickson et al. 1998). Formulating diets targeted to specific CP requirements may help to reduce total endogenous urea-N production, plasma urea-N, and urinary urea-N excretion (Reynolds and Kristensen, 2008; Huntington et al., 2009) when high protein by-products such as DDGS are fed.

2.7.2 Canola Screenings / Fines

Canola is a significant oilseed crop in Canada with about 6.47 million hectares grown in 2011. Most of the canola is grown in the three prairie provinces of Saskatchewan, Manitoba, and Alberta (Statistics Canada, 2010). The average production since 2008 is 13.6 million tons, and the forecast production for 2012 is 15.4 million tonnes. About 45% of canola is processed in Canada with the majority crushed (Canola Council of Canada, 2012). Seed delivered to the extraction plant from the farm is graded following standards established by the Canadian Grain Commission. The protocol is based primarily on visual inspection for immature, damaged or heated seed, weed seeds and inert material, as well as moisture content. Prior to the oil extraction process, seeds are cleaned to remove plant stalks, grain seeds and other materials from the bulk of the seed. Aspiration, indent cleaning, sieving, or some combination is used in the cleaning process. Dockage ranges between 4% and 5% depending on the variety of the seed (Canola Council of Canada, 2012).

Canola screenings are derived from the cleaning of canola seed before crushing and oil extraction. The screened material not crushed is referred to as canola screenings. Beames et al. (1986) defined this by-product feed as a combination of chaff, grain, dust, cereal grains, and small canola and weed seeds.

Canola screenings are commonly classified as refuse screenings due to their high concentration of weed seeds, hulls, chaff and dust. However, industry commonly refers to canola screenings as "coarse screenings" or "fines" based on visual appraisal of canola and weed seed content (Pylot, 1999).

The physical and chemical composition of canola screenings has been reported to be highly variable (Keith and Bell, 1983; Beames et al., 1986; Stanford et al., 2000; Beames et al., 1986) as a consequence of cultivars grown, environment, harvesting methods, weed control, and

type of seed cleaning equipment (Pylot, 1999). Regarding physical composition, Stanford et al. (2000) reported that canola screenings consisted of 32.1% immature canola seed, 16.8% cracked canola seed, 15.1% coarse weed seeds, 15.0% chaff and dust, 11.1% whole canola seed, and 9.9% fine weed seeds (by weight). Previous data showed that canola screenings contain on average 25 - 55% canola (Bell and Shires, 1980; Beames et al., 1986), 17 - 38% weed seeds (Beames, 1986; Bell, 1980; Keith and Bell, 1983), and 15 - 46% inert material (Bell and Shires, 1980; Darroch et al., 1990). Chemical composition of canola screenings is reported in Table 2.3 (Adapted from: Stanford et al. 2000).

Table 2.3: Nutrient composition of canola screenings

Analysis (%, DM basis)	Range[1]	Mean (n=14) [1]
OM	85.7 – 92.1	89.0
CP	10.9 – 16.2	14.2
EE	5.2 – 11.6	8.40
NDF	36.9 – 47.5	41.7
ADF	22.7 – 33.3	28.8
Ash	NS	NS
Ca	0.90 – 1.22	1.07
P	0.33 – 0.53	0.41

[1]Adapted from: Stanford et al. 2000.

Pylot (1999) compared the chemical composition of canola fines and coarse fractions. Chemical differences between both fractions are due to canola fines consisting of small canola and weed seeds while the course fraction consists of more dust, chaff and large seeds (Pylot, 1999). The coarse fractions contain on average 31.4% less CP, 18% more NDF, 7% more ADF, 70% less EE, and 39% more ash. Table 2.4 shows the chemical composition of the coarse and fines fractions of canola dockage (Adapted from: Pylot 1999).

It is important to highlight that canola seed contains 40% EE, which consists of oleic (51%), linoleic (25%), and linolenic (14%) acids (Khorasani et al., 1991). The negative effect of dietary fat greater than 6% on fiber digestion (Moore et al., 1986) and feed intake (Zinn, 1988) may be minimized by feeding crushed full-fat canola seed (Murphy et al., 1987; Hussein et al., 1995) Pylot et al. (1999) compared nutrient availability in steers fed raw or processed canola screenings. Authors concluded that although DMI was depressed, digestibility of DM, CP and EE improved with grinding and pelleting of canola screenings.

Table 2.4: Chemical composition of the coarse and fines fraction of canola dockage (Adapted from: Pylot 1999)

% Nutrient (DM basis)	Coarse	Fines
CP	14.2	20.7
NDF	41.1	34.9
ADF	24.6	23.0
EE	7.1	23.4
Ash	8.5	6.1

Adapted from: Pylot 1999

Few studies have been conducted to assess the feeding value of canola screenings for ruminants (Tait et al., 1986; Wiesen et al., 1990; Pylot et al., 2000a). Canola screenings have similar CP, DM, and OM digestibility compared to mixed feed oats (Tait et al. 1986). In addition it has been suggested that a high level of inclusion of this by-product feed (>30% DM basis) may have negative effects on feed intake due to the level of fat in the total diet (Beames et al., 1986). Fat levels greater than 6% of DM have a negative effect on DMI (Zinn, 1988) and fiber digestion (Moore et al., 1986; Zinn and Plascencia, 1996). Weisen et al. (1990) fed rapeseed screenings in diets for lactating cows at levels of 0, 7, and 14% of diet DM with no effects of treatment on milk yield or DMI. Ether extract levels ranged from 3.1% to 5.4% and were below thresholds previously reported by Zinn et al. (1988) to cause detrimental effects.

Pylot et al. (2000a) evaluated animal performance and rumen function of growing steers fed graded levels of canola screenings (ground and pelleted) in combination with barley grain. Feeding diets with 6.7, 10, 12.8 and 16.2% fat resulted in a quadratic decrease in DMI (kg d^{-1}). Results of this study showed that DM digestibility and DMI were not affected by feeding fat up to 10% of DM when canola screenings were processed and that addition of canola screenings improved apparent digestibility of DM, CP, and fatty acids (Pylot, 2000a). These results challenged previous data that had shown a negative effect of dietary fat on DMI (Zinn, 1988) and fiber digestion (Moore et al., 1986; Zinn and Plascencia, 1996) when levels were greater than 6% of DM.

Canola screenings also have the potential to serve as a fiber and energy source for growing and finishing cattle (Pylot et al, 2000b). Using different ratios (100:0; 75:25; 50:50; 25:75) of canola screenings to barley in a finishing barley-based diet, Pylot et al. (2000b) showed that DMI was not different among diets. Moreover, feed efficiency (G:F) and ADG responded linearly and negatively to increased levels of canola screenings. These authors conducted a

metabolism trial using the same diets fed in the finishing trial, and observed that barley-based diets provided more rapidly fermented carbohydrates than screening-based diets, leading to a higher production of total VFA, propionate and decreased ruminal pH (Pylot et al., 2000b). Increasing rapidly fermented carbohydrate has been shown to reduce rumen pH and decrease A:P ration (Kaufmann et al., 1980; McAllister et al., 1990; Hatfield et al., 1997). Thus, canola screenings are a good source of energy, mainly as fat, but their lack of fermentable carbohydrate for propionate production could lead to poorer performance in finishing animals (Jenkins and Thonney, 1988). Pylot et al. (2000b) also showed that ruminal NH_3-N increased linearly as canola screenings replaced barley. In agreement with Deacon et al. (1988) and Wang et al. (1997), Pylot et al. (2000b) concluded that the higher NH_3-N concentration in canola screening-based diets is in part due to rapid degradability of protein. In addition, lack of readily fermentable carbohydrate may lead to wastage of this ammonia in the rumen.

In summary, canola seed and canola screenings are both valuable sources of protein and energy for finishing cattle. In addition, the wide availability of this by-product in Canada makes it even more attractive for producers. However, suboptimal rumen fermentation can lead to reduced microbial protein synthesis due to asynchrony of energy and protein availability in the rumen (Nocek and Russell, 1988). Balancing diets for rumen available energy and protein when feeding canola screenings may reduce total N excretion, with more impact on reducing urinary N, and may improve performance.

2.7.3 Cereal Grain Screenings

Grain screenings are a by-product of the process of cleaning grain for export or use in specialized markets within Canada. At 2.5 to 3.5% dockage, 800 to 1,000 thousand tonnes of screenings are removed annually from grain in Canada (Chow and Lapka, 1975; Harrold and Nalejawa, 1977). Cereal grain screenings are defined as any material present in a parcel of grain, other than kernels of that grade Class III or better (The Grain Act, Government of Canada). Cereal grain screenings are classified in the following four categories: No.1 and 2 feed screenings, unclean screenings, and refuse screenings. The criteria for this classification are based on their content of original grain, broken or shrunken grains, hulls, weed seeds, and dust (Canadian Grain Commission 1996).

As a consequence of the variable amount of weed seeds, hulls, and dust present in grain screenings, unprocessed screenings are difficult to handle. In addition, they can potentially spread weed seeds (Janzen, 1995). Pelleting has been shown to be a viable alternative to minimize these issues. Moreover, in order to get the most of their nutritional value, screenings need to be processed by grinding, rolling or pelleting. The effect of processing has been evaluated by Tait et al. (1986) who fed steers to compare refuse screenings unpelleted vs. pelleted. In this study, the digestibility of OM, CP, and gross energy were greater for pelleted than unpelleted screenings. However, apparent digestibility of ADF and NDF did not differ between pelleted and unpelleted screenings. Similarly, Janzen (1995) reported that OM, CP and gross energy digestibilities of pelleted refuse screenings were greater than unpelleted refuse screenings fed to sheep. Although in this study pelleting did not affect NDF digestibility, apparent digestibility of ADF was decreased. In addition, Janzen (1995) conducted an *in vitro* organic matter digestibility trial to compare untreated vs. pelleted screenings, concluding that pelleting increases OMD due to disruption of seed coat from grinding and steam pelleting.

The physical and chemical composition of grain screenings has been reported to be highly variable (Beames et al., 1986). Regarding physical composition Beames et al. (1986) reported that No 1 feed screenings consisted of 52 - 70% grain, 19 - 39% weed seeds, and 0.6 - 3.5% chaff and dust (by weight). These authors reported that uncleaned screenings contain 35 - 85% grain, 5 - 39% weed seeds, and 0 - 8% chaff and dust. Refused screenings were reported to be in the range of 1 - 22% grain, 0.2 - 17% weed seeds, and 35 - 67% chaff and dust (Beames et al., 1986).

Regarding chemical composition, grain screenings are a good source of crude protein containing between 11.7 to 17.1% CP (Beames et al., 1986; Janzen, 1995). Energy, starch and sugar levels are reduced relative to the original cereal grain; while fiber and oil are increased (Belyea et al., 1989). Reported values for ADF range between 18.6 - 28.8% for pelleted and 29.8 - 33.0% for untreated refuse screenings (Beames, 1986; Janzen, 1995). Moreover, Beames et al. (1986) reported a higher level of EE in refuse (5.4%) and No 1 feed screenings (3.1%) compared to barley grain (1.9%). A more recent study conducted by Marx et al. (2000) compared the nutrient composition of barley grain and grain screenings (Table 2.5).

Table 2.5: Nutrient composition of Barley grain and grain screenings

Nutrient (% DM basis)	Barley	Grain screenings
CP	13.1	15.1
ADF	5.7	20.9
NDF	22.7	33.7
Starch	57.3	26.2
Fat	2.4	9.9
Ash	2.2	7.0
TDN	83	75

Adapted from Marx et al. (2000)

Marx et al. (2000) conducted an in situ nylon bag trial to measure rumen degradability characteristics of grain screening pellets compared to barley grain. They showed that effective ruminal degradability as well as degradation rate of DM, CP, NDF and starch were higher for barley grain (Marx et al., 2000). Although grain screenings had lower ruminal degradability of starch than barley grain, they are still highly fermented feeds (93.2 vs. 97.3%). Therefore, their inclusion in diets can result in rumen disturbances such as bloat and acidosis (Owens et al., 1998). Conversely, Marx et al. (2000) concluded that the risk to acidosis using grain screening pellets is lower than when using barley grain, due to the lower starch content.

Few studies have been conducted to evaluate the nutrient utilization of grain screenings for ruminants. Marx et al. (2000) formulated seven diets with different levels of a grain screening pellet, and thin or regular barley at ratios of 100:0; 75:25; 50:50: 25:75 to determine VI and total tract nutrient digestibility coefficients. Results showed that DMI of sheep fed grain screening pellets decreased linearly as the substitution rate for regular and thin barley grain increased in the diets. The likely reason for this relationship is the high starch and low fiber content of barley grain compared to grain screening pellets (Marx et al., 2000). As well, the total tract digestibilities of DM, NDF, and GE decreased as the level of grain screening pellets increased (Marx et al. 2000). Total tract digestibility of DE decreased linearly only when grain screenings pellets replaced regular barley.

Marx et al. (2000) conducted a trial to evaluate the growth of cattle fed barley grain and/or grain screening-based backgrounding diets. Animals were fed a control diet consisted of 41% barley concentrate mixture, 35% barley silage, 13% brome hay and 11% straw and a experimental diet consisted of 60% grain screening pellets, 25% barley concentrate, 7% brome

hay and 8% barley straw. Both diets were formulated to 67% TDN and 12.5% CP. Results showed no significant differences in DMI or ADG between treatments. However, cattle fed the grain screening-based diet were more efficient. A second trial to assess the feeding value of grain screenings in backgrounding diets showed calves fed grain screening performed better.

Grain screenings have the potential to serve as a valuable source of energy and protein. In addition, the wide availability of this by-product in Canada makes it even more attractive for producers. However, one of the major disadvantages associated with the use of cereal grain screenings includes chemical and physical inconsistency between batches; usually high in fiber and ash content; and possible high weed-seed contamination. Also, the lower DE content of grain screenings pellets has to be considered as it can impair performance compared to barley grain (Marx et al., 2000). Nevertheless, cereal grain screenings have been used by cattle producers as a substitute for cereal grains.

2.7.4 Oat Hulls

Oat hulls are a by-product of the oat processing industry in western Canada. The hull represents up to 25% of the oat seed (Crosbie et al., 1985). This by-product is high in fiber (46.4% ADF and 85.3% NDF) and low in crude protein (2.9%). The hull typically contains 5.8% acid-detergent lignin, a chemical constituent that is negatively related to digestibility (Thompson et al., 2000).

Oat hulls are classified as a low-quality forage, due to their poor nutritive value. Ruminants are capable of digesting high fiber feeds (Van Soest, 1994). However, high-lignin ingredients are less digested due to their lignin content that impedes bacteria access to cellulose and hemicellulose (Gabrielsen et al., 1990). In an attempt to minimize the negative effect of the high-lignin content of oat hulls, Rowe and Crosbie (1988) compared a novel low-lignin hull cultivar with a traditional oat cultivar in oat-based cattle diets and showed that improvements in apparent digestibility of OM, NDF, ADF are potentially achievable in diets containing the novel low-lignin hull variety.

Thompson et al. (2000) reported differences in chemical composition and feeding value of hulls from 10 western Canadian oat varieties. Varieties used in this study were Calibre, Derby, Triple Crown, AC Assiniboia, AC Juniper, AC Medallion, AC Mustang, AC Preakness, CDC Boyer and CDC Pacer. Interestly, results showed that there are large differences among varieties.

For instance AC Assiniboia oat has a much lower ADL content (80%) than the other varieties (1.3% vs. 5.5 - 7.7%). In vitro DM digestibility of hulls derived from the AC Assiniboia oat variety (68.2%) was almost double that of the rest (33.1 - 43.3%).

Several studies have been performed to evaluate the feeding value of oat hulls (Hsu et al., 1987; Round, 1988; Birkelo and Lounsbery, 1991; Thompson et al., 2000; Yu et al., 2005). An initial study by Birkelo and Lounsbery, (1991) showed that unground oat hulls can replace ground alfalfa hay (8% of the DM) as a source of roughage in finishing diets without affecting final body weight, ADG, DMI, or feed efficiency. This study also concluded that using oat hulls reduces total feed costs. Currently the price of alfalfa is even higher; thus one would expect to see a larger difference in the cost of feed. Consequently, oat hulls are an alternative source of roughage and can be used to reduce the cost of feed.

Birkelo and Ropp, (1995) showed that feeding ammoniated oat hulls resulted in higher ADG than medium quality alfalfa hay. Thompson et al. (2001) evaluated performance of steers fed diets composed of barley silage or barley silage plus ammoniated or untreated oat hulls (50% on DM basis). Daily gain was highest for steers fed the ammoniated oat hull diets, intermediate in those animals fed the control diet, and the lowest for those fed the untreated diet. Moreover, in the same study feed efficiency was superior in those animals fed the control and ammoniated oat hull diets.

In summary, current data suggest that the use of oat hulls may potentially reduce feed cost, but inclusion rates need to be evaluated in concordance with other feed ingredients to avoid detrimental effects on performance.

2.7.5 Wheat Middlings

Canada produces approximately 22 to 24 million tonnes of wheat per year with the majority coming from Saskatchewan. Of the total wheat crop 14 to 17 million tonnes are exported, 2.6 to 2.9 million tonnes are used for food domestically, 3.6 million tonnes for feed and dockage with carryover of 4 to 5 million tonnes (Canada Grains Council 2007). One of the by-products from the wheat processing industry (milling durum for semolina or wheat for flour) is wheat middlings. This by-product has the potential to reduce livestock feeding costs. Wheat middlings generally include coarse and fine particles of bran, shorts, germ, flour remnants, and the waste from the milling process "from the tail of the mill" (ZoBell et al., 2003; Dhuyvetter et

al., 2010). Generally, feed, livestock, and milling industries refer to this by-product as wheat midds or middlings. Wheat middlings have been fed to livestock species such as swine (Kim and Lei, 2005), poultry (Audren, 2002), and dairy and beef cattle (Dalke et al., 1997; ZoBell et al., 2003 and 2005; Bargo et al., 2006).

Wheat middlings contain higher levels of fiber, protein, and minerals than the parent grain with reduced amounts of starch and energy. Although high fiber levels are typically associated with low energy values, the fiber in wheat middlings is highly digestible by ruminants (Dhuyvetter et al., 2010). However, since the particle size of the fiber is extremely small, the fiber in wheat middlings is less effective in rumen stimulation and buffering as compared to long fiber from forages (Dhuyvetter et al., 2010). Its nutrient composition is variable depending on wheat type (Cromwell et al., 2000), but wheat midds are high in macro and microminerals and a particularly good source of phosphorous and potassium than whole wheat grain (Kunkle et al., 2000).

Wheat middlings are characterized to contain 89% DM, 35% NDF, 36.5% starch, 83% TDN, 1.37 NE_g, 18.45 CP, 77.2 RDP, 3.2% EE, 0.15% Ca, 1.00% P (NRC, 1996). Wheat middlings have crude protein levels intermediate between most feed grains and high protein oil seed meal by-products. Moreover, the protein in wheat middlings is mainly degraded in the rumen. The gross nutrient profile of wheat middlings indicates that it has a feeding value similar to that of cereal grains (with the exception of high fiber), and therefore may be used either in whole or part to replace the grain component in ruminant rations (ZoBell et al., 2003; Dhuyvetter et al., 2010). Wheat middlings have also been used as energy or protein source in ruminant diets and it was shown to be an effective substitute for cereal grains resulting in similar production and growth (Heldt et al., 1999; ZoBell et al., 2003; Holtshausen et al., 2011;Heldt et al., 1999).

ZoBell et al. (2003) conducted two studies to evaluate the value of wheat middlings relative to barley grain in beef cattle diets with varying concentrate to roughage levels. In the first study steers were fed corn silage-alfalfa hay-based growing diets where the concentrate source (35% of the DM) was either barley grain (control) or wheat middlings, while in the second trial steers were fed a corn-based finishing diet replacing either 35% or 50% of the corn with wheat middlings. Result from both trials showed that all performance parameters and carcass characteristics measured were not affected by treatment. These authors also conducted a metabolic trial to assess rumen fermentation characteristics of steers fed a control corn-based

finishing diet, where corn was replaced by wheat middlings at 50% of DM. Total VFAs increased and acetate reduced in those animals fed wheat middlings. Also, pH levels were reduced when corn was replaced by wheat middlings (5.81 vs. 5.55, respectively). Dry matter and ADF digestibilities were not affected by feed treatment.

Contrary to this study, gain:feed ratio trended to be lower when corn was replaced by wheat middlings (53% of diet DM) in steers fed a growing diet composed of 52% concentrate, 40% alfalfa hay, and 8% supplement (Drouillard et al., 1999).

Similarly, Blasi et al. (1998) conducted a study to evaluate growth performance of beef heifers fed wheat middlings in a sorghum silage-based ration (40% of DM). Diets were formulated without wheat middlings (46.6 dry rolled corn, 10.8 soybean meal plus 2.6 supplement) or with wheat middlings replacing 33, 67, or 100% of corn plus soybean meal. Results showed that ADG decreased linearly when heifers were fed increasing concentrations of wheat middlings (16 to 52% of diet DM) because of lower feed intake, but feed efficiency was not affected (Blasi et al., 1998).

Another study was conducted to assess the feeding value of pelleted wheat middlings as a replacement for either the concentrate or roughage components of finishing diets of steers (Dalke et al., 1997). Steers were fed a corn-based finishing diet in which pelleted wheat middlings replaced 15% of the dry-rolled corn or up to 10% of the alfalfa hay. Replacing corn with pelleted wheat middlings, DMI increased linearly, and G:F decreased linearly, while replacing alfalfa hay by pelleted wheat middlings decreased DMI, but G:F efficiency was not affected. Daily gain and final weight of the steers were not influenced by wheat middlings replacement of corn or alfalfa hay. In this study DM, OM, and starch digestibilities decreased by increasing replacement of corn with wheat middlings, and replacing ALF increased DM and OM digestibilities linearly.

From this research it can be concluded that wheat middlings can be fed to growing cattle as an alternative to more traditional concentrate sources such as corn or barley. However, reductions in ADG and G:F in finishing cattle need to be considered.

2.8 Summary

In conclusion, by-product feeds available in western Canada include several feedstuffs whose nutrient content varies widely due to either their inherent nature or effects of industrial processing. Their unique nutrient content and availability make many of these by-products

attractive feed sources for cattle producers. With respect to by-products, recent literature has documented the feeding value of these by-products in finishing and backgrounding cattle (Pylot, 1999; Marx et al., 2000; Thompson et al., 2000; ZoBell et al., 2003; Walter et al., 2010). However, it has also been shown that no by-product by itself is the ultimate solution for use as a sole supplement for backgrounding or finishing cattle as these by-products have limitations such as excessive content of either fiber or fat, and they may represent an environmental threat as a consequence of high N and P content. Each by-product has shortfalls that could be improved by combining ingredients and manufacturing a blended feed that has targeted nutritional characteristics. However, no research has been conducted to evaluate the feeding value and nutrient digestibility of blended by-product feeds in beef cattle. Therefore, there is a promising opportunity to strategically blend combinations of specific by-product feeds to develop feed products that are targeted at the specific needs of different classes of beef cattle.

Ruminants are able to use a variety of by-product feeds as sources of nutrients due to a highly specified symbiotic relationship, amongst rumen microbes and with the host (Church, 1988). Rumen microorganisms are responsible for fermentation of carbohydrate, protein and fiber that results in production of energy or VFA and microbial protein that are utilized by the host. Amino acids supply in ruminants relies upon microbial crude protein synthesized in the rumen, RUP and endogenous protein. Balancing the supply of fermentable carbohydrate with RDP in an appropriate ration and synchronising the rate of degradation of energy and protein in the rumen have been suggested as a mechanism for maximizing the capture of RDP and optimizing microbial growth rate and efficiency in ruminants. Moreover, N losses may be diminished by maximizing microbial protein synthesis and capture of RDP.

In order to maximize metabolizable energy and protein supply, and thereby improve animal performance, it is imperative to focus on optimizing energy and protein available in rumen, improving fiber digestion, and/or increasing by pass energy and protein. It is therefore important to investigate the feeding value (animal performance, rumen fermentation and digestibility) of blended by-product feeds for beef cattle.

The hypothesis of the research conducted in this thesis was that strategic blending of by-product feeds that vary in rumen available energy and protein content can be accomplished to meet metabolizable energy and protein requirements of growing cattle and minimize over feeding of nutrients such as protein and phosphorus. The objectives of the studies that follow

were to compare the feeding value of a barley-based diet with diets supplemented with strategically blended by-product feeds that vary in rumen available energy (Starch vs. Fat) and soluble protein content (High vs. Low) on 1) animal performance, 2) ultrasound carcass traits, 3) diet digestibility and dry matter intake and 4) rumen fermentation.

3 PERFORMANCE OF GROWING CATTLE FED DIETS BASED ON BLENDED BY-PRODUCT PELLETS VARYING IN RUMEN AVAILABLE ENERGY AND PROTEIN

3.1 Introduction

Environmental concerns and government regulations are forcing beef producers to focus on more productive, profitable and sustainable management systems. Expansion of value-added processing of the cereal and oil seed industries in western Canada has created a large supply of by-product feeds at competitive prices. These include dried distillers grains with solubles (DDGS) from the ethanol industry, canola meal from canola crushing industry, oat hulls from oat processing industries, and grain and oil seed screenings from industrial processing of crops. These by-products have unique nutritional characteristics particularly in terms of minerals, rumen available energy and/or protein content, either as a result of their inherent nature or due to industrial processing (Marx et al., 2000; Pylot et al., 2000a; Thompson, 2001; Nuez-Ortín, 2010). The unique nutrient content and their commercial availability make these by-products attractive feed sources for cattle producers. However, several questions remain unanswered regarding their feeding value. Currently, many of the by-products have been studied individually and their nutritional value is known. Examples include canola screenings (Pylot, 1999), wheat DDGS (Beliveau and McKinnon, 2008), grain screenings (Marx et al., 2000), peas (Mustafa et al., 1998), oat hulls (Thompson, 2001), and wheat and corn DDGS (Nuez-Ortín, 2010; Walter et al., 2010). While these studies have been useful in categorizing and defining the nutritional value of each by-product studied, they failed to achieve optimal utilization of nutrients contained in each product.

For example, Walter et al. (2010 and 2011) showed that although performance of finishing cattle was improved when wheat and corn DDGS were included in the diet at levels up to 40% of DM, there was a significant increase in N and P excretion in the urine and manure, respectively. Similar results regarding N and P excretion of DDGS fed cattle were shown by Spiehs and Varel (2009). Likewise, McKinnon and Walker (2008) concluded that ADG and gain efficiency were improved by replacing barley grain with wheat DDGS at levels up to 50% of DM in backgrounding diets. However, the dietary CP level reached 21% on a DM basis, a value that would greatly exceed the animals' requirements. Overfeeding of N above that required for growth results in an increase in urinary N excretion (Hristov et al., 2011). Therefore,

environmental issues associated with high levels of nitrogen and phosphorous excreted in the feces and urine when DDGS are included in rations have to be considered in manure management programs.

Canola screenings are another by-product available in western Canada. Pylot et al. (2000a) reported that addition of canola screenings to a barley-based diet improved apparent digestibility of DM, CP, and fatty acids. Moreover, they showed that DM digestibility and DMI were not affected by adding fat from canola screenings at levels up to 10% of DM when the canola screenings were processed (Pylot et al. 2000a). Also, canola screenings are a good source of both energy and protein for backgrounding cattle but lack sufficient energy for finishing cattle (Pylot et al. 2000b).Other by-products include peas and oat hulls. Mustafa et al. (1998) showed that peas are a good source of soluble starch and protein, and as a result are rapidly fermented in the rumen. However, uncoupled rumen fermentation and therefore less microbial protein synthesis can result when rumen fermentation of starch and protein are asynchronous (Nocek and Russell, 1988; Casper et al., 1999). With respect to fibre content and availability, pea and oat hulls have been studied (Thompson, 2001; Soto-Navarro et al., 2004). The main difference between the two by-products is the availability of fibre to rumen microbes.

The above studies indicate that by-product feeds have been extensively studied and used by industry. Although their individual advantages and disadvantages are known, this research reveals that no by-product by itself possess an ideal nutritional content for use as a supplement for backgrounding or finishing cattle. Moreover, nutritional shortfalls in specific by-product feeds may be improved by combining ingredients and manufacturing a blended feed that has targeted nutritional characteristics. Such blended feeds could target specific needs of different classes of beef cattle. This can be accomplished by focusing on optimizing energy and protein availability in the rumen, improving fiber digestion, and/or increasing by-pass energy and protein in order to maximize metabolizable energy and protein supply. However, there is limited information about the feeding value of these by-products in growing - finishing diets when they are strategically blended and pelleted. The objective of this research was to compare the feeding value of a barley-based diet with diets supplemented with strategically blended by-product feeds that vary in rumen available energy (Starch vs. Fat) and soluble protein content (High vs. Low) on performance of growing beef cattle.

3.2 Material and Methods

3.2.1 Animals, Housing and Experimental Design

In Trial 1, three hundred cross-bred steers (320 ± 21.6 kg; mean ± SD) were purchased in December, 2010 and housed at the Beef Cattle Research Station at the University of Saskatchewan. Steers were treated with long-acting oxytetracycline (Liquamycin LA-200; Pfizer Canada Animal Health Group) and for both external and internal parasites with Bimectin®. Also, steers were treated with Covexin 8™ (Schering-Plough, Kirkland, QC) to prevent clostridial infections and with Biostar, Starvac 4 Plus™ (Novartis, Mississauga, Ontario) for infectious bovine rhinotracheitis, bovine viral diarrhea (types 1 and 2), Parainfluenza type 3 virus, and bovine respiratory syncytial virus. Somnu-Star PH™ (Novartis, Mississauga, ON) was used to prevent Pasteurella haemolytica and Histophilus somni. All cattle received an implant with Synovex - S upon arrival. All cattle were housed in pens (12 x 24 m) with 3.3 m-high windbreak (20 cm m^{-1} porosity) fencing. After a 21 d acclimation period, the cattle were sorted by weight and were randomly assigned within each weight class to one of 25 pens (n=5 pens $diet^{-1}$). The trial was designed as a randomized complete block design (RCBD). Cattle were fed a receiving diet for 21 days that consisted of 27.9% barley silage, 27.1% hay, 37.4% barley grain, and 7.6% supplement (DM Basis) and had free access to water through the entire trial. Diets were formulated to allow 1.35 kg d^{-1} daily gain. Trial 2 used 180 cross-bred steers (326 ± 20.3 kg). The cattle were acquired in April, 2011 and shipped to the Beef Cattle Research Station at the University of Saskatchewan. During pre-trial processing, steers were treated for both external and internal parasites with Bimectin® and received a clostridial vaccine (Ultrabac 7/Somnubac (Pfizer Animal Health, Kirkland, QC). Also, the steers were treated with Bovashield Gold 5 (Pfizer Animal Health) to prevent infectious bovine rhinotracheitis, bovine viral diarrhea (types 1 and 2), Parainfluenza type 3 virus, and bovine respiratory syncytial virus. All cattle received an implant Component-ES with Tylan (Elanco Animal Health, Inc.). Steers were randomly assigned to one of 15 pens with each pen randomly assigned to one of three treatments in a completely randomized design (CRD). Cattle were fed the same receiving diet as in Trial 1 for 21 days. Diets were formulated to target 1.30 kg d^{-1} gain. Both trials were designed to last 70 days. Cattle were cared for following the guidelines set out by the Canadian Council on Animal Care (CCAC 1993).

3.2.2 Dietary Treatments and Composition

Samples of specific by-products from the crop and oil seed processing sectors including wheat DDGS (n=8), oat hulls (n=8), grain screenings (n=10); canola screenings (n=6); pea screenings (n=10), and wheat midds (n=9) were collected over the period 2009 to 2010 by West Central Pelleting Ltd. Wilkie, SK and chemically characterized using the Cornell Net Carbohydrate and Protein System (CNCPS; Sniffen et al. 1992). Analysis was carried out by Cumberland Valley Analytical Service. Results are presented in Appendix A. The results were used to develop blended feed pellets (BP) that have unique energy and protein combinations designed to manipulate site of digestion in growing cattle. Blended feed pellets were designed using a least cost ration program (General System Inc. Version 1.41). The four BP were formulated to vary in rumen available energy and protein content by manipulating ingredient make-up. Blended feed pellets were formulated to be high in starch (HS) (45% DM Basis) or fat (HF) (8.8% DM Basis) and to vary in soluble protein (HSP 37% vs. LSP 27% of CP) content. All BP were formulated to be isonitrogenous (17.0% CP) and isocaloric (1.92 and 1.28 Mcal NE_m and NE_g Mcal kg^{-1} DM, respectively). Trial 1 utilized five dietary treatments. The control diet consisted of 30.9% barley silage, 7.8% oat hulls, 7.8% canola meal, 8.2% alfalfa-grass hay, 37.3% rolled barley grain and 8% vitamin-mineral supplement (DM basis). It was formulated to contain 12.7% CP and 1.63 and 1.03 Mcal kg^{-1} NE_m and NE_g, respectively (DM basis). The remaining four treatments consisted of 39.9% barley silage, 8.6% oat hulls and 51.5% BP (DM basis) and were formulated to 12.6% CP and 1.63 and 1.03 Mcal kg DM^{-1} of NE_m and NE_g, respectively. In Trial 2, three dietary treatments were used. These included the two HF BP used in Trial 1 and a barley-based control ration. The control diet consisted of 31.2% barley silage, 7.9% oat hulls, 6.3% canola meal, 15.2% alfalfa-grass hay, 31.4% rolled barley grain and 8% vitamin-mineral supplement (DM basis). It was formulated to contain 1.57 and 0.97 Mcal kg^{-1} NE_m and NE_g, respectively. The remaining two treatment diets consisted of 40.4% barley silage, 8.7% oat hulls, 7.6% alfalfa-grass hay and 43.4% BP (DM basis) and were formulated to 1.57 and 0.97 Mcal kg^{-1} of NE_m and NE_g, respectively. All diets were formulated to meet NRC requirements for CP, NE_m, NE_g, and vitamin-minerals for the targeted gain (NRC, 1996). The diets were balanced to maintain a calcium:phosphorus ratio of 2:1 using limestone. Additionally, diets were supplemented with 33 mg kg^{-1} DM of monensin. Blended feed pellets were supplied by West Central Pelleting Ltd. of Wilkie, SK. Pellets were delivered to the Beef Cattle Research

Station at the University of Saskatchewan and stored individually. Barley silage (AC Rosser) was grown at the University of Saskatchewan farm. The alfalfa-grass hay was purchased from commercial sources and tub ground prior to feeding through a 9.5 cm screen (Haybuster H-1000, DuraTech Industries International, Jamestown, ND.). Oat hulls were purchased from Can-Oat Milling, Martinsville, Sk. Barley grain was purchased from commercial sources (56.1 ± 8.2 kg hL^{-1}) and processed to a PI of 75% by dry rolling (RossKamp Champion, Waterloo, IA).

3.2.3 Data Collection and Analytical Procedures

Feed was offered once daily, *ad libitum* (target 5% orts). Animals were weighed individually before the morning feeding on two consecutive days at the beginning and at the end of each trial to determine initial and final weights. Cattle were also weighed every two weeks throughout the feeding period prior to the morning feeding. Feed bunks were cleaned every two weeks and any orts were weighed, recorded and discarded. Daily DM delivered to each pen was corrected for orts recorded every two weeks. Performance (ADG, Feed efficiency, and DMI as % of BW) was calculated using shrunk body weight (Full BW x 96%). Ultrasound subcutaneous fat thickness (USFAT) and *longissimus dorsi* area (USLD) measurements were taken at the start and at the end of each trial according to Bergen et al. (1997) using an Aloka 500V real time ultrasound machine, equipped with a 3.5-MHz, 17.2-cm linear array transducer. Dietary NE_m levels based on animal performance were calculated according to Zinn et al. (2002) using the retained energy formula for large-framed steer calves ($RE = (0.0493 \times BW^{0.75}) \times ADG^{1.097}$; NRC 1984). Net energy for maintenance was used to calculate dietary NE_g concentration according to Zinn and Shen (1998). During both background trials, samples of total mixed rations were collected weekly and immediately dried in a forced-air oven at 55 °C for 72 h. Individual ingredient samples were obtained at the beginning of Trial 1 and 2 to assess chemical composition and DM percentage. Throughout Trial 1, samples of barley silage were collected weekly and dry matter content determined and used to adjust the silage proportion in the total diet. During Trial 2, feed samples were taken weekly for barley silage and biweekly for oat hulls and hay. All samples were immediately dried in a forced-air oven at 55 °C for 72 h. Rolled barley grain, canola meal, and supplement were sampled every time that a new load arrived at the research station. Blended feed pellets were made in a single batch and a representative sample was obtained.

3.2.4 Chemical Analysis

Dry feed and total mixed ration samples were ground (1-mm screen) using a hammer mill (Christie-Norris Laboratory Mill, Christie-Norris Ltd. Chelmsford, UK). Total mixed rations were composited bi-weekly and analyzed in duplicate according to the Association of Official Analytical Chemists (AOAC; 2000). Samples were analyzed for DM by drying at 135 ºC for 2 h (method 930.15; AOAC, 2000), ether extract (method 920.39; AOAC, 2000), crude protein by Kjeldahl method of nitrogen determination in feed and forages using a 2400 Kjeltec analyzer unit (method 984.13), and soluble crude protein using the method published by Roe et al. (1990). Starch was analyzed using the method described by Hall (2009), including the use of acetate buffer and corrected for free glucose, and ash (method 942.05; AOAC, 2000). With respect to fiber analysis, NDF was carried out with heat stable α-amylase and the addition of sodium sulphite (method 2002.04; AOAC, 2000) and ADF according to method 973.18 (AOAC, 2000). Calcium and P were analyzed using the dry ashing procedure (methods 927.02 and 965.17; AOAC, 2000, respectively). Calcium was determined using an atomic absorption spectrophotometer (Perkin-Elmer, Model 2380, CN, USA) while P concentration was read at 410 nm on a spectrometer (Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden).

3.2.5 Statistical Analysis

Data from Trial 1 were analyzed as a randomized complete block design (RCBD) using the mixed procedure of SAS (Version 9.2; SAS Inst. Inc. Cary, NC) with pen as the experimental unit, treatment as a fixed effect and initial weight block as a random effect. The model used for the analysis was $Y = \mu + \alpha_i + \beta_j + \varepsilon_{ijk}$, where Y was the observation of the dependent variable, μ is the population mean, α_i is the fixed effect of treatment, β_j is the random effect of block, and ε_{ijk} is the random error associated with the observation. Statistical analyses for Trial 2 was performed using the mixed procedure of SAS (Version 9.2; SAS Inst. Inc. Cary, NC) using a completely randomized design (CRD). The model used for the analysis was $Y = \mu + \alpha_i + \varepsilon_{ijk}$, where Y was an observation of the dependent variable, μ was the population mean, α_i was the fixed effect of treatment, and ε_{ijk} was the random error associated with the observation. In both trials, pen was the measure of replication. For all statistical analyses, significance was declared at a P-value ≤ 0.05 and trends at a P-value ≤ 0.10. Differences among treatments were evaluated using pre-planned contrasts. In Trial 1, pre-planned contrasts of interest included: Control vs. HS

BP; 2; Control vs. HF BP; 3: HS BP vs. HF BP; and 4: High vs. Low SCP BP. In Trial 2, comparison of interest included: 1: Control vs. HF BP; and High vs. Low SCP BP. Variance component estimation was done by REML. Satterthwaite's method was used to approximate degrees of freedom and a Kenward Roger adjustment was used to adjust standard errors. All data were analyzed using the mixed procedure of SAS (Version 9.2; SAS Inst. Inc. Cary, NC).

3.3 Results

The chemical analysis of the four BP and their ingredient make-up used in Trial 1 and 2 is given in Table 3.1. The HS pellets were formulated to be 45% starch while the HF pellets were formulated to be 8.8% EE. Analysis showed the two HS pellets averaged 50% starch while the HF pellets averaged 7.7% EE. The pellets were also formulated to vary in soluble crude protein content (37 vs. 27% of CP). Actual SCP averaged 37.9% and 21.2% (% of CP) for the HSP and LSP pellets, respectively. All pellets were formulated to be isonitrogenous (17.0% CP) and isocaloric (1.92 and 1.28 Mcal NE_m and NE_g kg^{-1} DM, respectively). While there was some variation in CP levels among the four pellets (range 14.6 to 16%), their average was 15.2 ± 0.61% CP. Net energy of gain values as determined using the Weiss equation (Weiss, 1992) averaged 1.26 ± 0.03 Mcal kg^{-1} for the HS BP and 1.05 ± 0.08 Mcal kg^{-1} for the HF BP. The discrepancy between formulated vs. actual nutrient content, particularly for soluble crude protein could result from a number of factors. First, nutrient specifications for the ingredients used in the formulation were based on the 2009 - 2010 crop years. It is possible that the specific ingredients used in the pellets which were mixed in 2011 differed from our original sample set. It is well known that differences in the nutrient value of crops used for feed vary from one year to the next due to environment, agronomic practices and storage conditions (Beames et al., 1986; Givens et al., 1993). As well, the BP were manufactured by a commercial factory and it is possible that there were issues with mixing accuracy.

Table 3.1: Ingredient composition and chemical analysis of strategically blended feed pellets used in Trial 1 and 2

	Blended pellets [z]			
	HS HSP	HS LSP	HF HSP	HF LSP
Ingredients (*% DM basis)*				
Oat hulls	4.89	10.4	6.80	14.3
DDGS	-	13.2	1.87	15.3
Pea screenings	25.7	-	40.8	-
Grain screenings	2.94	-	37.4	42.3
Wheat midds	43.4	63.4	-	14.6
Peas	19.7	9.30	-	0.39
Canola screenings	-	-	10.1	9.87
Min/Vit/Salt/Monensin	3.39	3.68	2.97	3.24
Blended Pellet analysis (*% DM basis)*				
DM	86.5	85.3	88.3	88.8
CP	15.4	14.6	16	14.9
Soluble Protein[y]	36.3	24.2	39.5	17.9
Fat	4.80	4.30	7.90	7.40
Starch	50.1	49.7	18.3	17.4
Sugar	3.90	3.70	4.40	2.70
NFC	55.9	55.2	29.3	30.6
ADF	8.60	8.80	26.4	27.2
NDF	18.1	21.4	37.8	39.4
Ash	7.0	6.0	11.3	10.2
Ca	1.07	1.04	1.19	1.31
P	0.38	0.46	0.36	0.41
NE_m Mcal kg^{-1} [x]	1.92	1.87	1.72	1.61
NE_g Mcal kg^{-1} [x]	1.28	1.23	1.10	0.99

[z]HS HSP: high starch - high soluble protein; HS LSP: high starch - low soluble protein; HF HSP: high fat - high soluble protein; HF LSP: high fat - low soluble protein.
[y]As % of Crude Protein.
[x]Calculated using Weiss equations (1992).

3.3.1 Trial 1

The ingredient and chemical composition of the total mixed rations fed in Trial 1 is given in Table 3.2. As designed, ether extract levels were higher in diets supplemented with HF pellets than those supplemented with HS BP and relative to the control diet (5.5, 3.5 and 2.5%, respectively; Table 3.2). Similarly, starch content was higher in the control and the HS diets (25.4 and 22.9 vs. 14.6%) compared to HF diets. Diets supplemented with HF pellets contained higher levels of ADF (28.7 vs. 22.6 and 25.2%) and NDF (50.8 vs. 43.8 and 43.0%) compared with the control and HS diets, respectively. This was a result of the formulation of the HF BP which used high levels of fibrous materials such as oat hulls, pea and grain screenings. The difference in SCP (% of CP) between diets supplemented with HS BP was 49.6 vs. 47.5%, while with the HF pellets, dietary SCP varied from 44.9 to 40.9%. The soluble CP content of the control diet was 34.4% which was 14.2 and 8.5% lower than the average of diets supplemented with HS and HF BP, respectively. Crude protein content of the diets averaged 12 ± 0.49%, meeting recommended levels for the targeted performance of 1.35 kg d^{-1} (NRC, 1996).

Start of test weight averaged 320 ± 21.6 kg (Table 3.3). The trial was designed to last 70 days. There was no effect ($P>0.05$) of treatment on final body weight which averaged 420 ± 23.2 kg (Table 3.3). Similarly, there was no effect ($P>0.05$) of treatment on ADG which averaged 1.43 ± 0.10 kg d^{-1} across all treatments (Table 3.3). Dry matter intake was lower ($P<0.01$) for steers fed the diets supplemented with the HS BP compared to steers fed the control and HF BP. Dry matter intake was similar ($P=0.16$) between steers fed the control and HF BP diets (Table 3.3). The similar daily gain between all treatments combined with lower DMI of cattle fed diets supplemented with the HS BP resulted in superior ($P<0.01$) gain:feed ratio compared to the cattle fed the HF BP diets. Cattle fed the control diet also had superior ($P<0.01$) gain:feed ratio relative to steers supplemented with HF BP due to numerically higher gains and lower DMI. There was no effect ($P>0.05$) of SCP content on DMI, ADG and gain:feed ratio (Table 3.3). Slight but significant differences were observed in calculated NE_m and NE_g values (Table 3.3). Dietary NE_g content (Mcal kg^{-1} DM) as calculated from animal performance was 7.5% lower ($P<0.01$) for cattle fed the HF diets relative to the control diet. Similarly, NE_g content of the HF diets were 8.7% lower ($P<0.01$) than that of the HS diets (Table 3.3). Ultrasound subcutaneous fat thickness and *longissimus dorsi* area gain measurements were not affected by treatment (Table 3.3), other than a trend to greater ($P=0.08$) ribeye area gain with the HS vs. the HF pellets.

Table 3.2: Ingredient composition and chemical analysis of total mixed rations (Trial 1)

	Dietary Treatment[z]				
	Control	HS HSP	HS LSP	HF HSP	HF LSP
Ingredients (% DM basis)					
Barley Silage	30.9	39.9	39.9	39.9	39.9
Oat hulls	7.8	8.6	8.6	8.6	8.6
Grass Hay	8.2	-	-	-	-
Canola Meal	7.8	-	-	-	-
Supplement	8.0	-	-	-	-
Barley grain	37.3	-	-	-	-
Blended pellets	-	51.5	51.5	51.5	51.5
Supplement composition (% DM basis)					
Barley grain	63.9	-	-	-	-
Canola oil	3.3	-	-	-	-
Limestone	12.2	-	-	-	-
Ionophore premix[y]	6.8	-	-	-	-
Trace mineral salt[x]	5.0	-	-	-	-
Vitamin premix[w]	8.8	-	-	-	-
Ration Analysis (% DM basis ± SD)[v]					
CP	12.7 ± 0.38	12.2 ± 0.32	11.4 ± 0.19	11.8 ± 0.21	11.8 ± 0.18
ADF	22.6 ± 0.46	26.9 ± 1.91	23.4 ± 1.62	29.4 ± 0.78	28.0 ± 0.52
NDF	43.8 ± 0.55	43.8 ± 4.24	42.1 ± 3.21	50.9 ± 3.28	50.7 ± 3.57
Ether extract	2.5 ± 0.11	3.4 ± 0.08	3.5 ± 0.22	5.4 ± 0.27	5.5 ± 0.67
Starch	25.4 ± 0.90	22.6 ± 5.02	23.1 ± 2.13	15.1 ± 2.21	14.0 ± 1.46
Calcium	0.63 ± 0.10	0.64 ± 0.05	0.54 ± 0.03	0.64 ± 0.02	0.76 ± 0.03
Phosphorus	0.40 ± 0.02	0.36 ± 0.01	0.37 ± 0.00	0.35 ± 0.00	0.37 ± 0.01
SCP (%CP)	34.4 ± 2.70	49.6 ± 3.59	47.5 ± 2.66	44.9 ± 2.07	40.9 ± 2.27

[z]HS HSP: high starch - high soluble protein; HS LSP: high starch - low soluble protein; HF HSP; high fat - high soluble protein; HF LSP: high fat - low soluble protein.

[y]University of Saskatchewan Feed Unit Ionophore Premix: contains 96.77% barley and 3.23% Rumensin® Premix containing monensin (as monensin sodium) at 200 g kg^{-1} (Elanco, Guelph, ON) (DM basis).

[x]Trace mineral salt: 95% NaCl, 12, 000 ppm Zn, 10, 000 ppm Mn, 4000 ppm Cu, 400 ppm I, 60 ppm Co, 30 ppm Se.

[w]University of Saskatchewan vitamin A & D supplement = 440,500 IU vitamin A, and 88,000 IU vitamin D3 kg^{-1}.

[v]Values shown with standard deviation of means (n=4).

Table 3.3: Effect of strategically blended feed pellets on performance of backgrounding cattle (Trial 1)

Variable	Dietary Treatment[z]					SEM[y]	*P*-values Contrasts			
	Control	HS HSP	HS LSP	HF HSP	HF LSP		Control vs. HS	Control vs. HF	HS vs. HF	HSP vs. LSP
Body Weight (kg)										
Initial[w]	319	319	319	321	320	9.63	-	-	-	-
Final[w]	425	420	416	419	421	11.3	0.14	0.27	0.84	0.62
Average daily gain (kg d^{-1})[x]	1.51	1.44	1.38	1.40	1.44	0.05	0.09	0.13	0.82	0.89
Dry matter intake (kg d^{-1})	9.52	9.10	8.79	9.84	9.71	0.29	<0.01	0.16	<0.01	0.14
Gain:Feed[w]	0.159	0.158	0.158	0.142	0.149	0.01	0.85	<0.01	<0.01	0.33
NE_m[x v]	1.75	1.77	1.78	1.64	1.68	0.02	0.51	<0.01	<0.01	0.15
NE_g[x v]	1.13	1.14	1.15	1.02	1.07	0.02	0.46	<0.01	<0.01	0.20
US subcutaneous fat thickness (mm)[t]										
Start of test	1.8	1.9	1.3	1.2	1.8	0.32	-	-	-	-
End of test	4.6	4.6	4.6	4.5	4.4	0.33	0.86	0.53	0.33	0.69
Gain	2.8	2.7	3.3	3.3	2.6	0.18	0.32	0.79	0.37	0.37
US *longissimus dorsi* area (cm^2)[t]										
Start of test	46.3	45.9	45.9	46.6	46.7	0.98	-	-	-	-
End of test	61.1	60.9	60.7	59.3	60.7	0.99	0.71	0.21	0.26	0.41
Gain	14.8	15	14.8	12.7	14	0.83	0.94	0.17	0.08	0.55

[z]HS HSP: high starch - high soluble protein; HS LSP: high starch - low soluble protein; HF HSP: high fat - high soluble protein; HF LSP: high fat - low soluble protein.

[y]SEM= Pooled standard error of the mean (n=5).

[w]Initial and final weights are reported on a 4% shrunk basis.

[x]Values calculated bases on shrunk BW.

[v]Calculated using NRC (1996) metabolizable energy values and equations for conversion to NE_m and NE_g.

[t]Ultrasound measurements of subcutaneous fat thickness; Ultrasound measurements of *longissimus dorsi* area.

A simple economic analysis was conducted to determine feed cost of gain ($ kg^{-1}) and total feed costs ($ $animal^{-1}$) resulting from the use of the strategically BP (Appendix C, Table C.1). Feed costs used for calculations were based on average prices between the period from January to March (2011) and prices included transport and processing: Barley: \$179 $tonne^{-1}$, Canola meal: \$323 $tonne^{-1}$, Alfalfa Hay: \$88 $tonne^{-1}$, Barley Silage: \$49 $tonne^{-1}$, Oat Hulls: \$34 $tonne^{-1}$, Vit-Min Supplement: \$206 $tonne^{-1}$, HS HSP: \$195 $tonne^{-1}$, HS LSP: \$212 $tonne^{-1}$, HF HSP: \$128 $tonne^{-1}$, and HF LSP: \$143 $tonne^{-1}$. Feed costs per kilogram of gain for the barley grain/barley silage control, and the HS and HF BP diets were \$1.14, and \$1.17 and \$0.98, respectively (Figure 2.1). Similarly, when total feed cost was calculated, taking into account the number of days on feed, only those steers supplemented with HF BP resulted in a significant improvement relative to the control fed cattle. Animals fed the HF BP diets had a saving of \$23 per head over the 70 day period (Figure 2.1).

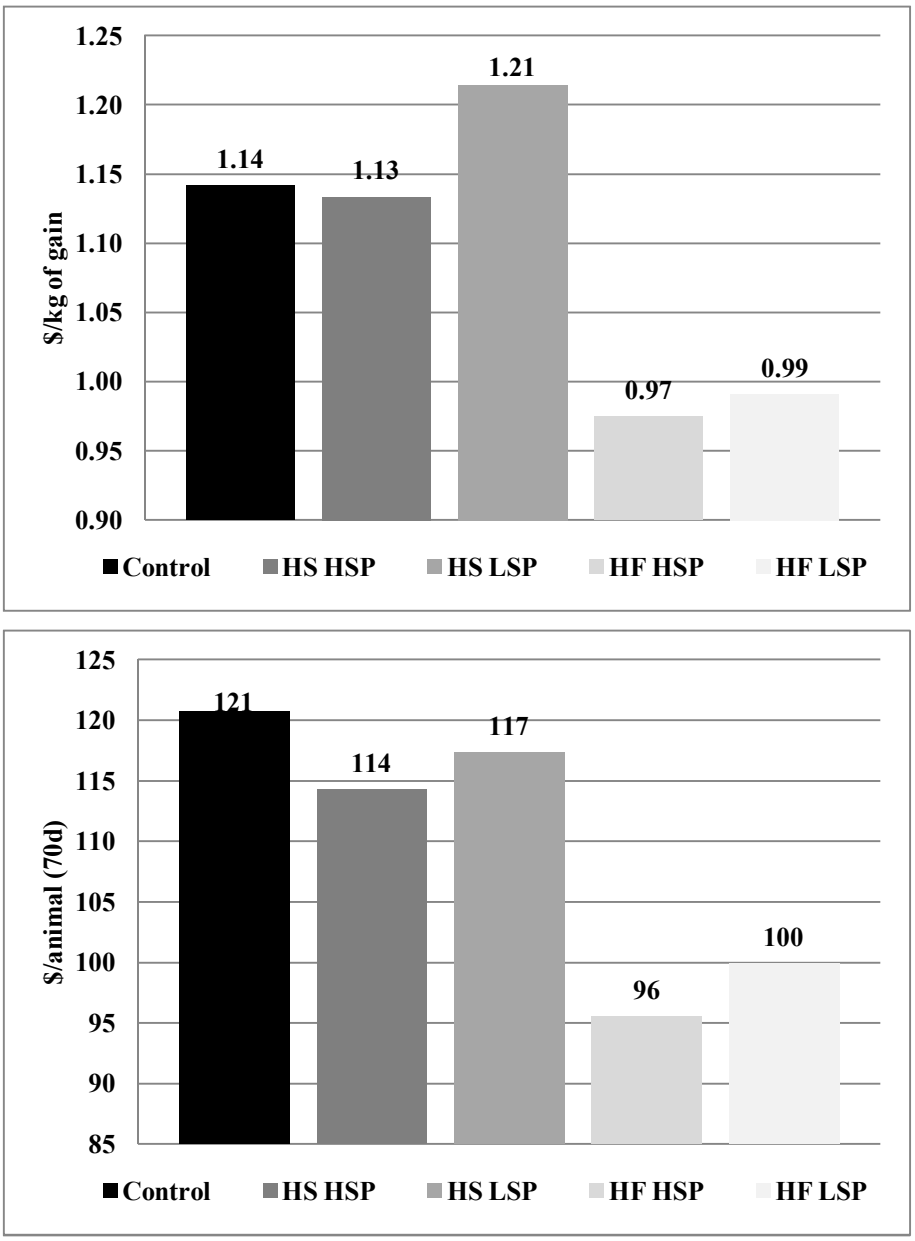

Figure 2. 1: Feed cost of gain ($ kg of gain^{-1}) and total feed costs ($ animal^{-1}) of using strategically blended feed pellets (Trial 1; HS HSP: high starch - high soluble protein; HS LSP: high starch - low soluble protein; HF HSP: high fat - high soluble protein; HF LSP: high fat - low soluble protein).

3.3.2 Trial 2

In Trial 2, only three treatments were used. These included the two high fat treatments and the control. This was based on the performance results of Trial 1 and the resulting cost of gain which favoured the two high fat treatments. The ingredient composition and chemical make-up of the diets are given in Table 3.4. As with Trial 1, diets supplemented with the HF BP were higher in EE (5.1 vs. 2.6%), NDF (56 vs. 45.2%), and ADF (33.7 vs. 27.5%) content relative to the control diet. The difference in SCP (% of CP) content of the total mixed diets supplemented with HF BP was 36.4 vs. 34.9% for the high vs. the low SCP BP, respectively. The SCP content of the control ration was 28.5% (% of CP). Crude protein content of the diets averaged 11.0 ± 0.41%, meeting minimum recommended levels for the targeted performance of 1.30 kg d^{-1} (NRC, 1996).

Start of test weights averaged 326 ± 20.3 kg (Table 3.5). As with Trial 1, the trial lasted 70 days. Slight but significant increases (P=0.04) in final body (439 vs. 434) weight were observed among cattle fed the control diet compared to steers fed the diets supplemented with the HF BP. Similarly, ADG was lower (P=0.04) and DMI higher (P=0.04) for steers fed the diets supplemented with the HF BP compared to steers fed the control diet (Table 3.5). Consequently, cattle fed the control diet had superior (P<0.01) gain:feed relative to steers supplemented with HF BP. There was no effect (P>0.05) of SCP content on DMI, ADG or gain:feed ratio (Table 3.5). Similar to Trial 1, slight but significant differences were observed in calculated NE_m and NE_g values of total mixed rations (Table 3.5). Dietary NE_g content (Mcal kg^{-1} DM) as calculated from animal performance was 8.3% lower (P<0.01) for cattle supplemented with the HF BP relative to those fed the control diet. Ultrasound subcutaneous fat thickness and *longissimus dorsi* area gain measurements were not affected by treatment (Table 3.5).

As with Trial 1, a simple economic analysis was conducted to determine feed cost of gain ($ kg of $gain^{-1}$) and total feed costs ($ $animal^{-1}$) resulting from the use of the strategically BP (Appendix C, Table C.2). Feed costs used for calculations were based on average prices between the period from April to June (2011) and prices included transport and processing: Barley: $191 $tonne^{-1}$, Canola meal: $374 $tonne^{-1}$, Alfalfa Hay: $53 $tonne^{-1}$, Barley Silage: $51 $tonne^{-1}$, Oat Hulls: $37 $tonne^{-1}$, Vit-Min Supplement: $374 $tonne^{-1}$, HF HSP: $128 $tonne^{-1}$, and HF LSP: $143 $tonne^{-1}$. Feed costs per kilogram gain for the barley grain/barley silage control, and the HF BP diets were $1.23, and $1.00, respectively (Figure 2.2). When total feed cost was calculated taking

into account the number of days on feed, the steers supplemented with HF BP had a significant improvement in total feed costs, averaging $31 less than the control fed cattle (Figure 2.2).

Table 3.4: Ingredient composition and chemical analysis of total mixed rations (Trial 2)

	Dietary Treatment[z]		
	Control	HF HSP	HF LSP
Ingredients (% DM basis)			
Barley Silage	31.2	40.4	40.4
Oat hulls	7.9	8.6	8.6
Grass Hay	15.2	7.6	7.6
Canola Meal	6.3	-	-
Supplement	8.0	-	-
Barley grain	31.4	-	-
Blended pellets	-	43.4	43.4
Supplement composition (% DM basis)			
Barley grain	66	-	-
Canola oil	3.0	-	-
Limestone	11	-	-
Ionophore premix[y]	6.5	-	-
Trace mineral salt[x]	4.5		
Vitamin premix[w]	9.0		
Ration Analysis (% DM basis ± SD)[v]			
CP	11.4 ± 0.26	10.8 ± 0.25	10.6 ± 0.28
ADF	27.5 ± 0.31	34.1 ± 1.08	33.3 ± 0.73
NDF	45.2 ± 4.00	55.0 ± 3.28	57.0 ± 1.91
Ether extract	2.6 ± 0.12	5.2 ± 0.26	5.0 ± 0.28
Calcium	0.61 ± 0.05	0.62 ± 0.03	0.67 ± 0.03
Phosphorus	0.35 ± 0.01	0.29 ± 0.02	0.33 ± 0.02
SCP (%CP)	28.5 ± 2.80	36.4 ± 2.64	34.9 ± 2.23

[z]HF HSP: high fat - high soluble protein; HF LSP: high fat - low soluble protein.
[y]University of Saskatchewan Feed Unit Ionophore Premix: contains 96.77% barley and 3.23% Rumensin® Premix containing monensin (as monensin sodium) at 200 g kg^{-1} (Elanco, Guelph, ON) (DM basis).
[x]Trace mineral salt: 95% NaCl, 12, 000 ppm Zn, 10, 000 ppm Mn, 4000 ppm Cu, 400 ppm I, 60 ppm Co, 30 ppm Se.
[w]University of Saskatchewan vitamin A & D supplement = 440,500 IU vitamin A, and 88,000 IU vitamin D3 kg^{-1}.
[v]Values shown with standard deviation of means (n=4).

Table 3.5: Effect of strategically blended high fat pellets on performance of backgrounding cattle (Trial 2)

Variable	Dietary Treatment[z]			SEM[y]	*P*-values Contrasts	
	Control	HF HSP	HF LSP		Control vs. HF	HSP vs. LSP
Body Weight (kg)						
Initial[w]	326	326	327	0.20	-	-
Final[w]	439	435	433	2.02	0.04	0.46
Average daily gain (kg d^{-1}) [x]	1.61	1.55	1.51	0.03	0.04	0.37
Dry matter intake (kg d^{-1})	10.6	11.0	10.8	0.13	0.04	0.20
Gain:Feed[x]	0.153	0.140	0.140	<0.01	<0.01	1.00
NE_m [x v]	1.71	1.60	1.61	0.01	<0.01	0.81
NE_g [x v]	1.09	1.00	1.00	0.01	<0.01	0.66
US subcutaneous fat thickness (mm) [t]						
Start of test	1.2	1.2	0.9	0.10	-	-
End of test	2.7	2.5	1.9	0.14	0.02	0.01
Gain	1.5	1.3	1.0	0.16	0.20	0.39
US *longissimus dorsi* area (cm^2) [t]						
Start of test	51.8	51.9	53.3	0.74	-	-
End of test	63.2	64.4	64.2	0.67	0.21	0.83
Gain	11.4	12.5	10.9	0.75	0.77	0.15

[z]HF HSP: high fat - high soluble protein; HF LSP: high fat - low soluble protein.
[y]SEM= Pooled standard error of the mean (n=5).
[w]Initial and final weights are reported on a 4% shrunk basis.
[x]Values calculated bases on shrunk BW.
[v]Calculated using NRC (1996) metabolizable energy values and equations for conversion to NE_m and NE_g.
[t]Ultrasound measurements of subcutaneous fat thickness; Ultrasound measurements of *longissimus dorsi* area.

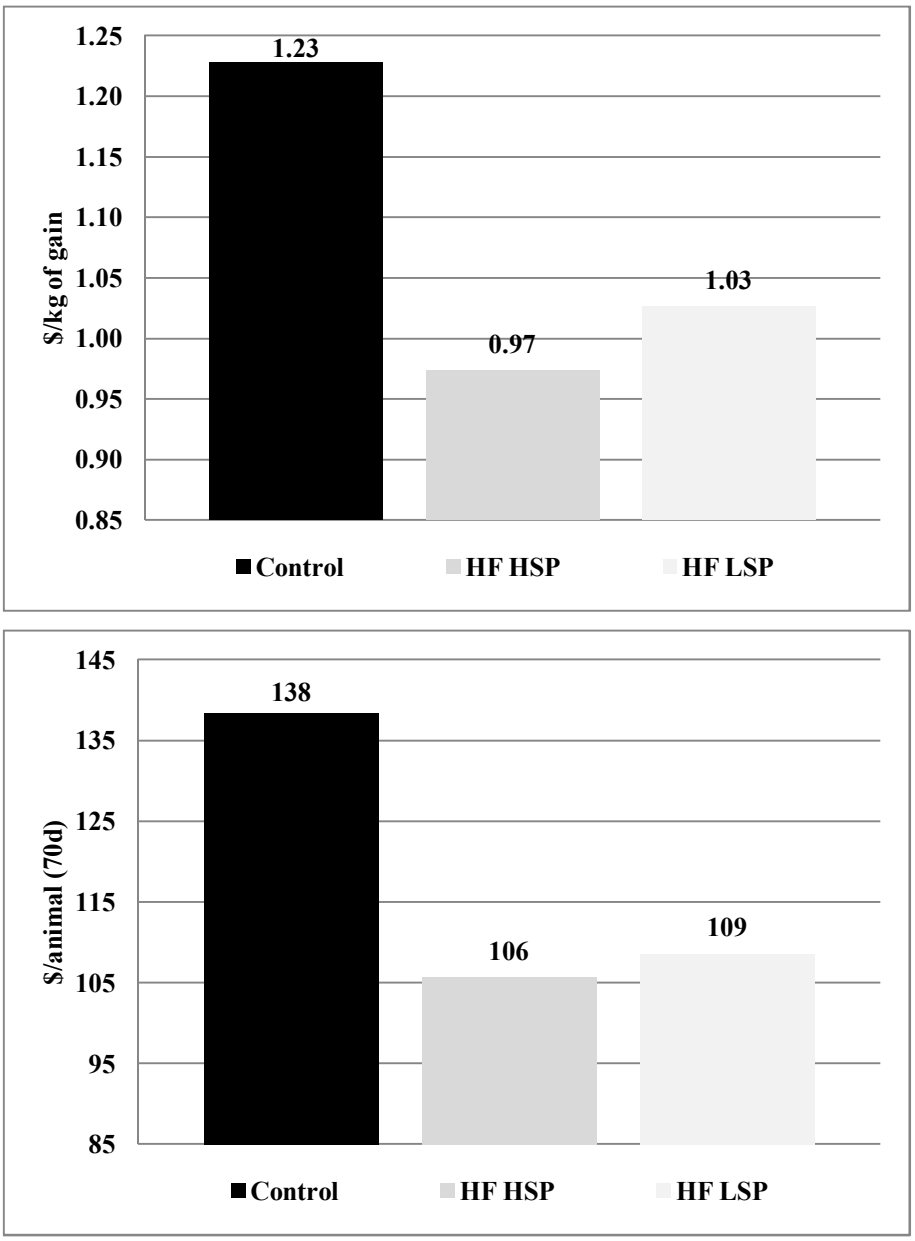

Figure 2. 2: Feed cost of gain ($ kg of gain^{-1}) and total feed costs ($ animal^{-1}) of using strategically blended feed pellets (Trial 2; HF HSP: high fat - high soluble protein; HF LSP: high fat - low soluble protein).

3.4 Discussion

Cattle in backgrounding programs are fed with low concentrate and high forage diets to achieve moderate growth increments (Block et al., 2001; Bengochea et al., 2005; Williams et al., 2008). The rationale is to promote muscle deposition and allow for skeletal development while minimizing fat deposition (Vaage et al., 1998; Block et al., 2001; Bengochea et al., 2005; Williams et al., 2008). Throughout the backgrounding phase in the current study, diets were formulated to forage:concentrate ratios of 48.5:51.5 and 56.6:43.4% (Trial 1 and 2; DM basis) (Table 3.2 and 3.4). The diets were similar in nutrient specifications to other studies which involved backgrounding cattle in western Canada (Block et al., 2001; Wang et al., 2003; Bengochea et al., 2005; Williams et al., 2008). Average daily gain of all cattle fed in this study was higher (1.48 kg d^{-1}) than targeted levels (1.30 kg d^{-1}).

Dry matter intake of cattle has been shown to be influenced by diet (Allen, 2000). Cattle fed diets high in readily fermentable carbohydrate have been shown to have a lower DMI due to either higher energy density of the diet (Baile and Forbes, 1974; Bartle et al., 1994; Galyean and Defoor, 2003; Krehbiel et al., 2006), increased propionate production (Allen, 2000), rumen digestive upset (Owens et al., 1998) or a combination of these factors. In the present trial, cattle fed the HS BP had a lower DMI relative to cattle fed the control diet supplemented with barley and processed to a PI of 75%. The starch content of the barley used in the control diet was 56% (DM basis). Calculated starch intake (g d^{-1}) for the control cattle averaged 2418. This was 374 g d^{-1}greater than cattle fed the HS BP (2044 g d^{-1}) diets. Therefore, the difference in DMI between cattle fed the control diet and those supplemented with the HS BP is not a reflection of total starch intake. It is possible, however that the nature of the pellets influenced DMI between the HS and control fed cattle. The HS BP used ground wheat as a starch source relative to barley grain in the control diet. Rate and extend of starch digestion in the rumen is increased when grains are highly processed (Cheng et al., 1973; Van Soest, 1994). Moreover, ground wheat is a more fermentable cereal grain when compared to rolled barley grain. Research has shown that finely ground wheat is readily fermentable by rumen bacteria and can lead to severe and sub-acute acidosis and therefore decrease DMI (Stock, 1993). Thus, differences in the source of starch may have contributed to the lower DMI of the HS fed cattle relative to the control fed cattle.

Dietary fat level and type have also been shown to influence DMI (Brandt, 1995; Elliott et al., 1997; Allen, 2000). In the present study, average dietary fat levels for the two HF diets were 5.4 ± 0.48% and 5.1 ± 0.27% (Trial 1 and Trial 2, respectively). Doreau and Chilliard (1997) stated that supplementing fat at levels up to 5% of ruminant diets has minimal effects on DMI. Supporting this statement, Elliot et al. (1997) did not find any difference in DMI when corn starch was replaced with different sources of fat to supply 5% total fat (DM basis). Similarly, a decrease in DMI due to increasing fat level in the diet has been reported only when fat levels exceed 4 to 5% in finishing diets (Brandt, 1995) and 4 to 7% in forage diets (Jenkins and Palmquist, 1984; Moore et al., 1986). In the current study, dietary fat levels were below 5.5% and no differences were observed in terms of DMI between the Control and HF diet (Trial 1). In contrast DMI was increased with HF BP, particularly relative to the HS BP (Trial 1) and relative to the control diet in Trial 2. The likely explanation for this effect is that HF BP were lower in net energy for gain than the HS BP and the barley they replaced in the control diets. This is evident from the fact that the cattle fed the HF BP were less efficient than either the control or HS fed cattle. They consumed more feed to gain the same weight; indicating a lower energy density for the two HF diets. This was confirmed by the calculated NE_g density based on animal performance. Diets formulated with HF BP were 7.5% and 8.7% lower in NE_g than those fed the control and HS diets, respectively. Cattle performance is a good indicator of the energy value of any feedstuff as it accounts for various factors that may influence the energy values of feeds such as nutrient composition, particle size, level of inclusion, feed replaced, and associative effects (Jonhson et al. 1995). It is also possible that differences in DMI can be attributed to the environment and its effect on fat utilization (Brandt, 1995; Elliott et al., 1997; Allen, 2000) and feed intake (Bhattacharya and Warner, 1968). Brandt, (1995) indicated that feeding supplemented fat in cold weather may be a disadvantage as fat does not increase the animal's internal heat production, thus they may have to eat more to maintain core body temperature (Young, 1986). It has been shown that fat-supplemented diets had higher NE_m and NE_g (30 and 35%, respectively) in summer than in winter trials (Brandt, 1995; Elliott et al., 1997; Allen, 2000).

Poor feed efficiency in cattle supplemented with dietary fat does not agree with other published results (Zinn, 1989; Brandt, 1995; Elliott et al., 1997; Allen, 2000; Ramirez and Zinn, 2000; Hutchison et al., 2006; Hess et al., 2008). Although, a decrease in DMI due to increasing

fat level in the diet has been reported only when fat levels exceed 4 to 7% (Jenkins and Palmquist, 1984; Moore et al., 1986; Brandt, 1995; Elliott et al., 1997; Allen, 2000), in the current study the replacement of readily fermentable carbohydrate with fat (i.e. a more dense source of energy; Jouany et al., 2000) did not result in a superior G:F ratio. Indeed, animals fed HF BP diets had the poorest conversion rate compared to those fed the other treatment diets. Interestingly, these results were consistent in both trials. Again, these results are a reflection of the lower calculated NE_g of the HF diets in both trials (Table 3.3 and 3.5). Similar results were shown by Pylot et al. (1999) who found a negative response in feed efficiency as canola screenings replaced barley grain suggesting that barley diets had more digestible and fermentable energy than diets formulated with increasing levels of canola screenings. Moreover, higher total volatile fatty acid levels and lower acetate:propionate ratios were associated with increasing levels of barley grain (Pylot, 1999). Authors proposed that a possible explanation for their findings is that the digestion of starch results in more propionate production, which is the major precursor for glucose in ruminants (Young, 1977; Brockman and Laarveld, 1986). Moreover, authors highlighted the fact that propionate is more energetically efficient than acetate in promoting animal performance (Jenkins and Thonney, 1988). Since in the present study, the HF BP diets had less calculated NE_g (Mcal kg^{-1}) than the HS BP and control diets; the hypothesis proposed by Pylot (1999) would help to explain the poor efficiency in cattle supplemented with dietary fat.

Highly fermentable carbohydrates promote ruminal microbial growth if available N is present (Stern et al. 1978). The replacement of fermentable carbohydrate by a fat source could lead to a reduction in microbial protein synthesis and as a result to a reduction in metabolizable protein supply. However, ADG across all treatments was higher than expected with minimal differences in gains between treatments. This suggests that metabolizable protein supply did not limit growth in this study. This conclusion is further supported by the fact that differences in SCP did not influence performance. Moreover, based on actual gains (1.43 ± 0.05 and 1.55 ± 0.05 kg d^{-1}; Trial 1 and 2, respectively) the CP intake of all treatment diets (1126 ± 0.08 and 1180 ± 0.03 g CP d^{-1}; Trial 1 and 2, respectively) met recommended levels for growing beef cattle (1100 g CP d^{-1}; estimated from Table 9-1 in National Research Council (NRC, 2000) for a steer of 350 kg BW and gaining 1.50 kg d^{-1}).

It is interesting to compare the economic results of cattle fed BP with that of cattle fed the control barley silage/barley grain backgrounding diet (Figure 2.1 and 2.2). In both studies the performance results were similar, thus they are discussed as an average to assess the economic impact of feeding BP relative to barley silage/barley grain based diet. In this study, cattle fed the control diets gained in average 1.56 kg d^{-1} and had a gain:feed ratio of 0.156 (Table 3.3 and 3.5). Cattle fed HS BP exhibited average gains of 1.41 kg d^{-1} and gain-to-feed ratios of 0.158, similar to those fed the control diet (Table 3.3). The cattle fed the HF BP exhibited average gains of 1.48 kg d^{-1} and feed efficiency of 0.143 (Table 3.3 and 3.5). Feed costs per kilogram of gain for the barley grain/barley silage control, and the HS and HF BP diets were $1.19, $1.17 and $0.99 per kg of gain, respectively. It was only when cattle were fed the HF BP that the cost of gain decreased markedly ($0.20 per kg of gain) and therefore a significant improvement in total feed costs, averaging $27 less than the control fed cattle (Figure 2.1 and 2.2). This reduction in feed costs with the HF BP can be attributed to the relatively good performance of the cattle fed this product and the low cost of the ingredients used to make this pellet.

3.5 Conclusion

Results indicate that strategically blended feed pellets can be a viable alternative for supplementing energy and protein in backgrounding diets. Results from both trials suggest that steers exhibited increased feed intake, had similar or decreased gains and thus decreased feed efficiency when fed HF BP. As a result the NE_g of the HF diets were lower than either the control or HS diets. Improvements in feed efficiency in cattle supplemented with HS BP occurred as result of their higher net energy of gain relative to the HF BP. Nonetheless, cattle performed in a cost-efficient manner with exceptional gains when fed HF BP diets, indicating that strategically HF BP offer potential cost savings as a replacement for barley in backgrounding programs. The economics of feeding strategically BP will depend on availability and price relative to other feed sources such as cereals grains. However, caution needs to be exercised when feeding HF pellets due to poorer G:F ratios and potential negative impacts on cost of gain. Further research is needed to understand rumen fermentation and digestibility of BP in backgrounding cattle as well as their impact on nutrient excretion into the environment.

4 EFFECT OF FEEDING STRATEGICALLY BLENDED FEED PELLETS ON RUMEN FERMENTATION AND NUTRIENT DIGESTION

4.1 Introduction

The cost of cereal grains has been under upward pressure as a result of rising oil prices and increasing demand for ethanol. Beef producers are increasingly looking for alternative feeds to cereal grains in backgrounding and finishing rations. By-product feeds while not new to western Canada are increasingly being used to replace cereal grains and to reduce feed costs (Clark et al., 1987; Belyea et al., 1989).

Available data of by-products regarding chemical composition, digestibility and nutritive value have shown their limitations and advantages. For example, Pylot et al. (1999a) found that by grinding and pelleting canola screenings, DMI was not affected at levels up to 10% of dietary fat coming from canola screenings. However, it has been also reported that when canola screenings were replaced with a source of energy with higher fermentable carbohydrate ADG and feed efficiency improved (Pylot et al. 1999b). Moreover, replacement of barley grain with corn or wheat DDGS improved animal performance (Walter et al., 2010), although nitrogen and phosphorus excretion increased with increasing levels of wheat and corn DDGS (Walter et al., 2011). These studies and others (Dhuyvetter et al., 2010) show that no by-product by itself is the ultimate solution for use as the sole supplement for backgrounding or finishing cattle. The initial study conducted for this project attempted to strategically blend by-product feeds to optimize rumen available energy and protein content (Section 2.0). Four strategically blended feed pellets (BP) were formulated to be either high starch (HS 45% DM basis) or high fat (HF 8.8% DM basis) and either low or high in soluble protein (LSP 27% of CP; HSP 37% of CP DM basis). Results revealed that steers increased feed intake, had similar or decreased gain and decreased feed efficiency when fed the HF BP. Feed efficiency was improved when cattle were supplemented with the HS BP, likely as a consequence of their higher net energy of gain relative to the HF BP. The lowest dietary net energy for gain (NE_g) values were observed with the cattle fed the HF BP. Reasons for this reduced performance are unclear but may relate to reduced nutrient digestibility coefficients in the HF BP diets, alterations in rumen fermentation parameters such as VFA production or pH. As by-product feeds tend to be higher in crude protein that cereal grains, it would also be of value to examine the route of nitrogen excretion as

N release to the environment from intensive livestock operations is a concern facing both producers and society.

The objective of this experiment was to determine the effect of feeding blended feed pellets on nutrient digestibility coefficients, nitrogen balance and impact on rumen fermentation parameters.

4.2 Materials and Methods

4.2.1 Experimental Design and Animals and Housing

A metabolism trial was conducted (October, 2010) in the Livestock Research Building (LRB) at the University of Saskatchewan. Five cross-bred ruminally cannulated heifers (631 ± 31 kg, mean ± SD) were housed in the livestock research barn (LRB). Heifers were kept in individual 9 m^2 pens equipped with water bowls and rubber floor matting. Pens were scraped and cleaned every day before the morning feeding. The animals were assigned to one of 5 dietary treatments in a 5 x 5 Latin square design. The trial lasted 160 days with periods of 32 d. Each period included a 12 d adaption period followed by 6 d (d 13-18) for determination of voluntary intake (VI). On d 17 and 18, the animals were weighed before the morning feeding. Rumen fluid was taken on d 19 and indwelling pH probes inserted (d 20) to continually measure rumen pH (21 - 23). On day 24, feed intake was restricted to 95% of *ad libitum* intake (DM basis) to help ensure total ingestion of feed. Days 27 through 32 were used for total collection of urine and feces. The cattle were cared for following the guidelines set out by the Canadian Council on Animal Care (1993).

4.2.2 Treatments, Dietary Composition and Feeding

On a DM basis, the control diet consisted of 35.6% rolled barley grain, 32.5% barley silage, 7.5% oat hulls, 7.7% canola meal, 7.7% mineral and vitamin supplement, and 9.1% alfalfa grass hay (Table 4.1). The four experimental diets consisted of 42.1% barley silage, 8.2% oat hulls, and 49.7% of one of four strategically blended pellets (BP) (DM basis, Table 4.1). All diets were formulated to meet NRC (1996) requirements for CP, NE_m, NE_g, and vitamin-minerals for the targeted gain (1.35 kg d^{-1}). The diets were balanced for calcium and phosphorus with monensin added at 33 mg kg^{-1}. Pellets were supplied by West Central Pelleting Ltd. of Wilkie, SK. Pellets were delivered to the livestock research barn at the University of

Saskatchewan and stored individually. Barley silage (AC Rosser) was grown at the University of Saskatchewan farm. The barley grain was purchased from commercial sources (62.5 kg hL^{-1}). The alfalfa-grass hay was purchased from commercial sources and ground (Haybuster H-1000, DuraTech Industries International, Jamestown, ND.) through a 9.5 cm screen prior to feeding. Oat hulls were supplied from Can-Oat Milling, Martinsville, Sk.

Heifers were fed *ad libitum* (target at least 10% orts) at 0800 and 1600 in two equal feedings. Water was available *ad libitum*. Before the first daily feeding, feed bunks were cleaned and the residue weighed and recorded. Treatments were the same as those used in Trial 1. In order to calculate voluntary intake as a percentage of body weight, heifers were weighed on two consecutive days prior to feeding (d 17 - 18).

4.2.3 Rumen Metabolism

4.2.3.1 In-dwelling Ruminal pH Measurement

Ruminal pH was measured and recorded at regular intervals of 60 s, over 72 h (days 21 - 23) using the Lethbridge Research Centre Ruminal pH Measurement System (LRCpH; Model Dascor, Escondido, CA) as described by Penner et al. (2006). Briefly, each indwelling probe was calibrated in pH 4 and 7 buffer solutions immediately before and after placing them into or taking them out of the rumen. Each probe was pre-warmed in water (~39 °C) prior to the initial standardization. After removal from the rumen, the probes were washed and kept in warm water (~39 °C) until standardized again. The data was then downloaded and recorded. The shift in millivolt readings from the electrodes between the start and the end of standardization was assumed to be linear and used to convert millivolt readings to pH units. The LRCpH system was equipped with two 900-gram weights to keep the probes in the ventral sac of the rumen. For each treatment and its data set, minimum, mean, maximum pH values, and the duration (min d^{-1}), area (pH x min), duration kg^{-1} DMI, and area kg^{-1} DMI under ruminal pH 5.8 were calculated as described by Penner et al. (2007 and 2009). An acidosis index was calculated by dividing the area that ruminal pH was below pH 5.8 by DMI to evaluate the severity of ruminal acidosis normalized for DMI and to determine whether or not the severity of ruminal acidosis is related to factors other than DMI (Penner et al., 2009). The threshold of 5.8 was used as this pH value has been defined as representing the cut-off for mild rumen acidosis (Nocek, 1997; Maekawa et al., 2002; Beauchemin and Yang, 2005; Penner et al., 2007).

Table 4.1: Composition and analysis of control and treatments rations

	Dietary Treatment[z]				
	Control	HS HSP	HS LSP	HF HSP	HF LSP
Ingredients (% DM basis)					
Barley Silage	32.5	42.1	42.1	42.1	42.1
Oat hulls	7.5	8.2	8.2	8.2	8.2
Alfalfa grass Hay	9.1	–	–	–	–
Canola Meal	7.7	–	–	–	–
Supplement	7.7	–	–	–	–
Barley grain	35.6	–	–	–	–
Blended pellets	–	49.7	49.7	49.7	49.7
Supplement composition (% DM basis)					
Barley grain	66				
Canola oil	3.0				
Limestone	11				
Ionophore premix[y]	6.5				
Trace mineral salt[x]	4.5				
Vitamin premix[w]	9.0				
Ration Analysis (% DM basis ± SD)[v]					
CP	11.9 ± 0.23	15.1 ± 0.03	14.6 ± 0.28	13.1 ± 0.03	13.5 ± 0.03
ADF	17.9 ± 0.86	18.3 ± 1.12	18.7 ± 1.27	23.7 ± 0.12	22.1 ± 1.12
NDF	31.9 ± 0.33	33.2 ± 0.43	33.9 ± 0.46	40.4 ± 0.43	40.2 ± 0.43
Starch	32.6 ± 0.79	27.2 ± 1.03	27.2 ± 1.11	17.9 ± 1.03	18.6 ± 1.03
EE	1.99 ± 0.06	2.53 ± 0.07	2.35 ± 0.04	4.99 ± 0.07	5.13 ± 0.07
Ash	6.41 ± 0.18	7.31 ± 0.24	7.10 ± 0.24	8.42 ± 0.24	7.88 ± 0.24
OM	93.6 ± 0.18	92.6 ± 0.24	92.8 ± 0.24	91.5 ± 0.24	92.0 ± 0.24
GE	4.12 ± 0.01	4.14 ± 0.01	4.16 ± 0.02	4.21 ± 0.01	4.28 ± 0.01
SCP (% of CP)	44.1 ± 0.01	51.9 ± 0.01	46.5 ± 0.02	46.9 ± 0.01	40.8 ± 0.01

[z]HS HSP: high starch - high soluble protein, HS LSP: high starch - low soluble protein, HF HSP: high fat - high soluble protein, HF LSP: high fat - low soluble protein.

[y]University of Saskatchewan Feed Unit Ionophore Premix: contains 96.77% barley and 3.23% Rumensin® Premix containing monensin (as monensin sodium) at 200 g kg^{-1} (Elanco, Guelph, ON) (DM basis).

[x]Trace mineral salt: 95% NaCl, 12, 000 ppm Zn, 10, 000 ppm Mn, 4000 ppm Cu, 400 ppm I, 60 ppm Co, 30 ppm Se.

[w]University of Saskatchewan vitamin A & D supplement = 440,500 IU vitamin A, and 88,000 IU vitamin D3 kg^{-1}.

[v]Values shown with standard deviation of means (n=5).

4.2.3.2 Rumen Fluid Sampling

On d 19 of each period, rumen fluid was collected at 0800 before feeding and every two hours thereafter for 24 h. Rumen fluid samples were obtained by thoroughly mixing representative volumes (at least 250 ml) collected from the anterior, ventral, and posterior sacs of the rumen and from the rumen mat. Subsequently, samples were strained through four layers of cheese-cloth. Three 10 ml proportions of filtrate were sub-sampled into 15 ml tubes. One was preserved for volatile fatty acid (VFA) analysis by adding 2 ml of 25% (wt/vol) metaphosphoric acid. Another aliquot was taken for evaluation of ammonia nitrogen (NH_3-N) concentration by adding 2 ml of 1% H_2SO_4 (sulphuric acid). The final sub-sample was designated as a spare and did not receive any addition of preservative. The tubes were then sealed, mixed and stored at -20 °C until analysis.

4.2.3.3 Volatile Fatty Acid Analysis

Samples were thawed at 4 °C overnight, vortexed and centrifuged at 12000 x g at 4 °C for 10 minutes using a Beckman Coulter Avanti J-E centrifuge (Indianopolis, IN). Subsequently, 1.4 ml of supernatant was transferred to a 1.5 ml microcentrifuge tube (Eppendorf®). Duplicate microcentrifuge tubes were centrifuged at 16000 x g, at 4 °C for 10 minutes. Subsequently, 1 ml of the supernatant from each duplicate was transferred to gas chromatography (GC) vials. Immediately following this step, 0.2 ml of internal standard was added to the GC vials (iso-caproic acid was used as a standard), vortexed, and refrigerated at 4 °C . Reference and blank samples were also prepared. Acetate, propionate, butyrate, valerate, iso-butyrate, iso-valerate and caproic acids were quantified by gas chromatography (Agilent 6890 Series GC System with FID, Santa Clara, CA, USA). Volatile fatty acids were separated on a 30 m × 0.32 mm × 0.25 µm film Zebron™ ZB-FFAP high performance GC capillary column (Phenomenex, Inc. Torrance, Calif. USA). Initial and final oven temperatures were 90 and 170ºC respectively, with an increase of 10 ºC min^{-1} followed by a 2 minute hold. A standard curve was prepared using pure individual short chain VFAs of interest and was used to identify and quantify the concentration of the above mentioned short chain fatty acids. Total VFA concentration was determined by summing the concentrations of all measured VFAs (Ghorbani et at. 2002; Beauchemin et al. 2003).

4.2.3.4 Rumen NH_3-N

Ruminal NH_3-N was determined using the phenol hypochlorite method (adapted from: Broderick and Kang, 1980). Samples were thawed at 4 °C overnight, vortexed and then transferred (1.4 ml) to micro-centrifuge tubes and kept on ice before centrifuging at 14000 x g for 10 min. Twenty five µl of supernatant was then added to duplicate test tubes. Subsequently, 1.5 ml of phenol reagent and 1.0 ml of hypochlorite reagent were added and the sample vortexed. Tubes were covered with a marble parfilm and placed in a 95 °C water bath for 5 minutes. Subsequently, tubes were placed in ice-water for 3 minutes. Finally, 2.5 ml of double distilled water was added and the sample vortexed. Samples were read on a spectrophotometer (Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden) at 630 nm. Samples were kept in ice-water during the entire procedure, except for the water bath stage.

4.2.4 Total Tract Diet Digestibility

Total tract nutrient digestibility coefficients and nitrogen balance for each treatment were determined over five days of total collection of feces and urine. Total daily fecal output was collected from the floor and placed in covered and clean plastic containers. Animals were monitored for each 24 h period, hourly from 0500 to 1800 and every 90 min until midnight. Total daily fecal output for each heifer was weighed, mixed thoroughly before a sub-sample of 6% of the daily total output was taken and placed in pre-weighed aluminum drying containers, sealed and stored at −20 °C . Total urine output was collected using indwelling catheters (75-ml-capacity balloon, Bardex Foley Catheter, C. R. Bard Inc. Covington, GA) inserted 24 h prior to the beginning of collection. Urine was collected into 20 L containers into which 200 ml of concentrated hydrochloric acid was added to achieve a urine pH of less than 2 (Stockdale and Rathbone, 1992). The acidification of urine is necessary to prevent microbial degradation and the loss of volatile NH_3-N. In the first day of urine collection, urine pH was measured to be sure that pH was ranging between expected values. Daily urinary output was weighed, mixed thoroughly, and samples were taken (15% of the total daily excretion), and pooled for each heifer during each collection period. After each period, urine was thawed, mixed thoroughly, and subsampled in 500-ml Nalgene bottles in duplicate for further analysis. Samples were stored at -20 °C until analyzed for total N. During the five days of total collection any feed left in the bunk prior to the morning feeding was weighed, and a representative sample was taken for further analysis.

4.2.5 Chemical Analysis

Concentrates and forages were sampled weekly during the data collection period. Samples were dried at 55 °C in a forced-air oven for 72 h. Dry matter content was determined weekly and used to adjust the proportion of each ingredient in the total diet. Samples were ground through a 1-mm screen and composited by heifer for each experimental period. Frozen fecal sub-samples were thawed and dried at 55 °C until constant weight, and then ground using a hammer mill with 1-mm screen (Christie-Norris Laboratory Mill, Christie-Norris Ltd. Chelmsford, UK). Ground fecal samples were then composited per heifer for each experimental period. Orts were dried at 55 °C for 72 h, ground through a 1-mm screen, composited by heifer for each period, and stored. Samples of feces, orts, and feed ingredients were analyzed in duplicate according to the AOAC (2000). Samples were analyzed for DM by drying at 135 ºC for 2 h (method 930.15; AOAC, 2000) and ether extract determined according to method 920.39 (AOAC, 2000). Crude protein was determined by Kjeldahl method of nitrogen determination in feed and forages using a 2400 Kjeltec analyzer unit (method 984.13; AOAC, 2000) and soluble crude protein using the method published by Roe et al. (1990). All samples were subjected to a water wash (500 ml) before fat extraction (method 922.06; AOAC, 2000). Starch was analyzed using the method described by Hall (2009), including the use of acetate buffer and corrected for free glucose, and ash (method 942.05; AOAC, 2000). With respect to fiber analysis, NDF was carried out with heat stable α-amylase and the addition of sodium sulphite (method 2002.04; AOAC, 2000) and ADF according to method 973.18 (AOAC, 2000). Gross energy values of feed ingredients, orts and fecal samples were determined using a bomb calorimeter (Model 1281, Parr Instrument Company, Moline, IL). Apparent nutrient digestibility coefficients were determined as the difference between the amount of nutrients in feed and feces.

4.2.6 Statistical Analysis

Voluntary intake, nitrogen balance, in-dwelling pH measurements, and total tract nutrient digestibility coefficients were analyzed as a Latin square design using the mixed procedure of SAS (Version 9.2; SAS Inst. Inc. Cary, NC). The statistical model was $Y_{ijk} = \mu + \rho_i + \delta_j + \alpha_k + e_{ijk}$, where, μ is the overall mean, ρ_i is the fixed effect of the ith period, δ_j is the random effect of the jth cow, α_k is the fixed effect of the kth treatment and Y_{ijk} is the observation for the experimental unit in the ith period, jth cow, the kth treatment effect and e_{ijk} = residual error term,

which was distributed normally. Rumen pH, VFA and ammonia data were analyzed as a Latin square design with repeated measures. The statistical model included period, treatment, time, and treatment by time interaction as fixed effects, and heifer as a random effect. The statistical model was $Y_{ijk} = \mu + \rho_i + \delta_j + \alpha_k + (\rho\alpha)_{ik} + e_{ijk}$, where, μ is the overall mean, ρ_i is the fixed effect of the *i*th period, δ_j is the random effect of the *j*th cow, α_k is the fixed effect of the *k*th treatment and Y_{ijk} is the observation for the experimental unit in the *i*th period, *j*th cow, the *k*th treatment effect and e_{ijk} = residual error term, which was distributed normally. The Kenward Roger option was used to adjust standard errors. Nine covariance structures were tested. These included autoregressive 1 (AR [1]), compound symmetry (CS), heterogeneous autoregressive (ARH [1]); unstructured (UN), variance components (VC), Toeplitz (Toep), heterogeneous compound symmetry (CSH), heterogeneous Toeplitz (Toeph), and simple. The covariance structure with the lowest AIC and BIC values was selected (Littell et al. 2000). For all statistical analyses, significance was declared at a P-value ≤ 0.05 and trends at a P-value ≤ 0.10. Differences among treatments where evaluated using pre-planned contrasts: Control vs. High Starch blended feed pellets; 2; Control vs. High Fat blended feed pellets; 3: High Starch vs. High Fat blended feed pellets; and 4: High vs. Low blended feed pellets.

4.3 Results and Discussion

4.3.1 Blended Pellets Analysis

The chemical analysis of the four BP and their ingredient make-up is given in Table 4.2. The HS BP were formulated to be 45% starch while the HF BP were formulated to be 8.8% EE. Analysis showed the two HS pellets averaged 43.6% starch while the HF pellets averaged 8.3% EE. The pellets were also formulated to vary in soluble crude protein content (37 vs. 27% of CP). Actual SCP averaged 39.6% and 22.0% (% of CP) for the HSP and LSP pellets, respectively. All pellets were formulated to be isonitrogenous (17.0% CP) and isocaloric (1.92 and 1.28 Mcal NE_m and NE_g kg^{-1} DM, respectively). While there was some variation in CP level of the four pellets (range 16.2 to 21.1%), they averaged 18.4 ± 2.36% CP. Net energy of gain values as determined using the Weiss equation (Weiss et al., 1992) were 1.18 ± 0.04 Mcal kg^{-1} for the HS BP and 1.16 ± 0.05 Mcal kg^{-1} for the HF BP. As discussed in Trial 1, the discrepancy between formulated vs. actual nutrient specifications particularly for the SCP and CP levels could result from a number of factors. First, nutrient specifications used in the formulation were based on

2009-2010 crop years. It is possible that the specific ingredients used in the pellets which were mixed in 2011 differed from our original sample set. As well the BP were manufactured by a commercial factory and it is possible that there were issues with mixing accuracy.

Table 4.2: Chemical analysis of strategically blended by-product pellets used in Trial 3

	Blended pellets [z]			
	HS HSP	HS LSP	HF HSP	HF LSP
Pellet analysis (% DM basis)				
DM	88.3	88.6	89	88.8
CP	21.1	19.7	16.2	16.7
Soluble Protein[y]	44.7	33.7	34.5	22.2
Fat	3.7	3.0	8.4	8.2
Starch	42.7	44.4	22	21.9
Sugar	1.9	1.2	2.0	1.5
NFC	49.5	49.5	30.5	37.5
ADF	11.4	12.1	23.6	22.6
NDF	19.7	22.3	37.8	31.7
GE	4.17	4.21	4.32	4.45
Ash	7.3	6.8	9.6	8.7
Ca	0.94	0.99	0.95	1.08
P	0.44	0.43	0.37	0.47
NE_m Mcal Kg^{-1} [x]	1.83	1.76	1.74	1.81
NE_g Mcal Kg^{-1} [x]	1.21	1.15	1.12	1.19

[z]HS HSP: high starch - high soluble protein; HS LSP: high starch - low soluble protein; HF HSP: high fat - high soluble protein; HF LSP: high fat - low soluble protein.
[y]As % of Crude Protein.
[x]Calculated using Weiss equations (1992).

4.3.2 Diet Composition and Analysis

The ingredient and chemical composition of the total mixed rations fed in the metabolic trial is given in Table 4.1. As designed, ether extract was higher in diets supplemented with HF pellets than those supplemented with HS BP and compared to the control diet (5.6, 2.44 and 1.99%, respectively; Table 4.1). Similarly, starch content was higher in the control and the HS diets (32.6 and 27.2 vs. 17.9%) compared to HF diets. Diets supplemented with HF pellets contained higher levels of ADF (22.9 vs. 17.9 and 18.5%) and NDF (40.3 vs. 31.9 and 33.6%) compared with the control and HS diets, respectively. This was a result of the formulation of the HF BP which used high levels of fibrous materials such as out hulls, pea and grain screenings. The difference in SCP (% of CP) between total mixed diets supplemented with HS BP was 51.9 vs. 46.5%, whereas with the HF pellets, dietary SCP varied from 46.9 to 40.8%. The soluble CP

content of the control diet based on ingredient analysis was 44.1%. Crude protein content of the control diet averaged 11.9 ± 0.23% while the four treatments diets averaged 14.1 ± 0.93%. All diets met recommended levels for cattle gaining at the targeted performance of 1.35 kg d^{-1} (NRC, 1996).

4.3.3 Dry Matter and OM Intake

Relative to cattle fed the control diet, DMI and OMI (Kg d^{-1} or % of BW daily) were not affected (P>0.05) by replacing barley grain with either the HS or HF BP (Table 4.3). Nor was there any difference between cattle fed HS vs. the HF BP. In agreement with these results, Elliot et al. (1997) did not find any difference in DMI or OMI when corn starch was replaced with different sources of fat to supply 5% total fat to each diet. Levels of added fat were close to those used in the current study (5% EE; DM basis). In another experiment by Hussein et al. (1995), it was concluded that fat from canola seed supplying 5% of dietary DM had no detrimental effect on DMI when diets containing different levels of forage were fed *ad libitum* to steers. Moreover, Leupp et al. (2006) did not find any differences in DMI and OMI when steers were fed low-quality hay and whole or ground canola seed (8% of dietary DM), suggesting that ground canola seed has no negative effects on ruminal and total tract digestibility. Similar results were reported by Aldrich et al. (1997) who replaced corn starch with canola seed at 10% of diet DM.

These results, however, differ somewhat from the backgrounding trials conducted as part of this research (Section 3), where it was found that steers fed the HF BP had higher (P<0.05) DMI compared to the control and HS BP diets. There are several possible explanations for this observation. One reason is that all treatments were formulated to be equal in net energy for gain content. Analyzed average NE_g content (Mcal Kg^{-1} DM) of the two HF pellets in the metabolic trial were 1.16 ± 0.05, while in Trial 1 they averaged just over 1.00 Mcal Kg^{-1} DM. Cattle fed the pellets from trial 2 would be able to consume less DM to get the same energy as the cattle in Trial 1. Secondly the discrepancy in DMI between trials may reflect the influence of the environment and its effect on fat utilization (winter vs. controlled environment). Brandt, (1995) reported that supplemental fat in cold weather may be a disadvantage as fat does not increase an animal's internal heat production to keep them warm, thus they may have to eat more to maintain core body temperature (Young, 1986). It has been shown that fat-supplemented diets had higher NE_m and NE_g (30 and 35%, respectively) in summer than in winter trial (Brandt, 1995).

Additionally, DMI varies between animals fed *ad libitum* vs. restricted intake regimens (Tyrrell and Moe, 1975), and group-fed vs. individual-fed (Coppock et al., 1972; Warnick et al., 1977), which may also explain why no differences were detected in DMI between treatments in the current study.

There was a trend (P=0.09) for cattle fed the high soluble protein BP to have higher DMI than cattle fed the low soluble protein BP. Similar to the current trial, Devant et al. (2000) reported no effect on DMI when heifers were fed diets formulated to contain different levels of CP and ruminal degradable protein (41 vs. 31.4, % of CP). Similar results were reported by Shain et al. (1998) and Pina et al. (2009). Contrary to these studies, positive effects of increasing levels of RDP on DM and OM intake has been reported with poor quality grasses (McCollum III and Horn, 1990; Köster et al., 1996; Heldt et al., 1999).

4.3.4 Ruminal pH

A significant time effect (P<0.01) was detected for rumen pH. This was expected as it is known that rumen pH changes over the course of the day as bacterial fermentation progresses (Russell and Diez-Gonzalez, 1997). No treatment by time interaction was detected for any measured parameter (P>0.05; Table 4.3). The variation in ruminal pH over time is a physiological response to feeding. The profile of ruminal pH has been well characterized with pH falling after each feeding, and thereafter rises progressively until the next meal (Penner et al., 2006). All treatments followed this pattern. The nadir was reached approximately three hours after morning feeding and approximately two hours after the second feeding. Even though after the second feeding all treatments followed the typical pattern, the control diet exhibited a more pronounced drop in ruminal pH (Appendix B, Figures B.1 and B.2). Relative to the cattle fed the control diet there was no effect of HS BP on mean ruminal pH (P=0.65). Heifers fed HF BP had higher (P=0.05) mean pH values than those fed the control diet and trended (P=0.07) to have higher mean pH than those fed the HS BP (Table 4.3). Heifers fed the HF BP also exhibited higher (P<0.01) minimum pH values than those fed the control diet and the HS BP (P=0.05; Table 4.3). Heifers fed the control treatment trended (P=0.06) to have rumen pH (min d^{-1}) values below the pH value of 5.8 for a larger period than those fed the HF treatment. Moreover, heifers fed the HF treatment showed a significant (P=0.03) reduction in duration of ruminal pH values below 5.8 threshold (min d^{-1}) when compared to those fed HS BP. As well, pH area below the

Table 4.3: Effect of strategically blended by-product pellets on dry matter and organic matter intake , and on rumen pH parameters

Variable	Dietary Treatment[z]					SEM[y]	*P*-values Contrasts			
	Control	HS HSP	HS LSP	HF HSP	HF LSP		Control vs. HS	Control vs. HF	HSP vs. LSP	HS vs. HF
Dry Matter Intake (kg Day^{-1})	13.9	14.4	13.2	14.9	13.4	1.11	0.89	0.80	0.09	0.65
Dry Matter Intake (% BW)	2.20	2.30	2.03	2.44	2.24	0.17	0.81	0.35	0.08	0.17
Organic Matter Intake (kg Day^{-1})	12.0	12.4	12.3	11.4	11.7	0.85	0.66	0.54	0.89	0.23
Organic Matter Intake (%BW)	1.92	1.98	1.90	1.88	1.96	0.14	0.89	1.00	0.97	0.86
Mean Daily Rumen pH										
In-dwelling pH										
Mean pH	6.21	6.24	6.25	6.33	6.40	0.11	0.65	0.05	0.55	0.07
Minimum pH	5.53	5.69	5.68	5.82	5.88	0.12	0.13	<0.01	0.81	0.05
Maximum pH	6.79	6.69	6.79	6.82	6.83	0.09	0.48	0.69	0.4	0.20
Rumen pH parameter 5.8 or lower										
Total duration (min d^{-1})	210	232	189	149	36.7	75.5	1.00	0.06	0.13	0.03
Total duration (min kg^{-1}DMI)	14.9	16.7	13.4	10.7	2.7	5.54	0.94	0.07	0.13	0.04
pH area (pH*min)	41.1	36.9	27.1	22.6	3.63	13.3	0.41	0.02	0.13	0.05
pH area (area kg^{-1}DMI)	2.98	2.80	1.98	1.67	0.29	1.03	0.50	0.03	0.14	0.07

[z]HS HSP: high starch - high soluble protein, HS LSP: high starch - low soluble protein, HF HSP: high fat - high soluble protein, HF LSP: high fat - low soluble protein.

[y]SEM= Pooled standard error of the mean (n=5).

[x]Significant effect of time of collection (*P*=<0.01)

critical cut-off value of 5.8 was greater ($P<0.05$) for heifers fed the HS and the control treatments than for those fed the HF BP. This resulted in heifers on the control and HS treatments spending approximately 2 h d^{-1} more than heifers on the HF treatment with ruminal pH <5.8.

Animals fed the control diet also had greater ($P=0.02$) pH area (pH*min) below 5.8 than those fed the HF BP. Similarly, heifers fed the HS treatment showed a greater ($P=0.05$) pH area (pH*min) below 5.8 than heifers fed the HF BP. Cattle supplemented with the HF BP had lower ($P=0.07$ and $P=0.03$) acidosis index than cattle fed the HS BP and the control diets, respectively. The threshold of 5.8 was used as it has been proposed that values between pH 5.5 and 5.8 represent mild ruminal acidosis (Nocek, 1997; Maekawa et al. 2002, Beauchemin and Yang, 2005, Penner et al. 2007). Aschenbach et al. (2011) used pH 5.8 as a critical threshold based on changes in microbial diversity and activity. The pH results from the present study all point to the fact that cattle fed the HF BP had less acidic rumen environment that animals fed the HS BP and the control diets. These data indicate that heifers fed the control and HS BP diets experienced mild ruminal acidosis as defined by Penner et al. (2007) although no clinical signs were observed during the trial.

A likely explanation for the fact that mean pH values were higher in animals fed HF BP compared to those fed the other treatments is replacement of rapidly fermentable carbohydrate with non fermentable fat and possibly the effect of fatty acid bio-hydrogenation within the rumen. It is known that fermentation of carbohydrate produces short chain fatty acids (SCFA) which can dissociate, consequently decreasing rumen pH (Allen, 1997; Russell and Rychlik, 2001). Following this logic, lower levels of fermentable carbohydrate in the HF BP diets would result in increased ruminal pH relative to the control and HS BP diets. Elliot et al. (1997) reported that replacing cornstarch with different sources of fat resulted in an increase in ruminal pH. Similar results have been reported when canola screenings were replaced with a source of energy with higher fermentable carbohydrate (Pylot et al. 1999). It is also known that when fermentation of carbohydrate occurs, protons are released, thus, decreasing pH. In contrast fat sources with high degree of unsaturated fatty acids capture protons when they are hydrogenated in the rumen (Doreau and Yves, 1997). It should be noted however that only 1 -2% of the metabolic hydrogen is used in this process (Harfoot and Hazlewood, 1988).

There was no effect (P>0.05) of level of SCP (HSP vs. LSP) for any ruminal pH parameters measured (Table 3.3). Similar results were shown by Shain et al. (1998) who fed supplemental RDP using increasing levels of urea in diets of finishing cattle.

4.3.5 Rumen Fermentation Parameters (VFA and NH_3-N)

As expected, there was a significant time effect (P<0.01) for ruminal NH_3-N and VFA concentration. Rumen fermentation showed a diurnal pattern after feeding with an increase in VFA and ruminal NH_3-N after both morning and afternoon feedings in agreement with France and Dijkstra (2005) and Nagaraja and Titgemeyer (2007), (Appendix B, Figures B.3 and B.4, respectively). There was no treatment by time interaction (P>0.05) for any measured rumen parameter. As well, other than valerate there was no (P>0.05) effect of SCP. Total VFA concentration did not differ (P>0.05) among treatments (Table 4.4). However, a tendency for lower (P=0.06) total VFA production was observed in animals fed HF diets compared to those fed HS BP diets. This result likely reflects the difference in rumen fermentability of carbohydrate versus fat. Heifers fed HF BP had lower propionate production than those fed the control and the HS diets (P=0.04 and 0.01, respectively). Additional rumen available starch has been reported to result in higher propionate production (Phillipeau et al. 1999, Jouany et al. 2000). Replacing highly fermentable carbohydrate with a source of less fermentable energy has been shown to reduce microbial fermentation activity, decrease propionate and total VFA production, and increase ruminal pH (Ørskov, 1986). There was no difference in A:P ratio (P>0.05) across treatments (Table 4.4); however a tendency (P=0.09) to increase the A:P ratio was observed when heifers were fed HF BP relative to heifers supplemented with HS BP. This was due to the lower propionate concentration relative to heifers fed HS BP previously reported.

There was no effect (P>0.05) of either form of BP on acetate (Table 4.4). This result can be explained by the absence of an effect of treatment on ADF and NDF digestibility as will be discussed in next section. Generally, rumen fermentation parameters such as VFA levels in cattle fed diets containing 50:50 forage:concentrate have not been altered when fat supplementation was below 6% (Palmquist, 1991; Bock et al. 1991; Zinn and Shen, 1996). Valerate, isobutyrate, and isovalerate were higher (P<0.05) in HS BP compared to the control and HF BP treatments. These branched chain VFA are the by-products of catabolism of branched-chain AA (Allison, 1970) suggesting that rumen available energy and protein was higher for this treatment. These

results are similar to Aldrich et al. (1993) who fed diets formulated to vary in rumen available energy and protein content. They reported higher molar proportion of valerate when cattle were fed with higher rumen available energy, and higher isobutyrate and valerate when higher rumen available protein levels were fed.

Ruminal NH_3-N values in the current study were within the range (3.3 to 8.5 mg dL^{-1}) previously cited as optimum for rumen fermentation (Kang-Meznarich and Broderick, 1980) and at or above the upper limit (5 mg NH_3-N dL^{-1}) reported as adequate for optimal microbial protein synthesis as suggested by Satter and Slyter (1974). However, it is difficult to suggest an optimum level of NH_3-N for rumen function as it depends on the fermentability of a particular diet (Erdman et al. 1986). Heifers fed the control diet exhibited lower ($P<0.01$) NH_3-N concentration than heifers fed the HF or HS BP (Table 4.4). This difference may be a result of the CP content of the total mixed diets as well as due to the processed nature of the pellets (Beauchemin et al. 2001; Pylot et al. 2000; William. 2007). The control diet was 11.9% CP relative to 14.9 and 13.3% CP for the HS and HF BP diets, respectively. Yang et al. (2000) reported higher rumen ammonia concentrations when feeding highly processed grain. Likewise, heifers fed the HF treatment had lower ruminal NH_3-N concentration than heifers fed the HS treatment ($P<0.01$). This difference can partially be attributed to the fact that ruminal ammonia concentration increases as dietary CP increases (Satter and Slyter, 1974; Mehrez et al. 1977; Van Soest, 1994; Shain et al. 1997). Clear evidence of this increase in rumen ammonia is noted when barley is replaced for DDGS (Beliveau and McKinnon, 2009; Walter et al. 2011) or when urea is added to the diet (Shain et al. 1997). When the level of soluble protein was contrasted (HSP vs. LSP) no differences ($P>0.05$) were detected for NH_3-N concentration.

4.3.6 Apparent Nutrient Digestibility Coefficients

Relative to heifers fed the control diet there was no effect ($P>0.05$) of HS and HF treatment on DM and OM digestibility. However, a trend for lower total tract OM digestibility was noted for heifers fed HF BP diets compared to those fed both the control and HS BP diets ($P=0.07$ and 0.06, respectively; Table 4.5). It has been reported that OM digested in the rumen and total tract OM digestibility were greater for animals fed a control diet with no added fat, than for those fed fat-supplemented diets (Zinn 1989; Elliot et al. 1997). Elliot et al. (1997) attributed this effect to the fact that fat was less fermentable than the starch supplement that was replaced.

Table 4.4: Effect of strategically blended by-product pellets on rumen fluid characteristics of cattle.

	Dietary Treatment[z]						*P*-values Contrasts			
	Control	HS HSP	HS LSP	HF HSP	HF LSP	SEM[y]	Control vs. HS	Control vs. HF	HS vs. HF	HSP vs. LSP
VFA *(mmol 100 mol^{-1})*										
Acetate	60.4	62.5	60.4	56.0	62.3	2.36	0.80	0.63	0.38	0.43
Propionate	28.7	27.4	26.5	22.4	23.8	1.59	0.42	0.01	0.04	0.88
Butyrate	10.7	12.7	12.1	10.6	12.3	0.85	0.12	0.44	0.31	0.54
Valerate	1.36	1.50	1.74	1.26	1.57	0.07	<0.01	0.52	<0.01	<0.01
Isobutyrate	0.81	1.09	1.03	0.91	0.94	0.04	<0.01	0.03	<0.01	0.75
Isovalerate	1.49	2.13	2.58	1.60	1.64	0.19	0.03	0.49	<0.01	0.22
Total VFA *(mmol L^{-1})*	104	108	105	93	103	5.36	0.67	0.24	0.06	0.42
A:P Ratio[x]	2.19	2.40	2.42	2.56	2.68	0.19	0.39	0.09	0.31	0.73
NH_3-N *(mg dL^{-1})*	4.92	13.1	11.6	9.91	10.6	0.68	<0.01	<0.01	<0.01	0.31

[z]HS HSP: high starch - high soluble protein, HS LSP: high starch - low soluble protein, HF HSP: high fat - high soluble protein, HF LSP: high fat - low soluble protein.

[y]SEM= Pooled standard error of the mean (n=5).

P-value for time was significant (*P*=0.01) for all tested variables; the *P*-value for treatment x time was not significantly different for any variables.

[x]A:P Ratio=Acetate (A, *mM*) : Propionate (*P*, *mM*) ratio

Ether extract digestibility was higher (P=0.01; <0.01) for heifers fed both forms of energy supplement (i.e. starch and fat, respectively; Table 4.4) relative to heifers fed the control diet. Grinding and pelleting as a method of processing feed have been shown as effective methods to improved apparent digestibility of fatty acids (Pylot et al. 1999; Aldrich et al. 1997). Greater (P<0.01) digestibility of EE was observed for heifers fed the HF BP relative to those fed the HS pellets. Dietary EE (% of DM) content was highest for HF, intermediate for HS, and lowest for the control diets (Table 4.1). Increasing dietary EE content has been associated with increasing EE digestibility (Moore et al. 1986; Jones, 1994). However, the relationship between dietary fat content and EE digestibility seems to vary upon EE intake (Moore et. al 1986; Zinn, 1994; Jones, 1994). Moreover, a detrimental effect on EE digestibility has been observed only when dietary fat intake exceeded 600, 650 and 730 g d^{-1} (Moore et al. 1986; Brandt, 1995; Pylot et al. 1999). In our study the averaged dietary fat intake was 715 g d^{-1}. No negative effect on EE digestibility was observed.

Crude protein digestibility was higher (P<0.05) for both types of energy supplement (i.e. starch and fat; Table 4.4) compared to the control diet, again showing the effect of processing on apparent total tract digestibility (Pylot et al. 2000a). Moreover, heifers fed the HF BP had lower CP digestibility than heifers fed HS BP. Readily fermentable carbohydrate drives microbial protein synthesis (Bach et al. 2005), which plays an important role in terms of ruminal digestion (Jouany et al. 2000). Since HS BP were designed to be higher in rumen available energy than HF BP, the greater total tract digestibility of CP may be a result of greater ruminal bacterial fermentation activity.

In terms of starch digestibility, the control treatment had higher (P<0.01) digestibility than HS and HF pellets. A possible explanation for this finding is that barley used in the control diet was temper-rolled which is highly digestible in the rumen (Beauchemin et al. 2001). These authors showed apparent total tract digestibility values in a range of 96.5 to 98% for temper-rolled barley grain processed to varying thicknesses (PI index from 82 to 65). High fat BP exhibited higher (P=0.04) starch digestibility than HS, the same was observed when LSP was compared to HSP (P=0.01). The reason for this finding is unclear, but may be a result of differences in the digestibility of the starch of the ingredients used (Herrera-Saldana et al. 1990; McAllister et al. 1990).

Table 4.5: Effect of strategically blended by-product pellets on apparent nutrient digestibility coefficients

Variable	Dietary Treatment[z]					SEM[y]	*P*-values Contrasts			
	Control	HS HSP	HS LSP	HF HSP	HF LSP		Control vs. HS	Control vs. HF	HS vs. HF	HSP vs. LSP
Apparent nutrient digestibility coefficient (% DM basis)										
Dry matter	69.0	68.8	67.7	63.4	65.2	2.32	0.80	0.11	0.12	0.88
Organic matter	71.4	71.5	70.2	65.7	67.2	2.13	0.84	0.07	0.06	0.96
Ether extract	80.3	85.8	84.1	90.8	91.4	1.35	0.01	<0.01	<0.01	0.70
Crude Protein	67.3	75.0	76.3	70.2	71.8	1.73	<0.01	0.10	0.02	0.41
Neutral detergent fiber	40.8	41.6	41.0	35.8	38.1	2.57	0.88	0.21	0.11	0.74
Acid detergent fiber	32.2	34.9	34.0	28.2	30.2	3.14	0.57	0.43	0.12	0.86
Starch	98.2	91.7	92.2	90.6	96.0	0.95	<0.01	<0.01	0.21	0.01
Gross energy	67.6	68.3	67.7	60.2	61.8	1.61	0.83	0.01	<0.01	0.76
Digestible energy (Mcal kg^{-1})	2.78	2.83	2.81	2.53	2.65	0.07	0.66	0.03	<0.01	0.48
NE_m (Mcal kg^{-1})[w]	1.41	1.45	1.43	1.22	1.31	0.05	0.63	0.03	<0.01	0.46
NE_g (Mcal kg^{-1})[w]	0.83	0.86	0.85	0.66	0.74	0.05	0.63	0.03	<0.01	0.45

[z]HS HSP: high starch - high soluble protein; HS LSP: high starch - low soluble protein; HF HSP: high fat - high soluble protein; HF LSP: high fat - low soluble protein.

[y]SEM= Pooled standard error of the mean (n=5).

[w]Calculated using NRC (1996) metabolizable energy values and equations for conversion to NE_m and NE_g.

Gross energy digestibility was lower (P<0.01) for heifers fed the HF BP relative to heifers fed the control and HS BP. Thus, diets supplemented with the HF BP had lower (P<0.05) DE (Mcal kg^{-1}) and NE_g (Mcal kg^{-1}) content than heifers fed the control and HS BP diets (Table 4.5). There was no difference (P>0.05) when the level of soluble protein was contrasted (HSP vs. LSP) for any digestibility coefficient or energy value (P>0.05), with the exception of starch digestibility.

4.3.7 Nitrogen Balance

Regarding total fecal output (kg d^{-1}; DM basis), heifers fed HF BP showed higher fecal output than those fed HS (P=0.01) and control (P=0.02) diets. Urine output (g d^{-1}) was lower (P<0.01) in heifers fed HF BP and the control diet compared to those fed the HS BP treatment (Table 4.6). Total N intake (g d^{-1}) was significantly higher for animals fed HS BP reflecting the higher CP level in this diet compared to the control and HF BP fed cattle (P=0.04; 0.01, respectively) (Table 4.6). Satter et al. (2002) reported that in grain-based diets fed in the finishing period, urinary-N accounts for 75% or more of excreted N. However, special circumstances can modify the route of N excretion. When fermentable carbohydrates reaches the lower tract, fermentation in this area of the gut can cause a shift in the route of N excretion to a greater proportion in feces vs. urine (Giger-Reverdin et al. 1991; Bierman et al. 1999). When HF BP diets are fed to ruminants, both the site of fibre and starch digestibility can be modified due to the antimicrobial effects of fatty acids (Jenkins, 1994; Doreau and Chilliard, 1997; Montgomery et al. 2007). Such a shift would affect microbial protein synthesis leading to an increase in CP concentration in feces. When fecal and urinary N excretion were analyzed as percentage of total N excretion, animals fed the control diet showed higher fecal (P<0.01) and lower urine N excretion (P<0.01) than those supplemented with the HF and HS diets (Table 4.6). No treatment differences (P>0.05) were observed in N retention (% of N intake) (Table 4.6). However, values ranged from 49.4 to 95.8 (g d^{-1}; Table 4.6) which are high. Nitrogen retention values of 22 to 26 g d^{-1} (Kohn et al. 2005; Ferrell and Jenkins, 1998), relate to a daily lean gain of approximately 2 kg in heifers. Nitrogen retention is calculated as the difference between N input and N output (Spanghero and Kowalski, 1997). This means that N retention can often be affected by errors in

Table 4.6: Effect of strategically blended by-product pellets on the nitrogen (N) balance in heifers.

Variable	Dietary Treatment[Z]					SEM[y]	*P*-values Contrasts			
	Control	HS HSP	HS LSP	HF HSP	HF LSP		Control vs. HS	Control vs. HF	HSP vs. LSP	HS vs. HF
Total N intake (g d^{-1})	244	324	303	259	274	20.6	0.04	0.24	0.83	0.01
Fecal output (kg d^{-1})	4.18	4.35	4.40	5.08	4.98	0.31	0.51	0.01	0.90	0.02
Urine output (kg d^{-1})	9.61	14.4	12.5	9.59	10.3	0.81	<0.01	0.36	0.11	<0.01
Fecal N excretion (g d^{-1})	80.1	80.9	73.5	77.1	77.1	5.68	0.60	0.57	0.41	0.98
% of total N excretion	44.7	34.7	36.2	36.8	36.7	2.21	<0.01	<0.01	0.75	0.56
Urine N excretion (g d^{-1})	101	153	135	133	135	14.9	0.02	0.05	0.53	0.44
% of total N excretion	55.3	65.3	63.8	63.2	63.3	2.21	<0.01	<0.01	0.75	0.56
N retained (g d^{-1})	62.8	89.4	95.8	49.4	61.9	14.8	0.11	0.68	0.52	0.02
% of N intake	26.2	27.4	30.7	18.5	22.5	4.62	0.62	0.31	0.45	0.09
Total N excreted (g d^{-1})	181	234	208	210	212	18.5	0.04	0.10	0.41	0.49
% of N intake	73.8	72.6	69.3	81.5	77.5	4.62	0.62	0.31	0.45	0.09

[Z]HS HSP: high starch - high soluble protein; HS LSP: high starch - low soluble protein; HF HSP: high fat - high soluble protein; HF LSP: high fat - low soluble protein.

[y]SEM= Pooled standard error of the mean (n=5).

N determination leading to overestimation of retained N. Finally, no treatment effects were seen on total N excretion (g d^{-1} or % of N intake), with the exception of heifers fed the HS pellets exhibiting higher (P=0.05) N excretion (g d^{-1}) than those fed the control diet (Table 4.6). This result may be due to the higher N intake in those animals fed HS BP, and the strong positive relationship between total N intake and total N excretion (Van Soest, 1994).

4.4 Conclusion

The results clearly demonstrate that feeding diets supplemented with HF BP increased rumen pH. Overall, animals fed the BP treatments had higher rumen NH_3-N than cattle fed the control diet. Acetate and total VFA concentrations were not affected by feeding HS or HF BP reflecting the absence of any negative effect on fiber digestion. However, propionate was decreased in heifers fed HF BP due to lower fermentability of the ingredients making up the BP than that found in the HS BP and the control diets. The use of strategically BP did not have any marked effects on apparent nutrient digestibility. Gross energy digestibility as well as DE content (Mcal kg^{-1}) were lower when diets were supplemented with HF BP. No effect of soluble protein content was observed suggesting that all diets contained adequate levels of SCP to support rumen fermentation. Nitrogen excretion in the feces was increased when animals were fed HF BP relative to the animals fed HS BP diets. However, no treatment effect was observed in total N excretion when it was analyzed as % of N intake. The results from this trial indicate strategically blended feed pellets can be used as a complete substitute for barley grain with no adverse effects on rumen fermentation parameters. However, caution needs to be exercised when feeding extensively processed feed like HS BP due to increased ruminal fermentation rate which may increase the risk of acidosis.

5 GENERAL DISCUSSION

The research reported in this thesis involved field and metabolic trials designed to test the use of strategically blended feed pellets on feedlot performance, rumen fermentation and nutrient digestibility. Two trials were designed (Trials 1 and 2) to evaluate backgrounding performance and real-time ultrasound carcass characteristics of steers fed strategically blended feed pellets (BP) in backgrounding diets. These pellets were formulated to be high in starch (HS) or fat (HF) and either high (HSP) or low (LSP) in soluble protein. Results from Trial 1 suggest that steers fed HS BP exhibited decreased feed intake, had similar gains and feed efficiency when compared to the control-fed animals. The difference in DMI between cattle fed the control diet and those supplemented with the HS BP was not a reflection of total starch intake. It is possible, however that the nature of the pellets (i.e. processing and/or form of starch) influenced DMI between the HS and control fed cattle. The HS BP used ground wheat midds as a starch source relative to barley grain in the control diet which is more rapidly fermented by rumen bacteria. The use of ground wheat can lead to issues with acidosis and digestive upsets and therefore decrease DMI (Stock and Britton, 1993). However, this speculation was not confirmed by the results of the metabolic trial where pH profiles did not differ between heifers fed the control and the HS BP diets.

On the other hand, results from both trials suggest that steers exhibited increased feed intake, had similar or decreased gains and thus decreased feed efficiency when fed HF BP. The likely explanation for these results is that the HF BP were lower in net energy for gain than the HS BP and the barley grain. This is evident from the fact that the cattle fed the HF BP were less efficient than either the control or HS BP fed cattle. Steers fed HF BP consumed more feed to gain the same weight, indicating a lower energy density for the two HF diets. This was confirmed by the calculated NE_g density based on animal performance. Diets formulated with HF BP were 7.5 and 8.7% lower in NE_g than those fed the control and HS BP diets, respectively.

In the current study the replacement of readily fermentable carbohydrate with fat did not result in a superior G:F ratio. Poor feed efficiency in cattle supplemented with dietary fat does not agree with other published results (Zinn, 1989; Brandt, 1995). The results of the current study are a reflection of the lower NE_g of the HF diets and not due to disruption of rumen microbial fermentation activity. Since the HF BP diets had less calculated NE_g (Mcal kg^{-1}) than that of the HS BP and control diets, this would help to explain the poor efficiency in cattle

supplemented with the HF BP. The cattle simply had to eat more to gain the same. Moreover, a lower propionate production, a trend to have lower total volatile fatty acid levels and higher acetate:propionate ratios were observed in those animals fed the HF BP relative to the those fed the HS BP and the control diets. This may also help to explain the poorer G:F ratio as it has been proposed that digestion of starch results in more propionate production, which is the only major precursor for glucose in ruminants (Young, 1977; Brockman and Laarveld, 1986). Moreover, it is important to highlight the fact that propionate is more energetically efficient than acetate in promoting animal performance (Jenkins and Thonney 1988). It is well known that fermentation of carbohydrates produce short chain fatty acids (SCFA) which can dissociate, consequently decreasing rumen pH (Allen, 1997; Russell and Rychlik, 2001). Lower levels of fermentable carbohydrate in the HF BP diets resulted in increased ruminal pH relative to the control and HS BP diets which had higher starch levels. Elliot et al. (1997) reported that replacing corn starch with various sources of fat resulted in an increase in ruminal pH. The pH results from the metabolic trial all point to the fact that cattle fed the HF BP had a less acidic rumen environment than animals fed the HS BP and the control diets. This data indicates that heifers fed the control and HS BP diets experienced mild ruminal acidosis as defined by Penner et al. (2007) although no clinical signs were observed during the trial.

Ultrasound carcass traits including *longissimus dorsis* area and subcutaneous fat thickness were unaffected by treatment. While steers consuming BP were able to sustain the same average daily gain as steers consuming barley-based diet, they were not as efficient.

Regarding apparent nutrient digestibility coefficients relative to the heifers fed the control diet there was no effect of HS and HF treatment on DM and OM digestibility. However, a trend for lower total tract OM digestibility was noted for heifers fed HF BP diets compared to those fed both the control and HS BP diets. It has been reported that OM digested in the rumen and total tract OM digestibility were greater for animals fed a control diet with no added fat, than for those fed fat-supplemented diets (Zinn 1989; Elliot et al. 1997). Elliot et al. (1997) attributed this effect to the fact that fat was less fermentable than the starch supplement that was replaced. Ether extract and crude protein digestibility was higher for heifers fed BP relative to heifers fed the control diet. Grinding and pelleting as a method of processing feed has been shown as effective methods to improved apparent digestibility of fatty acids (Pylot et al. 1999; Aldrich et al. 1997). No detrimental effect on EE digestibility was been observed in the present study. In terms of

starch digestibility, the control treatment had higher digestibility than HS BP and HF BP. Gross energy digestibility was lower for heifers fed the HF BP relative to heifers fed the control and HS BP. Thus, diets supplemented with the HF BP had lower DE and NE_g that heifers fed the control and HS BP diets. These results confirmed the lower NE_g values for the BP diets determined in Trial 1 based on animal performance. There was no difference when level of soluble protein was contrasted (HSP vs. LSP) for any digestibility coefficient or energy value, with the exception of starch digestibility. The reason for this finding is unclear, but may be a result of the reduced spread in SCP between treatments than formulated (i.e 3.0 vs. 10) or due to differences in energy availability of the ingredients used (Herrera-Saldana et al. 1990; McAllister et al. 1990).

The final objective of this thesis was to determine the quantity of nitrogen excreted and retained when feeding BP. No treatment effects were seen on total N excretion, with the exception of heifers fed the HS BP exhibiting higher N excretion than those fed the control diet as a consequence of the higher N intake in those animals. When fecal and urinary N excretion were analyzed as percentage of total N excretion, animals fed the control diet showed higher fecal and lower urine N excretion than those supplemented with the HF and HS diets. No treatment differences were observed in N retention as % of N intake. This result suggests that feeding strategically BP has potential positive implications for the environment as it can lead to reduced nutrient (N) excretion.

Although the inclusion of BP in diets for backgrounding cattle caused reduced or increased intake and similar or poorer feed efficiency, cattle were able to maintain the same average daily gains as cattle consuming a barley-based backgrounding diet. Performance results from the feedlot trial are supported by the results of the metabolism trial, including the decrease in propionate production and the lack of any effect on DM digestibility.

A brief economic analysis is listed in Appendix B and is based on the performance of animals from Trial 1 and 2. It is interesting to compare the economic results of cattle fed BP with that of cattle fed the control barley silage/barley grain backgrounding diet. Feed costs per kilogram of gain averaged on both trials for the barley grain/barley silage control, and the HS BP and HF BP diets were $1.19, and $1.17 and $0.99 per kg of gain, respectively. It was only when cattle were fed the HF BP that the cost of gain decreased markedly ($0.20 per kg of gain) and therefore a significant improvement in total feed costs, averaging $27 less than the control fed

cattle. The main reason for this pricing difference was due to the fact that HF BP were formulated with less costly (oat hulls) and more energetically dense ingredients (i.e. canola screenings) than those used for HS BP (i.e. wheat middlings).

The development of strategically blended feed pellets using by-products arising from industrial processing of oil seeds and cereal grains is a promising alternative for Saskatchewan since it is a leader in the development of the Canadian ethanol industry, canola and oat processing and cereal grain growing. The development and use of these BP can lead to a profitable beef cattle sector generating exciting opportunities for value-added growth of the feed industry. Consequently, competitiveness of Saskatchewan cattle producers and the value of crop by-products will be enhanced. Moreover, the integrated development of the cattle, crop processing and ethanol industries may help each of these sectors to reach their potential and create a renewed rural economy.

Besides the economic benefit of using BP, feeding BP does not increase the potential of having nutrient excretion issues. Therefore, strategically blended feed pellets can be supplemented into barley-based backgrounding rations with minimal impacts on performance, but a large economic impact.

In conclusion, results support the hypothesis indicating that strategic blending of by-product feeds that vary in rumen available energy and protein content can be accomplished to meet metabolizable energy and protein requirements of growing cattle and minimize over feeding of nutrients such as protein and phosphorus.

Future areas of research should concentrate on:

1. The impact of feeding BP on performance of finishing cattle;
2. Omasal sampling in cattle fed increasing inclusion rates BP diets to determine rumen passage rate, microbial protein synthesis as well as nutrient digestion ruminally and post-ruminally;
3. The impact of feeding HF BP on performance of receiving calves;
4. The effect of feeding HF BP on reproductive performance of breeding beef cows;
5. Alternatives to minimize variation in feed components such as use of NIR.

6 GENERAL CONCLUSION

The results of this thesis indicate that strategically blended feed pellets can be a viable alternative for supplementing energy and protein in backgrounding diets. Results suggest that steers exhibited increased feed intake, had similar or decreased gains and thus decreased feed efficiency when fed HF BP. The likely explanation for these results is that HF BP were lower in net energy for gain than the HS BP and the barley grain. This is evident that cattle fed the HF BP were less efficient than either the control or HS BP fed cattle. Steers fed HF BP consumed more feed to gain the same weight, indicating a lower energy density for the two HF diets. This was confirmed by the calculated NE_g density based on animal performance. Also, results clearly demonstrate that feeding diets supplemented with HF BP increased rumen pH.. Overall, animals fed the BP treatments had higher rumen NH_3-N than cattle fed the control diet due to mainly high N intake and feed processing. Acetate and total VFA concentrations were not affected by feeding HS BP or HF BP reflecting the absence of any negative effect on fiber digestion. Moreover, no treatment effect was observed in total N excretion when analyzed as % of N intake, thus feeding BP does not increase the potential of having nutrient excretion issues in the environment. Nonetheless, cattle performed in a cost-efficient manner with exceptional gains when fed HF BP diets, indicating that strategically blended high fat feeds offer potential cost savings as a feed ingredient for intensive backgrounding programs. The economics of feeding strategically BP will depend on availability and price relative to other feed sources such as cereals grains. However, caution needs to be exercised when feeding HF pellets due to poorer G:F ratios and potential negative impacts on cost of gain.

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8 APPENDICES

8.1 Appendix A: Nutritional Composition and Variation in By-product Feeds of the Oil Seed and Grain Processing Sectors

8.1.1 Objective

The purpose of this trial was to determine nutrient composition and variability of by-products feeds arising from processing grain and oil seed sectors.

8.1.2 Material and Methods

8.1.3 Sample Collection and Analytical Procedures

Over two years, samples Canola (n=6), DGGS (n=8), oat hulls (n=8), pea screenings (n=10), grain screenings (n=10) and wheat midds (n=9) were taken by West Central Pelleting Ltd. Wilkie, SK. Subsamples of these materials were analyzed by Cumberland Valley Analytical Laboratory (Hagerstown, MD) according to the Association of Official Analytical Chemists, 2000 (AOAC). Analysis were carried out for moisture, DM, CP, adjusted protein, soluble protein, ADFP, NDFP, ADF, NDF, lignin, lignin:NDF ratio, sugar, starch, EE, ash, minerals, TDN, NE_l, NE_m, NE_g and NFC.

8.1.4 Results

The nutrient composition and statistical analysis of specific by-product feeds collect over the course of 2010 – 2011 by West Central Pelleting Ltd. Wilkie, SK. are reported in Table A.1, Table A.2, Table A.3, Table A.4.

Table A.1: Protein content and fraction of by-product feeds collected over the course of 2010 – 2011.

Group	Statistic	Dry Matter (%)	Protein				
			CP (%DM)	Adj. Protein (%DM)	Sol. Protein (%CP)	ADF Protein (%DM)	NDF Protein (%DM)
Canola Screenings (n=6)	Average	92.18	21.35	19.05	26.36	4.08	6.05
	SD	2.84	1.23	1.35	6.77	2.00	2.57
	Range	7.60	3.30	3.60	16.40	4.78	6.40
	CV (%)	3.09	5.77	7.11	25.67	48.98	42.42
DDG (n=8)	Average	89.44	37.21	37.21	16.89	2.92	4.94
	SD	0.96	2.27	2.27	1.58	0.61	0.56
	Range	3.00	5.40	5.40	4.90	1.54	1.70
	CV (%)	1.08	6.10	6.10	9.34	21.02	11.25
Oat Hulls (n=8)	Average	91.11	4.85	4.85	32.44	0.91	1.11
	SD	0.39	0.54	0.54	3.89	0.03	0.17
	Range	1.00	1.60	1.60	12.70	0.08	0.50
	CV (%)	0.43	11.08	11.08	11.98	3.60	15.52
Pea Screenings (n=10)	Average	90.40	20.31	20.31	49.66	1.16	1.90
	SD	0.66	2.35	2.35	9.19	0.38	0.72
	Range	2.30	7.50	7.50	29.30	1.16	1.90
	CV (%)	0.73	11.58	11.58	18.51	33.15	38.12
Grain Screenings (n=10)	Average	90.64	14.93	14.75	31.83	1.29	1.76
	SD	0.51	1.14	1.34	1.68	0.27	0.45
	Range	1.50	3.50	4.40	5.50	0.80	1.70
	CV (%)	0.57	7.64	9.09	5.28	21.06	25.30
Wheat midds (n=9)	Average	88.84	15.25	15.25	27.83	0.59	1.01
	SD	0.51	1.60	1.60	5.33	0.27	0.16
	Range	1.50	4.90	4.90	16.60	0.79	0.50
	CV (%)	0.58	10.46	10.46	19.15	45.43	15.98

Table A.2: Carbohydrates fraction of by-product feeds collected over the course of 2010 – 2011.

Group	Statistic	Carbohydrates						
		ADF (%DM)	NDF (%DM)	Lignin (%DM)	Lignin/NDF ratio (%NDF)	Sugar (%DM)	Starch (%DM)	NFC (%DM)
Canola Screenings (n=6)	Average	16.65	26.07	4.85	18.68	4.70	2.42	11.82
	SD	2.59	2.80	0.63	2.08	1.43	1.06	2.20
	Range	7.10	6.60	1.67	5.80	4.20	2.70	5.60
	CV (%)	15.53	10.74	12.95	11.12	30.39	43.67	18.65
DDG (n=8)	Average	13.89	28.04	4.25	15.16	6.01	4.35	25.70
	SD	1.12	1.09	0.42	1.48	1.02	2.78	2.53
	Range	3.90	3.30	1.48	4.60	3.10	7.60	8.50
	CV (%)	8.04	3.89	9.80	9.76	16.95	63.91	9.84
Oat Hulls (n=8)	Average	41.43	74.08	6.49	8.76	1.38	10.80	15.39
	SD	1.75	2.68	0.36	0.41	0.47	1.41	1.96
	Range	4.70	8.20	0.95	1.20	1.40	3.90	6.30
	CV (%)	4.21	3.62	5.57	4.72	34.50	13.04	12.77
Pea Screenings (n=10)	Average	16.42	25.63	3.30	12.98	4.74	31.67	44.65
	SD	3.05	3.94	0.63	2.36	1.07	4.63	5.45
	Range	8.50	11.60	1.96	6.00	3.40	13.40	16.70
	CV (%)	18.59	15.35	19.18	18.19	22.66	14.62	12.20
Grain Screenings (n=10)	Average	20.13	33.89	4.34	12.87	3.46	35.92	41.80
	SD	3.77	3.54	0.59	1.75	0.70	5.39	4.22
	Range	10.70	9.70	1.56	5.60	2.40	13.90	11.10
	CV (%)	18.71	10.46	13.54	13.61	20.31	14.99	10.09
Wheat midds (n=9)	Average	4.51	14.96	1.85	13.37	3.18	60.97	65.18
	SD	1.07	1.84	0.39	3.44	0.39	3.49	4.09
	Range	2.70	5.10	1.07	10.10	1.30	10.90	13.70
	CV (%)	23.70	12.30	21.16	25.70	12.17	5.72	6.28

Table A.3: Fat content and energy values of by-product feeds over the course of 2010 – 2011.

Group	Statistic	Fat	Energy/Indexes			
		Crude Fat (%DM)	TDN (%DM)	Mcal/Kg		
				NE_l	NE_m	NE_g
Canola Screenings (n=6)	Average	42.76	137.16	3.46	3.56	2.60
	SD	5.13	9.65	0.26	0.27	0.21
	Range	11.00	21.50	0.57	0.60	0.46
	CV (%)	12.00	7.03	7.55	7.67	8.06
DDG (n=8)	Average	8.79	83.46	1.97	2.04	1.38
	SD	1.36	3.89	0.10	0.11	0.10
	Range	4.40	12.80	0.33	0.37	0.33
	CV (%)	15.47	4.66	5.11	5.58	7.16
Oat Hulls (n=8)	Average	1.68	53.93	1.21	1.11	0.54
	SD	0.37	1.36	0.04	0.05	0.04
	Range	1.10	4.20	0.11	0.15	0.13
	CV (%)	22.05	2.52	3.05	4.45	7.50
Pea Screenings (n=10)	Average	5.14	77.20	1.80	1.85	1.22
	SD	1.23	2.55	0.06	0.08	0.07
	Range	3.50	7.80	0.20	0.22	0.20
	CV (%)	23.92	3.30	3.53	4.06	5.39
Grain Screenings (n=10)	Average	5.71	74.55	1.73	1.78	1.15
	SD	0.69	2.44	0.06	0.08	0.07
	Range	2.20	7.80	0.20	0.24	0.22
	CV (%)	12.11	3.28	3.53	4.23	5.95
Wheat midds (n=9)	Average	2.81	82.77	1.93	2.02	1.37
	SD	0.55	1.91	0.05	0.06	0.05
	Range	1.60	7.40	0.20	0.22	0.20
	CV (%)	19.62	2.31	2.69	2.82	3.75

Table A.4: Mineral content of by-product feeds collected over the course of 2010 – 2011.

Group	Statistic	Ash (%DM)	Mineral ppm										Cl^- (%DM)
			Ca	P	Mg	K	S	Na	Fe	Mn	Zn	Cu	
Canola Screenings (n=6)	Average	4.34	0.39	0.66	0.37	0.94	0.44	0.01	110.60	50.40	54.40	2.60	0.02
	SD	0.39	0.03	0.07	0.03	0.14	0.02	0.01	31.31	15.69	15.06	0.89	0.01
	Range	0.90	0.08	0.19	0.07	0.39	0.04	0.02	78.00	38.00	36.00	2.00	0.01
	CV(%)	9.01	8.43	10.75	7.10	14.86	3.74	65.08	28.31	31.14	27.68	34.40	22.82
DDG (n=8)	Average	5.56	0.14	0.90	0.42	1.32	0.59	0.27	191.17	120.50	130.17	7.00	0.18
	SD	0.61	0.04	0.06	0.04	0.07	0.21	0.05	49.34	61.60	56.06	2.10	0.01
	Range	1.90	0.13	0.16	0.10	0.24	0.59	0.15	133.00	154.00	147.00	5.00	0.03
	CV(%)	10.91	31.51	6.75	9.94	5.67	35.47	17.23	25.81	51.12	43.06	29.97	6.83
Oat Hulls (n=8)	Average	5.13	0.12	0.12	0.10	0.63	0.09	0.02	140.00	53.43	49.71	6.75	0.09
	SD	0.35	0.02	0.02	0.01	0.10	0.02	0.01	27.68	10.75	27.37	1.04	0.02
	Range	1.00	0.05	0.04	0.03	0.33	0.07	0.04	74.00	27.00	69.00	3.00	0.05
	CV(%)	6.82	13.62	13.54	10.10	16.31	25.83	64.87	19.77	20.13	55.06	15.33	19.81
Pea Screenings (n=10)	Average	5.69	0.32	0.42	0.24	0.97	0.27	0.02	356.80	55.78	72.11	9.44	0.11
	SD	1.72	0.12	0.03	0.02	0.18	0.04	0.01	67.66	11.18	19.30	3.81	0.03
	Range	5.60	0.38	0.09	0.06	0.54	0.11	0.01	178.00	32.00	66.00	12.00	0.08
	CV(%)	30.18	36.97	6.57	8.21	18.33	16.55	26.75	18.96	20.04	26.77	40.36	25.73
Grain Screenings (n=10)	Average	5.91	0.28	0.37	0.25	0.73	0.24	0.02	324.00	78.33	75.22	5.56	0.10
	SD	1.00	0.14	0.04	0.09	0.11	0.05	0.00	99.61	18.59	18.17	1.13	0.02
	Range	3.00	0.43	0.13	0.30	0.31	0.18	0.01	351.00	58.00	53.00	4.00	0.06
	CV(%)	16.88	50.41	10.04	35.95	14.51	23.16	22.43	30.74	23.73	24.16	20.35	17.74
Wheat midds n=9)	Average	2.64	0.07	0.38	0.18	0.56	0.19	0.01	68.83	47.11	53.67	2.89	0.08
	SD	0.64	0.03	0.05	0.02	0.07	0.04	0.00	19.16	15.51	18.15	0.93	0.02
	Range	1.90	0.09	0.19	0.07	0.18	0.11	0.01	45.00	58.00	62.00	2.00	0.05
	CV(%)	24.15	38.43	13.71	13.39	12.52	19.77	18.85	27.83	32.93	33.82	32.12	19.92

8.2 Appendix B: Effects of strategically blended feed pellets on VFAs, rumen ammonia-N and rumen pH

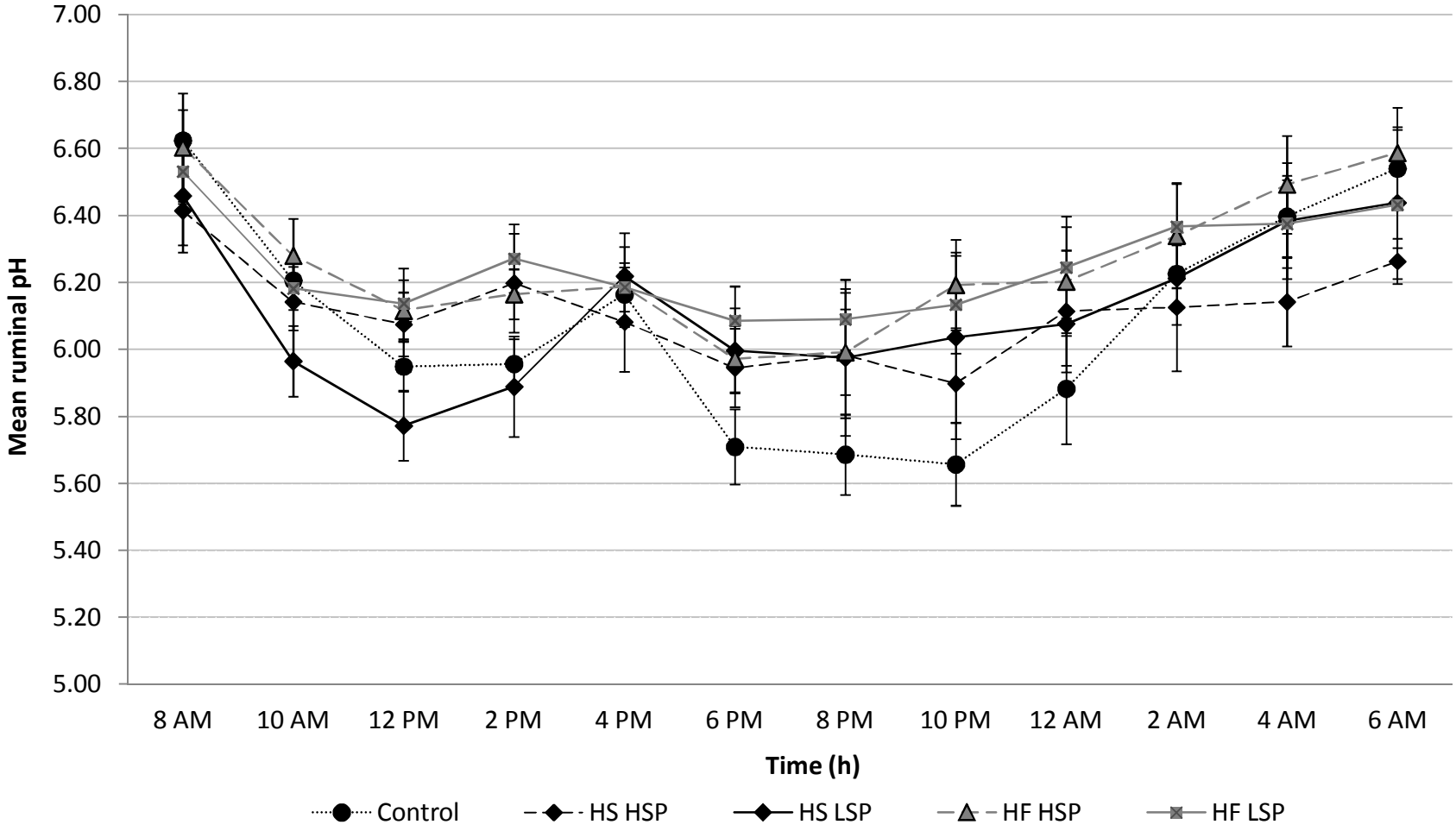

Figure B. 1: Effect of strategically by-product blended pellets on rumen pH of heifers using spot samples over a 24 h feeding period.

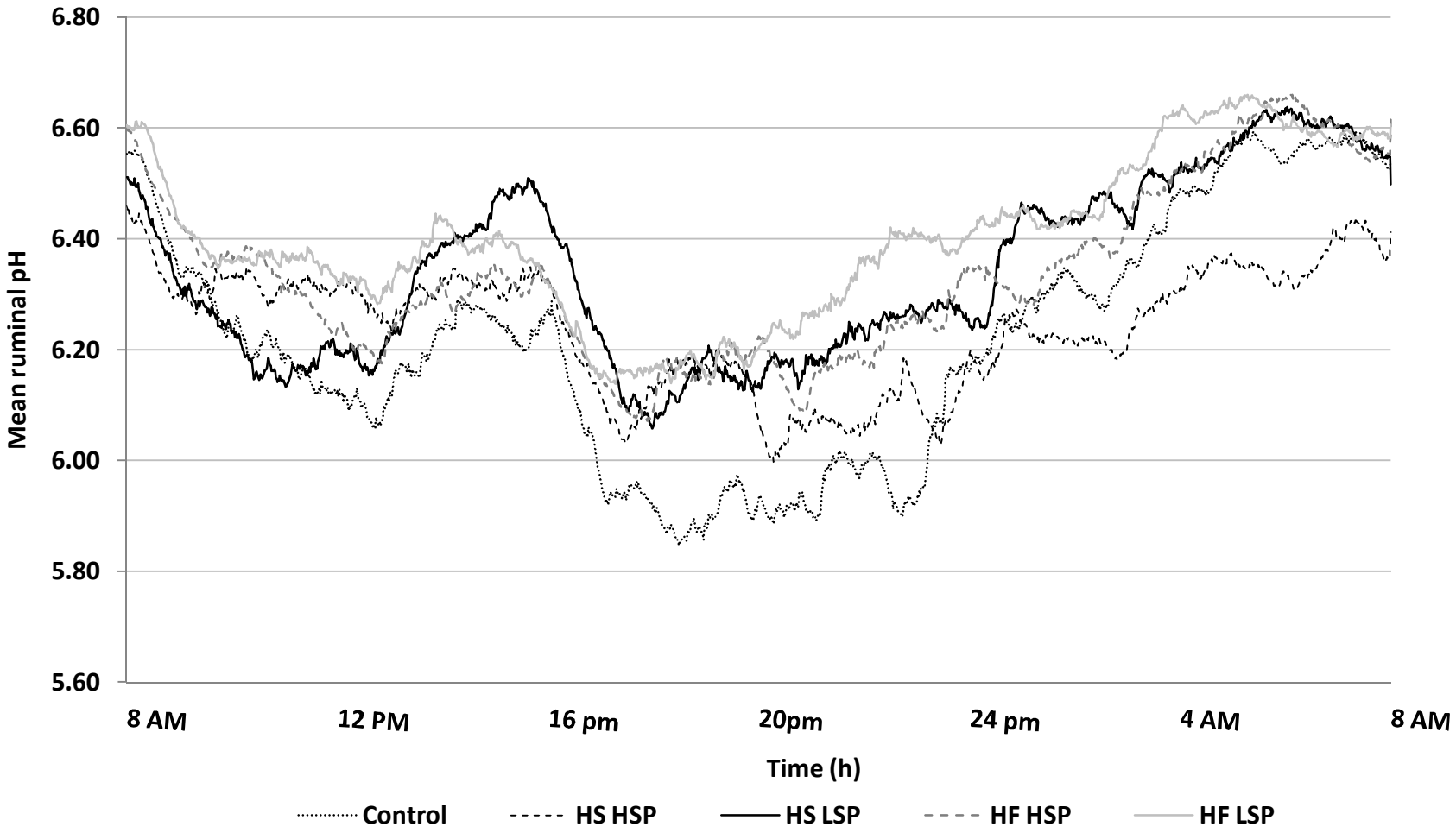

Figure B. 2: Effect of strategically by-product blended pellets on rumen pH of heifers using indwelling pH probes over a 24 h feeding period.

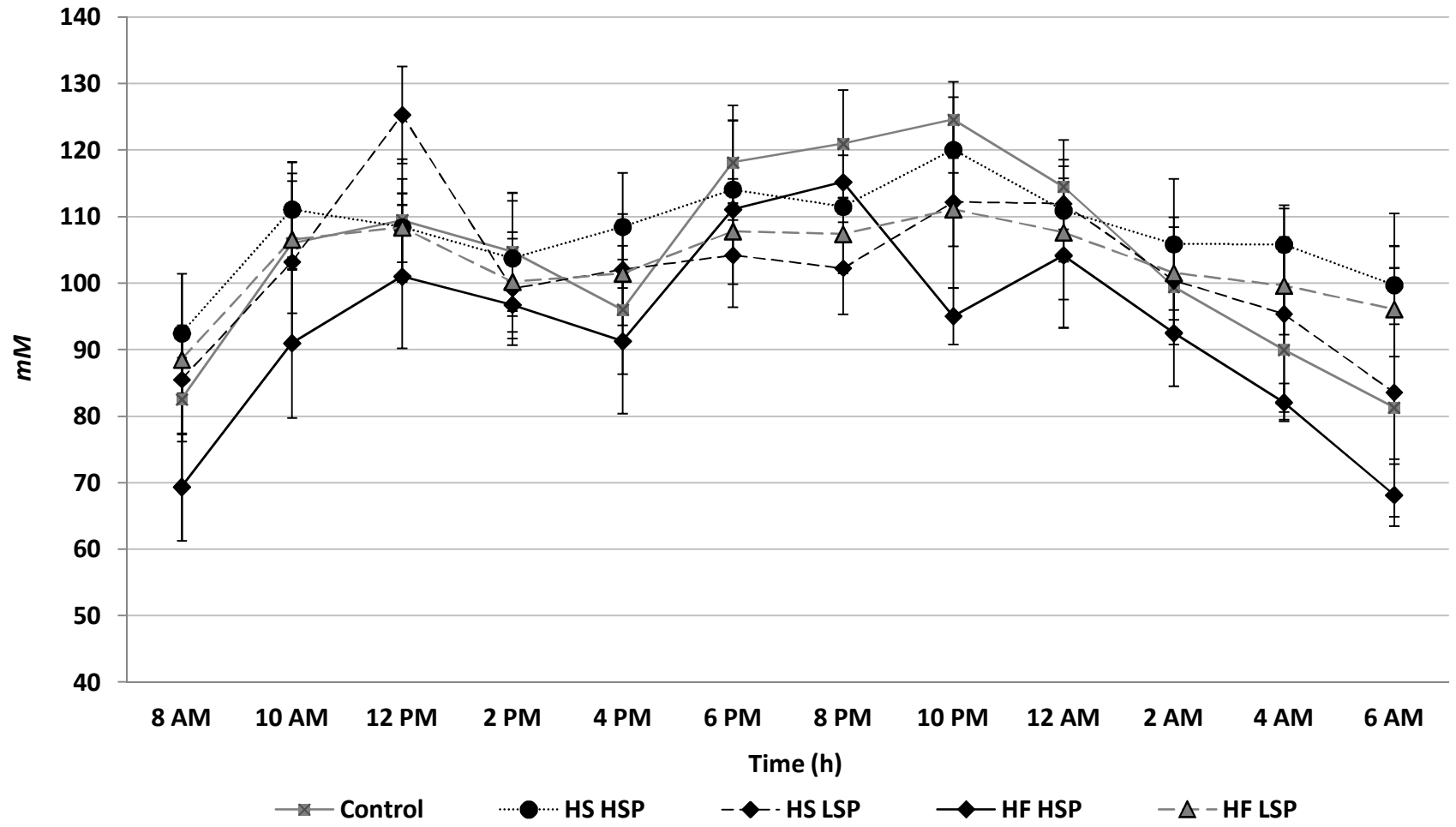

Figure B. 3: Effect of feeding strategically by-product blended pellets on the total volatile fatty acid concentration (mM) over a 24 h feeding period.

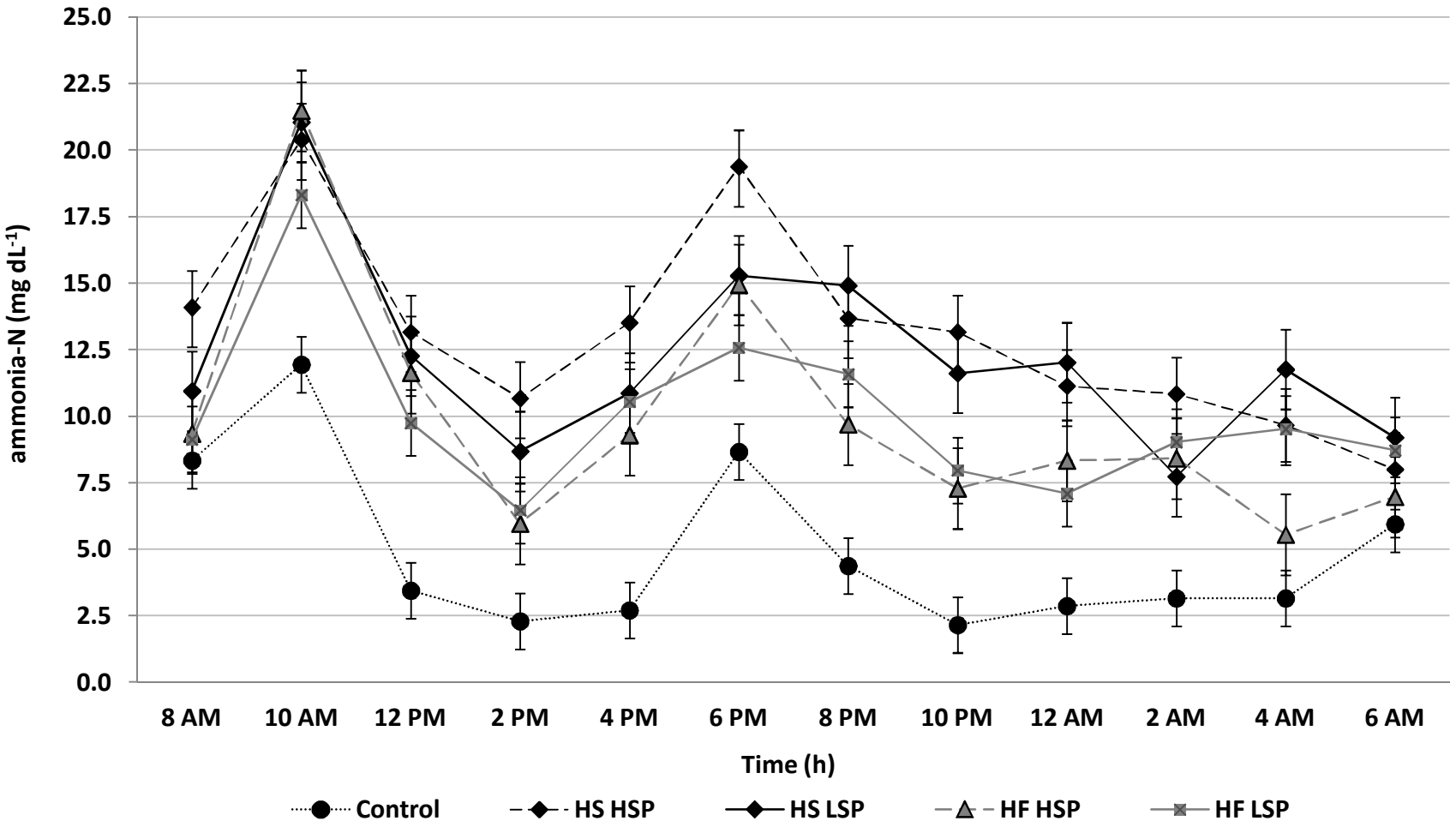

Figure B. 4: Effect of feeding strategically by-product blended pellets on rumen ammonia-N levels (mg dL^{-1}) over a 24 h feeding period.

8.3 Appendix C: Economic Results

A brief economic analysis was conducted using the animal performance data presented above. All costs were calculated for the 70 day period cattle on both trials.

Table C.1: The effects of strategically blended pellets on the cost of backgrounding calves over a 70 day period (Trial 1)

	Treatment				
	Control	HS HSP	HS LSP	HF HSP	HF LSP
Feed cost of grain ($ kg^{-1})	1.14	1.13	1.21	0.97	0.99
Total feed costs ($ $animal^{-1}$)	121	114	117	96	100

Prices include transport and processing (January - March, 2011): Barley: $179/tonne, Canola meal: $323/tonne, Alfalfa Hay: $88/tonne, Barley Silage: $49/tonne, Oat Hulls: $34/tonne, Vit-Min Supplement: $206/tonne, HS HSP: $195/tonne, HS LSP: $212/tonne, HF HSP: $/128tonne, HFLSP: $/143tonne.

Table C.2: The effects of strategically blended pellets (HF) on the cost of backgrounding calves over a 70 day period (Trial 2)

	Treatment		
	Control	HF HSP	HF LSP
Feed cost of grain ($ kg^{-1})	1.23	0.97	1.03
Total feed costs ($ $animal^{-1}$)	138	106	109

Prices include transport and processing (April - June, 2011): Barley: $191/tonne, Canola meal: $374/tonne, Alfalfa Hay: $53/tonne, Barley Silage: $51/tonne, Oat Hulls: $37/tonne, Vit-Min Supplement: $374/tonne, HF HSP: $/128tonne, HFLSP: $/143tonne.