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Evaluation of triticale dried distillers grain as a substitute for barley silage in feedlot finishing diets

by

Kristopher Troy Wierenga

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EXAMINING COMMITTEE

Dr. Masahito Oba, Agricultural, Food and Nutritional Science, University of Alberta

Dr. Tim A. McAllister, Agriculture and Agri-Food Canada

Dr. Darryl J. Gibb, Agriculture and Agri-Food Canada

Dr. Erasmus K. Okine, Agricultural, Food and Nutritional Science, University of Alberta

Dr. John J. McKinnon, Department of Animal and Poultry Science

DEDICATION

I would like to dedicate this thesis to my Lord and Savior Jesus Christ for watching over me during my academic adventures, and providing me with the ability and perseverance to get to this point. I pray that He will be able to use my learned abilities for His Glory in one way or another.

I would also like to dedicate this to my loving fiancée, Michelle. Completing this thesis has also been a huge commitment and time sacrifice on her part and I thank her for her support and patience.

ABSTRACT

This study assessed the value of triticale dried distillers grains with solubles (DDGS) in a feedlot finishing diet using 144 intact, and 16 ruminally cannulated crossbred yearling steers. Substituting triticale DDGS for a portion of dry-rolled barley grain (20% diet DM) decreased the prevalence of ruminal acidosis and tended to increase dry matter intake and fat deposition, but increased the incidence and severity of liver abscesses. Further substitution of triticale DDGS for barley silage (5 and 10% diet DM) increased the prevalence of ruminal acidosis, but tended to improve feed efficiency without affecting carcass characteristics. These findings suggest that feedlot finishing diets containing triticale DDGS allow producers to decrease dietary forage inclusion without affecting performance, but may require use of an antimicrobial to control liver abscesses.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
ADG	Average daily gain
ADIN	Acid detergent insoluble ash
AIC	Akaike information criterion
AOAC	Association of Analytical Communities
A:P	Acetate: propionate ratio
ARA	Acute ruminal acidosis
AUC	Area under the curve
AUC / kg	Area under the curve corrected for dry matter intake
BS	Barley silage
BUN	Blood urea nitrogen
BW	Live body weight
CON	Control feedlot diet containing 85% dry-rolled barley grain, 10% barley silage and 5% vitamin/mineral mix formulated on a dry matter basis.
CP	Crude protein
D-0S	Feedlot diet substituting in triticale dried distillers grains with solubles at 30% of the diet DM for a portion of the dry-rolled barley grain (20% diet DM) and all of the barley silage (10% of diet DM)
D-5S	Feedlot diet substituting in triticale dried distillers grains with solubles at 25% of the diet DM for a

	portion of the dry-rolled barley grain (20% diet DM) and half of the barley silage (5% of diet DM)
D-10S	Feedlot diet substituting in triticale dried distiller grains with solubles at 20% of the diet DM for a portion of the dry-rolled barley grain
DDGS	Dried distiller grains with solubles
DGS	Distillers grains with solubles; encompasses the wet and dried products
DM	Dry matter
DMI	Dry matter intake
DRB	Dry-rolled barley grain
EG	Energy gained
G:F	gain to feed ratio
K_d	Rate of ruminal OM digestion
K_3EDTA	Potassium ethylenediaminetetraacetic acid
Kg	Kilogram
K_p	Rate of ruminal OM passage
LRC	Lethbridge research center
LRCpH	Lethbridge Research Centre Ruminal pH Measurement System
LPS	Lipopolysaccharide
mL	Milliliter
MW	average shrunk body weight

N	Nitrogen
NDF	Neutral detergent fiber
NE_g	Net energy for gain
OM	Organic matter
OM_{48h}	48-h in situ organic matter digestibility
OM_{eff}	Effective ruminal organic matter digestibility
PCV	Packed cell volume
peNDF	Physically effective neutral detergent fiber
PI	Processing index
R_0	Residue in nylon bag after 0-h of incubation
R_t	Residue in nylon bag after t hours of incubation
SARA	Sub-acute ruminal acidosis
SD	Standard deviation from the mean
t	Time
TNF-α	Tumor necrotic factor alpha
VFA	Volatile fatty acid
WDG	Wet distillers grains
WDGS	Wet distillers grain with solubles
wt/vol	Weight per unit of volume concentration

1.0 INTRODUCTION

1.1 Dried Distillers Grains with Solubles

The production of ethanol from cereal grains is not a new process and the resulting by-product, dried distillers grains with solubles (DDGS), has been included in cattle rations for many years. Research evaluating distillers' grains was conducted as early as 1894 (Henry, 1894: in Kononoff and Christensen, 2007). Ethanol being the fuel of choice for the Ford Model T in the early 1900s meant a significant quantity of DDG would have been available. However, gasoline was cheaper and as a result it became the fuel of choice. Today, the price of crude oil has increased significantly and there is a new impetuous to develop alternative, renewable fuel sources. Over the past 10 years, more than 100 ethanol distillation plants have been built in the Midwestern USA to increase renewable bio-ethanol production (http://www.ethanolrfa.org, in Robinson et al. 2008). In 2006, the USA produced an estimated 10 million tonnes of DDGS and is expected to increase to 25 million tonnes by 2011 (Robinson et al., 2008). North American DDGS production reached 27 million tonnes in the 2007-2008 crop years. The increased production of bio-fuel has increased the demand for grains such as corn in the USA and Eastern Canada and wheat in Western Canada. Increased demand has resulted in significantly higher grain prices, which have forced animal nutritionists and producers to find alternative feed stuffs to lower the costs of feeding. With the increasing supply of DDGS on the market, there is a growing body of research exploring new approaches to utilizing DDGS in livestock rations, particularly as a competitive energy source.

1.1.1 Sources of DDGS and Chemical Composition

Corn is the most abundant grain produced in North America with about two thirds of the kernel comprised of starch (Klopfenstein et al., 2008). Therefore corn DDGS is the most abundant source of DDGS in North America. Wheat is the primary cereal grain grown in Western Canada and has similar starch content to that of corn (Temelli, et al., 2003). However, research has also studied DDGS from other sources such as barley, rye, sorghum, and triticale (Greter et al., 2008; Mustafa et al., 2000a, b; Schingoethe, 2006). During the milling process, the starch component is fermented to produce ethanol. With the starch removed, the remaining nutrients in DDGS (protein, fiber, fat, and minerals such as phosphorus and sulphur) are concentrated three fold (Kononoff et al., 2007; Schingoethe, 2006; Spiehs et al., 2002).

Depending on the type of DDGS and processing, crude protein (CP) content can range from 28 to 43.6% DM (Boila and Ingalls, 1994; Penner et al., 2009; Schingoethe, 2006; Spiehs et al., 2002). Corn grain has a lower protein content (~8%) than wheat grain (~14%) and therefore the resulting DDGS from corn and wheat have different CP content (28 to 32% vs. 29 to 44% respectively). Robinson et al. (2008) reported that newer processing techniques using continuous grinding and more efficient fermentation methods can produce corn DDGS with CP content up to 41%.

Distillers grains are high in CP, and in recent history can be cheaper than other protein sources such as soybean meal and canola meal, although currently

canola meal is cheap. Therefore, it has traditionally been utilized as a source of protein in ruminant diets (Ham et al., 1994). Previously, DDGS has been considered as a good source of rumen undegradable protein (RUP; Benton et al., 2006; Boila and Ingalls, 1994; Martin et al., 2007; Kleinschmit et al., 2007). Kleinschmit et al. (2007) reported RUP content in corn DDGS to be as high as 72% of total CP. However, others have reported that the RUP content of DDGS can vary and be as low as 21% of total CP which may reflect processing variations during drying of wet DDGS or the amount of condensed solubles added (Cao et al., 2009; Kononoff et al., 2007; Oba et al., 2008).

Although the starch is removed during the fermentation process, DDGS is still relatively high in energy content (3.18 Mcal ME/kg DM; NRC 2000), which led to studies substituting DDGS for corn and barley grain in high energy diets. The high energy content of DDGS can be partly attributed to readily digestible NDF as well as the high fat content in corn DDGS. DDGS is high in readily fermentable NDF (Schingoethe, 2006; Spiehs et al., 2002) as it represents the majority of the carbohydrate fraction in DDGS. The NDF content of DDGS can vary depending on source and processing with a range from 25.6 to 54.6% (Clark and Armentano, 1997a; Kononoff and Christensen, 2007; Penner et al., 2009). Although fermentable fiber is degraded more slowly than non-structural carbohydrates, it is still an important source of energy for ruminants (Ham et al., 1994). The fat content of corn DDGS can be 10 to 15.9% (Kononoff and Christensen, 2007; Spiehs et al., 2002) owing to the high level of oil associated with the germ; although newer processing methods are producing low oil corn

DDGS (Robinson et al., 2008). The fat content is typically lower for DDGS from cereal grains ranging from 3.1 to 10.7% (Penner et al., 2009; Schingoethe, 2006) with an average of about 6.7% for wheat DDGS.

1.1.2 Effects of DDGS Inclusion on Feedlot Cattle Performance

Dried DGS are high in protein and consequently have traditionally been fed as a protein source in both ruminant and monogastric diets (Aines et al., 1986; Ham et al., 1994; Klopfenstein et al., 1978). However, feedlot cattle do not have a high protein requirement (12 to 16% CP; NRC, 2000) and therefore most feedlot studies have looked at feeding DDGS as an energy source (U.S. Grains Council, 2007).

1.1.2.1 Feedlot Growth Performance

Recent work done by Buckner et al. (2007) and Gibb et al. (2008) studied the effects of increasing inclusion of corn DDGS and wheat DDGS in corn- and barley-based diets, respectively, on finisher cattle performance. Interestingly, these studies depict the production systems of the U.S. and Western Canada, respectively. Buckner et al. (2007) included corn DDGS at 0, 10, 20, 30, 40 and 50% of the diet (DM basis) in replacement of dry rolled corn (DRC). Intake was not affected by dietary treatment, but a quadratic trend was observed for final BW and average daily gain (ADG) with the 20% corn DDGS treatment being the highest for both. The authors also observed numerically optimum Feed:Gain (F:G) with the 20% DDGS inclusion. In contrast, Gibb et al. (2008) reported a

linear increase in DMI with increasing inclusion rate (0, 20, 40, and 60% DM basis) of wheat DDGS. However, there was no significant difference in ADG, which resulted in a linear decrease in Gain:Feed (G:F) when dietary inclusion of wheat DDGS exceeded 20% of diet DM. Although corn DDGS and wheat DDGS had different effects on DMI, ADG and feed conversion, both studies concluded that optimal inclusion was 20% of dietary DM. A meta-analysis was conducted (Klopfenstein et al., 2008) analyzing 5 studies reporting the effects of increasing dietary DDGS inclusion on feedlot performance. Overall there was a quadratic response in ADG and a cubic response in G:F as DDGS inclusion increased from 0 to 40% DM. Gain:feed and ADG were maximized when DDGS was included at 10-20% and 20-30% DM, respectively.

Vander Pol et al. (2006b) found similar quadratic responses in ADG and F:G when increasing amount of wet distillers grains with solubles (WDGS; up to 50%) were substituted for equal proportions of high moisture and dry rolled corn. However, a study by Larson et al. (1993) reported a linear increase in ADG and G:F as wet distillers grain (WDG) inclusion increased to 40% of dietary DM. Similarly, Firkins et al. (1985) reported linear responses in ADG as WDG inclusion increased (0, 25, 50% dietary DM). These data suggest that the optimal inclusion of WDG products in feedlot cattle diets is about 40% of dietary DM.

1.1.2.2 Carcass Characteristics

Feeding distillers grains with solubles to feedlot cattle has variable effects on carcass composition. Gibb et al. (2008) reported a quadratic increase in back

fat thickness as dietary wheat DDGS inclusion increased; with 20% wheat DDGS resulting in the highest back fat deposition. Cattle that were fed the wheat DDGS treatment diets had more back fat than cattle fed the steam-rolled barley control. In addition, cattle fed wheat DDGS tended to exhibit decreased meat yields. Conversely, Buckner et al. (2007) reported that feeding corn DDGS tended to quadratically increase hot carcass weight with the heaviest weights for cattle fed 20% corn DDGS. Vander Pol et al. (2006b) fed increasing amount of corn WDGS (0 to 50% DM basis) substituting high moisture- and dry-rolled corn. Hot carcass weights had a quadratic response with cattle fed 30% corn WDGS having the highest carcass weights. Lodge et al. (1997a) also reported no effect of feeding wet or dry sorghum distillers grains (40% DM) on back fat measurements. However, the meta-analysis conducted by Klopfenstein et al. (2008) showed a significant effect of dietary DDGS inclusion rate on yield grade. As the dietary DDGS inclusion increased, yield grade linearly increased up to 40% DDGS inclusion. Marbling score however tended to linearly decrease as DDGS inclusion increased.

1.1.2.3 Metabolism and Digestion of DDGS in Feedlot Diets

At this point, the metabolic circumstances responsible for observed performance responses of cattle fed diets containing distillers grains (i.e., particularly corn) substituted for up to 50% of the grain in finishing diets (Buckner et al., 2007; Firkins et al., 1985; Gibb et al., 2008; Larson et al., 1993; Vander Pol et al., 2006a,b; 2007) remain undefined. There are a few performance

trends observed in cattle fed distillers grain diets which require discussion; the first is improved growth performance in beef cattle when distillers grains substitute other cereal grains. Several factors may potentially explain this observation. Corn DDGS contains three times the fat content as corn grain. With fat having three times the NE_g/kg compared to corn grain, the fat from corn WDGS and DDGS was calculated to account for 9-10% of the increased feeding value than corn grain (Ham et al., 1994; Larson et al., 1993). The feeding value is the calculated net energy for gain content (NE_g/kg) of a feedstuff determined from observed growth performance (Larson et al., 1993; Klopfenstein et al., 2008; Zinn et al., 2002). The fat content in cereal grains such as wheat or sorghum is much less than corn grain and therefore the respective DDGS is also lower in fat compared to corn DDGS (Beliveau et al., 2008; Depenbusch et al., 2009). This may explain why lower feeding values have been realized for wheat and sorghum DDGS compared to the barley or corn grain it replaced (Gibb et al., 2008; Lodge et al., 1997a).

Another factor contributing to improved performance may be a reduced incidence of sub-acute ruminal acidosis (SARA). Although high starch diets are rapidly fermented in the rumen and are good sources of energy, the resulting acid loads in the rumen can result in SARA (Owens et al., 1998; Nagaraja and Titgemeyer, 2007). Subacute ruminal acidosis has been shown to reduce ADG and G:F (Stock et al., 1990) in finisher cattle. The fiber supplied by DDGS is not fermented as rapidly as starch, however it is still readily fermented by rumen microbes (Schingoethe, 2006). Therefore, even though the starch content of the

diet is decreased, the fermentable fiber content is increased, thereby increasing rumen pH without limiting the energy available to the microbes and ultimately the animal (Larson et al., 1993; Klopfenstein et al., 2008).

A final factor that may be contributing to the high feeding value of DDGS is its high RUP content (Larson et al., 1993; Lodge et al., 1997b). Protein that by-passes rumen fermentation is enzymatically digested in the small intestine, reducing the amount of ATP utilized by the microbes for the production of microbial protein (Larson et al, 1993). Lodge et al. (1997b) formulated a composite diet containing wet corn gluten feed (WCGF), corn gluten meal (CGM) and tallow to simulate wet distillers grains. When the CGM (high in RUP) was removed from the composite diet, G:F tended to decrease. Similarly, when the composite minus tallow diet substituted dry-rolled corn or WCGF, G:F improved; which was attributed to more efficient protein utilization. This factor may play less of a role when DDGS inclusion is greater than 20% DM as the dietary protein available for digestion is in excess.

The second observation is the optimal inclusion level of WDGS in feedlot diets is higher than DDGS. The optimal inclusion level of wheat DDGS is reported to be 20% of the diet DM (Gibb et al., 2008), whereas cattle fed corn WDGS have optimal growth performance at 40% diet DM inclusion (Vander Pol et al., 2006b). Ham et al. (1994) compared the feeding values of corn DDGS and corn WDGS included at 40% DM in feedlot diets. Compared to the dry-rolled corn control diets, cattle fed the DDGS and WDGS treatment diets were 9.5% and 18.8% more efficient, respectively; with the improvement in efficiency for corn

WDGS twice that of the corn DDGS fed cattle. The corn WDGS had 1.39 times more NE_g than corn grain, whereas corn DDGS had 1.2 times more NE_g than corn grain. Similarly, Buckner et al. (2007) reported that corn DDGS had 125% NE_g of DRC, and Larson et al. (1993) reported that corn wet distillers byproducts (WDB) had 1.6 times more NE_g than corn in yearling steers. Residual ethanol, which is found in WDGS, can be used as an energy source for some microbial species (Emery, et al., 1959) or rapidly absorbed in the rumen (Larson et al., 1993) and metabolized to acetate in the liver, and used for energy or lipogenesis. During the drying process of DDGS, ethanol is volatilized and should not be present. This may be one explanation for the greater NE_g/kg for WDGS compared to DDGS. However, a study by Kreul et al. (1994) reported that supplementing 4% ethanol did not have an effect on feed conversion in feedlot steers fed DRC. Furthermore, Ham et al. (1994) found that adding water to the DDGS diets reduced DMI and rate of passage. It was suggested that added moisture could enlarge particle size by hydration, leading to a decreased rate of passage. Therefore, the higher moisture content of WDGS might have decreased the rate of passage and improving NDF digestibility compared to DDGS (Ham et al., 1994; Firkins et al., 1985). Lodge et al. (1997a) reported that cattle fed corn and sorghum WDGS had a greater apparent OM, apparent nitrogen and true nitrogen digestibility compared to cattle fed corn or sorghum DDGS. This might be explained by differences in particle size as described by Firkins et al. (1985). Some studies suggest that the drying process of WDGS can heat-damage the protein and decrease the nutritive value of the distillers grains as described in

Ham et al. (1994). This could also explain higher feeding values of WDGS compared to DDGS although some studies suggest drying does not have adverse effects on the quality of distillers grains (Ham et al., 1994; Klopfenstein, 1996).

The third trend noticed was the quadratic response in ADG and G:F with increased dietary inclusion of DGS. The initial improvement can be attributed to factors previously discussed such as the higher energy value of DGS compared to corn and barley grain, reduced instances of SARA, and supplying a higher proportion of RUP in the diet. However, beyond specific dietary inclusion levels (20% for DDGS and 40% for WDGS), ADG and G:F decrease. Klopfenstein et al. (2008) reported that corn DDGS at 20% inclusion had 123% of the NE_g of DRC; but decreased to 100% NE_g of DRC at 40% inclusion. Similarly, corn WDGS had 142% NE_g of DRC at 20% inclusion and decreased to 131% NE_g of DRC at 40% inclusion. Gibb et al., (2008) found that DM digestibility in finisher cattle decreased from 76.4% in the steam-rolled barley control diet to 68.9% in the 60% wheat DDGS diet; explaining the reduced energy content and feed conversion resulting from feeding increased dietary inclusion of wheat DDGS. The increased fat content in the diet may also explain the quadratic trend. Feeding high levels of dietary fat has negative effects on ruminal fiber digestion (Zinn et al., 2000); decreasing the digestible energy of the fiber. Furthermore, Plascencia et al. (2003) found that the intestinal fatty acid digestion decreased with increased total fatty acid intake. As the NE_g value of dietary fat is primarily a function of intestinal digestibility (Zinn et al., 2000), decreasing intestinal

digestibility of fatty acids with increasing DGS inclusion above 20 – 30% may account for the decreasing NE_g content.

Another reason for the quadratic response in energy values of DDGS compared to corn and barley grain can be due to the metabolic costs of converting excess nitrogen to urea for excretion. Dietary nitrogen supply will become excessive as dietary DGS is increased beyond 20% DM (Schingoethe, 2006). Typical finisher rations contain 12 -16% protein and diets containing greater than 40% DDGS can attain dietary CP concentration greater than 25% (Gibb et al., 2008). Therefore, metabolic costs associated with removing excess nitrogen will decrease the energy available for growth, and growth performance may decrease.

1.1.3 Triticale as a DDGS Source

Triticale is a drought resistant cereal grain grown in Western Canada on limited acreage. The starch content of triticale is comparable to wheat (65%; Chapman et al., 2005) and is therefore a potential substrate for bio-ethanol production. To date, there is limited feeding and composition data on triticale DDGS. Mustafa et al. (2000a, b) reported chemical composition and nutritive values of wet distillers' and thin stillage sourced from various cereal grains. However, Mustafa et al. (2000a) evaluated distillers' from a mixture of triticale, barley, wheat, and rye; consequently data arising from this experiment are not only attributable to triticale. Mustafa et al. (2000b) reported that triticale WDGS had higher protein and lower NDF content (29.8% and 71.2% respectively) compared to wheat wet distillers' grains (27.5% and 73.9% respectively). Greter

et al., (2008) compared the effects of feeding corn DDGS and triticale DDGS on milk yield, milk composition and plasma metabolites of lactating Holstein cows. Triticale DDGS was shown to have a higher lysine content than corn DDGS; a reflection of the more favorable amino acid profile of triticale grain. The cows that were fed the triticale DDGS had lower milk-urea nitrogen and plasma AA concentration compared to those that were fed corn DDGS. Oba et al., (2008) further reported that triticale DDGS had more CP digested in the small intestine compared to corn DDGS (14 vs.8.5 % of CP intake, respectively) suggesting that CP in triticale DDGS may be more utilizable than CP in corn DDGS. Increasing lysine supply in feedlot diets may be beneficial as lysine is an important limiting amino acid for growth (Merchen and Titgemeyer, 1992; Richardson and Hatfield, 1978). Although recent work (McKeown et al., 2008, 2009) has been completed using triticale DDGS in lambs, there is no published data using triticale DDGS in feedlot cattle.

1.2 Ruminal Acidosis

Changing dietary parameters such as feed processing, nutrient composition or intake has direct effects on rumen fermentation characteristics and pH. Dried DGS has historically been fed as a substitute for barley or corn grain in feedlot rations in North America. Therefore, starch is being replaced with a source of fiber that has a moderate rate of fermentation, but is still highly digestible. Slowing down the rate of fermentation in the rumen can decrease the incidence of SARA or acute ruminal acidosis (ARA) for cattle in feedlot settings

(Owens et al., 1998; Nagaraja and Titgemeyer, 2007). However, with DDGS being high in fermentable fiber (46% NDF; NRC, 2000), it is worth studying its effects as a non-forage fiber source in feedlot rations. Due to the smaller particle size of DDGS compared to forages, ruminal acidosis may be a concern and should be discussed in more detail.

1.2.1 Definition

Acute and subacute acidosis result when the rumen acid load reaches a certain threshold that negatively affects the rumen microflora leading to the clinical and subclinical symptoms previously mentioned. A study by Mackie and Gilchrist (1979) reported the ecological succession of various microbes in the rumen as pH decreased. Mackie and Gilchrist (1979) suggested that an index that weighs the time spent under the optimal ruminal pH by the magnitude of the deviation from this pH be used to diagnose ARA and SARA (Allen, 1997; Schwartzkopf-Genswein et al., 2003). There has been multiple pH thresholds suggested in literature as reviewed by Schwartzkopf-Genswein et al. (2003); typically SARA occurs when pH drops below 5.6 for more than 12 hours per day and ARA occurs when pH is below 5.2 for more than 6 hours per day (Owens et al., 1998).

1.2.2 Diagnosis of Acute and Subacute Acidosis

Ruminal acidosis is the result of rapid production of organic acids in the rumen from microbial fermentation of excessive amounts of fermentable

carbohydrates, leading to a concurrent drop in pH (Nagaraja and Titgemeyer, 2007). This metabolic disorder has also been associated with overeating, acute impaction, grain engorgement, founder, and grain overload (Owens et al., 1998). Ruminal acidosis is the term universally used to describe these conditions. The severity of ruminal acidosis can vary as the disorder encompasses a range of physiological conditions. It is commonly diagnosed as two forms; acute ruminal acidosis (ARA) and chronic or subacute ruminal acidosis (SARA). Acute acidosis, also known as lactic acidosis, is characterized by overt clinical signs and physiological changes (Dunlop, 1972; Huber, 1976). These include an increase in amylolytic and lactate-producing bacteria, a significant drop in pH, decreased rumen motility and function, intermittent diarrhea, dehydration and in severe cases death. Bouts of SARA typically do not show any clinical signs; however cattle will experience negative effects on performance such as reduced feed intake, ADG and G:F (Kleen et al., 2003; Nocek, 1997; Koers et al., 1976; Owens et al., 1998). Due to the feeding practices of the Canadian feedlot industry, cattle are highly prone to ruminal acidosis and it is common for cattle to experience SARA without clinical diagnosis.

1.2.3 Impacts on Profitability of Ruminant Industry

Ruminal acidosis has significant economic importance to the beef industry. Although ARA can result in acid bloat which accounts for 0.1 to 0.2% of pen deaths in Alberta feedlots (McAllister et al., 2000), SARA has greater economic consequences. High concentrate diets are fed to increase ADG and G:F,

ultimately decreasing the cost of gain. However, attempting to increase rumen fermentation efficiencies without properly managing rumen health may cause SARA, resulting in economic loss. It has been estimated that SARA can result in losses of $15-$20 per animal simply due to decreased animal efficiency (Schwartzkopf-Genswein et al., 2003). A more conservative estimate due to inefficiencies of sub-clinical grain overload is $9.40 per animal in feedlot cattle (McAllister et al., 2000).

There are secondary metabolic disorders resulting from SARA which can have an economic impact as well. Liver abscesses have been shown to frequently occur in cattle experiencing SARA (Brent, 1976; Brink et al., 1990, Goad et al., 1998). The 2005 National Beef Quality Audit (Garcia et al., 2005) reported that 24.7% of the livers processed were condemned with 54.2% of these being due to liver abscesses. Severe liver abscesses can adhere to the carcass; therefore increasing trim and significantly decreasing saleable product (Nagaraja and Chengappa, 1998). In 1995, liver condemnations totaled over $1,000,000 (McAllister et al., 2000). The occurrence of severe liver abscesses have been shown to adversely affect ADG and G:F in finishing feedlot cattle (Brink et al., 1990).

1.2.4 Etiology of Acidosis in Feedlot Cattle

There are many studies that have reported the physiological causes and management of ruminal acidosis. Acid balance in the rumen is a result of acid production and acid removal. When acid production is greater than the acid

removal, the acid balance in the rumen shifts and it can enter an acidotic state (Allen, 1997; Owens et al., 1998). Diets during the finishing period typically contain 85 to 95% concentrate (Stock et al., 1990) and as a result feedlot cattle are highly susceptible to rumen acidosis. There are a few factors which need to be considered when rumen acidosis in a feedlot environment is studied.

1.2.4.1 Effects of Organic Matter Fermentation in the Rumen

Rumen degradable organic matter (RDOM) provides nutrients to the rumen microbes for energy and growth. Microbial protein and organic acids are produced in the rumen as a result of microbial fermentation. The most abundant volatile fatty acids (VFA) produced in the rumen are acetate, propionate, and butyrate as well as succinate, lactate, valerate and the branched-chain fatty acids isovalerate, 2-methylbutyrate and isobutyrate. These VFAs are produced in the associated form and are then released by the microbes into the rumen. The average pKa for VFAs is approximately 4.8 (Owens et al., 1998). As rumen pH is typically higher than 4.8, most VFAs in the rumen almost immediately dissociate and release free H^+ into the rumen. Volatile fatty acids are the primary source of H^+ in the rumen; therefore increased VFA production decreases rumen pH. After a meal, a greater availability of nutrients leads to microbial growth and increased fermentation, resulting in higher organic acid production and a drop in rumen pH. As summarized by Van Soest et al. (1991), the rate of fermentation determines the amount of energy available at a given time for microbial growth. Assuming protein is not limiting, increased fermentation rates create a condition that reduces

the overall amount of energy directed toward maintenance of the microbial populations and more towards growth. Therefore increasing diet inclusion of high-starch feedstuffs in feedlot diets will increase the rate of fermentation of the diet and improve microbial growth efficiency (Bergen and Yokoyama, 1977). Inherently, increased microbial growth will also improve diet digestibility; increasing total digestible nutrients. This is beneficial to producers as their cattle can achieve greater live weight gains per unit of feed (Van Soest et al., 1991). Increasing dietary concentrate increases the proportion of amylolytic bacteria in the rumen (Goad et al., 1998; Tajima et al., 2001). Amylolytic bacteria such as *Bifidobacterium, Butyrivibrio, Eubacterium, Lactobacillus, Mitsuokella, Prevotella, Ruminobacter, Selenomonas, Streptococcus, Succinimonas,* and *Succinivibrio* can be as high as 90 to 95% of the culturable bacteria (Nagaraja and Titgemeyer, 2007). *Streptococcus bovis* is a mixed acid fermenter (acetate, formate, and ethanol from glucose) which attains 4 ATP per unit of glucose. However when substrate is not limiting, *S. bovis* alters its fermentation pathway to lactate production which yields 3 ATP per unit of glucose (Nagaraja and Titgemeyer, 2007). Although the energetic efficiency is reduced, the rate of fermentation and cell growth increases significantly allowing *S. bovis* to generate more ATP per hour than any other bacteria (Hungate, 1979). Lactic acid has a pKa of 3.8, which is 1 pH unit lower than the other VFAs. Therefore, increased production of lactic acid will further decrease rumen pH. As pH drops below 5, the rumen environment becomes toxic to *S. bovis* and to important lactic acid utilizers such as *Megasphaera elsdenii*. This creates the optimum environment

for the *Lactobacillus sp.* to proliferate, which maintains low rumen pH (Owens et al., 1998; Van Soest et al., 1991).

Cattle are most prone to acute ruminal acidosis during times of engorgement of readily fermentable carbohydrates. During these times, acid production rate (explained above) is faster than the rate of acid removal from the rumen resulting in decreased rumen pH. The transition of beef calves from a high forage diet to a high concentrate diet has been identified as a critical stage when ARA can occur (Bevans et al., 2005). During this time, the dominant microflora population shifts from fibrolytic to amylolytic bacteria (Goad et al., 1998; Tajima et al., 2001). This is characterized by increased rumen fermentation rates and VFA production. As such, there have been numerous studies in relation to rumen acidosis during the transition period. However, during the finishing period, diets can contain 80 to 90% concentrate (Stock et al., 1990). As a consequence, the rumen environment is exposed to chronically high acid concentration. Although the microbial population and the extent of fermentation are stabilized, any erratic intake or feeding patterns during the day may result in sudden acid production increases causing short instances of SARA or even ARA (Fulton et al., 1979; Stock et al., 1990). Therefore, identifying new feeding strategies and means of utilizing various by-product feedstuffs to reduce the effects of ruminal acidosis during the finishing period can be justified.

1.2.4.2 Effects of Acid Removal and Buffering

The other side of acid balance in the rumen is acid removal and buffering. There are a few mechanisms by which rumen pH is maintained. The most significant mechanism is VFA absorption across the rumen wall (Allen, 1997). Allen (1997) reported that 53% of the daily H^+ production is removed via VFA absorption across the ruminal wall. Volatile fatty acids in the associated form are passively absorbed across the rumen epithelium. As pH decreases towards the pKa of VFA, a greater proportion of VFAs are in the associated form which increases the rate of VFA absorption (Owens et al., 1998). The epithelial cells have a high affinity particularly for butyrate (Kristensen and Harmon, 2004), which is metabolized in the intracellular portion of the epithelial cell as a source of energy for the cell. The absorption of VFA aids in maintaining rumen pH. Ruminal bacteria known as lactate-utilizers are capable of metabolizing lactate to other VFAs such as acetate, propionate, and butyrate (Nagaraja and Titgemeyer, 2007). *Megasphaera elsdenii* is the most prominent lactate utilizer as it is more tolerant to acidic conditions compared to other lactate utilizing bacteria. Lactate metabolism helps maintain ruminal lactate concentration minimal and therefore low ruminal pH when lactate-producing bacteria are more prominent.

The second mechanism is neutralization of the acids by buffering from salivation, feed, and feed degrading products (Allen, 1997; Owens et al., 1998). Of these, saliva is the most important. Saliva contains both bicarbonate and hydrogen phosphate ions in relatively constant concentrations (Erdmann, 1988). Bicarbonate binds to H^+ to form carbonic acid which then becomes carbon dioxide and water. The carbon dioxide is then removed from the rumen via

belching. This is reported to remove 28% of the daily H^+ produced (Allen, 1997). Hydrogen ions, which associate with hydrogen phosphate ions and flow out of the rumen to the omasum, represent 9% of H^+ production (Allen, 1997). The buffering capacity of the rumen is greatly affected by the diet composition and feed characteristics. The most important characteristic would be the dietary fiber composition and particle size as they are related to chewing and stimulating salivation. This physical component of the diet will be discussed in more detail later in the fiber section of the review. The other important characteristic is the buffering capacity of the feed. This is characterized by the cation exchange capacity (CEC) of the fiber (Van Soest et al., 1991). Functional groups such as carboxyl, amino, free aliphatic hydroxyls, and phenolic hydroxyls which are found on the plant cell walls have various affinities for metal ions (McBurney et al., 1983; Van Soest et al., 1991). When rumen pH increases, plant cell walls in the fiber mat release H^+ ions, creating a negative charge along the wall surface. The H^+ ions released are exchanged for free metallic ions like Ca^{++} or Mg^{++}. However, as the rumen becomes more acidic, the 'bank' of metallic ions on the fiber surface is exchanged for free H^+ to maintain rumen pH. A study by McBurney et al., (1983) showed that there is a wide range of CEC potential over a range of feed stuffs. Although some by-product fiber sources have equal or better CEC, mature legume forages are the most effective at supplying total exchangeable buffering capacity when considering forage fiber's physical effectiveness to stimulate chewing (Van Soest et al., 1991). Some H^+ remains attached to the particulate matter and are removed from the rumen to the lower

digestive tract. The remaining hydrogen ions are removed from the rumen via flow into the omasum as associated with VFA, NH_4^+, or as free ions (Allen, 1997).

Rumen buffering capacity can be enhanced by adding buffers to the diet. Bicarbonate ions, which are biologically secreted in saliva, can be added to the diet in the form of a salt ($NaHCO_3$, or K_2CO_3) and help buffer H^+ from organic acid production (Ha et al., 1983). This has been shown to improve intake and growth performance of cattle recovering from SARA (Phy and Provenza, 1998) as well as healthy cattle by reducing the incidence of ARA (Kezar and Church, 1979; Nagaraja et al., 1982; Owens et al., 1998). The pKa for bicarbonate is 6.1; therefore when rumen pH is greater than 6.1, H^+ is released as the equilibrium shifts towards carbonate ion formation and decreases rumen buffering capacity.

1.2.4.3 Effects of Group Interactions on Feeding Behaviour and Acidosis

Previous research studying ruminal acidosis has focused on nutritional and physiological factors and the resulting animal performance (Erickson et al., 2003; Gibb et al., 1998; Robles et al., 2007; Schwartzkopf-Genswein et al., 2003, 2004). Scientists evaluated diet formulations, feed processing techniques, and feeding management methods to determine their effects on reducing metabolic disorders related to rumen acidosis (Schwartzkopf-Genswein et al., 2003). However, feeding behavior and animal interactions due to temperament of individual animals and social dominance in a group setting can exert equally significant effects on the incidences of SARA (Grant and Albright, 2001; Owens et al., 1998;

Voisenet et al., 1997). A study by Gibb et al. (1998) used radio frequency technology to observe bunk attendance patterns of feedlot cattle. The trial used 72 steers (18 steers per pen) that were fed a steam-rolled barley grain/ barley silage diet that contained 92% concentrates. The total daily attendance (head in bunk) for each steer averaged 33.6 minutes per day and averaged 7.5 bunk visits per steer per day. In contrast, Schwartzkopf-Genswein et al. (2002) observed 15 to 18 meals per day and a total eating time of 95 to 131 min/d per animal for 6 individually tethered steers and heifers. Comparison of these two studies suggests that individually-fed animals eat smaller, more frequent meals compared to animals housed in group pens with other animals. This difference in feeding behavior between group and individually housed animals could be attributed to group interactions (social or dominance behaviour) which can limit feed bunk attendance, whereas individually-fed animals have unrestricted access to feed. Studies have speculated that using feeding management strategies to reduce daily variation in intake may minimize instances of metabolic disorders (Bauer et al., 1995; Gibb et al., 1998; Owens et al., 1998; Schwartzkopf-Genswein et al., 2004).

As eating behavior can have significant effects on rumen fermentation patterns, it is important to house animals in groups when rumen fermentation characteristics are evaluated for feedlot cattle. This will allow feedlot trials to draw more applicable conclusions for animal production in feedlot environments. Previously, in metabolism studies, animals were individually housed and fed to attain repetitive rumen samples for pH measures and to acquire individual feed intakes. Recently, a continuous ruminal pH measurement system has been

developed (LRCpH data logger; Penner et al., 2006). This unit does not require animals to be tethered, therefore allowing for continuous measurement of rumen pH in a group feedlot setting with minimal animal handling. Likewise, use of the GrowSafe system (GrowSafe Systems Ltd., Airdrie, Alberta, Canada) will allow for measurements of feed intake for individual animals within a pen. Using continuous pH data in conjunction with individual feeding and performance data can give important information regarding relationships between feeding behaviour and diet characteristics on ruminal acidosis (Schwartzkopf-Genswein et al., 2003).

1.2.5 Effects of Rumen Acidosis on the Immune System

Until recently, there has been a lot of research looking into the effects of rumen acidosis on microbial fermentation, rumen pH, secondary metabolic diseases, feeding behavior, feed efficiencies and growth performance (Bevans et al., 2005; Nagaraja and Chengappa, 1998; Nagaraja and Titgemeyer, 2007; Owens et al., 1998; Schwartzkopf-Genswein et al., 2002, 2003, 2004). However, Nocek (1997) pointed out that reduced animal performance is not solely due to ruminal acidosis and could be attributed to dietary factors or poor bunk management. In addition to previous studies (Dougherty et al., 1975; Nagaraja, 1978), recent studies (Gozho et al., 2005, 2006, 2007) have shown evidence that ruminal acidosis may have indirect effects on the immune system of cattle, which may further explain decreased performance and intake.

1.2.5.1 Rumen Lipopolysaccharide Concentration as an Indicator of SARA

Lipopolysaccharide (LPS) is an endotoxin found on the cell wall of gram-negative bacteria (Carroll, 2007; Nagaraja et al., 1978). Nagaraja (1978) demonstrated that feeding a high concentrate diet resulted in a shift of dominant ruminal microflora from gram-negative to gram-positive bacteria and an almost 1,000% increase in ruminal endotoxin concentration. These findings were supported by a recent study where SARA was induced in three fistulated Jersey cows with wheat-barley pellets (Gozho et al., 2005). Ruminal LPS concentration increased from 3,715 endotoxin units (EU) to 12,589 EU after feeding a high concentrate diet for 4 days. There are a couple of explanations for the increased LPS concentrations. When the rumen experiences low rumen pH, LPS can be released in the rumen due to bacterial cell lysis (cell death). It is known that as pH drops below 6, fibrolytic bacteria decline in number and amylolytic bacteria begin to thrive (Goad et al., 1998; Tajima et al., 2001). As pH decreases further below 5.5, it becomes toxic to some amylolytic species as well (Nagaraja and Titgemeyer, 2007; Owens et al., 1998). The increased microbial death partially explains the increase in ruminal LPS concentration. Nagaraja (1978) proposed that rumen LPS concentration can also increase due to shedding of free LPS from rapidly growing gram-negative bacteria. Although the proportion of gram-negative bacteria decreased when rumen pH dropped, the total microbial count was increasing. Therefore ruminal LPS concentration is not entirely explained by negative effects of feeding high concentrate rations. Gozho et al. (2006, 2007)

identified a potential dietary threshold where LPS concentrations begin to increase significantly in dairy cattle. Below 41% dietary concentrate, rumen LPS concentration increases gradually but quadratically. Beyond 41% dietary concentrate, however, rumen LPS concentrations increase linearly up to 76% dietary concentrate (Gozho et al., 2006). It is suggested that LPS concentration may therefore be related to instances of SARA and potentially be an indicator of ruminal acidotic state (Emmanuel et al., 2007, 2008; Gozho et al., 2006, 2007). However, this is arguable due to the increased ruminal LPS concentration also observed during gram negative proliferation.

1.2.5.2 SARA Induces an Inflammatory Response

Recent studies are building evidence indicating that SARA can induce an inflammatory response via increased ruminal LPS concentration. As summarized by Gozho (2005), a few studies as early as Brent (1976) theorized that rumen endotoxins along with an acidic environment can negatively affect the integrity of the rumen epithelium. Decreased epithelial integrity could result in increased LPS translocation to the portal vein. A study by Emmanuel et al. (2007) looked at the permeability of rumen and colon tissue to ^{3}H-mannitol and LPS under acidic conditions. Although rumen permeability to ^{3}H-mannitol was not affected by decreasing pH alone, the addition of LPS at a pH of 4.5, which is similar to rumen pH experienced during acute ruminal acidosis, significantly increased translocation of ^{3}H-mannitol. The translocation of ^{3}H-mannitol did not occur at

pH 5.5 which is similar to ruminal pH experienced during SARA. However, rumen tissue was only exposed to the acidic fluid for 40 minutes for their study. It has been suggested that SARA occurs when rumen pH is below 5.6 for more than 3 hours (Cooper et al., 1999; Gozho et al., 2005). Therefore, if the tissue samples were exposed to pH 5.5 for a time that typically occurs in feedlot cattle, it is possible that LPS translocation could be significantly affected. Regardless, these findings as well as others (Khafipour et al., 2009) suggest that the rumen epithelium and mucosal integrity can be compromised during acidosis and increased LPS translocation. Interestingly, Emmanuel et al. (2007) also showed that LPS translocation across the rumen epithelium occurred at a neutral pH, indicating that rumen wall integrity may not be a significant factor in LPS translocation across rumen tissues. More research needs to be conducted to determine the relationship between rumen and blood LPS concentrations and to better understand the translocation of rumen LPS into the blood stream. Current speculation is that the effects of LPS on rumen wall integrity and its translocation can be a major etiological step in the development of other metabolic diseases such as rumenitis, laminitis, sudden death syndrome, liver abscesses and acute acidosis (Dougherty et al., 1975; Nagaraja et al., 1978). Each of these has own metabolic and economic costs to the feedlot operation such as decreased feed efficiencies, increased animal culls and deaths.

Serum amyloid-A, (SAA) and haptoglobin (Hb) are acute phase proteins produced by hepatocytes following stimulation from proinflammatory cytokines (Carroll, 2007; Gozho et al., 2005). The strong response in these acute phase

proteins during inflammation has led researchers to use them as indicators of inflammatory responses in livestock (Baumann and Gauldie, 1994). Gozho et al. (2005) observed consecutive increases in SAA from day 2 to day 5 of feeding concentrate and on day 3 and day 5 for haptoglobin. This indicates that as the time ruminal pH is below 5.6 increases, the intensity of the acute phase response increases. Chronically low levels of LPS that translocate to the portal vein are detoxified by the liver before it enters the hepatic vein. However, with high LPS concentration in the rumen and its potential role in causing epithelial damage in the rumen, large amounts of LPS may overwhelm the detoxification capacity of the liver leading to systemic endotoxaemia (Carroll, 2007). Lipopolysaccharide is a pathogen-associated molecular pattern (PAMP) which is highly recognized by the innate immune system (Carroll, 2007). High concentrations of LPS in the blood stream result in an acute phase response and corresponding immune response (Baumann and Gauldie, 1994; Carroll, 2007). An acute phase response was identified by Gozho et al. (2005, 2006, and 2007) in Jersey steers and Holstein cows induced with ruminal acidosis. Although the relationship between ruminal and blood LPS concentrations needs to be determined, the studies suggest that cattle induced with SARA also experience an inflammatory response which can have detrimental effects on animal performance.

1.2.5.3 Inflammatory Response and Growth Performance

An inflammatory response to ruminal acidosis (SARA or ARA) can be an important factor contributing to reduced animal performance. The relationship between reduced animal performance and immune responses has been identified previously in both monogastric and ruminant animals (Klasing, 1988; Klasing and Korver, 1997; Larson, 2005). Klasing and Korver (1997) proposed a few mechanisms by which an immune response can alter growth physiology. Production of cytokines can impair growth by direct action on the tissue or indirectly by its effects on the endocrine system. Tumor necrotic factor – alpha (TNF-α) is one cytokine that signals the production of SAA during infection and inflammation (Emmanuel et al., 2008). In porcine tissue, TNF-α has been shown to interfere with IGF-1 (Insulin-like Growth Factor 1) which promotes muscle cell development; potentially by increasing resistance to IGF-1 receptors (Broussard et al., 2003). This allows the animal to partition nutrients away from muscle accretion to support the needs of the immune system (Klasing and Korver, 1997; Larson, 2005), thereby decreasing animal growth efficiency.

1.3 Effective Fiber

Cattle have been evolved as grazers. In synergy with the rumen microbes, ruminants are able to utilize fiber as a primary source of energy. In grazing conditions, forage fiber requirements are met (Mertens, 1997) and buffering capacity and rumen health are typically not an issue. As beef production intensifies and producers demanded faster and more efficient gains, concentrates become increasingly important as a source of energy, particularly in feedlot

rations. This increases the fermentability of the diets, altering microbial populations and fermentation, and increasing organic acid production (Allen, 1997; Owens et al., 1998). Consequently, researchers and nutritionists realized there is a minimum fiber requirement because fiber stimulates chewing and salivation which influences the rumen buffering capacity (Allen, 1997; Armentano and Pereira, 1997). The 'effectiveness' of dietary fiber to maintain a healthy rumen environment is dependant on both the quantitative and qualitative aspects of the fiber as well as the chemical composition of the diet. There are a couple of measures commonly used to define fiber effectiveness. The first measure is termed physically effective fiber (peNDF). The peNDF is defined as the ability of forage (fiber) to stimulate chewing activity (Mertens, 1997). The peNDF is determined by considering two important feed components that influence chewing activity. The peNDF is a product of the NDF concentration and the physical effectiveness factor (pef) of the feed. The pef ranges from 0 (not effective at stimulating chewing) to 1 (very effective at stimulating chewing). The other is referred to as effective fiber (eNDF). The eNDF incorporates the physical and chemical characteristics of a feedstuff when replacing forage and its ability to maintain milk fat production (Allen, 1997; Armentano and Pereira, 1997; Clark and Armentano, 1993, 1997ab; Lofgren and Warner, 1970; Mertens, 1997). However this measure is more pertinent to dairy cattle and when attempting to identify lower limits of fiber inclusion as in feedlot diets, the physical characteristics of fiber are more critical (Mertens, 1997).

1.3.1 Factors Affecting Physical Effective Fiber Requirements

Acid production in the rumen fluctuates constantly as it is affected by various physical and chemical characteristics of diets (Woodford et al., 1986), which make defining a fiber requirement quite complex (Armentano and Pereira, 1997). Forage particle size is an important factor impacting the physical effectiveness of fiber as it influences chewing time and salivary secretion (Van Soest et al., 1991). Larger forage particles require more chewing to reduce the length to that necessary for feed stuffs to pass out of the rumen (Welch, 1982). For example, Grant et al. (1990) looked at the effects of particle size of hay on chewing activity and rumen fermentation parameters in dairy cattle. They reported significant increases in total chewing time (TCT) as forage particle size increased. Welch (1982) showed that stem length is not significantly altered by rumen incubation alone, indicating that chewing is important in reducing particle size to the critical length for passage to the omasum.. Grant et al. (1990) also reported that longer TCT resulted in significantly higher rumen pH, which was attributed to increased salivary secretion. Therefore, if forage particle size is smaller, the TCT is shorter and less salivary buffers are secreted; decreasing the effectiveness of fiber to buffer the rumen. In Allen (1997), 9 experiments studying the relationship between forage particle size and TCT in dairy cattle were combined for a correlation analysis. Although the individual studies reported significant relationships between forage particle size and TCT, the analysis did not show a clear relationship across experiments.

There are discrepancies between dairy and beef animals regarding particle size. A study by Shain et al. (1999) evaluated the effects of forage source and particle size on animal performance, ruminal metabolism and chewing activity in feedlot cattle. Different particle sizes within a forage type had no influence on TCT, rumen pH, VFA concentrations, or growth performance. This indicates that changing forage particle size did not alter the physical effectiveness of the fiber. This is contradictory to peNDF values used by Sniffen et al. (1992); peNDF decreases as forage particle size decreases. An explanation for this discrepancy may be the quantity of forage fed in diary and feedlot rations. Forage inclusion in dairy rations can range from 12.5% to 62.1% of dietary DM (Armentano and Pereira, 1997; Clark and Armentano, 1997a) whereas dietary roughage content in feedlot rations typically range between 5 and 15% of diet DM (Stock et al., 1990). The physical characteristics of fiber may therefore have more influence on chewing activities in dairy cattle rations than in feedlot cattle rations. Therefore, other factors must play a role in determining salivary buffer secretion, particularly in feedlot cattle.

Another factor affecting physical effectiveness of fiber is the source of fiber. Historically, forage such as hay or silage was the primary dietary ingredient supplying fiber. However, there is a group of by-product feeds such as soy hulls, DDG, or whole cotton seed which are not forages, yet are high in fiber (Clark and Armentano, 1993). These non-forage fiber sources (NFFS) have similar NDF content to that of forages but with a much smaller particle size similar to that of concentrates (Pereira et al., 1999). Theoretically, on a NDF% basis, NFFS can

replace forages as a fiber source. However, when larger proportions of dietary fiber are sourced from NFFS, the peNDF may decrease due to the overall reduction in particle size of the diet (Clark and Armentano, 1993). Therefore, a higher NFFS inclusion in diets would contribute less to meeting peNDF requirements.

The factor affecting peNDF requirements relates to confounding factors within the carbohydrate fraction of the diet as discussed by Armentano and Pereira (1997). Combining diet information from two feedlot studies (Bevans et al., 2005; Erickson et al., 2003), the NDF and non-fiber carbohydrate (NFC = OM – NDF – CP - EE) fractions constitute about 74% of the dietary OM. Therefore, a change in dietary NDF content results in an equal opposite change, and similar proportional change in NFC concentration (Armentano and Pereira, 1997). This means that a response in rumen pH (change in acid production or rumen buffering capacity) resulting from a change in dietary NDF (particle size or concentration) could be equally the result of the opposite change in dietary NFC concentration. Consequently, the quality and concentration of the dietary NDF and NFC components affect peNDF requirements. Utilizing a more fermentable source of NFC or increasing its quantity will increase the acid production in the rumen, which increases the requirement for peNDF and rumen buffering.

1.3.2 Indicators of Physically Effective Fiber

In order to determine the physical effectiveness of the fiber, response variables that have measurable responses to changes in dietary fiber need to be

identified (Armentano and Pereira, 1997). The TCT of livestock has been shown to have significant responses to changes in dietary fiber (Allen, 1997; Clark and Armentano, 1993; Woodford et al., 1986). It was first proposed by Balch (1971) to use TCT (minutes per kg of DMI) as a measure of peNDF instead of eating time or rumination time separately. He found with various types of forage, as forage DMI increased, TCT also increased. This was supported by Woodford et al. (1986) who reported significant increases in TCT as forage NDF intake increased from 3.2 to 5.8 kg/d. Two analyses by Armentano and Pereira (1997) showed that TCT per kg of DMI was the single best indicator of dietary forage NDF (R^2=0.82) and dietary non-forage NDF concentrations (R^2=0.67). However, TCT is only responsive to the direct physical effect of fiber but does not account for factors such as the composition of the NFC fraction which also affects physically-effective fiber requirements.

Rumen pH has been described as a more useful indicator of physically-effective fiber requirements as it is a measure of the acid balance in the rumen (Allen, 1997). It is responsive to diet composition, appetite, ruminal motility, microbial yield, fiber digestion and rumen buffering as summarized in Allen (1997). Physical aspects of the fiber such as particle size or fiber concentration in the diet influences the TCT of cattle which in turn affects salivary buffer flow into the rumen (Allen, 1997; Bailey and Balch, 1961; Emery et al., 1960; Grant, 1990). If there are changes in the buffering capacity of the rumen, rumen pH will respond accordingly. Using 106 treatment means from 26 experiments, Allen (1997) determined a positive relationship between forage NDF and rumen pH

primarily due to effects of physical characteristics of forages on rumen buffering. In this manner, rumen pH is an indicator of the physical aspects of dietary fiber. Mertens (1997) plotted the relationship of dietary peNDF (13 to 57 % DM) to ruminal pH. Ruminal pH appeared to plateau as it approached 6.5 to 6.7. However, the positive relationship between dietary forage NDF concentration and rumen pH does not hold true for dietary NDF concentration. Allen (1997) summarized multiple studies to show that there is not a significant relationship between dietary NDF concentration over a range of diets and daily rumen pH means. This can be partly attributed to differences in particle size of various forages and NFFS. Although dietary NDF concentration does not change significantly, the peNDF content decreases as particle size decreases, resulting in less time spent chewing and therefore decreasing rumen buffering capacity, decreasing rumen pH. Another reason is the confounding factors among carbohydrate fractions identified by Armentano and Pereira (1997). Feeding a more fermentable carbohydrate source such as wheat or extensively processed grains will increase rumen fermentation and acid production.

1.4 Feeding High Fiber By-Product Feeds in Finishing Diets

As discussed previously, by-product feedstuffs such as distillers grains, wheat middlings, beet pulp, and corn gluten feed are sources of fiber known as NFFS. Although they contain highly digestible fiber, particle size is small compared to forage fiber sources and result in a lower peNDF (Armentano and Pereira, 1997; Clark and Armentano, 1993). However, use of DDGS as an energy

substitute for high-starch feed ingredients may not be detrimental to rumen health because starch is replaced with a highly fermentable NDF source. Because NDF ferments more slowly than starch, acid production at any given time is lower, which may indirectly reduce the need for roughage to aid in buffering the rumen (Klopfenstein et al., 2008). Krehbiel et al. (1995) tested the effects of feeding wet corn gluten feed (WCGF), which has a similar composition to DDGS, on induced SARA recovery in finishing steers. He fed three experimental diets with the concentrate fraction (58% of diet DM) consisting of: 100% dry-rolled corn, 50% DRC/50% WCGF, and 100% WCGF. Although feeding WCGF did not eliminate acidosis as pH dropped after dosing, the total decrease in ruminal pH and total accumulation of ruminal VFA 24 h after dosing was greater for cattle fed the 100% DRC than the WCGF diets. They supported the use of WCGF in a high concentrate ration to minimize the use of roughage without increasing the severity of ruminal acidosis. A similar study by Ham et al. (1995) added WCGF at increments of 17.5% from 0 to 87.5% of diet DM replacing 0 to 100% of the DRC. A quadratic response was found for daily gain and DMI. A study by Loe et al. (2006) fed increasing dietary inclusion of WCGF in a dry-rolled barley diet and reported similar quadratic responses in final BW, DMI, DMI (% of BW), and ADG. These observations suggest a positive associative effect on rumen fermentation characteristics when high-starch feed ingredients is substituted with readily fermentable fiber sources. Similar quadratic trends were noted by others who evaluated distillers grains (Gibb et al., 2008; Buckner et al., 2007). Expanding on this theory, Farran et al. (2006) looked at the effects of reducing

dietary inclusion of alfalfa hay (AH; 0%, 3.75%, and 7.5% diet DM) in diets containing 0 or 35% WCGF to determine if effective fiber requirements are reduced. It was determined that feeding 35% WCGF in feedlot diets containing dry-rolled corn reduced the roughage requirement. The G:F increased as AH was removed from the diet containing 35% WCGF even though DMI decreased, which indicates that AH inclusion diluted the dietary energy content, requiring higher DMI to meet the energy demands to maintain ADG. It also suggests that AH played less of a role in controlling SARA in diets containing WCGF. However, little work has been completed to evaluate forage requirements in feedlot diets containing DDGS and therefore warrants evaluation.

1.5 Conclusion

Triticale is an under-utilized cereal crop which has potential for industrial purposes as a carbohydrate source in Western Canada. The triticale DDGS, a co-product of ethanol production, has similar nutritional characteristics to that of wheat DDGS; studies have shown its values as a protein and energy source for dairy cows and sheep, respectively. However, feeding values of triticale DDGS for beef cattle have not been studied. Multiple studies have shown that both corn and wheat DDGS replacing corn and barley grain have higher feeding values. This can be primarily explained by the higher fat content of DDGS and reduced instances of ruminal acidosis due to the substitution of barley starch with slowly fermentable DDGS fiber. However, research has shown that an optimal inclusion of DDGS ranges from 20 to 30% of the diet DM. At this point, the dietary forage

requirement to maintain rumen health of feedlot diets containing triticale DDGS as a partial replacement of barley grain are not known.

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2.0 EVALUATION OF TRITICALE DRIED DISTILLERS GRAIN AS A SUBSTITUTE FOR BARLEY SILAGE IN FEEDLOT FINISHING DIETS

2.1 Introduction

Corn and wheat dried distillers grains with solubles (DDGS) have been commonly used as energy and protein sources in cattle diets. Recent work has suggested that the optimal inclusion level of corn or wheat DDGS in feedlot cattle diets is 20% of the diet DM (Buckner et al., 2007; Gibb et al., 2008). When DDGS replaces a portion of the grain in feedlot diets, the dietary starch is diluted with slower fermentable fiber, which may decrease the rate of acid production in the rumen and the occurrence of sub-acute ruminal acidosis (SARA). Consequently, feedlot cattle fed diets containing DDGS may have a reduced forage fiber requirement (Klopfenstein et al., 2008). This may allow producers to reduce the capital investment for silage production and storage as well as provide an alternative feed when forage supplies are limited.

The development of the bio-refinery industry may limit the availability of grains as a feed source for livestock production. Triticale is a drought and disease resistant, high yielding cereal grain grown in Western Canada, but has a limited market as a feed for livestock or as a food for humans. The starch content of triticale is similar to that of wheat (65% of the DM; Chapman et al., 2005) and therefore triticale has a potential as a carbohydrate source for bio-ethanol production. However, information is limited on the feeding value of triticale

DDGS. The objective of this study was to assess the value of triticale DDGS as a substitute for barley silage in a barley grain-based feedlot finishing diet. It was hypothesized that by replacing a portion of the dry-rolled barley grain with triticale DDGS, the amount of forage required to maintain rumen health would be decreased, and that substitution of triticale DDGS for barley silage would improve growth performance as a result of increased dietary energy content.

2.2 Materials and Methods

2.2.1 Experimental design, animals and diets

All procedures and protocols used in this experiment were approved by the Lethbridge Research Centre Animal Care Committee (ACC0819). A feedlot finishing trial was conducted using 160 mixed breed yearling steers (457 ± 36 kg); 16 ruminally cannulated steers to monitor rumen function and 144 intact steers to measure growth performance and carcass data. An in situ study was conducted using 3 ruminally cannulated, dry Holstein cows to characterize the ruminal fermentation characteristics of the dietary treatments. Upon arrival at the Lethbridge Research Center feedlot, steers were treated with Fremicon 7/Somnugen, IBR Express 5-PHM, and Ivomec. Prior to the start of the study, the steers were implanted with Component TE-S with Tylan (Tylan, Elanco Animal Health, Guelph, ON, Canada).

A total of 16 feedlot pens (17 m × 12.7 m) were utilized, 8 pens with standard feed bunks and 8 pens equipped with the GrowSafe system (GrowSafe Systems Ltd., Airdrie, Alberta, Canada). Pens were separated by porosity fences

on two sides, and animals had free access to fresh water. The intact steers were blocked by weight and assigned to pens; whereas the 16 ruminally cannulated steers were assigned only to the pens containing the GrowSafe system. Cannulated steers received the dietary treatments in a 4 × 4 replicated Latin Square design with 28-d periods by moving them from one pen to another at the end of each period. This resulted in 2 fistulated steers and 8 intact steers in each GrowSafe pen. All steers housed in the GrowSafe system were tagged with Allflex (Allflex Canada, St-Hyacinthe, Canada) transponders that allowed us to record feeding behavior and intake. Data from one cannulated steer was excluded from period 1 and period 3 due to loss of the cannula.

Steers were fed one of four experimental diets (Table 1) containing (DM basis) 1) 85% DRB and 10% barley silage (CON); 2) 65% DRB, 20% triticale DDGS, and 10% barley silage (D-10S); 3) 65% DRB, 25% triticale DDGS, and 5% barley silage (D-5S), and 4) 65% DRB, 30% triticale DDGS (D-0S). All diets contained 5% vitamin and mineral supplement. Total mixed rations were prepared daily and offered *ad libitum* so as to ensure feed was available at all times during the day, with a daily minimum of 10% orts in each feed bunk. The triticale DDGS used is the present study contained 36.7% CP (% DM); 32.6% NDF (% DM), 5.9% starch (% DM) and 11.4% ADIN (% N); a composition similar to wheat DDGS (Beliveau and McKinnon, 2008). Barley grain was dry rolled to a processing index (weight of 250-mL after processing divided by weight of 250-mL prior to processing) of 84 ± 4%.

Table 2.1: Diet composition and in situ digestibility

Ingredients, %DM	CON	D-10S	D-5S	D-0S
Dry-rolled Barley	85	65	65	65
Barley Silage	10	10	5	--
Triticale DDGS	--	20	25	30
Rumensin Supplement[1]	5	5	5	5
Analyzed Composition				
DM	78.5	78.6	83.4	90.6
Protein	13.4	17.2	17.7	19.7
NDF	23.6	25.8	23.2	22.2
ADF	8.0	10.2	8.7	7.9
peNDF	2.02	2.29	1.42	0.83
Starch	51.4	41.5	41.8	44.0
Oil[2]	1.9	2.4	2.5	2.6
Calcium	0.78	0.78	0.71	0.87
Phosphorus	0.41	0.52	0.55	0.58
Ca:P	1.91	1.51	1.30	1.49
OM Disappearance				
Rate of OMD, %·hr^{-1}	13.1±0.02	11.1±0.02	14.8±0.02	11.8±0.02
Effective OM Digestibility[3]	60.8±0.28	58.6±0.28	65.1±0.29	61.0±0.28

[1]Supplement contained 562.6 g·kg^{-1} ground barley, 100 g·kg^{-1} canola meal, 25 g·kg^{-1} molasses, 30 g·kg^{-1} white salt, 10 g·kg^{-1} feedlot mineral, 20 g·kg^{-1} urea, 0.5 g·kg^{-1} flavor, 0.66 g·kg^{-1} Vit. E, 2.32 g·kg^{-1} rumensin (25mg/kg DMI Monensin), and 250 g·kg^{-1} calcium carbonate
[2]Calculated from ingredient composition
[3]Assuming an average rate of passage of 5%/h; Effective OMD = 48h OMD × (Kd / (Kd+Kp))

2.2.2 Ruminal pH, Rumen Fluid, Blood Samples, and Eating Behavior

Ruminal pH was measured using the LRCpH Data logger system (Penner et al., 2006). The electrodes were standardized in pH 4 and pH 7 buffers. Protective coverings were placed over the electrodes with large enough holes to allow free flow of rumen contents, while preventing contact of the electrode with the rumen epithelium. Loggers were inserted into the rumen 4 h after feeding (1300 h) on d 20 and removed prior to feeding (0800 h) on d 28 of each period. Data loggers were placed in the ventral sac using 0.5-kg weights and pH was recorded every min. Ruminal fluid and blood samples were collected on d 20 and 28 during insertion and removal of the loggers, respectively. Ruminal pH data were summarized for daily average, minimum and maximum, and SD as well as duration below and area under the curve (AUC) at pH 5.5 and 5.2 (Bevans et al., 2005). The AUC was calculated as the sum of the absolute value of pH deviations below pH 5.5 or pH 5.2 multiplied by the duration below pH 5.5 or 5.2, respectively and reported as pH × min. Durations and AUC for pH 5.5 and 5.2 were considered indicative of duration and severity of SARA and acute ruminal acidosis (ARA), respectively. Intake-corrected AUC was calculated as AUC divided by DMI and reported as AUC / kg of DMI. Ruminal pH below 5.5 for a duration of 12 h or more, and below 5.2 for a duration of 6 h or more per day were used to define bouts of sub-acute and acute ruminal acidosis, respectively (Reinhardt et al., 1997; Owens et al., 1998).

Ruminal contents were collected from the reticulum, ventral and dorsal sacs, and the fiber mat (250 mL from each site), and mixed and strained through 2

layers of PECAP nylon (Sefar Canada Inc., Ville St. Laurent, Canada). Two samples of collected fluid (5 mL) were mixed with 1 mL of 25% (wt/vol) metaphosphoric acid for VFA and lactate analysis, and with 1 mL of 1% H_2SO_4 for ammonia determination. Samples for VFA, lactate and ammonia analysis were stored at -20˚C until analysis.

Blood samples were collected into a 10-mL vacuum tube containing K_3EDTA (Vacutainer, No. 366643, Becton Dickinson, Mississauga, Canada) and two 8-mL vacuum tubes containing Li-heparin solution (Becton Dickinson). After centrifugation of the K_3EDTA tubes, packed cell volume (PCV) was estimated using a microcapillary reader (model MH, International Equipment Co. Boston, MA). Blood collected in Li-heparin tubes was centrifuged (12,000 × *g*; 2 min) and plasma was collected for determination of blood urea nitrogen (BUN) using a VetTest Blood Chemistry Analyzer (IDEXX Laboratories Canada Corp., Toronto, Canada).

Eating behavior data were analyzed separately for the cannulated and intact steers within GrowSafe pens. References to the effect of feeding behavior on ruminal pH were limited to the cannulated steers. A meal was defined as a visit to the bunk followed by an absence of 300 s or greater. The amount of feed consumed during a visit was used to calculate meal size. GrowSafe data were summarized to report the number of meals / d, the duration of each meal, and the interval between meals (Inter-meal interval). Variation in DMI was reported as the SD of DMI measured over the 7-d collection period. Eating rate for each meal was calculated by dividing the meal size by the meal duration.

2.2.3 Growth Performance and Carcass Measurements

Steers were weighed every 28 d to monitor ADG over the duration of the experiment. Initial and final live weights were determined by taking the mean live weight of the steers prior to feeding on two consecutive days at the beginning of the experiment and immediately prior to shipment of the steers to the abattoir. Steer weights were reported as shrunk weight by multiplying live weight by a correction factor of 0.96 to account for gut fill. Feed delivery was recorded daily and orts collected weekly to determine DMI as the difference between diet DM offered and orts DM collected. Average daily gain was calculated by dividing the shrunk live weight gained (Final BW minus Initial BW) by the number of days on feed. The G:F was calculated by dividing ADG by DMI. Due to the shortage of triticale DDGS, intact steers in non GrowSafe pens (n = 80) and those in GrowSafe pens (n = 64) were shipped to the abattoir after 92 and 112 d on feed, respectively. One intact steer from the GrowSafe pen fed the D-0S diet went off feed and was removed from the study on d 92. Cannulated steers were not included in the performance and carcass data.

Net energy of the diets was determined as described by Zinn et al. (2002) and Gibb et al. (2008). The net energy for gain (NE_g) for each diet was determined using the formula of retained energy for a large framed yearling steers (NRC, 1984);

$$EG = 0.0493 \times (MW \times (478/650))^{0.75} \times (ADG)^{1.097}$$

where EG = energy gained (retained energy; Mcal/d), and MW = average shrunk BW (kg) for the feeding period ((initial BW × 0.96 + final BW × 0.96)/2).

For slaughtered steers, hot carcass weight, dressing percentage, back fat thickness, rib eye area, saleable meat yield, and quality grade were determined by qualified graders. Liver scores were determined based on the ranking scale used by the Canadian Beef Grading Agency.

2.2.4 Diet Sampling and Chemical Analysis

Diets, orts and ingredients were sampled weekly, and analyzed for DM concentration by drying at 55˚C for 48 h. Diets were adjusted if the DM concentration of barley silage deviated more than 3 percentage units from the average. Weekly samples were composited by period and stored at -20˚C. A 500-g subsample from each diet was collected during each period and freeze-dried for later analysis for fat concentration. A 1-kg subsample from each diet composite was taken to determine peNDF content (Yang and Beauchemin, 2006), and an additional 1-kg subsample from each diet composite was ground through a 1-mm screen (Wiley mill; standard model 4, Arthur H. Thomas, Philadelphia, PA) for chemical analysis. Subsamples (5 g) were further ground with a ball grinder (mixer mill MM200, Retsch, Haan, Germany) and analyzed for N using flash combustion (Carlo Erba Instruments, Milan, Italy). The NDF and ADF concentration of the diet ingredients were determined as described by Van Soest et al. (1991), using amylase and sodium sulfite for the NDF analysis. The N

concentration of the ADF fraction was determined as described above to calculate the acid detergent insoluble nitrogen (ADIN) concentration of triticale DDGS. Starch was determined using an enzymatic method as described by Karkalas (1985). Starch in the samples was gelatinized with sodium hydroxide, and hydrolyzed to glucose using amylase. Free glucose was then reacted with glucose oxidase/peroxidase (No. P7119, Sigma, St. Louis, MO) and dianisidine dihydrochloride, and absorbance was measured using a plate reader (SpectraMax 190, Molecular Devices Corp., Sunnyvale, CA). Samples were extracted using diethyl ether and fat concentration was determined using a BÜCHI Extraction unit (Unit E-816, BÜCHI Labortechnik AG, Postfach) according to the AOAC official method (2003.06).

Ruminal VFA concentrations and lactic acid concentrations were quantified by gas chromatography (model 5890, Hewlett Packard, Little Falls, DE) using crotonic acid as an internal standard as described by Bevans et al. (2005) Ruminal ammonia concentration was determined by the indophenol-sodium salicylate method (Verdouw et al., 1978) using a Technicon autoanalyzer II (Pulse Instrumentation Ltd., Saskatoon, SK).

2.2.5 In situ Digestibility

Three Holstein cows fed a 75% dry-rolled barley diet, were used to determine the in situ digestibility of the 4 diets. A subsample (5 kg) of each diet was dried at 55˚C for 48 h and ground using a Wiley mill (Arthur H. Thomas, Philadelphia, PA) through a 4-mm screen. After grinding, 5 g were weighed into

10 cm × 20 cm nylon bags (50-µm pore size; Ankom Technology Corp., Macedon, NY) in triplicate for each sampling time point. The samples were soaked in warm water for 15 min prior to incubation in the rumen for 0, 1, 2, 4, 8, 16, 24, and 48 h. After incubation, samples were rinsed using cold water in a rinse cycle of a washing machine and under tap water until the water was clear. Bags were dried at 55˚C for 48 h, and hot-weighed at 105˚C to estimate the amount of residual DM remaining in each bag. Organic matter content of the residual DM was determined by determining ash content of samples (550˚C for 3 h) and the rate of OM disappearance was estimated using the following formula:

$$R_t = R_0 \times e^{-kt}$$

where R_t = residue at time t, R_0 = residue at time 0, t = time of ruminal incubation, and k = rate of disappearance. Assuming a rumen passage rate of 5%/h, effective ruminal OM digestibility (NRC, 2000) was calculated as:

$$OM_{eff} = OM_{48h} \times (k_d / (k_d + k_p))$$

where OM_{eff} = effective ruminal OM digestibility, OM_{48h} = 48 h in situ OM disappearance (potentially digestible fraction), k_d = rate of OM disappearance, and k_p = rate of OM passage.

2.2.6 Statistical Analysis

Mean ruminal pH, rumen VFA, lactate and ammonia concentrations, BUN, PCV, and eating behavior data associated with the 16 cannulated steers were analyzed as a 4 × 4 replicated Latin square using the MIXED procedure (SAS Institute Inc. 2005). Diet and period were considered fixed effects with

square and pen group nested within square as random effects. Multiple variance-covariance structures were fitted and compound symmetry or banded covariance matrices were the structures producing the lowest AIC values. Contrasts were generated to compare the CON diet to the D-10S diets as well as to test for linear effects of the substitution of triticale DDGS for barley silage.

Pen was the experimental unit for the growth performance and carcass data. Days-on-feed (block), treatment and their interactions were examined, and as there was no interaction between days-on-feed and diet, days-on-feed was removed from the model. A Chi square analysis was used to analyze for differences in marbling and liver scores among steers on different diets.

2.3 Results

2.3.1 Rumen pH Analysis

Over the duration of the experiment, a total of 21, 12, 30, and 44 incidences of SARA and 18, 14, 28, and 35 incidences of ARA were observed in steers fed CON, D-10S, D-5S, and D-0S, respectively (Table 2). Mean daily ruminal pH of CON steers was not different ($P = 0.75$) from that of steers fed D-10S. Mean ruminal pH linearly decreased ($P = 0.006$) as triticale DDGS replaced barley silage. The SD of ruminal pH was smaller ($P = 0.008$) for steers fed D-10S as compared to the CON. Steers fed CON had a lower ($P = 0.02$) daily minimum pH compared to steers fed D-10S. However, daily minimum ($P = 0.26$) and maximum ($P = 0.90$) was not affected by the substitution of triticale DDGS for barley silage. Steers fed D-10S had a similar duration below pH 5.5 ($P = 0.52$)

and pH 5.2 (P = 0.33), and similar AUC below pH 5.5 (P = 0.27) compared to steers fed CON. However, steers fed D-10S tended (P = 0.10) to have a lower AUC below pH 5.2 as compared to steers fed CON. The duration below pH 5.5 (P = 0.006) and pH 5.2 (P = 0.01) increased linearly as triticale DDGS replaced barley silage. Similarly, replacing barley silage with triticale DDGS linearly increased AUC below pH 5.5 (P = 0.02) and pH 5.2 (P = 0.05), respectively. The AUC below pH 5.5 (P = 0.06) and 5.2 (P = 0.09) per kg of DMI tended to decrease in steers fed D-10S as compared to CON. Additionally, AUC below pH 5.5 (P = 0.08) and pH 5.2 (P = 0.10) per kg of DMI tended to increase as triticale DDGS replaced barley silage.

The mean hourly ruminal pH (Figure 1) was similar for steers fed CON and D-10S except for 0-h (P = 0.02) and 23-h post feeding (P = 0.05) where mean hourly pH for steers fed D-10S was higher than CON. The mean hourly ruminal pH 4 to 10 h after feeding, and 15 to 23 h after feeding decreased linearly (P = 0.05) as dietary inclusion of triticale DDGS increased.

Table 2.2: Effect of substituting triticale DDGS for barley grain (D-10S) and barley silage (D-5S; D-0S) compared to a dry-rolled barley control (CON) on ruminal pH in feedlot steers (n=16 per treatment)

	Diet[1]					Con vs. D-10S[2]	Linear[3]
Item	CON	D-10S	D-5S	D-0S	SEM	*p*=	*p*=
Bouts of SARA[4]	21	12	30	44	--	--	--
Bouts of ARA[5]	18	14	28	35	--	--	--
Ruminal pH					--		
Mean	5.86	5.88	5.74	5.70	0.05	0.75	0.006
Minimum	4.81	4.94	4.87	4.89	0.04	0.02	0.26
Maximum	6.92	6.83	6.84	6.83	0.04	0.14	0.90
SD of mean pH	0.22	0.16	0.14	0.14	0.01	0.008	0.48
Duration of pH, h·d^{-1}							
<5.5	6.6	5.7	8.3	9.4	1.0	0.52	0.006
<5.2	2.8	1.8	3.3	4.2	0.67	0.33	0.01
Area under the curve, pH×min							
<5.5	117.6	81.6	135.8	159.8	22.2	0.27	0.02
<5.2	33.9	15.0	33.5	36.7	7.9	0.10	0.05
AUC/kg of DMI, pH×min							
<5.5	14.3	7.7	11.6	13.6	2.4	0.06	0.08
<5.2	3.26	1.36	2.82	3.09	0.74	0.09	0.10

[1]CON: 85% dry-rolled barley grain, 10% barley silage, 5% supplement; D-10S: 65% dry-rolled barley grain, 20% triticale DDGS, 10% barley silage, 5% supplement; D-5S: 65% dry-rolled barley grain, 25% triticale DDGS, 5% barley silage, 5% supplement; D-0S: 65% dry-rolled barley grain, 30% triticale DDGS, 5% supplement

[2]Contrast between CON diet vs. D-10S diet

[3]Linear effect of BS substitution

[4]A bout of sub-acute ruminal acidosis (SARA) is defined as having daily rumen pH below 5.5 for duration of 12h or more

[5]A bout of acute ruminal acidosis (ARA) is defined as having daily rumen pH below 5.2 for duration of 6h or greater

2.3.2 Rumen VFA Analysis

Samples taken prior to feeding (0 h) indicated that CON and D-10S fed steers had similar total VFA concentration ($P = 0.68$) and molar proportions of acetate ($P = 0.27$) and butyrate ($P = 0.52$; Table 3). However, molar proportion of propionate was lower ($P = 0.05$) for steers fed D-10S as compared to the CON. As a result, steers fed D-10S tended ($P = 0.06$) to have a higher acetate-to-propionate ratio (A:P) as compared to CON steers. Molar proportions of acetate linearly decreased ($P = 0.001$) and that of propionate linearly increased ($P = 0.02$) as triticale DDGS replaced barley silage; resulting in a linear decrease ($P = 0.005$) in A:P. At 4 h after feeding, steers fed CON and D-10S had similar concentrations of total VFA ($P = 0.25$) and molar proportion of butyrate ($P = 0.63$). However, molar proportion of acetate was lower ($P = 0.04$) for steers fed D-10S as compared to the CON, but there was no difference ($P = 0.27$) in A:P. Total VFA concentration ($P = 0.79$) and molar proportion of butyrate ($P = 0.74$) were not affected by triticale DDGS substitution for barley silage, however, molar proportion of propionate linearly increased ($P = 0.05$) and that of acetate ($P = 0.005$) and A:P ($P = 0.04$) linearly decreased as triticale DDGS replaced barley silage. Ruminal ammonia concentration was higher ($P = 0.04$) prior to feeding, and tended to be higher ($P = 0.07$) 4 h after feeding in steers fed D-10S as compared to steers fed the CON. Ruminal ammonia concentration was not affected by the substitution of triticale DDGS for barley silage. Concentrations of lactate were extremely low throughout the experiment and averaged below 0.11

mM, but prior to feeding there was a tendency for higher lactate concentration (*P* = 0.06) in steers fed D-10S as compared to CON.

Table 2.3: Effect of substituting triticale DDGS for barley grain (D-10S) and barley silage (D-5S; D-0S) compared to a dry-rolled barley control (CON) on ruminal VFA, ammonia-N and blood parameters (n = 16 per treatment)

Diet[1]:	CON	D-10S	D-5S	D-0S		CON vs. D-10S[2]	Linear[3]
Time after Feeding:		0h			SEM	*P* =	*P* =
Total VFA, m*M*	116.8	113.8	106.1	111.9	5.3	0.68	0.79
Acetate, mol·100 mol^{-1}	45.9±1	47.4	44.8	41.6	1.2	0.27	<0.001
Propionate, mol·100 mol^{-1}	39.0	35.1	37.5	39.7	1.7	0.05	0.02
Butyrate, mol·100 mol^{-1}	9.9	10.7	10.0	11.1	0.9	0.52	0.73
A:P[4], mol·100 mol^{-1}	1.18	1.36	1.22	1.08	0.08	0.06	0.005
Isovalerate, mol·100 mol^{-1}	2.4	2.6	2.7	2.0	0.2	0.39	0.02
Valerate, mol·100 mol^{-1}	2.6	2.3	3.0	3.7	0.2	0.35	< 0.001
Lactate, m*M*	0.06	0.07	0.06	0.07	0.004	0.06	0.33
Ammonia, m*M*	11.0	13.3	14.9	13.2	0.8	0.04	0.89
PCV, %	42.3	40.9	42.3	42.6	1.2	0.19	0.10
BUN, mg·L^{-1}	214	340	415	437	15.2	<0.001	< 0.001
Time after Feeding		4h					
Total VFA, m*M*	121.9	132.8	141.6	130.3	9.8	0.25	0.79
Acetate, mol·100 mol^{-1}	50.0	46.8	45.9	42.9	1.1	0.04	0.005
Propionate, mol·100 mol^{-1}	36.8	37.3	38.5	40.9	1.5	0.80	0.05
Butyrate, mol·100 mol^{-1}	9.2	9.6	9.7	9.9	0.6	0.63	0.74
A:P[4], mol·100 mol^{-1}	1.44	1.31	1.23	1.06	0.08	0.27	0.04
Isovalerate, mol·100 mol^{-1}	2.4	2.0	1.6	1.3	0.2	0.10	0.008
Valerate, mol·100 mol^{-1}	1.6	2.6	2.7	3.1	0.1	<0.001	0.006
Lactate, m*M*	0.11	0.10	0.08	0.09	0.02	0.71	0.80
Ammonia, m*M*	7.5	9.4	11.7	9.4	0.7	0.07	0.99
PCV, %	42.0	41.8	41.3	42.4	1.2	0.84	0.59
BUN, mg·L^{-1}	223.2	338.4	398.0	401.2	15.3	<0.001	<0.001

[1]CON: 85% dry-rolled barley grain, 10% barley silage, 5% supplement; D-10S: 65% dry-rolled barley grain, 20% triticale DDGS, 10% barley silage, 5% supplement; D-5S: 65% dry-rolled barley grain, 25% triticale DDGS, 5% barley silage, 5% supplement; D-0S: 65% dry-rolled barley grain, 30% triticale DDGS, 5% supplement

[2]Contrast between CON diet vs. D-10S diet

[3]Linear effect of BS substitution

[4]acetate: propionate ratio

2.3.3 Blood Measures

Packed-cell volume (Table 3) was relatively high across treatments (> 40%). For blood collected prior to feeding, there was a tendency for PCV to linearly increase ($P = 0.10$) as triticale DDGS was substituted for barley silage. Blood urea N concentration linearly increased ($P < 0.001$) as barley silage was replaced with triticale DDGS or by feeding D-10S as compared to CON

2.3.4 Feeding Behavior

Cannulated steers fed D-10S tended to have higher ($P < 0.08$) DMI compared to steers fed CON (Table 4). The daily variation in DMI of CON steers was about 50% higher ($P = 0.002$) compared to steers fed triticale DDGS. Meal frequency ($P = 0.67$), meal duration ($P = 0.13$), inter-meal interval ($P = 0.50$), meal size ($P = 0.29$) and eating rate ($P = 0.81$) were similar between steers fed CON and D-10S. Eating rate linearly increased ($P < 0.001$) and meal duration tended to linearly decrease ($P = 0.08$) as triticale DDGS replaced barley silage.

Table 2.4: Effect of substituting triticale DDGS for barley grain (D-10S) and barley silage (D-5S; D-0S) compared to a dry-rolled barley control (CON) on feeding behavior of cannulated steers (n = 16 per treatment)

	Diet[1]					Con vs. D-10S[2]	Linear[3]
Item	CON	D-10S	D-5S	D-0S	SEM	*p*=	*p*=
SD of DMI, kg·d^{-1}	2.6	1.9	1.5	1.8	0.2	0.009	0.68
Meal frequency, meal·d^{-1}	8.3	8.5	8.1	8.3	0.4	0.67	0.68
Duration, min·meal^{-1}	10.6	11.9	11.3	10.5	0.7	0.13	0.08
Inter-meal interval, min	172.6	166.0	179.1	173.6	7.1	0.50	0.44
Meal size, kg·meal^{-1}	1.23	1.36	1.58	1.53	0.1	0.29	0.14
Eating rate, g·min^{-1}	118.3	116.4	141.0	150.6	8.1	0.81	<0.001

[1]CON: 85% dry-rolled barley grain, 10% barley silage, 5% supplement; D-10S: 65% dry-rolled barley grain, 20% triticale DDGS, 10% barley silage, 5% supplement; D-5S: 65% dry-rolled barley grain, 25% triticale DDGS, 5% barley silage, 5% supplement; D-0S: 65% dry-rolled barley grain, 30% triticale DDGS, 5% supplement

[2]Contrast between CON diet vs. D-10S diet

[3]Linear effect of BS substitution

2.3.5 Growth Performance and Carcass Characteristics

Steers fed D-10S had similar shrunk final weight, DMI, ADG, and G:F as compared to steers fed the CON (Table 5). There was a tendency for a linear decrease ($P = 0.10$) in DMI for intact steers as more triticale DDGS replaced barley silage. Although ADG was not affected ($P = 0.56$), G:F tended to linearly increase ($P = 0.06$) as dietary inclusion of triticale DDGS increased.

Carcass traits (Table 6) were not affected by substitution of triticale DDGS for barley silage. However, steers fed D-10S had a lower ($P = 0.06$) dressing percentage, tended to have thicker back fat ($P = 0.10$) and smaller ($P = 0.10$) rib eye area, and decreased ($P = 0.06$) meat yield as compared to steers fed CON. Interestingly, steers fed D-10S had more liver abscesses ($P = 0.006$) compared to those fed CON. Similarly, the severity of abscesses was greater ($P = 0.006$) in steers fed D-10S as compared to steers fed CON.

Table 2.5: Effect of substituting triticale DDGS for barley grain (D-10S) and barley silage (D-5S; D-0S) compared to a dry-rolled barley control (CON) on growth performance and NE_g content (n = 4 per treatment)

	Diet[1]					Con vs. D-10S[2]	Linear[3]
Item	CON	D-10S	D-5S	D-0S	SEM	*P* =	*P* =
Shrunk initial weight, kg	455.3	457.9	457.9	456.3	6.1	0.76	0.85
Shrunk final weight, kg	652.6	657.7	654.1	663.3	7.5	0.64	0.61
DMI, kg d^{-1}	12	12.6	12.5	12	0.2	0.08	0.1
ADG, kg d^{-1}	1.95	1.97	1.98	2.03	0.07	0.83	0.56
G:F	0.169	0.162	0.165	0.173	0.003	0.19	0.06
NE_g of diet, Mcal / kg[4]	1.33	1.28	1.29	1.36	0.02	0.11	0.23

[1]CON: 85% dry-rolled barley grain, 10% barley silage, 5% supplement; 10-BS: 65% dry-rolled barley grain, 20% triticale DDGS, 10% barley silage, 5% supplement; 5-BS: 65% dry-rolled barley grain, 25% triticale DDGS, 5% barley silage, 5% supplement; 0-BS: 65% dry-rolled barley grain, 30% triticale DDGS, 5% supplement

[2]Contrast between CON diet vs. D-10S diet

[3]Linear effect of barley silage substitution

[4]Calculated from growth performance (NRC 1984; Zinn et al., 2002)

Table 2.6: Effect of substituting triticale DDGS for barley grain (D-10S) and barley silage (D-5S; D-0S) compared to a dry-rolled barley control (CON) on carcass characteristics and occurrence of liver abscesses (n = 4 per treatment)

	Diet[1]				Con vs. D-10S[2]	Linear[3]
Item	CON	D-10S	D-5S	D-0S	SEM	*P* =	*P* =[1]
Carcass weight, kg	394.8	402.5	405.7	407.3	4.5	0.25	0.47
Dressing percent	59.4	56.4	57.2	57	1	0.06	0.63
Back fat, mm	12.3	14.5	13.9	14.4	1	0.1	0.93
Ribeye area, cm^2	93.3	90.7	90.3	89.5	1.1	0.1	0.42
Meat yield, %	57.5	55.2	55.4	54.9	0.7	0.06	0.8
AAA, %[5]	8.11	11.1	11.4	8.57	--	0.26	--
Abscessed livers, %[5]	16.2	47.2	44.4	63.9	--	0.006	--
Severely abscessed, %[5]	5.4	30.6	16.7	30.6	--	0.006	--

[1]CON: 85% dry-rolled barley grain, 10% barley silage, 5% supplement; D-10S: 65% dry-rolled barley grain, 20% triticale DDGS, 10% barley silage, 5% supplement; D-5S: 65% dry-rolled barley grain, 25% triticale DDGS, 5% barley silage, 5% supplement; D-0S: 65% dry-rolled barley grain, 30% triticale DDGS, 5% supplement

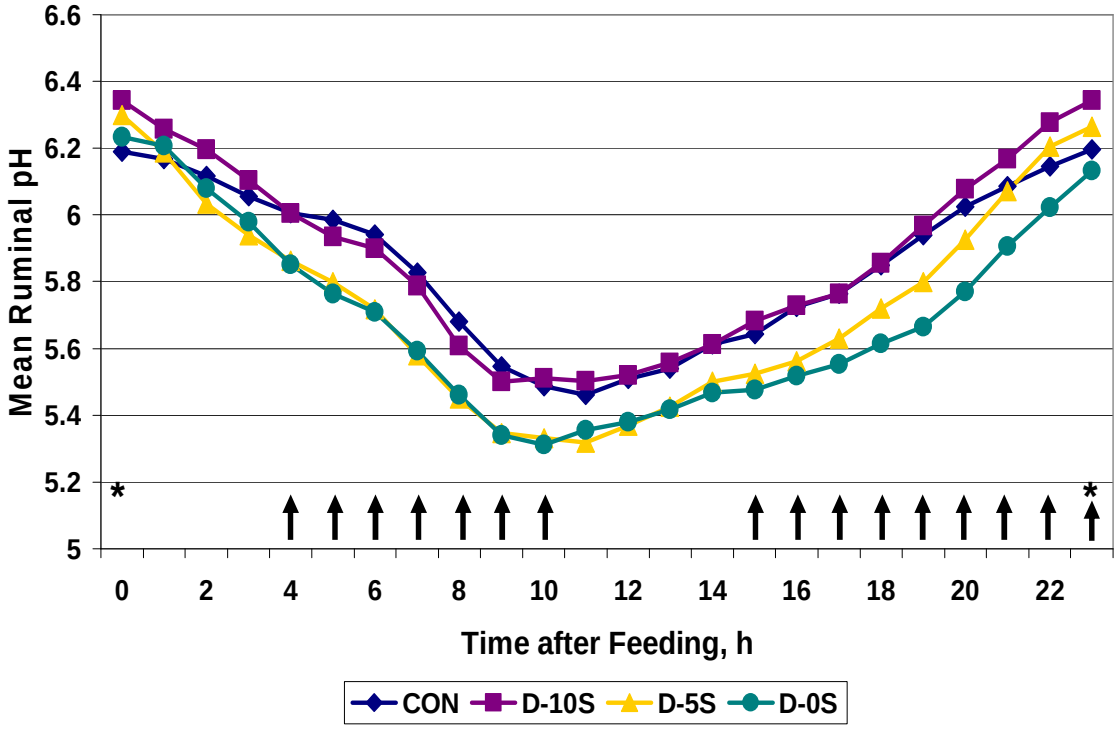
[2]Contrast between CON diet vs. D-10S diet

[3]Linear effect of BS substitution

[4]Calculated from growth performance (NRC 1984; Zinn et al., 2002)

[5]From Chi-squared analysis

Figure 2.1: Effect of substituting triticale DDGS for barley grain (D-10S) and barley silage (D-5S; D-0S) compared to a dry-rolled barley control (CON) on mean hourly rumen pH (pooled SE = 0.06). Hours where the effect of triticale DDGS substitution for barley silage are significantly different (P < 0.05) than the CON are marked with asterisks (*), and hours with a significant linear effect (P < 0.05) of barley silage substitution are marked with an arrow (↑)



2.4 Discussion

2.4.1 Nutrient Composition and Digestibility of Triticale DDGS

Triticale DDGS has similar ether extract, higher NDF, and lower CP levels than wheat DDGS (Beliveau and McKinnon, 2008; Gibb et al., 2008), reflecting the differences in composition of the whole grains (Chapman et al., 2005). In contrast, corn DDGS typically contains a higher level of ether extract and less CP than either wheat or triticale DDGS (Spiehs et al., 2002; McKeown et al. 2009). Therefore, the fermentation characteristics of triticale DDGS in the rumen are expected to be similar to wheat DDGS. The ADIN content of triticale DDGS used in our study was 11.4%, similar to that reported for wheat and corn DDGS (Ham et al., 1994; Beliveau and McKinnon, 2008).

In the present study, the effective OM digestibility and rate of OM disappearance were lower for the D-10S diet compared to the CON diet. Gibb et al. (2008) reported decreased apparent total tract DM digestibility in a diet containing wheat DDGS at 60% of dietary DM compared to a diet containing steam-rolled barley in place of wheat DDGS. Although DDGS contains highly digestible NDF (Ham et al., 1994), NDF digestion in the rumen of cattle may be suboptimal in high grain diets due to low ruminal pH (Depenbusch et al., 2009). Furthermore, drying of DDGS may lower CP digestibility (Uwituze et al., 2008a). In our study, rate of OM digestibility or effective OM digestibility was not affected by the replacement of barley silage with triticale DDGS. Reduction in dietary roughage content often decreases in vivo dilution rate (Goetsch et al., 1984) and may result in an increase in ruminal OM digestibility (Ledoux et al.,

1985). Our in situ results suggest that the substitution of triticale DDGS for barley silage did not adversely affect ruminal OM digestibility.

2.4.2 Rumen pH Response to DDGS Inclusion

2.4.2.1 Substituting Dry-Rolled Barley

The improved feeding value observed as DDGS is substituted for corn or barley grain in finishing diets can be in part attributed to an increase in ruminal pH (Larson et al., 1993; Ham et al., 1994; Klopfenstein et al., 2008). The partial replacement of rapidly fermentable, high starch cereal grains with DDGS may decrease the prevalence of SARA (Klopfenstein et al., 2008). Steers in our trial fed D-10S had fewer incidences of SARA and ARA compared to steers fed CON; and tended to have smaller AUC below 5.2 compared to CON, observations that support our hypothesis. However, changes in ruminal pH as a result of the inclusion of DDGS in the diet can be confounded by increases in total DMI (Klopfenstein et al., 2008; Uwituze et al., 2008a; Corrigan et al., 2009). Corrigan et al. (2009) reported lower mean ruminal pH and higher AUC below pH 5.6 and 5.3 when corn wet distillers grains with solubles (WDGS) replaced 40% of the diet DM of either dry-rolled corn, high moisture corn, or steam-flaked corn. However, in this study DMI was almost 1.8 kg higher for the WDGS diet as compared to the corn-based diets, leading to similar levels of total starch intake among diets. In our study, DMI of the cannulated steers fed D-10S was 1.1 kg higher than CON, but estimated starch intake was still lower for D-10S diet than CON (4.6 vs. 5.1 kg/d, respectively). Lower starch intake may limit the rate,

duration and extent of ruminal pH decline (Owens et al., 1998), a possibility that is supported by our study in which we observed an increased minimum ruminal pH as well as a reduced intake-corrected AUC below pH 5.5 and 5.2 in steers fed D-10S as compared to CON. Galyean and Defoor (2003) proposed that decreasing the grain to NDF ratio per unit of intake would stabilize ruminal pH. Similarly, Corrigan et al. (2009) have observed that substituting corn WDGS for a portion of corn grain also stabilized ruminal pH. These findings are consistent with our observation that the variation in mean ruminal pH declined when triticale DDGS replaced barley grain. Forage fiber is typically required to maintain ruminal pH (Allen, 1997; Mertens, 1997), particularly in high concentrate diets (Galyean and Defoor, 2003). However, our study suggests that partial replacement of barley grain at 20% of diet DM with triticale DDGS may reduce the dietary forage required to maintain rumen health.

2.4.2.2 Substituting Barley Silage

Forages are usually included in high grain finishing diets to reduce the occurrence of SARA (Stock et al., 1987, 1990; Shain et al., 1999). In our study, replacing barley silage with triticale DDGS increased the occurrence of SARA, a result that may be attributed to a decline in physically effective fiber in the diet (peNDF; Mertens, 1997). Zhang et al. (2009a, b) observed that chewing activity decreased in lactating dairy cows as triticale DDGS (20% diet DM) replaced an equivalent portion of barley silage in the diet. Decreasing the peNDF content of the diet reduces chewing and salivation (Allen et al., 1997; Zebeli et al., 2006),

thus lowering the buffering effect of saliva on ruminal pH. Although the substitution of triticale DDGS for barley silage increased the occurrence and severity of SARA, it did not increase the variation in ruminal pH. This response may be attributed to the dilution of fermentable carbohydrate (Galyean and Defoor, 2003) or alterations in feeding behaviour.

2.4.3 Feeding Behaviour

Increased variation in daily DMI has been associated with ruminal acidosis (Cooper et al., 1999). Stock et al. (1995) summarized data from individual feeding trials and reported that variation in feed intake is negatively correlated to G:F, a finding potentially attributable to ruminal acidosis (Cooper et al., 1999). In the present study, variation in DMI was lower for steers fed D-10S compared to steers fed the CON, which may be an indication of the severity of SARA. Although the occurrence of SARA and AUC below pH 5.5 and 5.2 increased as triticale DDGS replaced barley silage, variation in DMI was not affected. This observation suggests that ruminal acidosis may not adversely affect feed intake until a certain threshold level is reached.

Eating rate increased as more triticale DDGS replaced barley silage, likely due to a decrease in particle size of the diet (Allen, 1997; Shain et al., 1999). Meal duration decreased as more triticale DDGS was substituted for barley silage, an observation that is consistent with the smaller particle size of triticale DDGS compared to barley silage.

2.4.4 Performance and Carcass Characteristics

Steers fed D-10S tended to have higher DMI than steers fed CON, a finding that is in agreement with Gibb et al. (2008) who found DMI of feedlot heifers increased with increasing levels of wheat DDGS in barley grain finishing diets. Increasing the NDF concentration of high grain diets has been shown to increase DMI (Galyean and Defoor, 2003). Cattle experiencing SARA often exhibit reduced DMI (Fulton et al., 1979; Schwartzkopf-Genswein et al., 2003). Consequently, the lower incidence of SARA in steers fed D-10S as compared to CON may have also contributed to the higher DMI of steers fed D-10S. However, the effect of substitution of corn DDGS for corn grain on DMI in cattle fed finishing diets has not been consistent (Vander Pol et al., 2006; Buckner et al., 2007; May et al., 2009), an observation that may be related to differences in grain processing (Vander Pol et al., 2006).

Steers fed D-10S had increased DMI, but similar ADG compared to those fed CON. Similarly, Lodge et al. (1997) reported that sorghum DDGS had a NE_g value that was 80% of that of dry-rolled corn when fed at 40% of dietary DM. Conversely, it was reported that wheat DDGS has a similar NE_g content as dry-rolled barley (Beliveau and McKinnon, 2008) and a slightly lower NE_g content than steam-rolled barley (Gibb et al., 2008). Considering the triticale DDGS used in our study had a higher ADF and ADIN content than wheat DDGS (Beliveau and McKinnon, 2008), the quality of the triticale DDGS and resulting feed value may be lower than wheat DDGS. Conversely, feeding wheat or triticale DDGS at 20% of dietary DM to lambs had no effect on DMI, ADG or G:F (McKeown et

al., 2009). Variation in the feed value of DDGS may depend on the level included in the diet as well as differences in production methods among ethanol plants.

Replacing barley silage with triticale DDGS tended to decrease DMI and increase G:F without affecting ADG, suggesting that decreased ruminal pH did not adversely affect animal productivity. Similarly, Stock et al. (1990) reported increased G:F as dietary roughage content (50:50 mix of corn silage and alfalfa hay) decreased in a high moisture corn or dry-rolled sorghum based diet. Conversely, Kreikemeier et al. (1990) improved G:F of finishing steers by adding 10% roughage (50:50 mix of corn silage and alfalfa hay) to a diet containing steam-rolled wheat. Due to decreased dilution rate with decreasing roughage content (Goetsch et al., 1984), ruminal digestibility of grain may have increased due to longer ruminal retention time (Stock et al., 1987). Such a response may be beneficial in diets containing grains with slower rates of digestion (Stock et al., 1990) but detrimental in diets containing grain that ferments more rapidly (Kreikemeier et al., 1990). Therefore, increasing diet digestibility by increasing ruminal retention time may partially explain the increased G:F observed for steers as barley silage was replaced with triticale DDGS.

We also observed an increase in molar proportions of propionate as triticale DDGS replaced barley silage. Propionate is a VFA that acts as a hydrogen sink and is associated with reduced methane production (Johnson and Johnson, 1995). Propionate also serves as a precursor for glucose synthesis in ruminants, factors that may explain the increase in the NE_g content of the diet as triticale DDGS replaced barley silage.

In the present study, replacing barley silage with triticale DDGS did not affect carcass characteristics. Conversely, Miller et al. (2009) reported hot carcass weight and yield grade to increase and marbling to increase quadratically when alfalfa hay inclusion increased in a steam-flaked corn based finishing diet containing 25% corn DDGS. However, unlike our findings where ADG was maintained when triticale DDGS replaced barley silage, the author reported carcass-adjusted ADG to increase when alfalfa hay inclusion increased, resulting in increased NE_g intake (Owens et al., 1995). Therefore, the lack of carcass response to substitution of triticale DDGS for barley silage in the present study may be attributed to similar ADG, in spite of reduced DMI.

Replacing a portion of dry-rolled barley with triticale DDGS appeared to increase fat deposition in steers fed D-10S as compared to steers fed CON as these animals had increased back fat thickness and decreased meat yield. This is similar to studies feeding corn and wheat DDGS in place of dry-rolled corn and steam-rolled barley, respectively (Benson et al., 2005; Gibb et al., 2008). However, others have reported that feeding corn DDGS in place of steam-flaked corn had no effect on back fat and meat yield (Depenbusch et al., 2009). As cattle approach mature BW, fat accretion increases compared to lean tissue growth (Owens et al., 1995), which may suggest steers fed D-10S were closer to mature weight at slaughter compared to steers fed CON. Alternatively, Anderson et al. (1988) and McKinnon et al. (1993) have reported that increasing supplemental protein in feedlot diets increases fat deposition rather than lean accretion, suggesting that such a practice improves energy balance as opposed to protein

status. Improved energy balance resulting from protein supplementation may be the result of increased OM digestibility (McKinnon et al., 1993), an observation similar to that reported in the present study when triticale DDGS partially replaced dry-rolled barley.

2.4.5 Effects of DDGS on Liver Abscess Prevalence

Prevalence of liver abscesses has long been considered to be associated with feeding high-grain diets (Nagaraja and Chengappa, 1998), but the effects of feeding DDGS on liver abscesses in feedlot cattle has not been extensively investigated. Although ruminal pH was higher in the D-10S steers compared to the CON steers, prevalence and severity of liver abscesses were much higher for steers fed D-10S, a finding that contradicts the proposed etiology of the factors leading to the formation of liver abscesses (Tan et al., 1996; Nagaraja and Chengappa, 1998). A dietary antimicrobial was not included in the present study which may have contributed to the higher prevalence and severity of abscesses. Previous studies reported that feeding corn or wheat distillers grains with solubles (DGS) in place of cereal grains did not affect the prevalence of liver abscesses (Vander Pol et al., 2006; May et al., 2007; Depenbusch et al., 2009), but these studies included tylosin in the diet. Firkins et al. (1985) did not include an antimicrobial and found increased prevalence of liver abscesses in cattle fed wet corn gluten feed in place of dry-rolled corn. Recently, Beliveau and McKinnon (2008) fed wheat DDGS without an antimicrobial and reported that the prevalence of severe liver abscesses was numerically higher in steers fed wheat DDGS

compared to a barley grain based diet containing no wheat DDGS. Dietary N is fed in excess of requirements when feedlot diets contain DDGS greater than 20% of dietary DM (NRC 2000). Excess dietary N in the rumen is converted into ammonia N which is absorbed from the rumen into the hepatic portal vein and transported to the liver for detoxification (Abdoun et al., 2007). Argininosuccinate synthetase is one of the key enzymes in the urea cycle that condenses the N from citrulline and aspartate to form arginine. This enzyme is also involved in the metabolism of the lipid A portion of lipopolysaccharide (LPS; Satoh et al., 2008), a factor that has been implicated in promoting the development of liver abscesses. The higher rumen ammonia levels and BUN concentrations suggests that ruminal ammonia flux and activity of the urea cycle was increased in steers fed triticale DDGS. Consequently, it is possible that the availability of argininosuccinate synthetase to metabolize LPS may have been reduced, thereby creating conditions that were more conducive to the formation of liver abscesses. Further studies are required to clarify the role of argininosuccinate synthetase in LPS clearance in ruminants (Satoh et al., 2008) and to clearly identify adverse effects of feeding excess N on LPS detoxification and liver abscess development.

In conclusion, substituting dry-rolled barley with triticale DDGS at 20% of dietary DM in finishing diets decreased the prevalence of SARA, although it increased the incidence of liver abscesses. Furthermore, substitution of triticale DDGS for barley silage lowered ruminal pH and increased liver abscesses, but did not adversely affect growth performance. Diluting the dietary starch content by

feeding triticale DDGS may reduce the level of forage required to maintain rumen function in feedlot finishing diets, a potential advantage under conditions of high forage cost or limited availability. Feeding triticale DDGS in place of barley grain increased carcass fat content, but when triticale DDGS replaced barley silage, it did not affect carcass characteristics. The higher severity of liver abscesses in steers fed triticale DDGS indicates the need to include an antimicrobial in high DDGS diets for liver abscess control.

2.5 Conclusion

Substituting dry-rolled barley (DRB) with triticale DDGS at 20% of the diet DM in finishing diets decreased the prevalence of SARA. Furthermore, although barley silage substitution with triticale DDGS lowered rumen pH, it did not adversely affect growth performance. This suggests that diluting the dietary starch content with triticale DDGS may reduce forage requirements in feedlot finishing diets, a potential advantage under conditions of high forage cost or limited availability. Feeding triticale DDGS in place of DRB increased carcass fat content, but did not affect carcass characteristics when it was substituted for barley silage. Liver abscesses were more prevalent and severe in steers fed triticale DDGS, potentially making it advantageous to include an antimicrobial in the diet to control liver abscesses in cattle fed high DDGS diet

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3.0 GENERAL DISCUSSION

3.1 Study Summary

The present study was conducted to assess the value of triticale dried distillers grain with solubles (DDGS) as a substitute for barley silage in a dry-rolled barley (DRB) based feedlot finishing diet. The trial used 144 non-cannulated, and 16 ruminally cannulated crossbred yearling steers in one integrated feedlot trial, monitoring diet effects on performance and carcass characteristics as well as rumen fermentation and eating behavior while housed in the same group environment. The GrowSafe system (GrowSafe Systems Ltd., Airdrie, Alberta, Canada) was used to monitor eating behavior and a self-contained submersible rumen pH probe (Penner et al., 2006) was used to collect rumen pH data. Steers were fed one of four experimental diets containing (DM basis) 1) 85% DRB and 10% barley silage (CON); 2) 65% DRB, 20% triticale DDGS, and 10% barley silage (D-10S); 3) 65% DRB, 25% triticale DDGS, and 5% barley silage (D-5S), and 4) 65% DRB, 30% triticale DDGS (D-0S). All diets contained 5% vitamin and mineral supplement. Substituting a portion of the DRB with triticale DDGS in the D-10S diet did not affect mean rumen pH, however occurrence and severity of sub-acute ruminal acidosis (SARA) compared to CON steers was reduced. Further substation of triticale DDGS for barley silage increased the occurrence and severity of SARA as exhibited by increased duration and AUC below pH 5.5 and 5.2. Interestingly, steers fed the D-10S diet had lower variation in mean rumen pH than those fed the CON diet. Replacing barley

silage with triticale DDGS decreased the concentration of physically effective fiber (peNDF) in the diet, which explains the higher incidence of SARA. However, partial replacement of DRB with triticale DDGS diluted dietary starch, which may have contributed to the reduced fluctuations in rumen pH. Variation in DMI was also less in D-10S fed steers compared to CON steers. With decreased particle size and peNDF content as barley silage was replaced with triticale DDGS, eating rate increased, resulting in shorter meal durations. Steers fed the D-10S diet had higher DMI, but there was no difference in ADG or G:F as compared to CON-fed steers. However, intake decreased and G:F increased as barley silage was replaced by triticale DDGS. Replacing barley silage with triticale DDGS did not affect any of the carcass parameters measured in this trial, suggesting similar energy intake and nutrient partitioning. Compared to the CON diet, steers fed the D-10S diet had increased back fat thickness, and decreased dressing percentage, ribeye area, and meat yield; indicating more fat deposition in D-10S fed steers. Interestingly, liver abscesses were more prevalent and severe in steers fed the D-10S diet compared to steers fed the CON diet. Although rumen acidosis became more prevalent as barley silage was replaced with triticale DDGS, no effect on ADG and improved G:F suggests that lower rumen pH did not adversely affect rumen health. Triticale DDGS can partially substitute barley silage in finishing diets without adverse effects on growth performance or carcass quality in the diets containing triticale DDGS as a partial replacement of DRB. Dietary inclusion of an antimicrobial additive is recommended to control liver abscess.

3.2 Study Contributions

The present study evaluated a novel approach to use DDGS in feedlot finishing rations. The findings of our study provided evidence supporting the theory that the amount of forage required to maintain rumen health in barley grain based finishing diets decreases when a portion of DRB is replaced with triticale DDGS. Forages are usually included in high concentrate diets to promote rumen health, resulting in maximized energy (NE_g) intake and growth performance (Galyean and Defoor, 2003). However, the production of silage requires significant capital investment as well as the cost of storage. Furthermore, the availability of forages is often limited either due to drought or their costs per unit of energy makes them uneconomical for inclusion in feedlot diets as was the case in the 2009-2010 calf crop year in Alberta. Such situations require the use of alternative feeding strategies such as limit-feeding high energy diets to achieve desired ADG, or use of high fiber by-products such as oat hulls, soy hulls, or DDGS. However, compared to oat hulls or soy hulls, corn and wheat DDGS contain more energy (NRC 2000) and therefore would be a preferable source of dietary fiber. Based on findings from our trial, triticale DDGS can replace up to 100% of the barley silage in finishing diets without negative effects on performance, a result that supports the use of DDGS as means of conserving the utilization of forage in finishing feedlot diets.

This trial has provided some unique data to the literature in a couple of areas that require emphasis. We used two technologies in our study that allowed

us to house the rumen cannulated steers with intact steers in an environment that was similar to that present in a commercial feedlot. Previously, similar studies with rumen cannulated steers have been conducted in metabolism stalls, conditions that are clearly unlike those encountered within a feedlot. Therefore, what would have been considered a separate metabolism and growth performance trial previously in literature, has now been integrated into one study. Employment of the Lethbridge Research Centre rumen pH data logger (Penner et al., 2006) enabled continuous pH measurements under conditions that were more representative of that which would be experienced by steers housed in a feedlot. Coupling this technology with the GrowSafe (GrowSafe Systems Ltd., Airdrie, Alberta, Canada) feed intake system enabled us to relate changes in ruminal pH to eating behavior of the individual rumen-cannulated steers. Previous research studying ruminal acidosis has focused on nutritional and physiological factors and the resulting animal performance (Erickson et al., 2003; Gibb et al., 1998; Schwartzkopf-Genswein et al., 2003, 2004). Ruminal pH data have been typically collected from individually-housed cannulated animals and then the data were used to explain performance data measured from a corresponding trial using intact animals (Cooper et al., 1999). However, feeding behavior and animal interactions relating to temperament and social dominance in a group setting can exert equally significant effects on instances of SARA (Grant and Albright, 2001; Owens et al., 1998; Voisenet et al., 1997). This was aptly demonstrated in our study where we can observe differences in feeding behavior between rumen cannulated and intact steers within a pen (Table 3.1 and Table 3.2). Therefore,

using the GrowSafe system in conjunction with the LRCpH data loggers allows us to incorporate these potential behavioral influences on rumen pH, possibly making studies more applicable to feedlot conditions.

Table 3.1: Effect of substituting triticale DDGS for barley grain (D-10S) and barley silage (D-5S; D-0S) compared to a dry-rolled barley control (CON) on eating behavior of cannulated steers (n = 16 per treatment)

	Diet[1]					Con vs. D-10S[2]	Linear[3]
Item	CON	D-10S	D-5S	D-0S	SEM	*p*=	*p*=
DMI, kg·d^{-1}	9.9	11.0	12.1	11.9	0.6	0.08	0.14
DMI Deviation, kg·d^{-1}	2.6	1.9	1.5	1.8	0.2	0.009	0.68
Meal Frequency, meal·d^{-1}	8.3	8.5	8.1	8.3	0.4	0.67	0.68
Duration, min·meal^{-1}	10.6	11.9	11.3	10.5	0.7	0.13	0.08
Inter-Meal Duration, min	172.6	166.0	179.1	173.6	7.1	0.50	0.44
Meal Size, kg·meal^{-1}	1.23	1.36	1.58	1.53	0.1	0.29	0.14
Eating Rate, g·min^{-1}	118.3	116.4	141.0	150.6	8.1	0.81	<0.001

[1]CON: 85% dry-rolled barley grain, 10% barley silage, 5% supplement; D-10S: 65% dry-rolled barley grain, 20% triticale DDGS, 10% barley silage, 5% supplement; D-5S: 65% dry-rolled barley grain, 25% triticale DDGS, 5% barley silage, 5% supplement; D-0S: 65% dry-rolled barley grain, 30% triticale DDGS, 5% supplement

[2]Contrast between CON diet vs. D-10S diet

[3]Linear effect of BS substitution

Table 3.2: Effect of substituting triticale DDGS for barley grain (D-10S) and barley silage (D-5S; D-0S) compared to a dry-rolled barley control (CON) on eating behavior of intact steers (n = 16 per treatment)

	Diet[1]					Con vs. 10-BS[2]	Linear[3]
Item	CON	10-BS	5-BS	0-BS	SEM	*p*=	*p*=
DMI, kg·d^{-1}	11.6	12.0	12.6	12.3	0.4	0.38	0.48
DMI Deviation, kg·d^{-1}	1.50	1.86	1.42	1.53	0.08	0.004	0.007
Meal Frequency, meal·d^{-1}	9.0	9.5	9.1	9.1	0.52	0.31	0.46
Duration, min·meal^{-1}	12.2	11.0	11.0	10.4	0.87	0.18	0.48
Inter-Meal Duration, min	163.0	150.8	161.6	162.5	8.9	0.21	0.22
Meal Size, kg·meal^{-1}	1.43	1.35	1.52	1.47	0.08	0.48	0.26
Eating Rate, g·min^{-1}	157.4	168.2	169.6	187.6	11.0	0.49	0.22

[1]CON: 85% dry-rolled barley grain, 10% barley silage, 5% supplement; D-10S: 65% dry-rolled barley grain, 20% triticale DDGS, 10% barley silage, 5% supplement; D-5S: 65% dry-rolled barley grain, 25% triticale DDGS, 5% barley silage, 5% supplement; D-0S: 65% dry-rolled barley grain, 30% triticale DDGS, 5% supplement

[2]Contrast between CON diet vs. D-10S diet

[3]Linear effect of BS substitution

3.3 Study Improvements

In the present study, data were collected on rumen fermentation parameters, growth performance as well as ruminal digestibility characteristics of the diets. Of these, the digestibility data are the weakest section, primarily due to the methodology used. The in situ nylon bag technique was originally developed to provide an indication of rate and extent of rumen OM digestibility of forages (Dewhurst et al., 1995). However, there are several concerns with this methodology which limit its application in our trial. First of all, smaller particles (< 50 µM) may have disappeared from the nylon bags without first being degraded. As a result, an over-estimation in rate of digestion and estimated ruminal digestibility occurs because smaller particles may exit the bags before being digested or particles that are indigestible may exit the bag (Dewhurst et al., 1995), a phenomenon that is especially relevant to concentrate feeds. The other area of limitation in our trial is that effects of residence time in the rumen or rate of passage on nutrient digestibility were not accounted for (NRC 2000). Reducing dietary forage content in high concentrate diets, as in our study, has been shown to decrease ruminal dilution rate (Goetsch et al., 1984) and increase the digestibility of the grain (Ledoux et al., 1985). However, due to the limitation of the nylon bag method, this possibility could not be reflected in our data.

A better approach would have been to use an indigestible marker such as chromic oxide as described by Gibb et al. (2008) as fed to individually-housed animals. In the study of Gibb et al. (2008), chromic oxide was top-dressed in the feed bunk for individually-housed animals (2 g of Cr) and fecal grab samples

were collected at 0900 and 1530 h. Digestibility was calculated from the ratio of Cr concentration in the diet to that in the feces. Such an approach is not very labor intensive and would account for effects of passage rate on digestibility, thus may be superior compared to the in situ nylon bag technique as it is an estimate of digestibility. However, incorporating this technique in the present study would be difficult as our cannulated steers were not individually housed, therefore raising the concern of even mixing of the marker in the feed wagon. Additionally, more intensive handling would be required to collect fecal samples, which would disrupt their natural eating behavior and resulting rumen pH.

Another source of potential errors in our trial was the amount of straw intake from the bedding pack, which was not measured. Animals were housed in outdoor clay-based feedlot pens and bedded with straw. Although some voluntary intake of the straw likely occurred across all treatments, it is not certain how much straw was actually consumed by animals, especially for cattle fed the 5-BS and 0-BS diets as they may have selectively consumed more straw due to the increased rumen acidity. There was no difference in meal bouts or frequency among diet treatments in the present study, which may indicate that selective straw intake by steers fed 5-BS and 0-BS diets either did not occur or was limited to a level that did not influence gut fill and satiety (Oba and Allen, 2000). However, careful interpretation of rumen pH data is required for steers housed with straw bedding, particularly when extreme diets are fed as in the present study. This may still indicate the need for rumen pH data to be collected in a

more controlled environment to enable us to attribute the responses in rumen pH solely to dietary factors.

3.4 Future Research

Although this trial has provided unique information to literature, there are a few areas in which further research is required. Firstly, it was hypothesized that triticale DDGS would have similar feeding value as wheat DDGS and allowed for similar growth responses because of similar nutritive characteristics of the corresponding whole grains. However, based on the findings of our trial, triticale DDGS appears to have a lower feeding value than that of barley grain when included at 20% of the diet DM. This contradicts to studies that reported wheat DDGS has similar or slightly lower NE_g compared to DRB (Beliveau and McKinnon, 2008; Gibb et al., 2008). Therefore, if triticale DDGS becomes readily available in Western Canada, the nutritive value of triticale DDGS in comparison to wheat DDGS needs to be assessed more clearly.

Liver abscess prevalence was significant in steers fed triticale DDGS which is an observation consistent in other trials feeding high-protein byproducts without a dietary antimicrobial (Beliveau and McKinnon, 2008; Firkins et al., 1985). This is an interesting observation as there is limited research on the prevalence of liver abscesses in cattle fed DDGS. Argininosuccinate synthetase is an important enzyme of the urea cycle and it condenses the N from citrulline and aspartate to form arginine in hepatocytes. This enzyme has also been found to be involved in the metabolism of the lipid A portion of LPS in mice (Satoh et al.,

2009), which is an important virulence factor in the development of liver abscesses. This opens up a window of opportunity to investigate the role of argininosuccinate synthetase in LPS metabolism in ruminants. Furthermore, effects of excess N supply to the liver on detoxification of LPS need to be explored.

Although triticale is known for its disease resistance (Chapman, et al., 2005), it has been previously associated with ergot and deoxynivalenol (DON) that is a mycotoxin derived from *Fusarium* species (JECFA, 2001). Increased liver abscess prevalence has been associated with feeding triticale in feedlot diets (McCloy, 1968; McCloy et al., 1971). Although rumen microbes are capable of metabolizing DON (Keese, 2008), lower rumen pH associated with feeding high concentrate diets can impair the rumen epithelium, allowing potentially-toxic substrates such as DON to enter the blood stream prior to being metabolized and potentially lead to the development of liver abscesses. We did not test our triticale DDGS for the presence of mycotoxins; however it could be a factor increasing animal susceptibility to liver abscesses and therefore should be investigated further.

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2.0 CONCLUSION

Wheat and corn DDGS have been accepted as feedstuffs in feedlot diets, substituting a portion of the cereal grain. Triticale grain has been identified as a potential replacement for wheat as the primary source of starch in Western Canada's bio-ethanol industry. Findings from the present study support the use of triticale DDGS at 20% of the diet DM in barley grain based finishing rations. Furthermore, substituting triticale DDGS for a portion of the barley grain diluted the dietary starch and decreased the prevalence of SARA. Additional substitution of triticale DDGS for barley silage increased SARA prevalence, but did not adversely affect growth performance or carcass quality. Findings from the present study indicate that the forage requirement to maintain rumen health decreases when triticale DDGS substitutes a portion of the barley grain in a feedlot finishing diet, however inclusion of a dietary antimicrobial is recommended to control liver abscess.