COMPARISON OF WHEAT OR CORN DRIED DISTILLERS GRAINS WITH SOLUBLES ON PERFORMANCE, CARCASS CHARACTERISTICS, RUMEN FERMENTATION PARAMETERS AND DIET DIGESTIBILITY OF FEEDLOT CATTLE

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ABSTRACT

Two trials were conducted, one using crossbred steers (Trial 1; N=275; 376±24 kg) and a second using Hereford heifers (Trial 2; N=5; 420±6 kg) to evaluate the performance, carcass quality, rumen fermentation and nutrient digestibility of cattle fed wheat or corn dried distillers grains with solubles (DDGS). The control ration averaged 87.7% rolled barley grain, 5.6% supplement and 6.8% barley silage (DM basis) over both trials. Dietary treatments included replacement of barley grain at 20 or 40% of the diet (DM basis) with wheat or corn DDGS. For Trial 1, steers were slaughtered at a constant finish weight of 645 kg. Data was analyzed as a completely randomized design using pen as the experimental unit. Feeding increasing levels of wheat DDGS quadratically increased dry matter intake (DMI) (P<0.01), whereas increasing levels of corn DDGS quadratically decreased DMI (P=0.01). Average daily gain was not influenced (P=0.13) by feeding wheat or corn DDGS but cattle fed corn DDGS exhibited a quadratic increase (P=0.01) in gain:feed. As a result, a quadratic increase (P<0.01) in calculated NEg of the diet was observed as corn DDGS levels increased. A linear decrease (P=0.04) in days on feed (169, 166 and 154 days) was noted when increasing levels of wheat DDGS (0, 20 and 40%) were fed. Dressing percentage increased in a linear fashion with wheat DDGS (P<0.01) inclusion level and in a quadratic fashion (P=0.01) as corn DDGS inclusion level increased although other carcass traits were not affected (P>0.10) by treatment.

Trial 2 evaluated the effects of corn and wheat DDGS on rumen fermentation and nutrient digestibility parameters. Rumen pH, duration and area under rumen pH thresholds of 5.8, 5.5 and 5.2 were not affected (P>0.05) by treatment. Wheat DDGS inclusion increased (P=0.01) rumen ammonia-N levels in a linear fashion, while the inclusion of both wheat and

corn DDGS resulted in quadratic (P=0.01) and linear (P=0.01) increases in butyrate concentration, respectively. Feeding corn DDGS also decreased total rumination time linearly (P=0.01) and DMI in a quadratic (P=0.04) fashion. Feeding wheat DDGS decreased (P=0.01) DM digestibility in a linear fashion. Wheat and corn DDGS inclusion quadratically increased (P=0.01) the digestibility of crude fat while feeding corn DDGS also linearly increased (P=0.01) the digestibility of crude protein. Neutral detergent fiber digestibility increased in a linear fashion (P=0.01) as both wheat and corn DDGS inclusion increased while ADF digestibility increased in a linear fashion (P=0.03) for wheat and in a quadratic (P=0.02) fashion for corn DDGS. The digestibility of both NDIN and ADIN increased (P=0.01) in a quadratic fashion for both corn and wheat DDGS inclusion level. Increased inclusions of wheat DDGS resulted in a linear decrease in gross energy digestibility (P=0.01), but neither wheat nor corn DDGS inclusion affected diet digestible energy content (P>0.05). Feeding both wheat and corn DDGS increased (P=0.01) the excretion of nitrogen and phosphorus.

Replacement of barley grain with up to 40% corn or wheat DDGS improved gain:feed and reduced days on feed, respectively with no detrimental effect on carcass quality grade or sub-primal boneless boxed beef yield. The results of this project also indicate that the inclusion of corn and wheat DDGS (up to 40%) in feedlot rations does not mitigate ruminal acidosis, however the inclusion of both byproducts strongly impacts nutrient (crude fat, ADF, NDF, ADIN and NDIN) digestibility.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
ADG	Average daily gain
ADIN	Acid detergent insoluble nitrogen
Ammonia-N	Ammonia nitrogen
BW	Body weight
CDS	Condensed distiller solubles
CP	Crude protein
d	Day
DDG	Dried distillers grains
DDGS	Dried distillers grains with solubles
DM	Dry matter
DMI	Dry matter intake
Feed efficiency	kg gain:kg feed
h	Hour
HCW	Hot carcass weight
US	Ultrasound
l. dorsi	*Longissimus dorsi*
mL	milliliters
N	Nitrogen
NDF	Neutral detergent fiber
NDIN	Neutral detergent insoluble nitrogen
NEm	Net energy maintenance

NEg	Net energy gain
P	Probability
SARA	Sub-acute ruminal acidosis
SAS	Statistical analysis system
SD	Standard deviation
SE	Standard error
SEP	Standard error of prediction
SC	Subcutaneous
SPBBB	Sub-primal boneless boxed beef
TS	Thin stillage
US	Ultrasound
VFA	Volatile fatty acid
WDG	Wet distillers grains
WDGS	Wet distillers grains with soluble
wt	Weight
%	Percentage

1.0 GENERAL INTRODUCTION

Ethanol production capacity has increased considerably in the last decade due to high energy prices, increased reliance on energy imports (with respect to the USA) and a switch to more environmentally conscientious transportation practices (Hill et al. 2006). Concurrent with this rise in ethanol production is a dramatic increase in the quantities of distillers grains being produced. In Canada, ethanol production has increased to 1.3 billion L resulting in 1.1 million tonnes of distillers grains (Canadian RFA 2009). In the USA, 139 ethanol plants produced 34 billion L of ethanol and 22 million tonnes of distillers grains in 2008 (RFA 2009; USDA-FAS, 2009). Exports of USA distillers grains increased in 2008 to 4.5 million tonnes with Canada serving as the second largest importer (0.7 million tonnes), next to Mexico (1.2 million tonnes) (USDA-FAS 2009). As a result of the Renewable Fuel Standards, fuel ethanol production is expected to increase to 57 billion L in the USA by 2015 resulting in a parallel increase in distillers grains (Renewable Fuels Association 2009).

Traditionally, distillers grains were fed as a protein supplement in dairy rations at levels <15% (DM basis), functioning as a high quality, rumen undegradable protein source (Firkins et al. 1985; Kleinschmit et al. 2006). At inclusion levels >15% distillers grains generally exceed the protein requirements of the animal and are considered to also function as an energy source in ruminant diets (Koster 2007). Due to the unique high fiber, high fat, high phosphorus and low starch content of distillers grains, feedlot cattle currently serve as the major consumer of distillers byproducts (Klopfenstein et al. 2008). An increase in ethanol production coupled to elevated feed costs has resulted in widespread usage and higher inclusion levels of distillers grains in feedlot rations.

Although various wet and dry distillers byproducts are produced (Stock et al. 2000), the most common product available to livestock producers is dried distillers grains with solubles (DDGS). Typically, corn is used as the feedstock for ethanol production due to its supply, price and high ethanol yield versus other cereal grains. Within western Canada, ethanol plants often use wheat or a blend of wheat and corn as the feedstock due to the relative abundance of feed grade wheat and lack of a local corn supply. In lieu of recent corn DDGS imports from the USA, livestock producers in western Canada have a variety of DDGS options available to feed.

To date, there has been considerable research with regards to the effect of corn DDGS in feedlot cattle rations on cattle performance and carcass quality (Ham et al. 1994; Buckner et al. 2008). Recent studies have also examined the digestibility and fermentation characteristics associated with feeding corn DDGS as an energy source in corn-based rations (Leupp et al. 2009; Spiehs et al. 2009). With respect to wheat DDGS, recent literature has investigated the feeding value of this byproduct in feedlot rations (Beliveau and McKinnon 2008; Gibb et al. 2008), although no detailed information currently exists in regards to the nutrient digestibility of wheat DDGS in feedlot rations. It is therefore important to investigate the digestibility of wheat DDGS in feedlot cattle, particularly with regard to nitrogen and phosphorus excretion. Furthermore, it is necessary to investigate the impact of wheat and corn DDGS in barley-based rations on feedlot performance, carcass characteristics, rumen fermentation and digestibility in a side by side trial.

The objectives of this literature review are to provide an overview of the research of DDGS production and nutrient composition and to highlight the feeding value of corn and

wheat DDGS in feedlot finishing diets from a performance, carcass quality, and feeding management perspective.

2.0 LITERATURE REVIEW

2.1 Dry Grind Ethanol and Distillers Grains Production

Distillers grains used in livestock rations are largely produced from fuel based ethanol production. Fuel ethanol production utilizes cereal grains with high starch content such as corn or sorghum in the USA, wheat or corn in Canada and in Brazil, sugar cane. Most plants using grains use an efficient dry grind process that involves grinding, cooking, liquefaction, saccharification and fermentation (Bothast and Schlicher 2005) (Figure 2.1). Grinding is the first step used on the whole grain to break the kernel into smaller particle sizes, thereby exposing a large starch surface area (Stock et al. 2000). The kernel particles are mixed with water and amylase before being heated to create a mash (cooking). Enzymes and yeast are added to the mash to convert starch to sugar and to ferment the sugars to alcohol, in two steps known as saccharification and fermentation (Stock et al. 2000; Bothast and Schlicher 2005). The end products of fuel ethanol production are alcohol, carbon dioxide and distillers grains (Spiehs et al. 2002).

After fermentation, the mash or fermented slurry is distilled to remove the ethanol (Stock et al. 2000 and Gibb et al. 2008). The remaining fermented slurry after distilling is called whole stillage and this fraction is centrifuged or screened to remove the coarse grain particles (Stock et al. 2000). At this point in the production line, the extracted coarse grain particles are called wet distillers grains (WDG) and can be dried to form dried distillers grains (DDG). Thin stillage (TS) is the remaining liquid fraction and can be evaporated to produce condensed distillers solubles (CDS). Alternatively, the TS can be added to the WDG to create wet distillers grains plus solubles (WDGS) or dried together to create dried distillers grains plus solubles (DDGS) (Figure 2.1).

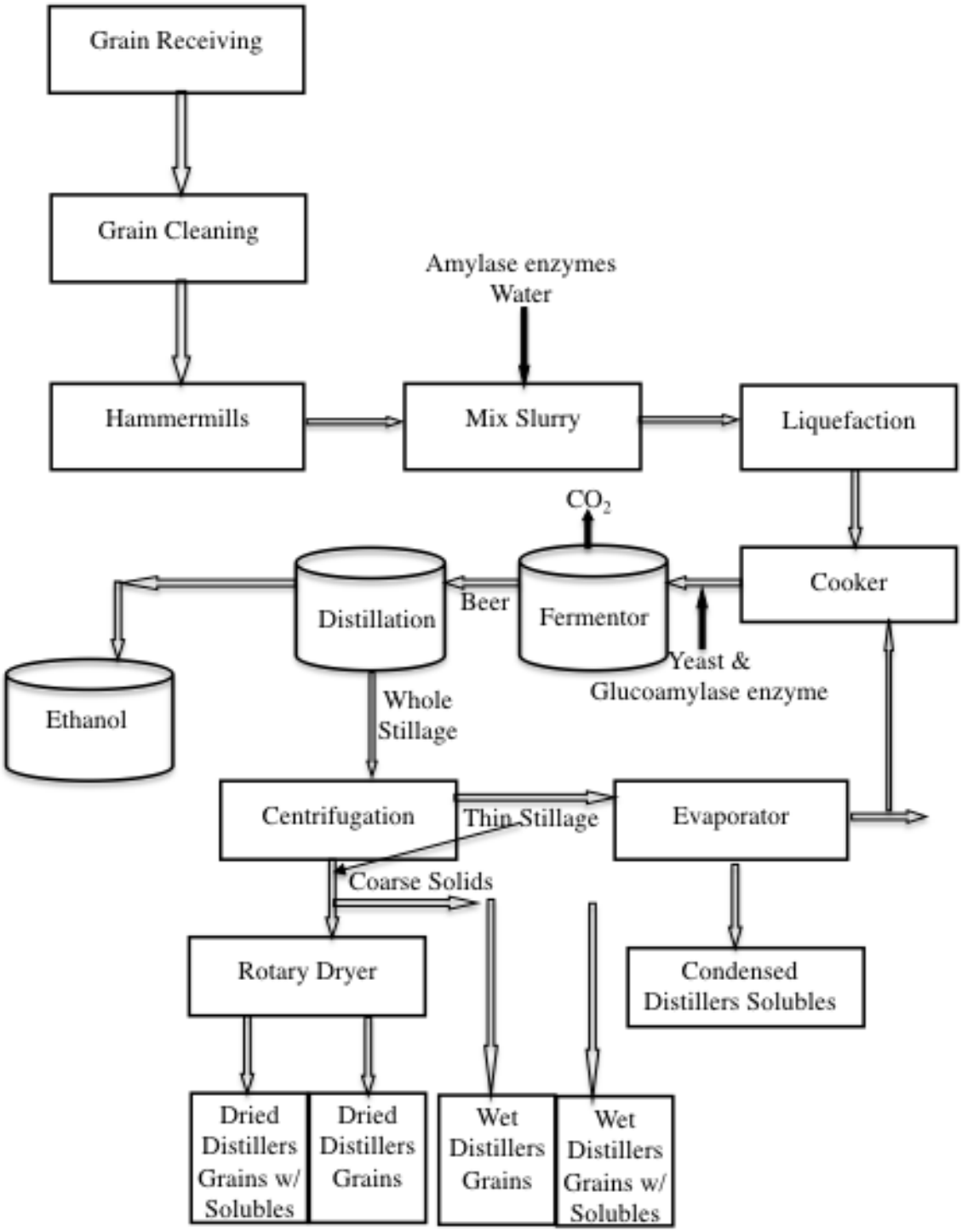

Figure 2.1. Dry grind ethanol process (adapted from Shurson et al. 2008)

As a result of ethanol production, a variety of coproducts are available for livestock feeding including WDG, DDG, TS, CDS, WDGS and DDGS. Wet distillers grains were previously the most common ethanol byproduct on the marketplace as dry distillers grains have a high energetic cost of drying. Dried distillers grains with solubles, however, are now the most common form of distillers grains available in North America. Dried distillers grains with solubles are dense and have a high dry matter content, facilitating transport ease and storage life relative to WDG or WDGS (Stock et al. 2000).

2.1.1 Dried Distillers Grains with Solubles Nutrient Composition

The starch used to ferment and produce ethanol, generally represents 70-72% of the corn grain and 77% of the wheat grain kernel weight (Huntington 1997; Bothast and Schlicher 2005). As a result of the fermentation process, distillers grains are largely starch free (7.3±1.4, %±SD, DM basis) (Stein and Shurson 2009) but concentrated in other remaining nutrients including protein, lipids, fiber, sulphur and phosphorus (Spiehs et al. 2002). The nutrient composition and overall quality of the distillers grains can be influenced by ethanol production parameters including front end processing, starch fermentation type and extraction efficiency (Spiehs et al. 2002), drying temperature and duration (Klenishmit et al. 2006) and the amount of solubles blended into the distillers grains (Stock et al. 2000). The original feedstock also impacts the nutrient composition of the distillers grains in terms of the type (Table 2.1) and the nutrient content of the grain used (Spiehs et al. 2002), as well as whether or not different grains were blended together to form the feedstock (Koster 2007). However, it should be noted that the major source of variation in the nutritional content of DDGS from the same grain results from the processing conditions at the plant as Belyea et al.

(2004) found a low correlation between the chemical composition of the feedstock and that of the DDGS produced.

2.1.1.1 Fat

Corn DDGS has three times the amount of crude fat (10.2 to 11.7±0.85, range±SD) compared to corn grain (Spiehs et al. 2002). The fat contributes significantly to the energy value of corn DDGS as lipids have three times the NEg of corn grain (Zinn 2007). The lipid from corn WDG was estimated to attribute 42% of the improved calculated NEg values to cattle fed a WDG-based diet relative to a control corn-based ration (Al-Suwaiegh et al. 2002). When comparing corn to wheat, corn grain has a higher fat level (4.1±0.64 and 2.3±1.21, mean±SD), contributing to corn's higher NEg content relative to wheat (1.55 and 1.50 Mcal kg^{-1} respectively) (NRC 2000). Due to the concentration of nutrients in DDGS, it is not surprising that corn DDGS (10.9±0.85, mean±SD) has a higher fat content than wheat DDGS (4.6±0.07, mean±SD) (Spiehs et al. 2002; Gibb et al. 2008).

In dairy cattle, an increase in feed efficiency has been found when corn DDGS was added into the diet at 20% (DM), replacing ground corn and soybean meal. This improvement was attributed to an increase in energy density associated with the higher lipid levels in the diet with corn DDGS feeding (Kleinschmit et al. 2006). In this study, the extra fat present in corn DDGS contributed to milk protein percentage reduction and a numerical decrease in milk fat percentage. However, the extra milk yield associated with feeding DDGS resulted in no change in total protein and milk fat content (Kleinschmit et al. 2006 and Hippen et al. 2004).

Table 2.1. Nutrient composition of wheat and corn feedstock grain and distillers grains (DDGS, WDG, TS).

	Feedstock							
Item *(%, DM)*	Corn				Wheat			
	Grain[z]	DDGS[x]	WDG[y,t]	TS[y,t]	Grain[z]	DDGS[v]	WDG[u]	TS[u]
DM *(%)*	90.0	88.9	29.7	4.7	90.2	93.8	-	-
Crude protein	9.8	30.2	25.0	17.9	14.2	39.3	27.0	36.6
Crude fat	4.1	10.9	14.6	8.7	2.34	5.0	5.5	5.9
Acid detergent fiber	3.3	16.2	-	-	4.2	11.0	22.9	8.5
Neutral detergent fiber	10.8	42.1	41.9	12.5	11.8	48.1	74.4	35.2
Starch	-	4.4[4]	7.6	23.6		6.3	2.0	3.0
Calcium	0.03	0.06	-	-	0.05	0.18	-	-
Phosphorus	0.32	0.89	-	-	0.44	0.91	-	-

Data sourced from: [z]NRC 2000; [y]Larson et al. 1993; [x]Spiehs et al. 2002; [v]Nuez-Ortin and Yu 2009; [u]Mustafa et al. 2000; [t]Ham et al. 1994

2.1.1.2 Crude Protein

Distillers grains have long been fed to dairy cattle as they are excellent source of rumen undegradable protein (RUP) (Firkins et al. 1985 and Kleinshmit et al. 2006). Corn DDGS has been reported to have a crude protein content of 28.7 to 31.6%, DM (SD=1.9) (Spiehs et al. 2002). In terms of wheat DDGS, protein levels increased from 14.2% in the wheat grain to 39.3% in wheat DDGS (DM basis) (Nuez-Ortin and Yu 2009). As a result, wheat DDGS has a higher protein content than corn DDGS (Nuez-Ortin and Yu 2009). Boila and Ingalls (1994) compared wheat DDGS to a blend of 70:30 wheat:corn DDGS and found crude protein content to increase from 37.5% to 43.6% when wheat DDGS increased in the blend. Accordingly, Widyaratne and Zijlstra (2007) found wheat DDGS (44.5%) to have a higher protein content than corn DDGS (30.3%) or a blended DDGS (4:1, wheat:corn) (42.4%).

Excessive heat during the drying process can cause an increase in the unavailable protein fraction (Kleinschmit et al. 2006). High ADIN content can be indicative of heat damage and protein unavailability thereby lowering expected protein digestibility values (Britton et al. 1986; Klopfenstein 1987). ADIN levels have served as a good indicator of forage nitrogen digestibility (Yu and Thomas 1976), but nitrogen digestibility and ADIN levels for DDGS do not appear to be as strongly correlated (r^2 = 0.24) (Nakamura et al. 1994). Kleinschmit et al. (2007) also found ADIN to be a poor predictor of rumen degradable protein, intestinal protein digestibility and total digestible protein in corn-based DDGS.

As a result of the concern over heat damage, nutritionists and producers have used a colour score to assign the amount of heat damage to corn DDGS. Although, studies report conflicting results with respect to the validity of this colour score when ADIN levels are lower than 13% N (Cromwell et al. 1993 and Harty et al. 1998). Ham et al. (1994) found no

difference in the gain:feed and ADG of cattle fed DDGS of differing ADIN levels (5.9 to 14.8% N). Klopfenstein (1996) observed a numeric increase in protein efficiency and no change to gain:feed as ADIN level in corn DDGS diets (fed at 40%) increased from 97 to 288 g kg^{-1} CP. This supports the concept that ADIN is a poor indicator of heat damage in DDGS or that drying has little effect on protein value of distillers grains (Klopfenstein, 1996).

Of concern to monogastric and dairy producers is the amino acid ratio of the DDGS. Lysine is the first limiting amino acid in corn DDGS, similar to corn itself and was shown to be the most variable among five DDGS sources (19.1 to 31.9 g kg^{-1} of CP, CV=13.2) (Kleinschmit et al. 2007). Speihs et al. (2002) recorded a lysine level of 24.6 to 33.1 g kg^{-1} of CP for corn DDGS (CV=17.3). The variability of lysine in DDGS is directly related to the level of drying of DDGS, as lysine is the most susceptible amino acid to heat damage (Kleinschmit et al. 2007 and Schwab 1995). The alpha-amino group of lysine binds with the reducing sugars in the Maillard reaction (Schwab 1995). Thus, even though ADIN is a poor indicator of the protein digestibility of DDGS, heat damage is important to monitor to ensure adequate lysine levels are present in the byproduct.

2.1.1.3 Fiber

With the removal of starch, fiber becomes the major constituent of DDGS. In the study by Widyaratne and Zijlstra (2007), NDF (treated with sodium sulphite) differed little from corn (31.2%) to wheat DDGS (30.3%). Although, the authors observed wheat DDGS had a notably higher ADF value (21.2%) relative to corn DDGS (14.6%) with a blend DDGS of 4:1 wheat:corn intermediate at 19.5%. Nuez-Ortin and Yu (2009) also found similar N-

adjusted NDF (NDFn) and ADF levels between wheat (48.1 and 11.0%) and corn DDGS (49.5 and 14.7%).

The high fiber levels in DDGS have been of concern to nutritionists and producers since ADF in cereal grains is not highly digestible. The digestibility of ADF in barley-based finishing diets (75% processing index) was 26.9% while the NDF digestibility was 56.4% (Beauchemin et al. 2001). Furthermore, the total tract digestibility of NDF was not different for wheat (57.2%) or corn (54.0%) (Martin et al. 1999). It has been observed that the fiber in distillers grains is highly digestible, causing a higher than expected energy value for the product (Ham et al. 1994; Al-Suwaigh et al. 2002). Ham et al. (1994) found that the NDF digestibility of a 40% wet distillers grains (69.6%) ration to be greater than that of a dry-rolled corn (62.5%) ration while Vander Pol et al. (2009) found the NDF digestibility of the 40% WDGS ration equal to that of a dry-rolled corn ration. When comparing diets containing either 30% corn DDGS or 30% sorghum DDGS, the total tract digestion of NDF and ADF was not different between the two DDGS types although ADF digestion was higher and NDF digestion numerically lower in corn (62.5 and 64.7%) than in sorghum (58.9 and 66.3%) DDGS-based rations (Al-Suwaigh et al. 2002).

Ham et al. (1994) speculated that since ruminal fiber digestion is depressed in finishing diets, a great deal of the fiber digestion associated with feeding distillers grains must occur post-ruminally. Thus a reduction in rumen produced acids is expected due to the lack of starch in combination with high fiber, fat and protein digestion post-ruminally when feeding distillers grains (Ham et al. 1994). The reduction in rumen fermentation should result in a reduction in the occurrence of sub-acute ruminal acidosis and its severity (Ham et al. 1994). However, inclusion of distillers grains in high concentrate finishing rations has not

been shown to alleviate sub-acute ruminal acidosis (SARA) (Ham et al. 1994; Beliveau and McKinnon 2009; Eun et al. 2009).

Physically effective NDF (peNDF) is used as a measure to provide adequately sized fiber particles that have the potential to reduce SARA through increased saliva production and rumen buffering potential (Yang and Beauchemin 2006a). Beliveau and McKinnon (2009) found the peNDF of wheat DDGS to be <10%, a value far less than the 22% effective fiber level recommended for dairy rations (Martens 1997). The lack of peNDF in DDGS correlates to a lack of saliva production and poor rumen buffering potential (Kononoff and Heinrichs 2003; Yang and Beauchemin 2006a). Furthermore, the acidity of DDGS is also high due to the addition of sulphuric acid in the processing step within some ethanol plants (Beliveau and McKinnon 2009). Even though DDGS has a highly digestible, high fiber content relative to cereal grains, the physical effectiveness of the fiber is low.

2.1.1.4 Minerals

When Spiehs et al. (2002) compared nutrient content of corn DDGS across new generation ethanol plants in South Dakota and Minnesota, little variation (CV <10%) was found for DM, DE, CP, crude fat and crude fiber but high variability was observed for mineral levels. The authors found phosphorus, which averaged 0.89% to have the lowest coefficient of variation (CV) for minerals of 11.7. Zinc, which averaged 97.5 ppm had the highest CV of 80.4%. Spiehs et al. (2002) pointed out that these differences could be attributed to differences in feedstock mineral levels. Differences in feedstock mineral levels can be equated to differences in soil mineral levels where the feedstock grain was grown. Further evidence of feedstock mineral levels contributing to highly variable DDGS mineral content is

that year to year differences within plants were found for mineral levels especially phosphorus (Spiehs et al. 2002).

Dried distillers grains with solubles are relatively low in calcium with an average of 0.15±0.02% (mean±SD) and 0.06±0.03% (mean±SD) for wheat and corn DDGS, respectively (Spiehs et al. 2002; Gibb et al. 2008). The low calcium content is a reflection of the original feedstock, which has been reported to be 0.05±0.03% and 0.03±0.07% (mean±SD) in wheat and corn, respectively (NRC 2000). As mentioned the average phosphorus level for corn DDGS is 0.89±0.10% (mean±SD) while wheat DDGS has a phosphorus level of 1.07±0.05% (mean±SD) (Spiehs et al. 2002 and Gibb et al. 2008). As a result of the high phosphorus and low calcium content in DDGS, additional calcium supplementation is important to eliminate metabolic problems associated with calcium absorption and metabolism (NRC 2000). Gibb et al. (2008) reported that calcium:phosphorus (Ca:P) ratios declined from 2:1 in control diets to 1.1:1 in 60% wheat DDGS diets that had no additional limestone. Steers fed 60% wheat DDGS and supplemented with additional limestone (1.6:1 Ca:P ratio) had numerically reduced DMI and ADG compared to 60% wheat DDGS fed steers that were not supplemented. As a result, the authors concluded that steers fed wheat DDGS had adequate calcium levels for growth without supplemental limestone.

Most of the phosphorus in concentrate feedstuffs is in the form of phytate, and is largely unavailable for degradation by mammals due to lack of necessary enzymes (Knowlton et al. 2007). Rumen microbes contain phytase, an enzyme that increases the availability of phytate phosphorus for ruminants (Knowlton et al. 2007). It has been shown that due to the fermentation process, DDGS has a higher phosphorus availability than the original cereal grain, an important consideration for formulating monogastric diets (Spiehs et

al. 2002). When comparing corn to wheat DDGS, hogs fed 40% wheat DDGS had a higher phosphorus intake but similar excretion levels to those fed corn DDGS (Widyaratne and Zijlstra 2007). Pedersen et al. (2007) found that the total tract digestibility of phosphorus in swine was higher for rations containing 50% corn DDGS relative to the control corn grain ration (59.1 vs. 19.3 %, respectively). The authors attributed this result arose from the hydrolysis of phytate phosphorus during ethanol fermentation. With respect to cattle fed up to 35% corn DDGS, Benson et al. (2006) found a linear increase in both phosphorus excretion and retention. In contrast, Spiehs and Varel (2009) found no change in phosphorus retention nor fecal phosphorus excretion but urinary phosphorus excretion increased in a linear fashion, supporting the contention that more phosphorus was absorbed as corn WDGS increased in the ration (up to 60%). Corn DDGS had a greater water-soluble phosphorus fraction (82.1%) as compared to soybean meal at (45%) and a higher rumen phosphorus disappearance rate (93.5%) as compared to soybean meal, hulls or extruded whole soybeans (Mjoun et al. 2008).

Sulphur is also an important mineral for producers and nutritionists to tabulate in the ration and water to ensure that the level is <0.4% of total DMI (NRC 2000). Sulphur levels in corn DDGS averaged 0.51% with considerable variation between (37.1 CV) and within plants (6.4 to 37.9 CV) as ethanol producers often use sulphuric acid to maintain batch pH (Spiehs et al. 2002). With high sulphur intakes, additional supplemental copper is recommended to alleviate potential copper and thiamine deficiencies (Gooneratne 1989). Buckner et al. (2008) found that when feeding corn DDGS with a sulphur level of 1.01%, total dietary sulphur levels increased from 0.15% to 0.60% for the control and 50% corn DDGS fed cattle, respectively. One steer fed the 40% corn DDGS ration and five steers from

the 50% corn DDGS ration exhibited symptoms of polioencephalomalacia after 22 days on feed (Buckner et al. 2008). In the study conducted by Gibb et al. (2008) steers were fed up to 60% wheat DDGS with no documented cases of polioencephalomalacia. Although no sulphur analysis was performed on the rations, the sulphur content of the wheat DDGS used in their study was 0.48±0.02%.

2.2 The Energy Value of Corn and Wheat Dried Distillers Grains with Solubles in Feedlot Rations

As DDGS supplies increased, higher inclusion rates of DDGS have been used in feedlot rations (Klopfenstein et al. 2008). When used at levels >15% of the ration, DDGS serves as both a source of energy and protein (Koster 2007; Klopfenstein et al. 2008). Factors that contribute to the increased energy value of corn DDGS relative to corn grain are a higher lipid content, added amino acids and metabolizable protein, higher ferementable fiber fraction and a possible reduction in SARA (Larson et al. 1993; Spiehs et al. 2002; Ham et al. 1994).

Relative to corn DDGS, wheat DDGS has a lower lipid content. Since its been estimated that 42% of the improved NEg of corn WDG is due to fat (Al-Suwaigh et al. 2002), the NEg of corn DDGS is most likely higher than wheat DDGS. Inclusion of 40% corn DDGS in dry rolled corn rations, resulted in a NEg value of 1.35 MCal kg^{-1} (Ham et al. 1994) while the inclusion of 40% wheat DDGS in rolled barley rations resulted in a NEg value of 1.09 MCal kg^{-1} (Gibb et al. 2008).

The high protein content of DDGS may also impact the energy value of the byproduct. Excessive rumen degradable protein is absorbed and converted to urea at a

metabolic cost to the animal (Klopfenstein et al. 2008). Wheat DDGS has a higher rumen degradable protein level in comparison to corn DDGS (Boila and Ingalls 1994), possibly having a detrimental impact on the energy value of wheat DDGS. Although as Klopfenstein et al. (2008) reported additional energy can come from the high rumen undegradable protein level in DDGS as it does not undergo fermentation losses.

2.2.1 Wet Distillers Grains with Solubles Compared to Dried Distillers Grains with Solubles

Wet distillers grains and DDG vary in their energy content with the wet product (WDG and TS) having a greater energy value than DDGS (Klopfenstein 1996). Ham et al. (1994) found that 40% WDG in the ration had a 54% higher energy level whereas DDGS rations (40% of the diet, DM) had a 30% higher energy value as compared to a corn-based ration. Ham et al. (1994) also found that although cattle fed corn WDGS (0.158) or DDGS (0.146) had greater gain:feed ratios than control fed (0.133) cattle, this improvement was more pronounced for cattle fed WDGS. Larson et al. (1993) fed WDGS at 40% of the ration and found that feed efficiency was improved 14% relative to control corn fed cattle. This resulted in a 35% higher feeding value for the WDGS based ration. A meta-analysis of corn WDGS studies showed a quadratic response for ADG and DMI with ADG optimized at 30% inclusion while DMI was lowest at a 50% inclusion level. Accordingly, gain:feed was optimized at a corn WDGS inclusion rate of 30 to 50% (Klopfenstein et al. 2008).

2.2.2 Performance of Cattle Fed Corn Dried Distillers Grains with Solubles in Dry Rolled Corn Rations

Buckner et al. (2008) fed corn DDGS at graded inclusion levels up to 40% of the ration (DM) and observed a quadratic effect on ADG with optimal inclusion at 20%. While the 20%

inclusion level resulted in the highest numerical ADG, all levels of corn DDGS resulted in higher ADG than a dry rolled corn-based diet (Buckner et al. 2008). Benson et al. (2005) also found a numerical increase in ADG when feeding graded levels of corn DDGS up to 35% (DM) with the 25% inclusion level tending to increase ADG as compared to the control fed cattle. In terms of DMI, Benson et al. (2005) found DMI to increase as corn DDGS increased in the ration. Buckner et al. (2008) noted a similar non-significant increase in DMI as corn DDGS increased in the ration. As a result, a quadratic trend was observed for feed efficiency with the lowest value for control fed steers and the highest predicted gain:feed occurring at a 24.7% inclusion level (Buckner et al. 2008). Benson et al. (2005) also reported a numeric increase in gain:feed in cattle fed corn DDGS (up to 35%, DM) while Ham et al. (1994) reported that cattle fed 40% corn DDGS had improved feed efficiency relative to control cattle.

Meta-analysis of several studies using corn DDGS (up to 40%, DM) showed a positive quadratic response for ADG and DMI and a cubic response for feed efficiency for cattle fed corn DDGS (Klopfenstein et al. 2008). Average daily gain and DMI were highest when corn DDGS was included between 20 and 30% of the ration while gain:feed was optimized between 10 and 20% (Klopfenstein et al. 2008). The feeding value of corn DDGS was 123% of that of corn grain at the 20% inclusion level, whereas at a 40% inclusion level the feeding value was similar to that of corn grain.

2.2.2.1 Impact of Corn Processing and Distiller Grains Inclusion on Feedlot Performance

The vast majority of corn distiller grains research has been done in the USA where the highest concentrations of ethanol plants exist. As ethanol production increases, new plants

are being built in the southern USA. In many areas of the USA, corn is extensively processed prior to feeding to cattle. This processing can be in the form of high moisture corn or steam flaked corn. Relative to dry rolled corn, steam flaked corn has a higher energy level (113%) while high moisture corn is comparable (104%) in energy to dry rolled corn (Owens et al. 1997). The increase in energy density of steam flaked corn is the result of destruction of the protein matrix and starch gelatinization due to steam exposure and results in improved rumen starch digestibility (Zinn et al. 2002). As a result, propionate production is increased and acetate:propionate ratio is decreased (Zinn et al. 1987).

Vander Pol (2006) found that comparing cattle fed corn WDGS (30%, DM) in a steam flaked corn diet relative to cattle fed WDGS in either a high moisture or a dry rolled corn ration, that ADG was reduced with the steam flaked corn diet (Vander Pol 2006). Feed efficiency was similar across all treatments with high moisture corn processing having the highest numerical gain:feed. Corrigan et al. (2007) also found that cattle fed corn WDGS, at levels up to 40% of the ration in steam flaked corn, dry rolled corn and high moisture corn rations had different responses not only to processing method but also to the inclusion level of WDGS. Cattle fed dry rolled corn rations had a linear increase in ADG and gain:feed as WDGS inclusion increased, while cattle fed steam flaked corn had a decreasing quadratic response to WDGS with the highest ADG at a 15% inclusion level. As a result, the proposed inclusion rate for corn DDGS in steam flaked corn diets is lower than that of its dry rolled corn counter-part (Klopfenstein et al. 2008).

2.2.2.2 Performance of Feedlot Cattle Fed Corn DDGS in Combination with Other Basal Cereal Grains

Most of the research done on corn distillers grains has focused on its use in corn based diets. However, in north-western states and western Canada, a shortened cool growing season dictates the planting of barley rather than corn for feed usage. As a result, barley is used as the primary cereal grain in feedlot rations. Relative to corn grain, barley has a lower NEg content (1.55 vs. 1.40 Mcal kg^{-1}) due to its reduced fat and high fiber content (NRC 2000). Rolling of barley is necessary as barley contains a pericarp and hull which are resistant to microbial digestion (McAllister et al. 1994). However, microbial access through the endosperm cell wall and protein matrix in barley is faster than in corn. Once rolled, barley starch granules are rapidly digested in the rumen resulting in increased acidosis and metabolic disease in barley fed cattle (Ørskov 1986). Thus, the mitigation of acidosis through the inclusion of DDGS may have greater potential in barley-based rations as compared to corn-based rations with the inclusion of DDGS.

2.2.3 Performance of Cattle Fed Wheat Dried Distillers Grains with Solubles

In a study that used growing cattle in a backgrounding program, replacing half (20%, DM) or all (40%, DM) of the rolled barley with wheat DDGS resulted in similar intakes and gain relative to cattle fed the control diet (Gibb et al. 2008). Further research on backgrounding cattle found feeding wheat DDGS at 25 and 50% resulted in similar DMI and improved ADG, resulting in improved feed efficiency relative to control cattle (McKinnon and Walker 2008). In contrast, Beliveau and McKinnon (2008) reported that backgrounding cattle fed

graded levels of wheat DDGS up to 32% exhibited cubic responses for DMI and ADG. Solving these equations gave theoretical minimum responses at 6.9% and 8.1% DDGS inclusion rates for DMI and ADG while theoretical maxima responses were at 27.2 and 30.8% inclusion rates for DMI and ADG. As a result, a quadratic response in terms of feed efficiency was found with the poorest theoretical gain:feed at 13% wheat DDGS. When cattle were fed 24 and 32% wheat DDGS, the feed efficiency was numerically equal to or slightly higher than control fed cattle (Beliveau and McKinnon 2008). As a result of similar or improved gain:feed in cattle fed wheat DDGS (>20%) in backgrounding rations relative to control barley fed cattle, the authors concluded that the energy value of wheat DDGS (>20%) in backgrounding rations was similar to barley (Gibb et al. 2008; McKinnon and Walker 2008).

Beliveau and McKinnon (2008), found that inclusion of wheat DDGS up to 23% (DM) had no negative effects on performance of finishing cattle. Gibb et al. (2008) found a linear increase in DMI and no change in ADG as wheat DDGS increased in the ration to 60% (DM). As a result, gain:feed declined as wheat DDGS increased, resulting in a linear decrease in the NEg value of the diet (Gibb et al. 2008). The NEg of DDGS relative to barley ranged from 97% at the 20% inclusion level to 91% at the 40% DDGS inclusion level (Gibb et al. 2008).

2.3 Carcass Characteristics Associated with Dried Distillers Grains with Solubles Feeding

Reinhardt et al. (2007) indicated when corn DDGS is added at levels over 23% in rations there is a linear decrease in yield grade adjusted marbling scores. Corah and McCully (2006)

also found marbling scores to decrease when DDGS were fed at inclusion levels higher than 30% (DM). The effect of DDGS on marbling scores could be the result of the lack of starch in the diet and thus less fat partitioned to marbling or the result of improved feed efficiency and thus less time on feed since marbling is largely time dependent (McPhee et al. 2006).

Supplementing corn DDGS to finishing cattle had a positive quadratic effect on hot carcass weight (HCW) and yield grades, responses also observed as supplementary fat is added in rations beyond recommended levels (>6-7%) (Reinhardt et al. 2007). Buckner et al. (2008) found that cattle fed 20% corn DDGS had the highest HCW. They also found a positive quadratic response to DDGS inclusion on HCW when cattle were fed to 167 days on feed. With regards to subcutaneous backfat, the increase in ADG associated with feeding corn WDGS caused cattle to accrue fat more quickly resulting in an increase in rib fat (Klopfenstein et al. 2008). Benson et al. (2005) also found that subcutaneous backfat and dressing percentage increased in a linear fashion as corn DDGS was fed (up to 35%). As a result, yield grade tended to increase with increased inclusion of corn DDGS (Benson et al. 2005). Meta analysis revealed a linear increase in yield grade and a linear trend for reduced marbling scores when corn DDGS was fed up to 40% of the diet (Klopfenstein et al. 2008).

2.3.1 Carcass Characteristics of Feedlot Steers Fed Wheat Distillers Grains

In regards to the impact of wheat DDGS on carcass quality, very little research has been conducted. Preliminary research conducted by Ojowi et al. (1997) found little difference in carcass quality between steers fed a barley control diet versus steers fed a wheat WDG (4.7%) ration, although steers fed wheat WDG displayed a higher level of intermuscular fat (Ojowi et al. 1997). No differences were found between finishing cattle fed either barley

control diets or increasing levels of wheat DDGS (up to 23%) on dressing percentage, marbling score, backfat thickness, *l. dorsi* area or yield grade (Beliveau and McKinnon 2008). Gibb et al. (2008) also found no differences between control barley fed cattle and those fed wheat DDGS in terms of dressing percentage or ribeye area although 20 and 40% wheat DDGS fed cattle had a higher subcutaneous backfat thickness relative to control cattle. There was also a trend for cattle fed wheat DDGS to have lower meat yield relative to barley fed cattle (Gibb et al. 2008).

2.3.2 Meat Quality from Steers Fed Distillers Grains

In terms of meat quality, steers fed wheat WDG tended to have increased saturated fatty acid levels relative to control barley fed cattle even though wheat WDG contained higher amount of unsaturated lipids (Shand et al. 1999). Wheat WDG or any form of wheat distillers grains has a much lower lipid content relative to corn distillers grains and thus wheat distillers grain has a lower total unsaturated fatty acid content relative to corn distillers grains. Consequently, alterations in meat lipid profile are more likely to occur in feedlot cattle fed corn as compared to wheat DDGS.

With respect to increasing the unsaturated lipid content in adipose tissue of cattle fed DDGS, a relatively high amount of unsaturated lipids must be included in the diet in order for significant quantities to escape microbial biohydrogenation in the rumen. Vander Pol et al. (2009) found that cattle fed 40% corn WDGS had a greater amount of unsaturated lipids reaching the duodenum than cattle fed the same level of lipids from corn oil. The authors concluded that the fatty acids in corn WDGS undergo less microbial biohydrogenation than those in corn oil. Futhermore, Roeber et al. (2005), found that when corn DDGS was fed at 40 to 50% of the diet, colour stability of meat quality began to decline, an observation that is

indicative of a higher unsaturated fatty acid content. Although, when corn DDGS was included at lower levels (10 to 25%), the shelf life of beef steaks was slightly enhanced with no effect on palatability.

2.4 Ruminal Acidosis

Acidosis is a common digestive disease in feedlot cattle resulting in reduced performance, morbidity and mortality and a subsequent loss of profitability for feedlot owners (Nagaraja and Titgemeyer 2007). Ruminal acidosis is the result of excess carbohydrate consumption and fermentation leading to an increase in organic acid production and a subsequent decrease in rumen pH (Nagaraga and Lechtenberg 2007). In severe cases of ruminal acidosis production of toxic factors such as endotoxins occur (Owens et al. 1998). The severity of ruminal acidosis can range from acute to sub-acute depending upon the amount, frequency and duration of grain feeding (Nagaraja and Titgemeyer 2007). Sub-acute ruminal acidosis is common in both feedlot and dairy cattle and can result in daily feed intake variation (Schwartzkopf-Genswein et al. 2003)

Rumen pH is a consequence of numerous factors including the diet and amount fed, buffering capability of saliva and the absorptive capacity of the rumen wall (Nagaraja and Titgemeyer 2007). Rumen pH decreases as the total volatile fatty acid (VFA) concentration (pKa of ~ 4.9) increases in the rumen (Nagaraja and Titgemeyer 2007). Volatile fatty acid concentration increases due to increased microbial fermentation of the fermentable carbohydrate in high grain diets (Owens et al. 1998). Due to the feeding of cereal grain-based diets, the rumen microbial population shifts to an amylolytic bacteria population rather than one based on cellulolytic bacteria (Figure 2.2). The growth rate of *Streptococcus bovis* (*S.*

bovis) becomes very high in the presence of glucose and as pH drops, *S. bovis* produces lactic acid rather than acetate (Owens et al. 1998; Schwartzkopf-Genswein et al. 2003). The pKa of lactic acid (3.9) is 10 fold lower than that of the common VFAs, thereby reducing rumen pH further and promoting the growth of *S. bovis* and other acid-tolerant species (Nagaraja and Titgemeyer 2007).

The increase in VFA concentration associated with feeding high concentrate diets is coupled to reduced rumen buffering capacity. Buffering capacity is impaired as a result of inadequate salivary secretion due to the lack of peNDF in the diet (Owens et al. 1998 and Maekawa et al. 2002a). Absorption of VFAs can increase rumen pH, but the absorption of VFAs can also be impaired by reduced rumen papillae surface area due to rumenitis that is also frequently associated with low rumen pH (Nagaraja and Titgemeyer 2007). Furthermore, VFAs are only passively absorbed if they exist in their undissociated forms (pKa of VFAs are ~4.9). If pH continues to drop in the rumen, the absorption of VFAs increases as more VFAs become undissociated (Nagaraja and Titgemeyer 2007). Unfortunately, the drop in pH is also accompanied by an increase in lactic acid production, which will continue to accumulate in the rumen and reduce rumen pH (Nagaraja and Titgemeyer 2007) (Figure 2.2). Rumen pH therefore is the result of a number of important metabolic and fermentation events occurring in the rumen of animals experiencing mild to acute acidosis.

In contrast to this line of thinking, Beliveau and McKinnon (2009) did not find a benefit in terms of ruminal pH when feeding wheat DDGS up to 21% of the diet. The authors found a cubic effect of rumen mean pH at thresholds <5.8 and 5.2. The authors also found a cubic effect on time spent below pH 5.2 with cattle fed the 7 and 14% wheat DDGS rations spending the greatest amount of time below 5.2.

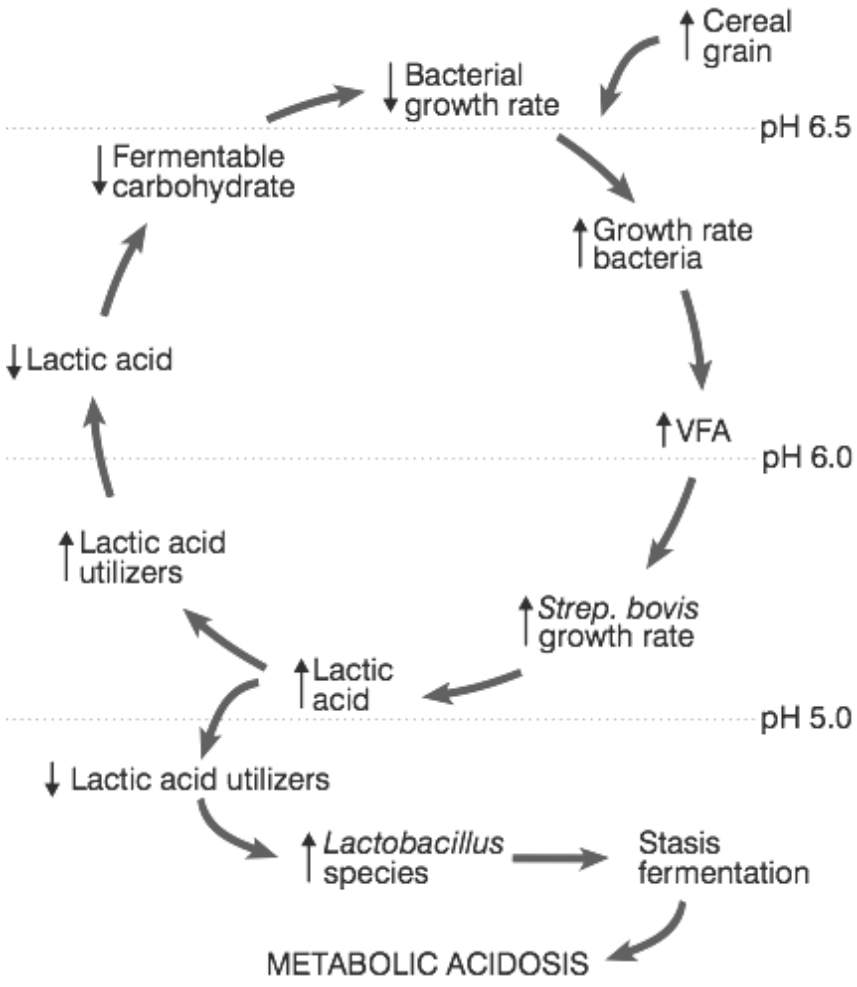

Figure 2.2. Ruminal pH and microbial population responses to ruminal acidosis (Source: Alberta Feedlot Management Guide).

Beliveau and McKinnon (2009) attributed the failure of DDGS to alleviate SARA to the small particle size of the by-product, which failed to stimulate rumination and was still subject to rapid ruminal fermentation. In agreement with these results, Peter et al. (2000) and Ham et al. (1994) also did not find any differences in ruminal pH when corn DDGS was substituted for 20% or 40%, of corn grain in the ration. In contrast, the study by Leupp et al. (2009) found increased inclusion of corn DDGS for corn grain (up to 60%) in a 70% concentrate diet was matched by a parallel increase in ruminal pH.

2.5 Impact of Distillers Grains on Rumen Fermentation

2.5.1 Volatile Fatty Acid Production

Rumen fermentation and subsequent VFA production is highly dependent upon the type of diet fed. The type of carbohydrate present in the feed is the main factor that impacts VFA production as carbohydrates form the major energy source for rumen microbes (France and Dijkstra 2005). Acetate, propionate and butyrate are the three primary VFAs formed as by-products of rumen microbial carbohydrate fermentation (Van Soest 1994). Other dietary components that can be fermented are short-chained lipids and rumen degradable protein (Van Soest 1994; France and Dijkstra 2005). Rumen degradable protein can be fermented to form secondary VFAs after the protein is hydrolysed and amino acids deaminated (France and Dijkstra 2005). Essential branch-chain volatile fatty acids for the microbes include isobutyric, isovaleric and 2-methylbutyric acid, formed from valine, leucine and isoleucine, respectively (France and Dijkstra 2005).

Dried distillers grains with solubles contain structural carbohydrates, similar to forages (cellulose, hemicellulose and lignin) (Van Soest 1994). Thus, it is expected that DDGS

would produce a VFA profile similar to forages, thereby lowering overall volatile fatty acid production while increasing the acetate:propionate ratio (Bergman 1990). Kleinschmit et al. (2006) found a decrease in total VFAs when dairy cows were fed diets containing 20% corn DDGS vs. those fed control corn-based diets. The authors attributed the difference to lower levels of non-structural carbohydrates (starch) and a decrease in rumen fermentation with the 20% corn DDGS diet. With respect to feedlot diets, Ham et al. (1994) found no difference in total or individual VFA production in steers fed finishing diets containing corn WDGS (40%), corn DDGS (40%) or a control corn based diet. In contrast, Leupp et al. (2009) found total VFA and acetate concentrations to decrease in a linear fashion, resulting in a linear decrease in acetate:propionate ratio when corn DDGS accounted for up to 60% of a 70% concentrate ration.

The type of concentrate fed also impacts VFA production as barley increases propionate production relative to corn grain (Beauchemin and McGinn 2005). Eun et al. (2009) fed 18.3% corn DDGS in barley based rations and found a trend for reduced total VFA production in cattle fed corn DDGS. Beliveau and McKinnon (2009) found a linear decrease in propionate production in heifers fed wheat DDGS (up to 21%) in barley-based finishing rations. As a result of no change in acetate levels, acetate:propionate ratio increased in a linear fashion as wheat DDGS inclusion increased, a result that is similar to that observed with high forage diets (Beliveau and McKinnon 2009).

2.5.2 Rumen Ammonia Production

An advantage of ruminants is that due to urea recycling, ruminants can survive on diets that contain no true protein (Nolan and Dobos 2005). Chen and Russell (1989) observed that only a few bacterial species have an obligatory requirement for peptides and amino acids from

feed protein. In essence, 40 to 95% of the nitrogen in rumen bacteria is derived from ammonia-N depending upon the diet fed (Neutze et al. 1986). The efficiency of microbial growth is improved by supplementation of true protein in ruminants fed highly fermentable carbohydrate diets, but not in those fed high roughage, low digestibility feedstuffs (Neutze et al. 1986).

Peptides, amino acids and the ammonia-N concentration change over time in the rumen depending on feed protein degradability and microbial growth conditions (Nolan and Dobos 2005). Formation of rumen ammonia-N results from the deamination of amino acids that arise from proteolysis of protein by microbes (Nolan and Dobos 2005). The released ammonia-N is used by other bacterial species for protein synthesis especially cellulolytic species (Nolan and Dobos 2005). Therefore, considerable cross-feeding of nitrogen occurs within the rumen resulting in a rumen ammonia pool with a rapid turnover rate (Nolan and Dugan 2005). Any excess ammonia-N can diffuse across the rumen wall depending upon the ionized concentration gradient where it will pass to the liver via the portal blood flow (Nolan and Dobos 2005).

Believeau and McKinnon (2009) found a linear increase in rumen ammonia-N concentration as wheat DDGS increased in the diet to 21%. The high protein content of DDGS would be expected to substantially increase rumen ammonia-N levels, although due to the large amount of rumen undegradable protein in DDGS, the authors did not find a large increase between the control and 21% wheat DDGS fed cattle (4.8 vs. 6.8 mg dL^{-1}).

2.6 Digestibility of Distillers Grains

Several researchers have investigated the energy value of corn wet and dry distillers grains with solubles (Larson et al. 1993; Klopfenstein 1996; Vander Pol 2009; Gunn 2009). Larsen et al. (1993) found that corn WDGS fed to yearling steers at 40% of corn based rations increased the NEg (1.48 Mcal kg^{-1} NEg) value of the diet by 22.3% as compared to a control corn-based diet (1.21 Mcal kg^{-1}NEg). The authors attributed 9% of this increase to the higher fat content of corn WDGS. Klopfenstein (1996) found that inclusion of 40% corn WDGS or DDGS increased the NEg of a corn-based diet by 21.5 and 11.9%, respectively. A composite feed with a nutrient composition comparable to corn WDGS was formulated by Lodge et al. (1997) in order to elucidate the role that fat, fiber and protein have in increasing the energy content of WDGS. Lodge et al. (1997) proposed a shift in organic matter digestion to the small intestine resulted in a higher energy value for WDGS as compared to the corn-based diets as energy losses associated with rumen fermentation were reduced.

Leupp et al. (2009) examined the digestibility of corn DDGS up to a 60% inclusion level in 70% concentrate diets. These workers found that organic matter intake decreased in a quadratic response with the highest intake at 15% while fecal organic matter output decreased linearly with increasing DDGS inclusion. True ruminal organic matter digestion decreased in a linear fashion while post-ruminal organic matter digestion increased linearly with DDGS. Leupp et al. (2009) speculated that this was a result of increased ruminal passage rate of DDGS due to the small particle size; resulting in decreased ruminal digestion. These authors also found effects on specific nutrients with total crude protein digestion increasing as DDGS inclusion level increased, inferring that a greater degree of nitrogen digestion took place in the small intestine. Acid detergent fiber and NDF intakes followed a

similar trend to organic matter intake in that there was a decreasing quadratic response as corn DDGS level increased (Leupp et al. 2009). While these workers observed that total tract ADF and NDF digestion were not affected by treatment, the ruminal digestion of ADF and NDF exhibited a decreasing linear trend as DDGS inclusion increased in the ration.

Research on wheat DDGS has shown that dry matter digestibility of cattle fed a control barley diet (76.4%) and those fed 60% wheat DDGS (68.9%) was reduced by 9.8% (Gibb et al. 2008).

2.6.1 Distillers Grains and Shedding of *Escherichia coli 0157*

Yang and Beauchemin (2006b) reported that a high fecal pH is indicative of minimal fermentation occurring in the large intestine. An increase in the amount of starch reaching the large intestine can increase VFA production in the large intestine reducing pH (Russell et al. 2000). A low hindgut pH results in the survival and growth of acid tolerant *Escherichia coli* (*E. coli*) bacterial species (Russell et al. 2000). At time of slaughter, fecal contamination can result in the contamination of *E. coli* 0157:H7, a human pathogen, on the carcass. Russell et al. (2000) also commented that there could be an independent effect of fiber on improving hindgut pH rather than just reducing total dietary starch concentration. Fiber reduces the passage rate of grain, increases rumen pH and has the potential to attract water and other buffers into the hind gut (Russell et al. 2000).

Studies with distillers grains, a high fiber feedstuff have shown conflicting results on the impact of *E. coli* 0157 prevalence (Peterson et al. 2007; Jacob et al. 2008). Jacob et al. (2008) found that feeding 25% corn DDG with 5 or 15% corn silage resulted in increased prevalence of *E. coli* 0157 relative to control steam-flaked corn diets. Peterson et al. (2007) did not find a difference when feeding WDGS (up to 50%) at any inclusion level and the

control corn based ration (dry rolled and high moisture corn) on the prevalence of *E. coli* 0157 in fecal or mucosal samples. Looking at the data numerically, feeding corn WDGS up to 30% decreased *E. coli* 0157 mucosal levels while feeding corn WDGS at 40 and 50% resulted in an increase of the shedding of *E. coli* 0157 (Peterson et al. 2007).

2.7 Nitrogen Balance

2.7.1. Nitrogen Utilization in Ruminants

Crude protein fed to ruminants can be broadly termed into two classes with the first as rumen degradable protein (RDP), available to the rumen microbes to degrade and the second being rumen undegradable protein (RUP). RDP undergoes degradation by the microbes so that proteins can be assimilated (Nolan and Dobos 2005). Rumen nitrogen degradation rates are dependent upon the protein's solubility, secondary and tertiary structures and the degree of disulphide cross linkages (Nolan and Dobos 2005). Resulting nitrogen reaching the small intestine is comprised of microbial protein, RUP and endogenous protein. The microbial protein that passes through to the intestine is high quality, providing essential and non-essential amino acids that are needed for protein synthesis by the animal (Nolan and Dobos 2005).

The RUP amino acid composition in the small intestine is similar to that present in the feedstuff although it can be altered by rumen fermentation (Nolan and Dobos 2005). The various forms of nitrogen in the small intestine are likely to be digested and absorbed with a digestibility coefficient of 60-90% (Nolan and Dobos 2005). The remaining endogenous nitrogen, microbial nitrogen and RUP are utilized with urea from the blood to form microbial protein for the bacteria in the large intestine (Nolan and Dugan 2005). As a result, the

microbial protein produced in the large intestine is the major form of nitrogen excreted in the feces in cattle fed a highly digestible protein diet (Nolan and Dugan 2005).

2.7.1.1 Urea Nitrogen Metabolism

The majority of ammonia-N formed in the rumen that is in excess of that required for microbial protein synthesis is absorbed across the rumen wall and is converted into urea by the liver to prevent ammonia toxicity in the animal (Lobly and Lapierre 2001). Newly formed urea is released into the blood and transferred into the gastrointestinal tract (ruminal or intestinal) for urea recycling or is excreted by the kidney. The urea that passes into the gastrointestinal tract is degraded by microbial urease into ammonia-N where it is used to build microbial protein (Marini et al. 2004). The regulation of renal excretion of urea appears to decrease during times of low RDP availability thereby increasing urea flow to the rumen (Marini et al. 2004). Unfortunately for the animal, there is a cost to ammonia detoxification and urea synthesis of four ATP per mole of urea synthesized (McBride and Kelly 1990). Furthermore, maintenance energy costs may increase in animals consuming high nitrogen diets since the liver and kidneys undergo cell hypertrophy in response to excess nitrogen metabolism (Marini et al. 2004).

2.7.2 Nitrogen Retention

Nitrogen retention is calculated as the difference between nitrogen intake and nitrogen output. Unfortunately, nitrogen retention numbers are often skewed due to measurement errors with errors increasing as dietary nitrogen availability increases (Spanghero and Kowalski 1997). Nitrogen retention numbers are often higher if used to calculate lean tissue accretion relative to body weight gain. Lean tissue accretion is estimated assuming a body protein nitrogen content of 16% and a ratio of body protein:water of 1:3 (Spanghero and

Kowalski 1997). Spanghero and Kowalski (1997) listed drying of fecal samples and a lack of urine acidification as sources of error in regards to volatile ammonia losses. Dermal and scurf losses also contribute to increased nitrogen output but are often not measured in nitrogen balance trials. Using the NRC (2001) equation a 600 kg cow would lose 1.5 g of nitrogen per day due to dermal and scurf losses. Other proposed nitrogen outputs not typically measured are gaseous N_2 losses and nitrite/nitrate compounds that are not measured by the Kjeldahl technique.

2.8 Environmental Impact of Feeding Dried Distillers Grains with Solubles on Nitrogen and Phosphorus Excretion

2.8.1 Nitrogen Excretion

The high amount of nitrogen in DDGS often results in the overfeeding of nitrogen in feedlot rations. Feeding nitrogen above the animal's requirement results in an increase in nitrogen excretion and the potential to increase the volatization of ammonia in manure (Spiehs et al. 2002). The loss of manure nitrogen due to volatization causes a substantial loss in the manure nutrient value (James et al. 1999). Ammonia emissions also increase with an increase of urinary urea nitrogen since the urease enzyme in feces cleaves urinary urea nitrogen into ammonia (Elzing and Monteny 1997; James et al. 1999).

Due to the high level of RUP in DDGS, the amount of RDP content is less than of other protein feedstuffs (soybean meal) (Kleinschmit et al. 2006). A high RDP level can contribute to increased urinary urea nitrogen as rumen microbes breakdown the RDP to ammonia in the rumen. Since the lower content of RDP protein in corn DDGS equates to a lower milk urea nitrogen more nitrogen is excreted in the feces (Kleinschmit et al. 2006). In

contrast, Spiehs and Varel (2009) did not find fecal nitrogen excretion to increase although total tract nitrogen excretion increased as a result of the linear increase in urinary nitrogen excretion in cattle fed up to 60% corn WDGS in the diet. Considering that the rumen degradable nitrogen content of distillers grains is low a lack of a change in fecal excretion of nitrogen may reflect an increase in post-ruminal nitrogen digestion and absorption with increasing distillers grains in the ration.

2.8.2 Phosphorus excretion

Phosphorus intake is strongly correlated to phosphorus excretion (Mjoun et al. 2008). The phosphorus in DDGS will affect the nutrient density of manure. Thus manure handling practices and usage rates need to be adapted in order to maintain proper nitrogen:phosphorus manure and soil ratios (Benson et al., 1995). Erickson et al. (1998) reported that crops require a 5:1 ratio of nitrogen:phosphorus and that due to the volatization of 50-70% of manure nitrogen in the pen, the ratio in manure is generally 2:1. Evidentially, incorporating feedstuffs high in phosphorus such as DDGS becomes troublesome for manure handling procedures and application rates. Benson et al. (2005) researched the effect of corn DDGS (up to 35% of the diet) on phosphorus and ammonia-N levels of pen manure samples and found an increase in both as DDGS increased in the ration up to 35%. The conclusion of the authors was that a 75% increase in cropland area was needed to effectively use the manure from the 35% DDGS diet vs. the control diets (Benson et al. 2005).

2.9 Summary

Ethanol production is expected to increase in the USA as well as in Canada resulting in a parallel increase in the supply of distiller byproducts (wet distillers grains, condensed

solubles, dry distillers grains and dry distillers grains with solubles), predominantly in the form of DDGS. In western Canada, wheat is often used as the feedstock for ethanol production and as such considerable quantities of wheat DDGS and wheat:corn blend DDGS are currently produced. In the USA, corn DDGS is produced in increasing abundance and while local markets in the USA have become saturated with corn DDGS exports to Mexico and western Canada have steadily increased. As a result of increased domestic production and readily available imports, producers in western Canada have the ability to choose between corn and wheat DDGS for usage in their rations. Corn DDGS has been produced and fed commercially for decades whereas the production of wheat DDGS has increased only within the last few years. As such, there is a lack of information with respect to the feeding value of wheat DDGS in feedlot rations, particularly when fed as an energy source (levels > 15%).

The nutrient composition of both wheat and corn DDGS is a reflection of their respective feedstock grains with chemical composition (minus starch) concentrated ~3-fold in the distiller byproducts. Therefore, corn DDGS has a higher fat (10.9 vs. 4.6%, respectively) but lower protein (30.2 vs. 39.3%, respectively) content relative to wheat DDGS with both feedstuffs having similar NDF (49.5 vs. 48.1%, respectively) and ADF (14.7 vs. 11.0%, respectively) levels (Spiehs et al. 2002; Gibb et al. 2008; Nuez-Ortin and Yu 2009). The nutrient composition of these byproducts dictates their feeding value in finishing rations. Research in the USA has shown that corn DDGS has an energy value similar to corn in feedlot finishing rations when fed at ≤40% of the ration, DM (Buckner 2008). With respect to carcass quality, negative impacts on marbling scores and yield grades have been observed in cattle fed corn DDGS. Wheat DDGS has been shown to have comparable energy

to barley when fed at levels <23% (Beliveau and McKinnon 2008) and a decreasing energy value relative to barley when fed at 40 and 60% of the ration (Gibb et al. 2008). Rumen fermentation studies using corn or wheat DDGS in finishing diets have not been able to find a positive impact of either feedstuff on rumen pH (Ham et al. 1994; Beliveau and McKinnon 2009). Also, there is a significant information gap with respect to the total tract nutrient digestibility and excretion of corn and wheat DDGS. The lack of information is a concern as livestock producers need to be able to make informed feeding choices between corn and wheat DDGS.

The hypothesis of the research conducted in this thesis was that due to a more favourable combination of fat, fiber and protein, cattle fed wheat-based DDGS will experience less digestive disturbances and, as a result, will exhibit superior feedlot performance and carcass quality attributes than cattle fed corn-based DDGS.

Therefore, the objectives were to evaluate cattle fed wheat DDGS relative to that of cattle fed corn DDGS in feedlot finishing rations with respect to: 1) performance, 2) carcass characteristics, 3) rumen fermentation parameters and 4) nutrient digestibility as well as 5) to quantify the increased nitrogen and phosphorus excretion associated with feeding DDGS.

3.0 COMPARISON OF WHEAT OR CORN DRIED DISTILLERS GRAINS WITH SOLUBLES ON PERFORMANCE AND CARCASS CHARACTERISTICS OF FEEDLOT STEERS

3.1 Introduction

Growth of the ethanol industry has resulted in large increases in the supply and use of dried distillers grains with solubles (DDGS) in livestock rations. With regards to feedlot cattle, there has been a significant amount of research on the feeding value of corn-based DDGS as both a protein and energy source, and its associated effects on carcass traits (Ham et al. 1994; Klopfenstein et al. 2008). In terms of the energy value of corn distillers grains with solubles, Larson et al. (1993) observed that wet distillers grains with solubles (WDGS) when fed at levels ranging from 5.2 to 40% of DM, averaged 2.53 and 1.96 Mcal kg^{-1} NEg, when fed to yearlings and calves, respectively. These values averaged 169 and 128% the NEg value of dry rolled corn. Ham et al. (1994) reported that corn WDGS and DDGS fed at 40% of the ration resulted in NEg values of 2.16 and 1.87 Mcal kg^{-1}, respectively, an increase of 39 and 21% relative to corn grain. In finishing rations, corn DDGS has been successfully fed up to 40% of dietary DM, however, recent studies have suggested that inclusion at 20 to 25% of the ration DM optimizes feed efficiency in finishing cattle (Benson et al. 2005; Buckner et al. 2008).

Relative to corn DDGS, there have been relatively few studies that have examined the feeding value of wheat DDGS. Boila and Ingalls (1994) examined the digestibility of wheat DDGS and concluded that wheat DDGS is a good source of rumen bypass protein (63.5%, ruminally undegraded nitrogen). With respect to the inclusion of wheat DDGS as an energy

source (>15% of diet DM), the replacement of rolled barley with wheat DDGS at 25 and 50% of the ration in backgrounding diets increased ADG and improved feed efficiency (McKinnon and Walker, 2008). Diet NEg was 8.2% higher in diets supplemented with DDGS relative to a control barley-based diet (McKinnon and Walker, 2008). Beliveau and McKinnon (2008) found no effect on ADG, feed efficiency or DMI with the substitution of up to 23% wheat DDGS for rolled barley in the finishing rations. Gibb et al. (2008) observed that finishing cattle fed wheat DDGS up to 60 % of the diet had linear increases in DMI, similar ADG and subsequently poorer feed efficiency as wheat DDGS inclusion rate increased.

With respect to carcass quality, cattle fed corn DDGS have been shown to have reduced marbling scores, particularly when fed at levels greater than 23% of the diet (Reinhardt et al. 2007). Klopfenstein et al. (2008) using meta-analysis, reported a linear increase in yield grades and a trend for a linear decrease in marbling scores when corn DDGS comprised 40% of the diet DM. In contrast, studies with wheat DDGS have not reported an adverse effect on carcass quality (Beliveau and McKinnon, 2008) other than a quadratic increase in subcutaneous fat thickness (Gibb et al. 2008).

As the supply of both wheat and corn DDGS increases, there is potential for these two byproducts to compete as feedstuffs. To date, there has been no direct comparison on the relative feeding value of these feeds in finishing cattle diets. Therefore, the objectives of this trial were to compare the performance and carcass quality of steers fed wheat DDGS relative to that of cattle fed corn DDGS in feedlot finishing rations.

3.2 Materials & Methods

3.2.1 Housing and Experimental Design

All cattle utilized in this study were cared for under Canadian Council of Animal Care guidelines (CCAC 1993). Two hundred and seventy five crossbred steers were purchased, and shipped to the Beef Cattle Research Station at the University of Saskatchewan. Upon arrival, all steers were tagged and treated for internal and external parasites with Ivomec™ (Merial Canada Inc., Baie d'Urfé, QC, Canada). The cattle were vaccinated against clostridial diseases with Covexin 8™ (Schering-Plough, Kirkland, QC, Canada), *Pasteurella haemolytica* and *Histophilus somni* with Somnu-Star Ph™ (Novartis, Mississauga, Ontario) and infectious bovine rhinotracheitis, bovine viral diarrhea (types 1 and 2), Parainfluenza type 3 virus, and bovine respiratory syncytial virus with Biostar, Starvac 4 Plus™ (Novartis, Mississauga, Ontario). All cattle were fed a barley-based backgrounding ration (38.3% barley silage, 30.2% grass hay, 23.7% rolled barley grain and 7.8% supplement, DM basis) from arrival to the start of the trial.

Steers were weighed (376±24 kg, mean±SD) and implanted with a TBA-Estradiol combination implant (Synovex Choice™) (Wyeth Animal Health, Guelph, ON, Canada) at the start of the finishing trial. The steers were randomly assigned to one of 25 outdoor pens (n=5) with each pen randomly assigned to one of 5 treatments in a completely randomized design. The trial had a target end-point of 645 kg live weight (unshrunk basis) at which time the cattle were sent for slaughter.

3.2.2 Treatments & Dietary Composition

At the start of the trial, an 8-step diet adaptation was used to adapt the steers over a 21-day period from the backgrounding diet to the final finishing rations. The control diet was

composed of 86.6% rolled barley grain, 5.7% supplement and 7.7% barley silage (DM basis) (Table 3.1) and was formulated to 12% CP and 1.95 and 1.30 Mcal kg^{-1} NE_m and NE_g, respectively. The four treatments included replacement of barley grain with 20 or 40% wheat or corn DDGS (DM basis) (Table 3.1). Rations were formulated to meet or exceed NRC (2000) requirements for CP, trace minerals and fat-soluble vitamins (Table 3.1). The calcium:phosphorus ratio was formulated to range from 1.5:1 to 2:1 with limestone added to the supplement as the DDGS content of the ration increased. Monensin sodium was fed at 27 mg kg^{-1} (DM basis) (Elanco Animal Health, Guelph, ON) in all diets.

The barley silage (AC Rosser) used in the study was grown at the University of Saskatchewan, harvested and stored in plastic bags (Ag-Bag, Miller-St. Nazianz, Inc., St Naziance, WI). Barley silage samples were taken every two weeks with the dry matter (DM) content recorded and used to adjust daily feeding amounts as necessary. Barley grain (61.1±2.1 kg hL^{-1}, mean±SD) was purchased from commercial grain sources and dry rolled on site (RossKamp Champion, Waterloo, IA). The wheat DDGS was supplied by Noramera BioEnergy Corporation (Weyburn, SK) while the corn DDGS was purchased from ConAgra Foods (Omaha, NE). Bunk samples of the total mixed ration were collected every two weeks from each pen, while barley, DDGS (wheat and corn) and supplement samples were taken as each load was received.

3.2.3 Data Collection & Analysis

Cattle were fed *ad libitum* with feed being delivered twice daily in two equal allotments. The amount of feed delivered to each pen was recorded daily. Every two weeks, the bunks were cleaned and any orts were weighed and discarded.

Table 3.1. Composition and analysis of control and wheat and corn dried distillers grains with solubles (DDGS) rations

	Treatment				
		Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%
Diet Composition (% DM basis)					
Barley silage	7.7	7.6	7.5	7.6	7.6
Barley grain	86.6	66.3	47.1	66.4	47.2
Wheat DDGS	0.0	20.4	39.7	0.0	0.0
Corn DDGS	0.0	0.0	0.0	20.3	39.5
Supplement	5.7	5.7	5.7	5.7	5.7
Supplement composition (% DM basis)					
Barley	13.3	44.4	38.4	44.4	38.4
Canola meal	36.6	0.0	0.0	0.0	0.0
Limestone	21.8	30.4	36.6	30.4	36.6
Vitamin premix[z]	10.6	10.5	10.4	10.5	10.4
Ionophore premix[y]	7.7	7.6	7.6	7.6	7.6
Trace mineral salt[x]	7.1	7.1	7.0	7.1	7.0
Canola oil	1.9	-	-	-	-
Urea	1.0	-	-	-	-
Ration Analysis (% DM basis±SE)					
Crude protein	12.1 ± 0.22	15.8 ± 0.32	20.9 ± 0.37	15.2 ± 0.14	18.3 ± 0.13
Ether extract	2.0 ± 0.07	2.1 ± 0.06	2.5 ± 0.06	3.8 ± 0.09	6.2 ± 0.12
Acid detergent fiber	7.9 ± 0.60	9.3 ± 0.48	12.2 ± 0.62	9.2 ± 0.45	11.3 ± 0.59
Neutral detergent fiber	22.5 ± 0.96	23.6 ± 0.95	25.0 ± 0.90	24.2 ± 0.68	26.8 ± 0.61
Calcium	0.6 ± 0.03	0.7 ± 0.06	0.95 ± 0.05	0.7 ± 0.42	0.8 ± 0.04
Phosphorus	0.4 ± 0.01	0.5 ± 0.01	0.6 ± 0.02	0.5 ± 0.01	0.6 ± 0.01

[z] University of Saskatchewan vitamin A & D supplement= 440,500 IU vitamin A, and 88,000 IU vitamin D_3 kg^{-1}

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

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

Actual dry matter intakes for the pen were calculated based on the dry matter delivered to the bunk and corrected for any orts that were recorded every two weeks. Animals were weighed every two weeks, prior to the morning feeding. Ultrasound subcutaneous fat (USFAT) measurements were taken every 4 weeks in conjunction with a weigh day according to the procedure of Bergen et al. (1997) using an Aloka 500 V real-time ultrasound machine and a 17-cm linear array transducer. As the steers approached their target end weight, USFAT were taken every 2 weeks in accordance with weigh days. Ultrasound *longissimus dorsi* (USLD) measurements were taken at the start and end of the trial to calculate *longissimus dorsi (l. dorsi)* area gain. Net energy content of the diet was calculated according to Zinn and Shen (1998) as outlined by McKinnon and Walker (2008).

One hundred and seventy four of the steers were slaughtered at XL Beef Inc. in Moose Jaw, SK. The steers were shipped the day prior to the kill date and held overnight in lairage. Hot carcass weight (HCW) was obtained immediately after slaughter. After 24 h, carcasses were knife ribbed between the 12^{th} and 13^{th} ribs and carcass data (subcutaneous fat thickness, marbling score, *l. dorsi* area, estimated lean yield and any off-grades) was collected by Canadian Beef Grading Agency graders. Marbling scores were based on a 10 point system with 1=very abundant, 5=moderate, 7=small and 10=devoid. Liver abscess scores were subjectively measured using the Elanco classification system, as modified by McKinnon et al. (1992).

A subset of the steers (n=100) was slaughtered at the Agriculture and Agri-Food Canada Lacombe Meat Research Center (Lacombe, AB). The steers were shipped in 5 groups of 20 with 4 steers per treatment per load. Each load was shipped the day prior to the kill day and held overnight in lairage. Hot carcass and all viscera weights were recorded

immediately after slaughter. Carcasses were chilled for 24 h after which Canadian Beef Grading Agency Graders collected carcass data as per the protocol used for commercial slaughter. Carcass front and hind weights were determined by separating the left side of the carcass between the rib and loin sections. Both the front (24 h postmortem) and hind (48 h postmortem) quarters of the left side of each carcass were partitioned into sub-primal boneless boxed beef (SPBBB) and waste (fat and bone). The SPBBB was trimmed according to the Canadian Meat Council (2000) with the edible trim partitioned to 65 or 85% lean. To determine the fat content of the trim piles, the trim piles were each ground three times (Butcher Boy Meat Grinder Model TCA22 with a 3.18-mm grind plate, Lasar Manufacturing Co., Ayrshire, UK), mixed thoroughly and a 100 g sub-sample was dried in a mechanical convection oven (VWR Scientific Model 1370FM, Mississauga, ON) at 105°C for 24 h to determine moisture content. Free oil in the dried sample was decanted and weighed. The remaining dried product was pulverized and two 4 g sub-samples were extracted in petroleum ether using a Tecator Soxtec Extraction System Model 2050 (Foss Analytical AB, Hoganas, Sweden). Total crude fat in the sample was determined as the weight of the oil decanted plus the percentage of fat in the dried sample. Once the total crude fat analysis was recorded, lean trim was adjusted to the appropriate fat content (65 or 85%) by the addition or removal of extracted fat.

3.2.4 Chemical Analysis

All forage and bunk samples were dried in a forced air oven at 55ºC for 72 h. Dried forage samples were ground through a hammer mill fitted with a 1 mm screen (Christy & Norris 8" Lab Mill, Christy Turner Ltd. Chelmsford, UK). Bunk samples were dried on a pen basis and composited by treatment for each 2 week collection period. Bunk and concentrate samples

were ground through a 1 mm screen using a Retsch ZM100 grinder (Haan, Germany). Composite total mixed ration samples were analyzed in duplicate according to the Association of Official Analytical Chemists (2000) for DM by drying at 135ºC (AOAC method 930.15), CP (AOAC method 948.13), NDF treated with amylase and without the addition of sodium sulphite (AOAC method 2002.04), ADF (AOAC method 973.18) and ether extract (AOAC method 920.39). Calcium and phosphorus were analyzed using the dry ashing procedure (AOAC methods 927.02 and 965.17, respectively). Calcium was determined using an atomic absorption spectrophotometer (Perkin-Elmer, Model 2380, CN, USA) while phosphorus was read at 410 nm on a spectrometer (Pharmacia, LKB-Ultraspec III, Stockholm, Sweden).

Each batch of wheat (N=2) and corn (N=2) DDGS were analyzed by Cumberland Valley Analytical Services (CVAS, Hagerstown, MD) according to the Association of Official Analytical Chemists (2000). Samples were analyzed for DM by drying at 135ºC (AOAC method 930.15), CP (AOAC method 990.03) using a Leco FP-528 Nitrogen Combustion Analyzer (Leco, St Joseph, MI), ADF (AOAC method 973.18), ADIN (using ADF residue and Leco FP-528 Nitrogen Combustion Analyzer, Leco, St Joseph, MI), ash (AOAC method 942.05) and fat using a tecator extraction unit (AOAC method 2003.05). The methods of Van Soest et al. (1991) were used to analyze NDF content and the NDF residue was used for NDIN analysis (Leco FP-528 Nitrogen Combustion Analyzer, Leco, St Joseph, MI).

3.2.5 Statistical Analysis

Data was analyzed as a completely randomized design, with pen as the experimental unit and treatment as a fixed effect using the Mixed Model procedure of SAS (Version 9.1; SAS

Institute, Inc. Cary, N. C.). Satterthwaite's approximation on degrees of freedom was used with a Kenward-Roger adjustment on standard errors. Results were analyzed using a protected F-test (P <0.05). Polynomial contrasts were used to determine the linear and quadratic effects of wheat or corn DDGS inclusion rate. Significant results ($P \leq 0.05$) were presented using slope (linear) or local maxima/minima (quadratic) for the best fit polynomial regression equation. Marbling and liver abscess score data were analyzed using the GLIMMIX macro (SAS, Version 9.1; SAS Institute, Inc. Cary, N. C.) with a binomial error structure and logit data transformation.

3.3 Results and Discussion

The wheat DDGS utilized in this study averaged 39.3±1.2% CP, 3.9±0.4% EE, 41.4±0.9% NDF, 16.6±3.5% ADF, 23.6±2.0% ADIN (% N), 0.12±0.01% Ca and 0.97±0.12% P (mean±SE, DM). The CP, EE and NDF values for the wheat DDGS were similar to that previously reported (Beliveau and McKinnon 2008; McKinnon and Walker 2008). The ADF level in the wheat DDGS used in this study was higher than that reported by Beliveau and McKinnon (2008) (13.2%) but similar to Gibb et al. (2008) (19.5%). The ADIN content was considerably higher than that reported by Beliveau and McKinnon (2008) (10.5% N) and Gibb et al. (2008) (10.5% N). The high ADIN value of the wheat DDGS could reduce the nitrogen digestibility of the diet, although Nakamura et al. (1994) found a poor correlation between ADIN levels of DDGS and N digestibility. Furthermore, Kleinschmit et al. (2006) found no change in the feed efficiency of dairy cows fed a high ADIN (23.1% N) corn DDGS relative to those fed a low ADIN (9.4 and 10.3% N) corn DDGS.

The corn DDGS fed in this study averaged 31.8±0.1% CP, 13.7±0.7% EE, 43.8±0.5% NDF, 11.5±0.2% ADF, 11.6±0.1% ADIN (% N), 0.03±0.01% Ca and 0.89±0.01% P (mean±SE, % DM). The CP and NDF levels for the corn DDGS are comparable to previous findings (Spiehs et al., 2002). However the ADF levels are somewhat lower than those reported by Spiehs et al. (2002) (13.8 to 18.5%) and Kleinschmit (2007) (14.7 to 20.3%). The EE value for corn DDGS was slightly higher than previous reports of 10 to 12% by Spiehs et al. (2002) but comparable to the 13.9% reported by Gunn et al. (2009).

Substituting wheat or corn DDGS at 20 and 40% of the ration (DM basis) for barley increased CP content of the diets from 12.1% in the control diet to 15.8 and 20.9% in the 20 and 40% wheat DDGS diets and 15.2 and 18.3% for the 20 and 40% corn DDGS diets, respectively. In agreement with other studies (Benson et al. 2005; Beliveau and McKinnon 2008) ADF, NDF and P values (Table 3.1) increased with increasing level of wheat and corn DDGS in the diet. The EE content of the diet increased substantially with the addition of corn DDGS (2.0% in the control diet vs. 3.8 and 6.2% in the 20 and 40% corn DDGS rations, respectively). The EE content of the diet was not affected greatly by the inclusion of wheat DDGS (2.1 and 2.5% in the 20 and 40% rations, respectively).

3.3.1 Finishing Performance

Dry matter intake showed a differential response for cattle fed wheat or corn DDGS (Table 3.2). DMI increased (P<0.01) in a quadratic fashion (y=10.358-0.027x+0.001x^2, R^2 =0.73, SEP 0.212) as wheat DDGS increased in the ration while DMI decreased (P=0.01) in a quadratic fashion (y=10.358+0.027x–0.002x^{2,} R^2=0.88, SEP 0.295) with increased corn DDGS levels. Solving the equation for wheat DDGS gives a local minima for DMI at a 13% inclusion rate with intake increasing as wheat DDGS increases to the 40% inclusion level.

Beliveau and McKinnon (2008) noted a similar response to the current trial with cattle fed wheat DDGS up to 32% (DM) in a backgrounding trial. In contrast, these authors found no effect of wheat DDGS (up to 23% of the diet, DM) on DMI in finishing cattle. Gibb et al. (2008) observed a linear increase in DMI as wheat DDGS increased to 60% of the ration DM. These workers hypothesized that the increase in DMI was a compensatory response to a reduction in digestibility with increasing wheat DDGS as digestibility of the diet was reduced by 9.8% when wheat DDGS comprised 60% of diet DM.

There was no treatment effect (P=0.13) on ADG, although numerically cattle fed 40% wheat DDGS had the highest ADG (Table 3.2). This lack of significance is somewhat surprising as these cattle consumed more feed than the control cattle. However, calculated NEg based on performance was not different (P>0.05) between the control diet and the two wheat DDGS diets. Cattle fed wheat DDGS exhibited a linear decrease (P=0.04) in days on feed (y=170.63-0.375x, R^2=0.43, SEP 7.59) as concentration of wheat DDGS increased in the diet. This is likely a reflection of the increased DMI (P<0.01) and numerically higher ADG of the wheat DDGS fed steers, particularly those fed 40% wheat DDGS. The intake and ADG responses of the wheat DDGS fed cattle also explains why there was no effect of wheat DDGS inclusion level on gain:feed (Table 3.2). Beliveau and McKinnon (2008) reported similar results for ADG and gain:feed for finishing cattle fed up to 23% wheat DDGS. Gibb et al. (2008) found that DMI increased linearly with increasing levels of wheat DDGS in the diet (up to 60%) with no effect on ADG. As a result, these workers reported that gain:feed ratios decreased with increasing levels of wheat DDGS.

In contrast, cattle fed corn DDGS exhibited a quadratic decrease (P=0.01) in DMI as inclusion levels increased (Table 3.2). Solving the quadratic equation gives a local maxima

Table 3.2. Effects of feeding wheat or corn dried distillers grains with solubles (DDGS) at two inclusion levels on the performance of finishing cattle

	Dietary Treatment							P-value contrast			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[z]	*P*-value	Linear	Quad	Linear	Quad
Start of trial weight (kg)	375	376	377	376	376	0.80	0.70				
End of trial weight (kg)	654	649	648	652	653	2.28	0.34				
Average daily gain (kg d^{-1})	1.62	1.63	1.73	1.66	1.68	0.03	0.13				
Dry matter intake (kg d^{-1})	10.4	10.2	10.9	10.2	8.8	0.11	0.01	0.02	0.01	0.01	0.01
Gain:Feed	0.156	0.159	0.158	0.163	0.192	0.002	0.01	0.65	0.52	0.01	0.01
NEg of diet (MCal kg^{-1})	1.27	1.30	1.26	1.32	1.58	0.02	0.01	0.41	0.11	0.01	0.01
Days on Feed	169	166	154	163	162	3.26	0.05	0.04	0.37	0.12	0.46
US backfat thickness (mm)[y]											
Start of test	2.2	2.2	2.6	2.2	2.0	0.24	0.51				
End of test	8.4	8.8	9.8	9.0	9.2	0.51	0.41				
Gain	6.2	6.8	7.4	7.0	7.0	0.46	0.47				
US longissimus dorsi area (cm^2)[x]											
Start of test	59.0	59.8	58.6	58.8	59.4	0.55	0.56				
End of Test	89.4	90.6	89.4	91.8	89.2	1.10	0.42				
Gain	31.0	30.6	30.8	33.6	29.8	1.39	0.39				

[z] SEM = pooled standard error of the mean

[y] Ultrasound measurements of subcutaneous fat thickness

[x] Ultrasound measurements of *longissimus dorsi* area

for DMI at the 8.0% corn DDGS inclusion level. Eun et al. (2009) also found that replacing rolled barley with corn DDGS (up to 18.3%, DM) in finishing rations resulted in reduced DMI, with the lowest DMI at the highest DDGS inclusion level. The decrease in DMI associated with feeding corn DDGS in barley rations could be due to the increasing dietary fat level associated with diets that contain corn DDGS. Ether extract levels reached 6.2±0.12% on the 40% corn DDGS diet (Table 3.1). Zinn and Jorquera (2007) recommended a maximum dietary fat intake of 6 to 7% in high concentrate rations to prevent DMI depression. Allen et al. (2009) suggests that elevated serum fatty acid concentrations, particularly unsaturated fatty acids may have a satiety effect in accordance with the hepatic oxidation theory. This theory states that food intake is controlled by the hypothalamus, which in turn is alerted to the body's energy status by the degree of hepatic oxidation of a variety of metabolic fuels. However, this theory does not explain why DMI is not reduced when corn DDGS is fed in corn-based rations. For example, Buckner et al. (2008) did not find any effect on DMI when corn DDGS replaced corn grain at levels up to 40% (DM basis). Dietary fat levels reached 6.3%. Benson et al. (2005) reported a quadratic increase in DMI when corn DDGS replaced corn grain at levels up to 35% of the diet DM, with dietary fat levels reaching 7.3%.

Differences in the energy content of the two cereal grains may account for differences in the DMI observed in finishing diets containing corn DDGS. Barley contains 1.40 Mcal kg^{-1} NEg whereas corn has 1.55 Mcal kg^{-1} of NEg (NRC 2000). In the present study, it is logical to assume that cattle fed the barley based control diet were eating to meet their energy needs and thus were gaining at or close to their genetic potential. In this case, substituting corn DDGS with a higher NEg value for barley should result in reduced DMI, as observed (Table

3.2). In contrast, in studies where corn DDGS has replaced corn, differences in NEg content are not as great and thus large changes in DMI would not be expected.

As with wheat DDGS, there was no effect (P=0.13) of corn DDGS inclusion level on ADG (Table 3.2). This is in contrast to Ham et al. (1994) and Buckner et al. (2008) who noted higher gains on cattle fed corn DDGS relative to those fed a corn-based ration. The lack of response in ADG is consistent with the reduced DMI of the corn DDGS fed cattle as discussed above. Cattle fed corn DDGS exhibited (P<0.01) a quadratic increase in gain:feed (y=0.1564–0.0003x+0.00003x^{2,} R^2=0.95, SEP 0.004) with a local minima at the 4.6% inclusion level. These results support Larson et al. (1993) who reported cattle fed corn WDGS at 40% of the ration had a 20% improvement in gain:feed. Ham et al. (1994) also reported similar results for both corn WDGS and DDGS. Klopfenstein et al. (2008) in a meta-analysis of studies utilizing corn DDGS up to 40% of the diet reported a cubic trend on gain:feed with optimal efficiency at inclusion rates between 10 and 20%, while inclusion at 40% resulted in gain:feed similar to the control corn-based diets. In contrast to our study, Eun et al. (2009) reported no differences in gain:feed of cattle fed corn DDGS as a replacement for barley grain at levels up to 18.3% (DM), although inclusion of corn DDGS numerically improved gain:feed. Discrepancies between trials may arise from the higher inclusion level of corn DDGS as the steers fed 20% corn DDGS in this study had a gain:feed (0.163 vs. 0.162, respectively) that was similar to those fed a diet with 18.3% corn DDGS (Eun et al. 2009).

The effects of corn DDGS on DMI and gain:feed is supported by the calculated NEg content of the diet (Table 3.2). The NEg content of corn DDGS rations increased (P<0.01) in a quadratic fashion (y=1.274–0.0028x+0.0003x^{2,} R^2=0.96, SEP 0.029) as the level of corn

DDGS in the diet increased with a local minima at the 5.4% inclusion level. The NEg content of the control diet was estimated to be 1.27 Mcal kg^{-1} NEg while that of the 40% corn DDGS diet was estimated to be 1.58 Mcal kg^{-1} NEg, an improvement of 24%. Ham et al. (1994) reported a similar improvement (21%) in NEg content of the diet when corn DDGS replaced corn grain at 40% of the ration. This increase in NEg explains the reduction in DMI of the cattle fed 40% corn DDGS and the fact that gain was similar to the control cattle. Predicted NEg daily intake was similar for the control and 40% corn DDGS fed cattle (13.2 vs. 13.9 Mcal, respectively).

Ultrasound subcutaneous fat and USLD gain measurements were not affected by treatment (P>0.05) (Table 3.2). The lack of difference is likely a reflection of the similar NEg intakes amongst all diets (13.5±0.3 Mcal day^{-1}) (mean ± SD, DM) as well as the fact that the cattle were all taken to a common end point at slaughter.

No effects (P>0.05) of treatment were found on liver abscess scores (Table 3.3). Similar results were reported by Beliveau and McKinnon (2008) and Gibb et al. (2008). It has been proposed that adding DDGS to finishing diets would improve rumen pH due to its low starch and high fiber content (Galyean and Defoor, 2003; Klopfenstein et al. 2008). Beliveau and McKinnon (2009) however, reported that the addition of up to 21% wheat DDGS did not improve rumen pH relative to a barley-based control ration. These workers attributed the lack of sub-acute ruminal acidosis mitigation to low levels of physically effective fiber and reduced buffering capacity of DDGS. Furthermore, there was no difference in liver abscess scores between corn and wheat DDGS fed cattle (Table 3.3) and thus no evidence of a modulation influence on sub-acute ruminal acidosis as a result of the higher oil content of corn DDGS.

Table 3.3. Effects of feeding wheat or corn dried distiller grain with solubles (DDGS) at two inclusion levels on the carcass quality of finishing cattle

	Dietary Treatment							P-value contrast			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[z]	*P*-value	Linear	Quad	Linear	Quad
Shrunk ship weight (kg)	639	632	634	633	636	2.5	0.42				
HCW (kg)	371.9	370.8	374.8	375.3	375.6	5.34	0.54				
Dressing percentage	58.0	58.6	59.2	59.4	59.0	0.27	0.01	<0.01	1.00	0.02	0.01
Grade fat (mm)[y]	7.8	8.2	9.0	8.2	9.0	0.41	0.18				
Estimated lean yield (%)[x]	61.2	60.6	59.8	60.6	60.0	0.45	0.23				
L. dorsi area (cm^2)	97.2	94.6	92.2	92.6	94.0	1.42	0.14				
Marbling score[w]											
Percentage with score 5	0.0	3.6	0.0	1.9	0.0	1.32	0.92				
Percentage with score 6	5.5	0.0	0.0	1.9	0.0	1.39	0.57				
Percentage with score 7	23.6	23.6	20.4	9.3	13.0	6.10	0.40				
Percentage with score 8	58.2	50.9	66.7	79.6	74.1	7.24	0.09				
Percentage with score 9	10.9	20.0	13.0	5.6	13.0	5.03	0.45				
Liver Abscess Score[v]											
Percentage with score 0	67.3	56.4	66.7	61.1	61.1	7.22	0.81				
Percentage with score 1	5.5	14.5	9.3	14.8	13.0	4.17	0.50				
Percentage with score 2	16.4	7.3	7.4	13.0	9.3	3.51	0.34				
Percentage with score 3	10.9	21.8	16.7	11.1	16.7	5.01	0.54				

[z] SEM = pooled standard error of the mean

[y] Grade fat is a measure of subcutaneous fat assessed perpendicular to the outside surface, within the fourth quarter of the rib-eye at the minimum point of thickness.

[x] Estimated lean yield = 63.65 + 1.05 (muscle score) - 0.76 (grade fat)

[w] Marbling score: 1 = very abundant, 5 = moderate, 6 = modest, 7 = small, 8 = slight, 9 = traces and 10 = devoid

[v] Liver abscess score: 0 = no abscesses, 1 = one small abscess (≤1.25 cm), 2 = two to four small to medium (≤2.54 cm) abscesses, 3 = one or more large abscesses or greater than four small to medium abscesses.

3.3.2 Carcass Quality

There was no effect of DDGS (wheat or corn) inclusion level on hot carcass weight (P>0.54), estimated lean yield (P>0.23), grade fat (P=0.18) marbling scores (P=0.09 to 0.92) or *l. dorsi* area (P=0.14) (Table 3.3). However, dressing percentage linearly increased (P<0.01) with inclusion level of wheat DDGS (y=58.00+0.0300x, R^2=0.47, SEP 0.55). Beliveau and McKinnon (2008) also reported wheat DDGS at levels up to 23% in finishing rations had no effect on estimated lean yield or marbling scores. Gibb et al. (2008) observed a quadratic decrease in subcutaneous fat thickness as well as a trend for reduced lean meat yield, but no effect on dressing percentage as wheat DDGS inclusion increased (up to 60%) in finishing rations.

Dressing percentage increased (P=0.01) in a quadratic fashion (y=58.00+0.1150x–0.0023$x^{2,}$ R^2=0.50, SEP 0.658) as corn DDGS inclusion level increased in the ration with a local maxima at 26% (DM). Similar to the results of the present study, Benson et al. (2005) also found a positive linear effect of corn DDGS (up to 35%, DM) on dressing percentage. The higher dressing percentage when feeding corn DDGS is attributed to an increase in subcutaneous fat and poorer yield grades (Benson et al. 2005; Eun et al. 2009). In this study, wheat and corn DDGS at levels up to 40% (DM) had no effect (P>0.05) on estimated lean yield or grade fat although estimated lean yield (%) decreased and grade fat numerically increased numerically as DDGS (wheat and corn) increased (Table 3.3). In contrast, both Benson et al. (2005) and Eun et al. (2009) found yield grades to increase in response to greater inclusion levels of corn DDGS, again reflecting higher levels of subcutaneous carcass fat. The yields of sub-primal boneless boxed beef, trim and waste (fat and bone) were not affected by treatment (P>0.05) (Table 3.4), which is consistent with no differences in estimated lean yield and grade fat (Table 3.3).

Table 3.4. Effects of feeding wheat DDGS or corn DDGS at two inclusion levels on the yield of SPBBB, trim and waste (fat and bone)[z.]

	Dietary Treatment						
		Wheat DDGS		Corn DDGS			
	Control	20%	40%	20%	40%	SEM[y]	P-value
Left cold carcass weight (kg)	184.4	182.5	186.5	186.4	187.1	1.27	0.10
SPBBB, edible trim and waste (% of left cold carcass weight)							
SPBBB	61.13	60.49	59.61	60.51	60.15	0.466	0.27
Edible trim – 65% lean	1.42	1.29	1.36	1.42	1.47	0.130	0.89
Edible trim – 85% lean	7.97	7.57	7.66	7.70	7.36	0.424	0.38
Waste (bone and fat)	29.22	30.29	30.99	30.23	30.40	0.600	0.37

[z] Subsample of 100 steers; 20 from each treatment

[y] SEM = pooled standard error of the mean

3.4 Conclusion

The results of this study indicate that feeding wheat DDGS in finishing rations up to 40% of the ration causes an increase in DMI and reduced days on feed. In contrast, supplementing corn DDGS for barley in finishing rations at levels up to 40% results in a decrease in DMI and an improved gain:feed. Furthermore, feeding corn DDGS increased diet NEg. Inclusion of wheat or corn DDGS did not impact marbling scores, HCW, estimated lean yield, grade fat or sub-primal boneless boxed beef. However, dressing percentage increased as both wheat and corn DDGS inclusion increased. Results from this trial indicate that both wheat and corn DDGS can be supplemented for barley in finishing diets at levels up to 40% with no negative impact on performance, carcass quality or sub-primal boneless boxed beef yield. Cattle fed barley-based diets and supplemented with corn DDGS will exhibit improved gain:feed ratios due to decreased dry matter intake.

4.0 COMPARISON OF WHEAT OR CORN DRIED DISTILLERS GRAINS WITH SOLUBLES ON RUMEN FERMENTATION AND DIGESTIBILITY CHARACTERISTICS OF FEEDLOT HEIFERS

4.1 Introduction

The increased production of fuel based ethanol in North America has led to the feeding of distillers grains at high inclusion levels (20 to 40% of the ration) in feedlot rations. Dried distillers grains with solubles, the most common distillers byproduct, has a nutritional composition that is low in starch but concentrated three-fold in chemical composition (Spiehs et al. 2002). It has been speculated that since DDGS is essentially starch free, the incidence of SARA should be reduced relative to corn or barley grain fed cattle (Firkins et al. 1985; Larson et al. 1993). Furthermore, due to the lack of starch and subsequent high fiber content, VFA patterns and molar amounts are likely to change as a result of feeding DDGS (Ham et al. 1994). Research conducted by Ham et al. (1994) and Eun et al. (2009) did not find an effect of corn DDGS on mean ruminal pH or VFA concentration when fed at 40% of a corn-based finishing ration and up to 18.3% in a barley-based finishing ration, respectively. In contrast, Leupp et al. (2009) found total VFA and acetate decreased while propionate increased in a linear fashion, as corn DDGS inclusion increased up to 60% in corn rations.

Although limited research exists for wheat DDGS, Beliveau and McKinnon (2009) found propionate to decrease in a linear fashion with no effect on acetate levels as wheat DDGS increased (up to 21%) in barley-based rations. The authors, using *in-dwelling* rumen pH data loggers, also found a decreasing cubic effect on mean pH below the 5.8 and 5.5 thresholds in cattle fed wheat DDGS. Decreasing cubic effects were also found on pH area between 5.2 and 5.5 (pH x min) and time below 5.2 (min).

The digestibility of corn DDGS has been shown to be comparable to control corn-based 70% concentrate rations (Leupp et al. 2009). Leupp et al. (2009) also found that ruminal digestion of ADF and NDF in corn DDGS fed cattle tended to decline, however total tract digestion of both ADF and NDF were similar to cattle fed the control ration. In regards to environmental concerns over additional nitrogen and phosphorus intakes associated with feeding DDGS, Spiehs et al. (2009) found both nitrogen and phosphorus excretion to linearly increase as corn was replaced by corn WDGS (up to 60%) in high concentrate rations. In terms of wheat DDGS digestibility, Gibb et al. (2008) found dry matter digestibility of cattle fed a 60% wheat DDGS diet to decline by 9.8% relative to a barley-based diet.

To date, no research has been conducted to compare rumen fermentation parameters and digestibility of wheat vs. corn DDGS based rations. Therefore, the objectives of this study were to compare cattle fed wheat-based DDGS to those fed corn-based DDGS in terms of rumen fermentation parameters, nutrient digestibility and to quantify the increased nitrogen and phosphorus excretion associated with feeding DDGS.

4.2 Materials & Methods

4.2.1 Animals, Housing & Experimental Design

Five Hereford heifers (420 ± 6 kg, mean ± SD) were housed in 9 m^2 floor pens equipped with rubber floor mats and individual water bowls and feeders at the Livestock Research Barn (University of Saskatchewan). Upon arrival, all heifers received the same processing and vaccination protocol as the feedlot steers in Trial 1. After an acclimatization period (six weeks), all heifers were spayed and fitted with a soft, plastic rumen cannula (10 cm centre

diameter; Bar Diamond, Parma, ID). All cattle were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993).

Each heifer was randomly assigned to one of five treatments using a 5 by 5 Latin square design. The trial was 170 days in length with 34 day periods. Each period consisted of a 12 day adaptation period, a 6 day (d 13-18) voluntary intake phase and a 16 day (d 19-34) collection period. During the collection period, 24 h eating behaviour was observed (d 19), 24 h rumen fluid sampling was performed (d 21), *in-dwelling* pH data was collected over 3 consecutive 23 h periods (d 25-27) and total fecal and urine collections were carried out during the remainder of the period for 5 consecutive days (d 29-34).

4.2.2 Treatments, Dietary Composition & Feeding

Heifers were fed a standard barley-based finishing ration (90% barley grain, 5% barley silage and 5% supplement, DM) before the trial commenced. The treatments were matched to the feedlot trial so that the control diet, on DM basis consisted of 88.7% rolled barley grain, 5.8% barley silage and 5.5% supplement (Table 4.1). For the other four treatments, wheat or corn DDGS were substituted for barley grain at 20 and 40% of the diet DM (Table 4.1). Rations were formulated to meet or exceed NRC (2000) requirements for CP, trace minerals and fat-soluble vitamins (Table 4.1). The Ca:P ratio was formulated to range from 1.5:1 to 2:1 with limestone added to the supplement as the DDGS content of the ration increased. Monensin sodium was fed at 27 mg kg^{-1} (DM basis) (Elanco Animal Health, Guelph, ON) in all diets.

Table 4.1. Composition and analysis of control and wheat and corn dried distillers grains with solubles (DDGS) rations

	Treatment				
		Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%
Diet Composition (% DM basis)					
Barley silage	5.8	5.8	5.8	5.8	5.8
Barley grain	88.7	68.7	48.7	68.6	48.6
Wheat DDGS	-	20.0	39.9	-	-
Corn DDGS	-	-	-	20.1	40.0
Supplement	5.5	5.5	5.6	5.5	5.5
Supplement composition (% DM basis)					
Barley	-	43.9	37.9	43.9	37.9
Canola meal	47.5	-	-	-	-
Canola oil	3.2	-	-	-	-
Urea	1.6	-	-	-	-
Limestone	21.8	30.4	36.6	30.4	36.6
Vitamin premix[z]	10.6	10.5	10.4	10.5	10.4
Ionophore premix[y]	8.2	8.1	8.1	8.1	8.1
Trace mineral salt[x]	7.1	7.1	7.0	7.1	7.0
Ration Analysis (% DM basis±SE)					
Organic Matter	95.5 ± 0.05	94.3 ± 0.11	94.5 ± 0.02	94.4 ± 0.08	93.6 ± 0.10
Crude protein	12.8 ± 0.04	18.1 ± 0.14	24.0 ± 0.18	15.4 ± 0.03	18.9 ± 0.12
Ether extract	1.6 ± 0.01	2.0 ± 0.02	2.7 ± 0.01	3.2 ± 0.01	5.1 ± 0.02
Acid detergent fiber	8.5 ± 0.05	10.8 ± 0.12	13.4 ± 0.12	9.3 ± 0.05	10.6 ± 0.08
Neutral detergent fiber	18.0 ± 0.06	24.3 ± 0.28	30.4 ± 0.29	23.8 ± 0.05	30.2 ± 0.22
Acid detergent insoluble nitrogen	0.04 ± 0.001	0.33 ± 0.004	0.62 ± 0.005	0.16 ± 0.001	0.28 ± 0.002
Neutral detergent insoluble nitrogen	0.21 ± 0.001	0.96 ± 0.014	1.71 ± 0.011	0.49 ± 0.002	0.79 ± 0.003
Calcium	0.54 ± 0.02	0.72 ± 0.02	0.99 ± 0.04	0.72 ± 0.01	0.92 ± 0.03
Phosphorus	0.40 ± 0.01	0.49 ± 0.01	0.65 ± 0.01	0.46 ± 0.01	0.58 ± 0.01

[z] University of Saskatchewan vitamin A & D supplement= 440,500 IU vitamin A, and 88,000 IU vitamin D_3 kg^{-1}

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

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

The adaptation phase for all periods consisted of four equal steps in which the concentrate (barley and wheat DDGS or corn DDGS) was increased or decreased by 5 or 10%, at each step, depending on the target diet.

All animals were fed individually in two equal daily allotments at 0800 and 1600 h. Prior to the morning feeding, feed bunks were swept clean with orts removed, weighed and recorded. To determine *ad libitum* feed intake, heifers were fed so that 0.1 to 0.3 kg orts remained in the bunk the following morning. In order to calculate voluntary intake as a percentage of body weight, heifers were weighed on d 16 and d 17 prior to feeding. On d 22, a restricted intake period began prior to rumen insertion of *in-dwelling* pH probes, in which intake was restricted to 95% of *ad libitum* intake (DM basis). Feed was restricted to 95% of *ad libitum* intake to ensure all feed was consumed during the period of pH measurement and the total collection period. Following pH measurement, there was a 2 d rest period (d 28 and d 29) before total collections ensued.

The wheat and corn DDGS used in this trial was the same as that used for the feedlot trial. Supplements were formulated and mixed in one batch per treatment to maintain consistency throughout the trial (Table 4.1). Barley grain (63.3±0.6 kg hL^{-1}, mean±SD) was purchased from commercial grain sources and dry rolled (RossKamp Champion, Waterloo, IA). The barley silage (AC Rosser) was grown at the University of Saskatchewan, harvested and ensiled. Silage samples were taken bi-weekly with the samples dried to determine dry matter content and used to adjust feeding amounts, if necessary. Load samples for DDGS (corn and wheat) and barley, batch samples for supplements and the bi-weekly silage samples were taken for chemical analysis.

4.2.3 Rumen Fermentation

4.2.3.1 *In-dwelling* Rumen pH Measurement

On d 25-27, all heifers were fitted with indwelling rumen pH probes and data loggers using the In-dwelling Continuous pH Measurement System (Dascor, Escondido, CA) as described by Penner et al. (2006). The *in-dwelling* pH measurements allowed for the continuous monitoring (30 sec measurement) of rumen pH in the ventral sac for 3 continuous 23 h periods. Every morning, between 0700 and 0800, the rumen pH probes were removed from the rumen, cleaned, recorded data downloaded and recalibrated (pH 4 and 7).

The pH data was then averaged for each minute and combined with the calibration data using SAS (Version 9.1; SAS Institute, Inc. Cary, N. C.) to summarize minimum pH, mean pH and maximum pH. The duration (min d^{-1}) and pH area (min d^{-1} x pH) under the curve were also calculated using thresholds (pH 5.8-5.5, pH 5.5-5.2 and pH <5.2) to summarize degrees of acidosis as mild, moderate and severe, respectively, according to Nocek (1997) and Penner et al. (2007).

4.2.3.2 Rumen Fluid Collections

On d 21, rumen fluid was collected at two h intervals for 24 h, starting at 0800. Approximately, 250 mL of rumen contents were sampled from the rumen mat, ventral and dorsal caudal sacs and the reticulum to obtain a representative sample. The samples were combined, mixed and strained through four layers of cheesecloth. A Model 265A portable pH meter (Orion Research Inc., Beverly, MA) was used to measure the pH of the retained rumen fluid in duplicate immediately after straining. A representative portion of the collected fluid was stored and frozen (-20 ºC) in 10 ml quantities for further analysis of VFAs (mixed with 2

ml of 25% (wt/vl) metaphosphoric acid solution), ammonia (mixed with 2 mL of 0.1 M sulphuric acid solution) and osmolality.

4.2.3.3 Volatile Fatty Acid Analysis

Rumen fluid samples for VFA analysis were thawed overnight at 4°C before being centrifuged in a Beckman Centrifuge (Model JS-4.2SM; Palo Alto, CA) at 5,000 x g at 4ºC for 15 minutes. Subsequently, 120 µL of the supernatant was transferred into duplicate 1.8 ml Eppendorf™ centrifuge tubes with a glass syringe and 0.45um syringe filter (Nalgene, Rochester, NY). Then 500 µL of 1 mM trimethyl acetic acid in acetonitrile was also added to the Eppendorf™ tubes to act as the internal standard along with 880 µL of acetonitrile. Samples were vortexed for 3 seconds before centrifuging at 14,000 x g for 5 minutes in a Microfuge® 18 Microcentrifuge (Beckman Coulter™, Palo Alto, CA). The sample supernatant was pipetted (1 mL) into an Agilent™ GC glass vial and capped. An Agilent 6890 Series Gas Chromatography System (Wilmington, DE) including an Agilent 7683 Series injector (5 µL) fitted with a Zebron ZB-FFAP High Performance GC Capillary Column (30.0 m × 320 µm × 0.25 µm, Phenomenex, Torrance, CA) was used to identify and quantify VFAs (acetate, propionate, isobutyrate, butyrate, isovalerate, and valerate) in every sample. A standard curve was made from purchased standards (Nu-Chek Prep, Inc. Elysian, MN) and used to quantify the concentration (mM) of the individual VFAs. Samples were prepared daily and placed on the autosampler twice daily. Samples that were prepared daily, but not initially placed on the autosampler were stored in the fridge to minimize volatization .

4.2.3.4 Rumen Ammonia and Osmolality

Rumen ammonia-N and osmolality samples were thawed overnight at 4°C. Rumen ammonia-N samples were vortexed and centrifuged at 14,000 x g for 10 minutes at 4°C in an ICE

MicroCL 17R Centrifuge (Thermo Electron Corporation, Waltham, MA). The phenol-hypochlorite procedure by Broderick and Kang (1980) was used to quantify the ammonia concentration once the rumen ammonia-N samples were centrifuged. Rumen osmolality was determined after centrifuging the thawed, non-acidified rumen fluid samples at 3,000 x g for 15 min using a Beckman Centrifuge (Model JS-4.2SM; Palo Alto, CA). A Vapro™ Vapor Pressure Osmometer (Model 5520; Wescor Inc., Logan, Utah) was used to determine the osmolality of the samples in duplicate. Standards (100, 290 and 1000 mmol kg^{-1}) were run initially and after every 24 samples to calibrate the osmometer.

4.2.3.6 Feeding Behaviour

On d 19, a 24 h observation (0800-0800 h) was utilized to observe and record behaviour and physical activity using the methods of Maekawa et al. (2002b) and Yang and Beauchemin (2006c). Total time spent eating, ruminating and drinking as well as positions of standing, sitting and lying (resting) were recorded every 5 minutes and measured in min d^{-1}. It was assumed that animals that were observed exhibiting these behaviours continued to do so for the next five minutes (Meakawa et al. 2002b).

4.2.4 Total Tract Collections

Total tract collections were performed for five days (d 30 to 35) of each period to determine nutrient digestibility of each treatment diet as well as the route and form of nitrogen and phosphorus excretion. Heifers were haltered and tethered, allowing enough space for lying, standing, drinking and eating. Indwelling bladder catheters (Bardex Foley Catheter, 75 mL capacity balloon; C. R. Bard Inc., Covington, GA) were inserted by a veterinarian one day prior to collections. Urine was collected via Nalgene tubing into plastic sealed vesicles containing 100-150 mL of HCl acid at 0800 on d 30. The concentrated HCl was used in order

to reduce the pH to 2 so as to minimize volatization of ammonia (Stockdale and Rathbone 1992). The daily volume of collected urine was recorded at 0800 each day, mixed thoroughly, sub-sampled (20% of total daily output) and frozen at –20 ºC. At the end of each period, the urine was thawed, mixed and sub-sampled for further analysis of total nitrogen and ammonia-N as well as phosphorus.

Total fecal output was collected from the floor. Designated monitoring times for fecal collection were continuous monitoring from 0530 to 1300, 2 h intervals from 1300 to 2300 and 3 to 3.5 h intervals from 2300 to 0530 with feces collected and stored in a covered plastic Rubbermaid™ container. The total daily fecal output was weighed daily from d 31 to d 35 at 0800 hours with representative 500 g samples collected in duplicate into two pre-weighed aluminum drying containers. Feces were then dried at 55 ºC for at least 96 h. Fresh feces (1000 g) were sub-sampled on d 31 to d 35, stored at –20 ºC and used for pH, P and extractable NH_3-N measurements.

4.2.5 Chemical Analysis

All silage and fecal samples were dried in a forced air oven at 55ºC for 72 h. Dried forage samples were ground through a hammer mill fitted with a 1 mm screen (Christie Norris Laboratory Mill Size 8", Christie-Norris Ltd. Chelmsford, UK). Dried fecal and concentrate samples were ground through a 1 mm screen using a Retsch ZM100 grinder (Haan, Germany). All silage, dried fecal and concentrate samples were analyzed in duplicate according to the Association of Official Analytical Chemists (2000) for DM by drying at 135 ºC (AOAC method 930.15), CP (AOAC method 948.13), NDF treated with amylase and without the addition of sodium sulphite (AOAC method 2002.04), NDIN (using NDF residue and AOAC method 948.13) ADF (AOAC method 973.18) ADIN (using ADF residue and

method AOAC method 948.13) and ether extract (AOAC method 920.39). Calcium and phosphorus were analyzed using the dry ashing procedure (AOAC methods 927.02 and 965.17, respectively). Calcium was determined using an atomic absorption spectrophotometer (Perkin-Elmer, Model 2380, CN, USA) while phosphorus was read at 410 nm on a spectrometer (Pharmacia, LKB-Ultraspec III, Stockholm, Sweden).

Urine was analyzed for total phosphorus using the molybdenum-phosphate method (AOAC method 964.06) and ammonia-N as described for the rumen fluid samples (Broderick and Kang, 1980). Wet fecal material was thawed at 4°C for 48 h (until thawed) before being thoroughly mixed and composited per period by heifer. Water soluble ammonia-N measurements on wet fecal samples were performed by placing duplicate 1.00 g of wet feces into 15 mL centrifuge tubes and covering with 10 mL of distilled, deionized water. Samples were then capped and vortexed to create a fecal suspension and placed at 4°C overnight. Approximately, 24 h later samples were centrifuged with a Beckman Centrifuge (Model JS-4.2SM; Palo Alto, CA) at 1500 x g for 15 min at 4°C. A 100 µL aliquot of the supernatant was then used to determine NH_3-N with the phenol-hypochlorite method (Broderick and Kang, 1980). Wet feces (5 g) were vortexed in distilled deionized water (25 mL) to form a suspension to determine fecal pH using a Fisher Scientific AR50 pH Meter (Accumet Research, Hudson, MA) (Fox et al. 2007). Methods outlined by Wolf et al. (2005) and Kleinman et al. (2005) were used to determine the water-soluble phosphorus content of wet fecal samples via the molybdenum-phosphate method (AOAC method 964.06). Wet fecal samples (1:50 g mL^{-1}), shaken for 1 h at 150 rpm and centrifuged at 1500 x g were placed at 4°C overnight before being analyzed for soluble phosphorus content.

4.2.6 Statistical Analysis

Feeding behaviour, in-dwelling pH measurements, total tract nutrient digestibility and rumen fermentation parameters (pH, VFA, osmolality and ammonia-N) were analyzed as a Latin Square design using the mixed model procedure of SAS (Version 9.2; SAS Institute, Inc. Cary, N. C.) with the random effect of heifer and the fixed effects of treatment and period. The rumen fermentation data including the *in-dwelling* pH probes was analyzed using a repeated measures approach with the fixed effects of time (day) and treatment x time (day) included in the model. Denominator degrees of freedom were adjusted using the Satterwaithe adjustment. Results were analyzed using a protected F-test ($P \leq 0.05$) and trends were discussed at $P < 0.10$. Polynomial contrasts were used to determine the linear and quadratic effects of wheat or corn DDGS inclusion rate. Significant results ($P \leq 0.05$) were presented using slope (linear) or local maxima/minima (quadratic) for the best fit polynomial regression equation using Proc GLM.

4.3 Results & Discussion

The composition of the diets used in this trial are given in Table 4.1. The rations were formulated with the same corn and wheat DDGS as used in Trial 1. The samples used in this trial were obtained as sub-samples when both the corn and wheat DDGS from Trial 1 were transferred into bins for the present study. The wheat DDGS utilized in this study averaged 6.8±0.04% N, 4.7±0.06% EE, 47.8±0.77% NDF (43.8% NDFn), 19.6±0.35% ADF, 21.8±0.10% ADIN (% N), 58.9±0.11% NDIN (% N), 0.11±0.01% Ca and 0.97±0.07% P (mean±SD, DM). While the corn DDGS averaged 4.8±0.03% N, 10.7±0.13% EE, 47.4±1.06% NDF (45.8% NDFn), 12.7±0.21% ADF, 13.7±0.06% ADIN (% N), 35.4±0.01% NDIN (% N), 0.05±0.03% Ca and 0.79±0.002% P (mean±SD, % DM).

Similar to the feedlot trial, the amount of crude protein in the ration increased as both corn and wheat DDGS was included at 20 and 40% of the ration. Crude protein content increased from 13.0% in the control to 18.1 and 24.0% in the 20 and 40% wheat DDGS rations and to 16.6 and 18.9% in the 20 and 40% corn DDGS rations. The diet ADF and NDF levels also increased as both corn and wheat DDGS inclusion increased. The NDF and ADF fractions increased from 18.3 and 8.6% for the control, respectively to 30.4 and 13.4% for the 40% wheat DDGS ration and to 30.2 and 10.6% for the 40% corn DDGS rations. The amount of ADIN and NDIN in the rations increased as both corn and wheat DDGS inclusions increased with the 40% wheat DDGS ration containing the highest amount of NDIN (0.99% DM basis) and ADIN (0.62% DM basis). Similar to Trial 1 the amount of phosphorus increased in the ration as DDGS inclusion level increased.

4.3.1 Rumen pH (spot and in-dwelling)

The overall rumen pH for both in-dwelling and spot sample methods of measurement was not different (P>0.05) between treatments (Table 4.2). Similarly no differences (P>0.05) in rumen pH parameters below critical pH cut-off values of 5.8, 5.5 or 5.2 were detected including duration (min d^{-1} or min kg OMI^{-1}) and pH area (pHxmin). While there were no treatment effects on rumen pH measurements, all diets resulted in rumen fermentation conditions that approached mild (pH<5.8) to moderate (pH<5.5) acidosis (Nocek 1997; Penner et al. 2007). For example the rumen pH of cattle fed 40% corn DDGS was on average 10 hours per day while those fed 40% wheat DDGS spent 6.8 hours below the pH cut-off values of 5.8. Time below pH 5.5 ranged from 4 to 2.4 h for the 40% corn and 40% wheat DDGS treatments, respectively (Table 4.2). Similar results were found with the other treatments where time spent in moderate acidosis (pH<5.5) was 2.3, 5.7 and 3.7 hours for the control, 20% wheat and 20% corn DDGS treatments, respectively (Appendix B, Figure 1).

The lack of benefits with respect to mitigating rumen pH when feeding DDGS is surprising, as DDGS have a considerably different nutrient make up than barley, which was the basis of the control ration. It is estimated that feed barley contains 50-55% starch (Hart et al. 2008) while wheat or corn DDGS contain 6.3 and 4.4% starch, respectively (Nuez-Ortin and Yu 2009). It is estimated that 75 to 85% of corn starch and 80 to 85% of barley starch is degraded in the rumen with 95% of the starch digested in the total tract for both cereal grains (Huntington 1997; Harmon 2004). Owens et al. (1998) reported that the inclusion of rapidly degradable starch in ruminant diets is the major precursor for the onset of acidosis. Therefore, when replacing barley with DDGS a low starch feedstuff, a higher and/or a more stable rumen pH would be expected. The lack of acidosis mitigation for wheat and

Table 4.2. Rumen pH measurements of cattle fed wheat or corn DDGS at 20 and 40% inclusion levels

	Dietary Treatment						
		Wheat DDGS		Corn DDGS			
	Control	20%	40%	20%	40%	SEM[z]	*P*-value[y]
Mean Daily Rumen pH							
In-dwelling pH	6.00	5.87	5.98	5.95	5.87	0.11	0.81
Spot sample pH[x]	5.78	5.83	5.90	5.74	5.76	0.10	0.49
Rumen pH Parameter 5.8 or lower							
Mean pH	5.59	5.50	5.57	5.57	5.58	0.053	0.72
Total duration (min d^{-1})	434	576	407	517	604	155.0	0.85
Total duration (min kg OMI^{-1})	46.5	63.9	43.1	51.7	70.5	16.16	0.75
pH area (pH*min)	99.3	231.0	114.7	148.2	158.7	77.61	0.68
Rumen pH Parameter 5.5 or lower							
Mean pH	5.41	5.33	5.38	5.41	5.42	0.038	0.38
Total duration (min d^{-1})	138	342	146	224	237	127.8	0.73
Total duration (min kg OMI^{-1})	15.2	38.5	15.5	21.2	27.6	13.86	0.67
pH area (pH*min)	16.3	93.6	34.5	38.7	30.9	35.09	0.46
Rumen pH Parameter 5.2 or lower							
Total duration (min d^{-1})	5	152	46	13	40	57.7	0.28
Total duration (min kg OMI^{-1})	0.6	17.6	4.7	3.6	1.6	6.49	0.26
pH area (pH*min)	0.3	21.0	4.7	3.3	-	7.44	0.21

[z] SEM= Pooled standard error of the mean.

[y] *P*-values for Day and TreatmentxDay interaction are not shown as neither resulted in significant effects for any of the tested variables

[x] This variable was significant for time of collection (hour) (P=0.01)

corn DDGS treatments in the present study could be the result of a rapid disappearance of fraction (A) starch (starch and free glucose) in distiller byproducts. Batajoo and Shaver (1998) found the A fraction represented 26.7% of starch in barley and 77.7% of starch in corn DDGS. However, it's possible that the high estimate of rapidly degradable starch in DDGS is overestimated due to the small particle size of DDGS (Batajoo and Shaver 1998). Furthermore, although the size of fraction A starch in DDGS is high, the actual starch content is low relative to barley (4.4 vs. 51.6%, respectively) (Hart et al. 2008; Nuez-Ortin and Yu 2009). Thus, it would be unlikely that this would induce acidosis although this may lower the ability of distiller grains to mitigate acidosis.

The inability of both wheat and corn DDGS to mitigate acidosis could also be the result of poor peNDF (peNDF) (Beliveau and McKinnon 2009). Beliveau and McKinnon (2009) found a peNDF value for wheat DDGS of less than 10%. Mertens (1997) hypothesized that the peNDF content should be at least 22% of the ration in order to stimulate rumination behaviour in dairy cattle. Kleinschmit et al. (2006) also monitored the particle size of corn DDGS and found the mean particle diameter of 0.81 mm to have an estimated peNDF value of 12.4%, similar to that of Beliveau and McKinnon (2009). The lack of peNDF in DDGS could in part, explain why ruminal acidosis was not improved with DDGS inclusion.

4.3.2 Rumen fermentation (VFA, osmolality and NH_3-N)

There was a time effect (P=0.01) for all tested rumen fermentation parameters except valerate (P=0.20). The effect of time is well documented as rumen fermentation exhibits a diurnal pattern post-feeding (Appendix 2, Figures 2, 3 and 4) (Nagaraja and Titgemeyer 2007). Propionate concentration tended (P=0.10) to decrease in a quadratic and linear fashion

as wheat and corn DDGS inclusion increased, respectively. Beliveau and McKinnon (2009) found a linear decrease in propionate levels as wheat DDGS increased in the ration. A decrease in propionate production when feeding DDGS is not unexpected as high fiber feedstuffs promote acetate production (Sutton et al. 2003). Furthermore, concentrate feedstuffs such as barley promote propionate production, a gluconeogenic precursor (Sutton et al. 2003). Since DDGS are high in fiber and low in starch, the replacement of barley with DDGS in finishing diets would be expected to result in less propionate production and as a consequence result in less gluconeogenic precursors.

Butyrate increased in a quadratic fashion for wheat DDGS (y=10.8171+0.3551x-0.0078x^2, R^2=0.22, SEP=3.094) and in a linear fashion for corn DDGS (y=10.3661+0.1034x, R^2=0.28, SEP=2.694). Solving the equation for wheat DDGS gives a local maxima for butyrate concentration at a 22.9% DDGS inclusion rate. Kleinschmit et al. (2006) found that butyrate concentration increased in cattle fed 20% corn DDGS relative to a corn-soybean meal diet. Butyrate and acetate concentration increase with increasing amounts of forage in the ration (Sutton et al. 2003). Butyrate undergoes extensive metabolism in the rumen wall to ketone bodies (B-hydroxybutyrate or acetoacetate) and is used as an energy source by the rumen epithelium as only 10% of the butyrate produced in the rumen actually enters the portal drained viscera (Britton and Krehbiel 1993). Increased butyrate as observed in this study could supply the rumen epithelium with more energy, conserving propionate for gluconeogenesis. Thus even though propionate production decreased as both corn and wheat DDGS increased in the ration, a reduction in gain was not observed in Trial 1.

Table 4.3. Effects of feeding wheat or corn DDGS at 20 and 40% inclusion levels on rumen fluid characteristics of cattle.

	Dietary Treatment							*P*–value Contrasts			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[z]	*P*-value[y]	Linear	Quad	Linear	Quad
VFA (mmol 100 mol^{-1})											
Acetate	52.3	52.1	51.7	52.9	52.2	1.39	0.87				
Propionate	32.1	27.7	29.9	31.2	28.2	1.88	0.10	0.23	0.05	0.04	0.52
Butyrate	10.8	14.8	12.6	11.5	14.9	0.87	0.01	0.16	0.01	0.01	0.22
Isobutyrate	1.1	0.9	1.0	1.0	0.9	0.11	0.48				
Valerate	1.4	2.0	2.7	1.6	1.7	0.15	0.01	0.01	0.51	0.15	0.99
Isovalerate	2.1	2.5	2.1	1.8	2.0	0.20	0.23				
Total VFA *(mmol L^{-1})*	126.1	119.2	115.4	125.2	122.7	5.91	0.17				
A:P Ratio[x]	1.68	2.03	1.82	1.82	1.89	0.188	0.30				
Osmolality *(mOsm L^{-1})*	316.9	324.7	318.0	328.9	321.3	9.07	0.68				
NH_3-N *(mg dL^{-1})*	7.4	9.2	13.6	7.6	9.5	1.35	0.03	0.01	0.43	0.29	0.61

[z] SEM= Pooled standard error of the mean.

[y] *P*-value for time was significant (*P*=0.01) for all tested variables except valerate (*P*=0.20); the *P*-value for treatment x time was not significantly different for any variables

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

Valerate also increased in a linear fashion (y=1.3876+0.0320x, R^2=0.32, SEP=0.764) as wheat DDGS increased in the ration. Heldt et al. (1999) found the concentrations of valerate, isovalerate and isobutyrate to increase as total rumen degradable protein increased in the ration. This would explain why valerate concentration increased as wheat DDGS inclusion increased but not when corn DDGS was fed as wheat DDGS has a higher amount of rumen degradable protein relative to corn DDGS (Boila and Ingalls 1994a).

Although, corn and wheat DDGS increased butyrate and tended to decrease propionate, the total VFA concentration did not differ among treatments (P=0.17). Therefore, it is also unlikely that rumen pH or osmolality would be impacted by dietary treatment, since the concentration of volatile fatty acids contributes to predisposition of rumen acidosis (Owens et al. 1998).

There was no effect of treatment on rumen osmolality (Table 4.3). Decreased osmolality levels would be expected when feeding a high fiber byproduct relative to barley or corn based diets since the high structural carbohydrate levels together with the lack of starch and subsequent lack of free glucose in the rumen would result in slower rumen degradation rates and lower the rate and extent of acid production in the rumen (Owens et al. 1998). Since there was no effect of treatment on rumen pH (Table 4.2), it could be assumed that osmolality levels would not be affected by treatment.

Rumen ammonia-N concentration increased in a linear fashion (y=7.00+0.15x, R^2=0.23, SEP=4.62) as wheat DDGS level increased (Table 4.3). Beliveau and McKinnon (2009) found a similar linear increase in rumen ammonia-N levels as wheat DDGS increased up to 21% of the ration. Both wheat (24.0%) and corn (18.9%) DDGS rations had a higher protein content relative to the control ration (12.8%). Inclusion of corn DDGS did not result

in increased rumen ammonia-N levels (Table 4.3). This is likely a reflection of the higher content of rumen udegradable protein in corn DDGS. Boila and Ingalls (1994) found that 100% wheat DDGS had a lower level of rumen undegradable protein and a faster rumen degradation rate relative to blends of DDGS (70% wheat:30% corn and 75% wheat:25% corn). Corn DDGS also has a higher lipid content that could potentially increase the rumen undegradable protein content if the fat coats the feed particles. Although, limited research exists for estimating if ethanol fermentation changes the structure of these proteins, zein, the principle protein in corn grain is more resistant to ruminal degradation relative to gluten, the main protein in wheat (Messman et al. 1994). ,The high rumen undegradable protein content of both wheat and corn DDGS is due to processing conditions associated with ethanol production and subsequent drying of the distillers grains including dryer duration and temperature (Boila and Ingalls 1994; Spiehs et al. 2002).

4.3.3 Feeding Behaviour

Supplementing 20 and 40% corn DDGS relative to the barley based control ration resulted in linear decreases (P=0.01) in overall rumination time (y=265.2-1.7x, R^2=0.40, SEP=36.79) and rumination while sitting (y=251.5-1.8x, R^2=0.40, SEP=39.20) (Table 4.4). Two factors contributing to the reduction in rumination time in heifers fed DDGS diets include a lower peNDF and a quadratic decrease in voluntary dry matter intake (Table 4.4) relative to those fed the control diet. Time spent ruminating is highly correlated to the amount of saliva produced and thus the amount of rumen buffers produced including that of bicarbonate and phosphate (Owens et al. 1998; Maekawa et al. 2002a). As a result, decreased rumination time can result in inadequate rumen buffering (Maekawa et al. 2002a).

Table 4.4. Effect of graded levels of wheat or corn DDGS on the voluntary intake and eating behaviour of heifers fed a finishing ration

	Dietary Treatment							*P*–value Contrasts			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[z]	*P*-value	Linear	Quad	Linear	Quad
Dry Matter Intake (kg day^{-1})	9.7	10.0	9.6	9.9	9.1	0.35	0.02	0.82	0.09	0.05	0.04
Dry Matter Intake (% BW)	1.90	1.88	1.87	1.87	1.76	0.067	0.08	0.55	0.89	0.02	0.35
Organic Matter Intake (kg day^{-1})	9.2	9.5	8.9	9.4	8.5	0.33	0.01	0.28	0.10	0.02	0.05
Organic Matter Intake (% BW)	1.81	1.77	1.74	1.77	1.65	0.06	0.04	0.15	0.96	0.01	0.39
Time (min day^{-1})											
Eating	96	99	121	91	129	12.6	0.18				
Eating *(min kg OMI^{-1})*	10.0	10.7	13.5	10.1	15.2	1.58	0.13				
Ruminating	268	255	235	225	199	17.0	0.01	0.08	0.82	0.01	0.58
Ruminating *(min kg OMI^{-1})*	28.0	27.4	26.4	24.2	23.4	2.15	0.19				
Chewing[y]	364	354	356	316	328	25.1	0.34				
Drinking	19	35	29	26	33	5.5	0.24				
Standing	514	514	508	555	569	35.6	0.55				
Ruminating	17	27	10	9	21	5.9	0.11				
Sitting	746	771	814	754	730	42.4	0.56				
Ruminating	251	228	225	216	178	17.6	0.04	0.22	0.57	0.01	0.93
Sitting or Resting[x]	682	695	698	669	693	37.9	0.95				

[z] SEM= Pooled standard error of the mean.

[y] Chewing = Eating + Ruminating

[x] No Ruminating

This is supported by the fact that rumination per kg of OMI was not affected by treatment (P>0.05). It should be noted that in heifers fed the 40% corn DDGS diet, the visual appearance of a rumen mat during rumen fluid collections was either not present or not as obvious as other treatments. The lack of the rumen mat indicates poor peNDF and thus poor buffering potential of the feed.

Unlike rumination time, no difference was found for chewing (P=0.13) (eating + ruminating) (Table 4.4). Although, both 40% wheat (13.5 min kg^{-1}) and corn (15.2 min kg^{-1}) DDGS treatments resulted in the higher numerical time spent eating per kg OMI relative to the control treatment (10.0 min kg^{-1}).

4.3.3 Digestibility

No effect of wheat DDGS (P=0.09) was observed on the DMI of heifers during the metabolism trial (Table 4.4). However as observed in the feedlot trial with steers, DMI decreased (P=0.04) in a quadratic fashion (y=9.48+0.07x-0.002x^2, R^2=0.26, SEP=0.75) as corn DDGS level increased with a local maxima at a level of 16.75% inclusion rate (Table 4.4). Failure to see an effect of wheat DDGS on DMI may be attributed to the fact that the heifers were fed in individual stalls with no competition (Schwartzkopf-Genswein et al. 2003).

Although cattle fed wheat DDGS had similar intakes to those fed the control ration, the total tract digestibility of dry matter (y=80.91-0.12x, R^2=0.52, SEP=1.95) and organic matter (y=82.70-0.11x, R^2=0.48, SEP=1.97) decreased (P=0.01) in a linear fashion as cattle were fed increasing levels of wheat DDGS. The decrease in dry matter and organic matter digestibility between the control and 40% wheat DDGS fed heifers was 5.3 and 4.6%, respectively. The decrease is similar to the 9.8% decrease in dry matter digestibility found by

Gibb et al. (2008) when comparing cattle fed 60% wheat DDGS to those fed a barley control ration.

Contrary, to cattle fed wheat DDGS, corn DDGS had no effect on total tract dry matter digestibility (P>0.05) (Table 4.5). Research performed with corn WDGS at levels up to 60% of the ration showed no difference between corn WDGS treatments and the control corn based rations (Vander Pol et al. 2008; Spiehs and Varel 2009). The difference in the dry matter digestibility between wheat and corn DDGS treatments could be a reflection of the higher intake of ADF or ADIN or the lower intake of fat in cattle fed wheat DDGS (Table 4.1).

With respect to crude fat, the inclusion of both wheat and corn DDGS increased (P=0.01) the digestibility of crude fat in a quadratic fashion (Table 4.5). The inclusion of wheat DDGS (y=71.920+0.7263x-0.0143x^2, R^2=0.35, SEP=5.494) had a local maxima of 25.4% while the inclusion of corn DDGS (y=71.920+1.258x-0.0196x^{2,} R^2=0.85, SEP=4.002) yielded a local maxima of 32.1%. The quadratic effect of both DDGS sources on crude fat digestibility is likely the result of intestinal fatty acid digestion decreasing, regardless of the degree of saturation, as the intake of fatty acids increased (Zinn et al. 1994; Plascencia et al. 2003). Vander Pol et al. (2008) found the total tract digestibility of crude fat in cattle fed a 40% corn WDGS ration to be higher than that of cattle fed a corn diet supplemented with corn oil to obtain a similar level of crude fat (81 vs. 71%, respectively). The increase in digestibility was speculated to have been the result of an increase in unsaturated fatty acids reaching the small intestine of cattle fed the corn WDGS relative to those fed the corn oil diet due to decreased biohydrogenation of the fat in WDGS (Vander Pol et al. 2008).

Table 4.5. The effect of wheat or corn DDGS at 20 and 40% inclusion levels in finishing diets on the apparent nutrient digestibility coefficients of heifers

	Dietary Treatment							*P*-value Contrasts			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
Item (%)	Control	20%	40%	20%	40%	SEM[z]	*P*-value	Linear	Quad	Linear	Quad
Apparent nutrient digestibility coefficient (DM basis)											
Dry matter	80.42	78.55	76.15	81.55	79.49	0.864	0.01	0.01	0.79	0.46	0.16
Organic matter	82.18	80.36	78.42	83.33	81.40	0.824	0.01	0.01	0.95	0.49	0.14
Ether extract (crude fat)	71.51	80.73	78.10	88.22	90.84	2.146	0.01	0.04	0.03	0.01	0.02
Crude Protein	75.46	74.43	74.68	81.18	82.80	0.925	0.01	0.57	0.57	0.01	0.11
Neutral detergent fiber	53.39	58.97	64.50	65.79	70.54	1.650	0.01	0.01	0.99	0.01	0.09
Acid detergent fiber	43.46	51.70	55.20	61.75	56.50	3.700	0.04	0.03	0.58	0.02	0.02
Neutral detergent insoluble nitrogen	51.10	74.56	78.91	80.67	87.01	1.073	0.01	0.01	0.01	0.01	0.01
Acid detergent insoluble nitrogen	13.05	60.18	57.01	74.15	73.11	4.156	0.01	0.01	0.01	0.01	0.01
Gross energy	82.07	78.74	77.13	82.26	80.09	0.813	0.01	0.01	0.36	0.10	0.25
Digestible energy *(Mcal kg^{-1})*	3.87	3.43	3.45	3.61	3.65	0.162	0.39				
Digestible energy intake *(Mcal d^{-1})*	35.34	32.55	31.63	35.10	31.55	1.391	0.21				

[z]SEM= Pooled standard error of the mean.

Therefore, the increase in the digestion of crude fat with wheat and corn DDGS diets is likely due to increased amounts of unsaturated fatty acids in the small intestine. The protection of the fatty acids in DDGS relative to corn or barley grain may result from the ethanol fermentation and drying process thereby protecting the fat in DDGS and rendering it resistant to biohydrogenation.

Wheat and corn DDGS differentially increased the digestibility of ADF differentially. The inclusion of wheat DDGS increased (P=0.03) the digestibility of ADF in a linear fashion (y=43.454+0.317x, R^2=0.34, SEP=7.657), while the inclusion of corn DDGS caused a quadratic increase (P=0.02) in the digestibility of ADF (y=42.268+1.473x-0.028$x^{2,}$ R^2=0.57, SEP=7.48) with a local maxima at 26.3%. Similar to ADF digestibility, the digestibility of NDF increased in a linear fashion (P=0.01) as both wheat (y=52.565+0.303x, R^2=0.52, SEP=5.01) and corn (y=53.527+0.449x, R^2=0.80, SEP=3.99) DDGS increased in the diet. Preliminary research (DeHaan 1983), found the NDF digestibility of corn bran to be 87%. Ham et al. (1994) found the NDF digestibility of corn WDG, fed at 40% of a 90% concentrate ration to be higher than that of the a rolled corn (69.6 vs. 62.5%, respectively) ration. In contrast to these results, Leupp et al. (2009) fed increasing levels of corn DDGS (up to 60%, DM) in 70% concentrate diets (30% grass hay) and observed no effect on NDF digestibility and a trend for decreased ADF digestibility. Differences between studies are likely due to the amount and type of forage fed in the ration as grass hay would provide greater amounts of NDF and ADF, relative to the high concentrate diet fed in this trial. NDF intake (1.71 kg d^{-1}) and digestibility (53.4%) of the control ration in this trial was much lower than that presented by Leupp et al. (2009) (3.59 kg d^{-1} and 68%) but similar to the values for

cattle fed 86% medium-flat rolled barley in the study by Beauchemin et al. (2001) (1.78 kg d^{-1} and 53.3%).

The increase in the digestibility of both ADF and NDF with both wheat and corn DDGS in this trial is likely the result of an increase in the rumen fermentability of the DDGS fiber. Due to the ethanol fermentation process, the fiber in DDGS is potentially more soluble and fermentable than the NDF in barley or corn grain. Also, Ham et al. (1994) speculated that a substantial amount of post-ruminal fiber digestion might occur in cattle fed distillers byproducts resulting in higher than expected energy values. The increased fiber digestibility of DDGS relative to cereal grains also helps explain why the NEg of rations containing DDGS are similar to barley control based rations in Trial 1 (Table 4.2) even though the energy value of fiber is normally lower than that of starch. Also, an increase in the ruminal digestion of DDGS may result from less starch in the ration and therefore a higher rumen pH, favourable to cellulolytic bacteria growth (Ørskov 1986; Martin et al. 1999). Since rumen pH was not affected by DDGS inclusion, it is more likely that an increase in the ADF and NDF digestibility resulted from increased fermentability of ADF and NDF via the ethanol process.

The digestibility of crude protein also increased in a differential response to inclusion of wheat and corn DDGS. While the inclusion of wheat DDGS did not affect apparent crude protein digestibility (P>0.05), the inclusion of corn DDGS resulted in a linear increase (P=0.01) (y=76.616+0.170x, R^2=0.75, SEP=1.77) in crude protein digestibility (Table 4.5). These results will be discussed in the nitrogen excretion section.

The digestibility of NDIN increased (P=0.01) in quadratic fashions as wheat (y=51.063+1.653x-0.024x^2, R^2=0.960, SEP=2.692) and corn (y=51.063+2.066x-0.029x^2, R^2=0.989, SEP=1.826) DDGS inclusion increased (Table 4.5). This resulted in local

maximas for NDIN digestibility at 34.44 and 35.62% for wheat and corn DDGS, respectively. The NDIN content of feed equates to intermediate and slowly digestible protein fractions (B2 and B3). Both corn and wheat DDGS have high NDIN levels as the result of the ethanol fermentation and drying process. As the content of NDIN (Table 4.1) increased from 0.21% in the control ration DM to 1.71% and 0.79% for the 40% wheat and 40% corn DDGS rations, respectively, the digestibility of NDIN (Table 4.5) also increased from 51.1% to 78.9% and 87.0% for the control, 40% wheat and 40% corn DDGS diets, respectively. Therefore, NDIN serves as a highly digestible source of nitrogen in DDGS based rations.

The digestibility of ADIN also increased (P=0.01) in a quadratic fashion as both wheat (y=12.818+3.631x-0.063x^2, R^2=0.895, SEP=8.018) and corn (y=12.818+4.621x-0.078x^2, R^2=0.954, SEP=6.981) DDGS inclusions increased (Table 4.5). The solved local maximas for ADIN digestibility was 28.8 and 29.6% for wheat and corn DDGS levels, respectively. The increasing quadratic relationship for ADIN digestibility due to the inclusion of wheat and corn DDGS is somewhat surprising as ADIN, traditionally is a measure of protein heat damage (Licitra et al. 1996) and is deemed to be largely unavailable. The fact that digestibility of ADIN increased with increasing levels of corn or wheat DDGS suggests that these by-products had minimal heat damage of that ADIN levels do not reflect the amount of unavailable protein in DDGS. Previous research by Klopfenstein et al. (1996) and Ham et al. (1994) found no difference in the daily gain or protein efficiency of steers fed corn DDGS with different levels of ADIN (7.3 to 28.8%). Similar to these results, there was no effect of feeding the wheat DDGS with the high ADIN content (21.8% N) on ADG in Trial 1. It should be noted however that although the majority of the ADIN was digested (Table 4.5), the amino acid balance of the ADIN content is not known and therefore ADIN may not be

metabolized efficiently (Van Soest and Mason 1991). The increase in the digestibility of ADIN and NDIN is most likely an increase in solubility due to the ethanol fermentation process.

Gross energy digestibility decreased (P=0.01) in a linear fashion for wheat DDGS (y=82.1548-0.1346x, R^2=0.57, SEP=1.102) but was not affected (P>0.05) by corn DDGS inclusion (Table 4.5). The decrease in gross energy digestibility was likely the result of increased intake of ash and fiber and lower intake of starch and crude fat relative to the control treatment (Table 4.1). Although, gross energy digestibility decreased as wheat DDGS increased, the digestible energy content of the feed was not affected by treatment (P>0.05). Furthermore, the digestible energy intake (Mcal d^{-1}) of heifers was not affected by treatment (P>0.05), supporting the conclusion in Trial 1 of steers eating to energy satiety.

The similar digestible energy content of the diets (Table 4.5) is interesting as the control ration differs greatly in nutrient composition relative to DDGS treatments. The starch in the control ration would supply the majority of the energy to the cattle whereas in the corn and wheat DDGS treatments, the lack of energy from starch is replaced with energy from increased fat, fiber and protein (Table 4.1) and increased fat and fiber digestibility (Table 4.5). Larson et al. (1993) fed WDGS to yearlings and found a calculated diet NEg of 1.48 Mcal kg^{-1} when fed at 40% of the ration relative to 1.21 Mcal kg^{-1} for the control fed cattle. Although, NDF digestion was not measured, the authors contributed 9% of the increased energy content of WDB to fat and speculated that residual ethanol and a reduction in subacute ruminal acidosis would account for additional energy gains relative to the control corn-based ration. Lodge et al. (1997) designed and fed a composite distillers grain similar in nutrient composition to WDGS and found a 10% improvement in gain:feed relative to the

control corn ration (0.149 vs. 0.136, respectively) and a calculated NEg of 120% for the composite byproduct relative to the corn it replaced. When either the additional fat or protein from the composite was removed from the ration, similar decreases in gain:feed (2%) and energy (6%) were observed for both fat and protein removal relative to the composite byproduct fed cattle. Klopfenstein et al. (2008) concluded that an increase in energy from the protein in DDGS is likely the result of a higher rumen undegradable protein intake and thus a protein content that avoids rumen fermentation losses. The findings from this trial of increased fiber digestibility with DDGS supports the hypothesis that DDGS, when fed in feedlot finishing rations are a high energy concentrate feedstuff.

4.3.4 Nitrogen and Protein Excretion

Fecal (y=45.471+1.115x, R^2=0.75, SEP=11.72) and urinary (y=99.317+1.995x, R^2=0.78, SEP=18.86) nitrogen excretion linearly increased (P=0.01) as wheat DDGS increased in the ration (Table 4.6). The inclusion of corn DDGS also increased (P=0.01) the excretion of urinary nitrogen in a linear fashion (y=119.20+2.996x, R^2=0.19, SEP=25.98). As a result, total nitrogen excretion increased in a linear fashion as both wheat (y=144.788+3.110x, R^2=0.84, SEP=24.13) and corn (y=171.272+2.308x, R^2=0.11, SEP=27.42) DDGS increased in the ration. Although, urine is the major route of excretion for nitrogen the linear increase in fecal nitrogen excretion for wheat DDGS supplementation signifies poor protein availability in the rumen and/or total tract of the animal. Even though ADIN digestibility increased in a linear fashion for wheat DDGS inclusion the increased intake of ADIN resulted in an additional 24 g of ADIN excreted per day for the 40% wheat DDGS fed cattle relative to 3 and 7 g of ADIN for cattle fed the control and 40% corn DDGS fed cattle, respectively.

Table 4.6. The effect of wheat or corn DDGS at 20 and 40% inclusion levels in finishing rations on the nitrogen (N) and phosphorus (P) balance and fecal pH in heifers.

	Dietary Treatment							*P*-value Contrasts			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[z]	*P*-value	Linear	Quad	Linear	Quad
Fecal output, *(kg d^{-1})*	1.83	2.05	2.19	1.77	1.78	0.109	0.01	0.01	0.70	0.63	0.75
Urine output, *(kg d^{-1})*	7.71	9.38	12.66	8.28	10.57	1.491	0.03	0.01	0.49	0.06	0.50
Nitrogen (g d^{-1})											
Total N intake	193.31	275.37	352.77	256.90	261.62	12.391	0.01	0.01	0.80	0.01	0.02
Total N excreted	142.17	215.54	266.21	178.24	207.05	10.229	0.01	0.01	0.28	0.01	0.72
Feces	46.20	72.40	89.29	46.40	45.15	3.771	0.01	0.01	0.39	0.52	0.95
Water soluble ammonia-N	2.36	2.65	3.26	2.46	2.54	0.225	0.06	0.01	0.55	0.54	0.97
Urine	95.12	142.33	176.91	131.22	161.90	6.765	0.01	0.01	0.43	0.01	0.71
Urine ammonia-N	0.97	1.14	1.61	1.61	1.98	0.269	0.07	0.08	0.60	0.01	0.66
Apparent total N retained	47.99	61.73	86.57	83.33	54.57	12.074	0.06	0.02	0.67	0.65	0.03
Phosphorus (g d^{-1})											
Total P intake	36.76	46.62	59.51	45.01	49.84	1.960	0.01	0.01	0.24	0.01	0.22
Total P excreted	26.45	37.06	42.84	31.67	35.03	1.678	0.01	0.01	0.14	0.01	0.56
Feces	25.58	32.47	33.71	27.38	26.75	2.458	0.01	0.01	0.05	0.43	0.36
Water soluble P	1.30	1.59	1.24	1.59	1.48	0.151	0.11				
Urine	1.22	4.51	9.13	3.68	8.28	1.749	0.01	0.01	0.38	0.01	0.17
Apparent total P retained	9.57	9.85	16.66	14.16	14.81	1.863	0.06	0.01	0.17	0.06	0.39
Fecal pH	7.02	7.17	7.28	7.34	7.34	0.098	0.14				

[z]SEM= Pooled standard error of the mean.

Therefore the additional fecal nitrogen excretion is partly due to the higher ADIN intake of the 20 and 40% wheat DDGS (31 and 57 g d^{-1}, respectively) relative to the control (5 g d^{-1}) fed cattle, respectively.

Furthermore, the excretion of nitrogen is an environmental problem for feedlot operators if the nitrogen is volatile and thus lost to the atmosphere. Both wheat and corn DDGS tended to linearly increase (P=0.07) the amount of urinary ammonia. It is anticipated that the ammonia content of urine would immediately be volatized in a feedlot pen situation while urea would have the potential to be hydrolyzed into ammonia bacterial urease and be volatized (James et al. 1999). The inclusion of wheat DDGS tended (P=0.06) to linearly increase the amount of water-soluble ammonia in the feces. This finding could point to the potential for an increase in nitrogen run-off from manure or the susceptibility to volatize and create additional ammonia in the atmosphere.

The retention of nitrogen tended to increase (P=0.06) as a result of DDGS. Values for the control ration where 47.99 g d^{-1} and rose to 83.3 and 86.6 g d^{-1} for the 20% corn DDGS and 40% wheat DDGS fed cattle, respectively (Table 4.6). Spiehs and Varel (2009) also observed a numerical increase in nitrogen retention (59.4 to 72.6 g d^{-1}) in cattle fed increasing levels of corn WDGS (up to 60%). These values as well as those of the present study are relatively high. Spanghero and Kowalski (1997) estimated that 20 g of nitrogen per day were needed to put on 1 kg of body mass. Cattle fed 40% wheat DDGS and 20% corn DDGS diets should therefore be gaining upwards of 4 kg per day, which is not realistic. Sampling errors may have ensued, although the acidification of urine (pH<2) was checked every period. Furthermore, the ammonia content of urine was very minimal, signifying that there was adequate acidification (Table 4.6). Fecal nitrogen determination was performed on

fecal samples that were dried at 55 °C (96 h) as well as with wet samples with an average nitrogen difference of 0.6%. Other sources of elevated nitrogen losses could be in the form of gaseous N_2 losses or nitrate and nitrite formation by rumen microbes (Spanghero and Kowalski 1997).

Phosphorus excretion increased (P=0.01) in a linear fashion as wheat (y=26.991+0.412x, R^2=0.77, SEP=4.10) and corn (y=26.991+0.412x, R^2=0.77, SEP=4.10) DDGS inclusion increased. Fecal phosphorus excretion increased (P=0.01) in a quadratic fashion as wheat DDGS increased in the ration (y=23.604+0.645x-0.0098x^2, R^2=0.41, SEP=6.06). While, urinary phosphorus excretion increased (P=0.01) in a linear fashion as both wheat (y=2.033+0.166x, R^2=0.42, SEP=3.52) and corn (y=2.033+0.166x, R^2=0.42, SEP=3.52) DDGS increased in the ration. The increase in phosphorus excretion would result in an increase in the phosphorus content of the manure. Potential agronomic problems in trying to manage the correct nitrogen:phosphorus ratio applied to the land could ensue. Furthermore, an increase in water soluble phosphorus can lead to leaching from stockpiled or applied manure, although no impact of wheat or corn DDGS was found on the water soluble phosphorus content of manure (Table 4.6).

Although phosphorus excretion increased as both wheat and corn DDGS were fed, there was also a trend (P=0.06) for wheat and corn DDGS to increase the amount of phosphorus retained. Widyaratne and Zijstra (2007) observed that pigs fed DDGS (wheat and corn) retained more phosphorus than pigs fed a control wheat ration. Calcium digestion also increased linearly (P=0.02) from 15.82% for the control to 23.95% for the 40% wheat DDGS treatment and to 30.86% for the corn DDGS treatments (data not shown). The increase in calcium absorption is likely the result of an increase in diet calcium content and phosphorus

retention and the metabolism of the body in maintaining proper calcium:phosphorus ratios. The increase in phosphorus retention was likely the result of phosphorus being more soluble in DDGS and hence digestible (Widyaratne and Zijstra 2007) even though the control ration was formulated to meet their phosphorus requirements (NRC 2000).

There was also no effect of corn or wheat DDGS on fecal pH although numerically, the fecal pH of cattle fed the control ration was the lowest. The lack of an effect signifies that hind gut fermentation was not changed with the supplementation of a high fiber byproduct for the high starch barley grain.

4.4 Conclusion

The results of this study indicate that the inclusions of corn and wheat DDGS (up to 40%) in feedlot rations does not mitigate ruminal acidosis, however the inclusion of both byproducts strongly impacts nutrient digestibility. The inclusion of both wheat and corn DDGS resulted in quadratic and linear increases in butyrate concentration, respectively while feeding wheat DDGS also linearly increased rumen ammonia-N levels. The inclusion of corn DDGS decreased total rumination time and dry matter intake. With respect to the overall digestibility of the diet, the 40% wheat DDGS diet linearly decreased DM digestibility. Corn and wheat DDGS inclusion resulted in increased crude fat digestibility while the inclusion of corn DDGS also increased the digestibility of crude protein. The inclusion of both corn and wheat DDGS resulted in increased digestibility of ADF, NDF, ADIN and NDIN. Although, digestibility of gross energy decreased as wheat DDGS inclusion increased, digestible energy intake did not differ between treatments. In regards to nitrogen and phosphorus balance, wheat and corn DDGS treatments increased nitrogen and phosphorus excretion and tended to

increase the retention of both nitrogen and phosphorus. The results from this trial indicate that both barley and corn DDGS can be supplemented for barley at levels up to 40% with no negative impact on ruminal acidosis or digestible energy intake, although, cattle fed corn and wheat DDGS will have increased nitrogen and phosphorus excretion.

5.0 GENERAL DISCUSSION

The research conducted in this thesis involved a feedlot and a metabolic trial in order to elucidate the impact of corn and wheat based DDGS on feedlot performance, carcass quality, rumen fermentation and nutrient digestibility parameters. Trial 1 was designed to evaluate the performance and carcass quality of steers fed wheat DDGS relative to that of cattle fed corn DDGS in feedlot finishing rations. The inclusion of wheat and corn DDGS (up to 40% of the ration) had a substantial impact on the DMI of cattle. Cattle supplemented with wheat DDGS had a quadratic increase in DMI while the exact opposite occurred for cattle fed corn DDGS as DMI decreased in a quadratic fashion. Even though the intakes of cattle fed either wheat or corn DDGS differed greatly (2.1 kg between the 40% wheat and 40% corn DDGS fed cattle), ADG was not affected by treatment. As a result, cattle fed corn DDGS had improved gain:feed relative to control fed cattle. Calculated diet NEg, also increased as corn DDGS increased in the ration in a quadratic fashion whereas the inclusion of wheat DDGS had no impact on either gain:feed nor diet NEg. Although wheat DDGS did not effect ADG, the inclusion of wheat DDGS at 40% of the ration resulted in the highest numerical ADG (1.73 vs. 1.62 kg d^{-1}) and subsequently a linear decrease for days on feed. Therefore, based on the data obtained data in Trial 1, corn DDGS is a superior feedstuff to wheat DDGS in barley based rations due to its improved gain:feed and subsequent higher NEg value. However, the inclusion of wheat DDGS also resulted in performance and economic benefits with reduced days on feed in cattle fed increasing levels of wheat DDGS relative to the control fed cattle.

These novel findings likely relate to the energy content of the two sources of DDGS used in this trial. Corn DDGS has been shown to have energy levels superior or equal to corn

grain (Buckner et al. 2008) while limited research on wheat DDGS has shown it to be comparable in energy to barley grain (Gibb et al. 2008). Since, corn grain has a higher energy content relative to barley (1.55 vs. 1.40 Mcal kg^{-1} NEg) it is not surprising that corn DDGS has a higher energy content than barley grain and wheat DDGS. A large source of the differences in the DMI, gain:feed and diet NEg is likely due to the variation in fat intake between treatments. When calculated, cattle fed 40% wheat DDGS had a 29% higher intake of fat than the control (.27 vs .21 kg day^{-1}) while the 20 and 40% corn DDGS fed cattle had 86 and 162% higher fat intake (0.39 and 0.55 kg day^{-1}), respectively. Zinn (1989) found the energy value of supplemented fat to be 3 times the energy value of corn grain. Since barley has an even lower energy content than corn grain, the additional fat in the 40% wheat and 20 and 40% corn DDGS rations would supply a considerable amount of energy for cattle fed these treatments. With respect to Trial 2, similar or additional energy with DDGS inclusion would not only be associated with the higher fat intake but also with the increase in the digestibility of the crude fat in the ration. Also, the increase in the digestibility of both NDF and ADF with corn and wheat DDGS inclusions supports the performance results observed in Trial 1. If the digestibility of the fat and fiber of rations containing DDGS was similar or decreased relative to the control, the performance of cattle fed the DDGS would be decreased as the amount of DDGS increased in the rations. Therefore the increase in the digestibility of crude fat and fiber associated with feeding DDGS supports the conclusion of similar or improved feedlot finishing performance observed in Trial 1. Further research should focus on the repeatability of these findings in barley based finishing diets as well as a side-by-side comparison of these feedstuffs in barley based backgrounding diets when lean muscle growth is the focus rather than fat accretion.

The second objective was to determine the carcass characteristics of cattle fed either wheat or corn DDGS in barley based finishing rations. No effect of either corn or wheat DDGS was found on marbling scores, hot carcass weight, estimated lean yield or grade fat. However, dressing percentage increased as both wheat and corn DDGS inclusion increased. As Eun et al. (2009) pointed out the increase in dressing percentage when feeding DDGS (corn) is attributed to an increase in subcutaneous fat and poorer yield grades. While estimated lean yield and grade fat were not impacted ($P>0.05$) by treatment, grade fat increased (1.2 mm from the control to the 40% wheat and corn DDGS treatments) and estimated lean yield decreased (1.4 and 1.2% from the control to the 40% wheat and 40% corn DDGS treatments, respectively) numerically as both corn and wheat DDGS increased in the ration. The increase in dressing percentage also would be expected to correlate to an increase in retail cuts, trim or fat, but sub-primal boneless boxed beef yield was not impacted by feeding wheat or corn DDGS (Table 3.4). Results in Appendix A.2 and A.3 illustrate the lack of an impact on both front and hind retail cuts. A lack of an impact on sub-primal boneless boxed beef yield could be attributed to the fact that cattle in this study were killed at a pre-determined end weight (645 kg, unshrunk) and since ADG was similar amongst all treatments it could be assumed that both lean tissue and fat would be accrued at the same rate across all treatments. Although, the additional fat in the corn DDGS rations and in the 40% wheat DDGS rations would increase the triglyceride absorption in cattle, possibly resulting in greater adipose tissue accretion. Although no effect of DDGS supplementation was found with respect to marbling scores, the trend for decreased propionate production would have the potential to negatively impact marbling scores (Corah and McCully 2006). Further break-down of the marbling score data by grouping those with scores of 8 (small-AA) and 9 (trace-

A) together show that 69.1% of control animals, 79.7% of 40% wheat DDGS and 87.1% of 40% corn DDGS fed steers would have would have graded AA or lower. Even though it is hard to speculate if results are repeatable or substantial, decreases in marbling scores when feeding high levels of corn DDGS has been observed in the USA and a reduction in marbling represents issues for producers, packers and retailers. A decrease in propionate and a reduction in days on feed, together are likely to blame for any observed decreases in carcass quality grades. Further research looking at the impact of DDGS on retail yields using a greater number of animals should be conducted, in order to confirm the findings of this study.

All rumen fermentation parameters displayed a diurnal variation pattern correlating to twice daily feeding (Appendix B Figures 1,2,3 and 4). Feeding wheat or corn DDGS did not mitigate acidosis as measured by rumen pH, similar to the findings by Ham et al. (1994) and Beliveau and McKinnon (2009). The concentration of volatile fatty acids in the rumen were not affected by either corn or wheat DDGS inclusion, application to Trial 1 performance results would support the fact that ADG was not impacted by DDGS inclusions. Although, supplementing DDGS impacted other rumen fermentation parameters including butyrate concentration ($P=0.01$) and ammonia ($P=0.03$). The increase in butyrate concentration for both corn and wheat DDGS feeding is beneficial as the rumen wall primarily metabolizes butyrate for energy (Britton and Krehbiel 1993). Feeding DDGS to non-ruminants could also result in increased butyrate concentration and should be a focus of future research. Increased butyrate concentration in monogastrics could improve gut health by providing energy to the small intestine. The linear increase in rumen ammonia-N levels observed when feeding wheat DDGS agrees with the results of Beliveau and McKinnon (2009). The lack of an effect

of corn DDGS on rumen ammonia-N levels signifies that wheat DDGS has higher rumen degradable protein. Feeding the 40% wheat DDGS treatment resulted in an ammonia-N level of 13.6 mg dL^{-1}, outside the range of 3.3 to 8.5 mg dL^{-1} for optimal microbial fermentation (Kang-Meznarich and Broderick 1980) and 84 and 30% higher than the control and 40% corn DDGS fed cattle. Therefore, a large amount of this ammonia-N in cattle fed 40% wheat DDGS may have escaped microbial protein assimilation, potentially increasing the cost of urea recycling and excretion relative to the other treatments.

Wheat and corn DDGS inclusion increased fat digestibility and as discussed this is likely due to an increase in unsaturated fatty acids reaching the small intestine (Vander Pol et al. 2008). Unfortunately, duodenally cannulated animals or omasal sampling was not available to test his hypothesis but meat quality analysis was performed on 100 steers from Trial 1 (Aldai et al. 2009). Subcutaneous backfat from steers fed high wheat or corn DDGS had increased polyunsaturated fatty acids relative the control fed cattle (4.4 vs. 2.2%). The speculated increase in the unsaturated fatty acids reaching the small intestine could be partly explained by an over-abundance of fatty acids in the rumen and their subsequent escape from rumen biohydrogenation. This might explain the increased digestibility of the 40% corn DDGS treatment (5.1% crude fat, DM) but does not explain the increase in the digestibility of fat with the 40% wheat DDGS treatment (2.7% crude fat, DM) which was much lower in fat content. Therefore there may be an innate characteristic of DDGS (corn and wheat) that renders the fatty acids resistant to biohydrogenation in the rumen. Drying DDGS may cause the fat to be protected by protein (NDIN or ADIN) or alter its chemical structure. Regardless, the increase in fat content and the increased digestibility of that fat when feeding DDGS creates a high dietary energy value. This is especially the case for the 40% corn DDGS ration

which greatly explains the increased gain:feed and diet NEg in cattle fed increasing inclusions of corn DDGS in Trial 1.

The digestibility of the fiber in DDGS has been shown to be quite high in this study. Since, NDF and ADF form a major portion of both corn (60.1%) and wheat (67.4%) DDGS, it is highly beneficial from a ruminant nutritionist's point of view that the digestibility of fiber is increased in wheat and corn DDGS relative to barley. The increase in the digestibility of both NDF and ADF when feeding corn and wheat DDGS contributes to DDGS having a higher than expected energy value. Although, feeding DDGS increased fiber digestibility, no beneficial impact on acidosis mitigation was found. The small particle size of both corn and wheat DDGS results in a poor physically effective NDF content (Beliveau and McKinnon 2009). The failure of DDGS to stimulate rumination may also be enhanced by a high passage rate of the small particle sized DDGS. A high rumen turnover rate would also help explain why the fatty acids remain unsaturated at the small intestine and why post-ruminal digestion increases as DDGS inclusion increases (Leupp et al. 2009). The next focus of research should look at the passage rate of cattle fed finishing diets containing DDGS.

The digestibility of both NDIN and ADIN increased as the inclusion of corn and wheat DDGS increased in the ration. The increase in digestibility, particularly of ADIN is interesting as ADIN is largely unavailable in forages and traditionally used as an indicator of heat damage for distillers grains (Licitra et al. 1996). The increase in digestibility of both ADIN and NDIN is important as they compose a major amount of the nitrogen in DDGS. Also, the ADIN and NDIN content increases in concentration in rumen bypass protein, and its digestibility is particularly important in dairy cattle. Further research should quantify the amino acid balance of the DDGS with respect to differences between corn and wheat DDGS

as well as the effect of heating on amino acid, particularly lysine availability in DDGS. It would also be of interest to quantify the amino acid balance of bypass protein entering the small intestine from corn and wheat DDGS to observe the amino acid quality.

The final objective of this thesis was to quantify the nitrogen and phosphorus excretion associated with feeding DDGS. Both corn and wheat DDGS linearly increased (P=0.01) the excretion of nitrogen and phosphorus. The increase in fecal nitrogen excretion associated with feeding wheat DDGS is partly due to the additional ADIN content in wheat DDGS (21.8% N) relative to corn DDGS (13.7% N). Although increased excretion of both nitrogen and phosphorus is expected, this does signify potential agronomic problems with nitrogen volatilization via ammonia losses and phosphorus leaching and indicates the need for proper nitrogen:phosphorus ratios when manure from cattle fed DDGS is applied to the soil. Further research needs to be conducted on the impact of nitrogen and phosphorus excretion losses associated with feeding DDGS. Also, results from this trial with respect to the nitrogen and phosphorus balance of cattle fed wheat and corn DDGS has shown trends for increased nitrogen and phosphorus retention. These trends have also been shown by Widyaratne and Ziljistra (2007) and Spiehs and Varel (2009). An increase in nitrogen retention is interesting, as sub-primal retail yield was not impacted by wheat and corn DDGS feeding (Appendixes A.2 A.3). With respect to the kidney, linear increases in weight were observed for both wheat and corn DDGS fed cattle (Appendix A.1). Hepatic cell hypertrophy results from extensive urea metabolism and excretion that occurs in the kidneys and liver (Fau et al. 1987; Fine and Norman 1989). Even though the kidneys grew in mass, the additional weight gain would not explain the 2-fold daily increase in nitrogen retention observed when feeding high levels of wheat and corn DDGS.

Even with potential nutrient excretion issues when feeding DDGS, both corn and wheat DDGS represent two readily available, nutrient and energy dense feedstuffs for livestock producers. The supply of corn DDGS is so extensive that the supply and demand of corn DDGS sets the price point, in contrast wheat DDGS is priced relative to barley. Since corn DDGS has proven to elicit superior gain:feed, DMI, diet NEg and similar nutrient digestibility relative to wheat DDGS, the demand for corn DDGS from feedlot operators is expected to be larger than their demand for wheat DDGS. Thus ethanol plants producing wheat DDGS are going to have to take into account the demand for their product relative to corn DDGS in order to set the price. A brief economic analysis is listed in Appendix C.1 based upon the performance of cattle in Trial 1. Feed cost of gain is similar amongst all treatments other than the cattle fed 40% corn DDGS which resulted in $0.11 per lb gain less, largely from the improved gain:feed. When total feed cost were calculated, taking into account the number of days on feed, all treatments resulted in numerically improved feed costs with the 40% wheat and 40% corn DDGS cattle finishing $33.65 and $68.82 cheaper than the control fed cattle. Therefore, both corn and wheat DDGS can be supplemented into barley-based finishing rations with no negative impacts on performance, carcass quality or economic impact due to its increased fat and fiber content and digestibility.

Further areas of research:

1. The impact of corn DDGS supplementation in barley-based backgrounding diets;
2. Commercial scale >100 head per pen carcass retail yield determination of wheat and corn DDGS finishing diets;

3. Omasal sampling in cattle fed DDGS in finishing diets to determine rumen passage rate as well as nutrient digestion ruminally and post-ruminally;
4. The agronomic and environmental impact associated with additional nitrogen and phosphorus excretion associated when feeding DDGS.

6.0 GENERAL CONCLUSION

Feeding wheat or corn DDGS in barley-based finishing rations at levels up to 40% (DM) resulted in no negative impacts to feedlot performance or carcass quality. Feeding wheat DDGS resulted in increased DMI but reduced days on feed while the inclusion of corn DDGS decreased DMI and increased gain:feed and diet NEg. Similar or improved performance with DDGS feeding was possible due to the nutrient digestibility characteristics of corn and wheat DDGS. The lack of starch originally was thought to reduce the energy content of distillers grains, but both wheat and corn DDGS were found to increase the digestibility of crude fat, ADF, NDF, ADIN and NDIN thereby providing energy to the animal with highly digestible fat, fiber and protein. However, further research is necessary to determine the impact of corn DDGS supplementation in barley-based backgrounding diets and the repeatability of both 20 and 40% wheat and corn DDGS inclusions on cattle performance and carcass quality.

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Appendix A:

Table A.1 Effects of feeding wheat DDGS or corn DDGS at two inclusion levels on the visceral composition of finishing steers.

	Dietary Treatment						*P*-value contrast			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[z]	*P*-value	Linear	Quad	Linear	Quad
Number of steers	20	20	20	20	20						
Ship weight *(kg)*	651	645	652	653	650	2.17	0.13				
Visceral weights, % of ship weight											
Head	2.74	2.69	2.76	2.69	2.73	0.026	0.26				
Front Feet	0.84	0.85	0.89	0.83	0.85	0.019	0.23				
Hind Feet	0.92	0.94	0.96	0.92	0.94	0.014	0.30				
Hide	7.99	8.23	8.02	8.07	8.02	0.153	0.71				
Tail	0.20	0.20	0.20	0.21	0.21	0.007	0.73				
Hanging Tender	0.19	0.20	0.20	0.20	0.20	0.006	0.74				
Kidney	0.18	0.19	0.20	0.18	0.21	0.004	0.01	0.01	0.87	0.01	0.14
Kidney fat	0.71	0.85	0.92	0.86	0.91	0.048	0.04	0.01	0.55	0.01	0.47
Liver	1.34	1.35	1.37	1.33	1.32	0.035	0.84				
Heart	0.45	0.45	0.45	0.43	0.44	0.013	0.86				
Spleen	0.19	0.22	0.21	0.19	0.20	0.009	0.35				
Lungs and Trachea	1.28	1.31	1.31	1.20	1.43	0.055	0.10				
Reproductive Organs	0.11	0.13	0.12	0.12	0.12	0.011	0.84				
Reproductive Fat	0.51	0.52	0.55	0.50	0.54	0.037	0.88				
Intestine, full	4.39	4.48	4.37	4.28	4.62	0.102	0.21				
Rumen, full	11.67	10.47	10.07	11.28	10.74	0.346	0.03	0.01	0.17	0.07	0.86

[z] SEM = pooled standard error of the mean

Table A.2 Effects of feeding wheat DDGS or corn DDGS at two inclusion levels on the yield of retail boneless boxed beef cuts from the front end of the carcass

	Dietary Treatment						
		Wheat DDGS		Corn DDGS			
	Control	20%	40%	20%	40%	SEM[z]	*P*-value
Number of steers	20	20	20	20	20		
Left cold carcass weight *(kg)*	184.4	182.5	186.5	186.4	187.1	1.27	0.10
Front cold carcass weight *(kg)*	101.6	100.5	102.9	102.4	103.1	0.72	0.11
Front cuts, % of left cold carcass weight							
Blade eye	5.48	5.42	5.30	5.30	5.16	0.079	0.08
Short cut clod	3.67	3.62	3.61	3.60	3.67	0.080	0.94
Chuck tender	0.87	0.85	0.85	0.86	0.84	0.017	0.91
Flat iron	1.42	1.43	1.44	1.41	1.43	0.025	0.94
Pectoral muscles	0.79	0.81	0.76	0.77	0.81	0.028	0.60
Boneless chuck	1.43	1.36	1.43	1.37	1.41	0.044	0.69
Neck meat	2.08	1.96	1.98	2.09	1.98	0.055	0.28
Shoulder	2.19	2.21	2.09	2.21	2.08	0.059	0.34
Brisket point	2.20	2.19	2.24	2.30	2.18	0.066	0.67
Boneless navel	3.28	3.32	3.19	3.29	3.25	0.057	0.58
Inside skirt	0.74	0.77	0.70	0.75	0.76	0.016	0.06
Outside skirt	0.39	0.39	0.39	0.37	0.37	0.012	0.70
Foreshank	1.71	1.70	1.74	1.61	1.71	0.048	0.34
2 X 2 steak style ribs	4.32	4.35	4.20	4.31	4.27	0.054	0.37
Blade meat	1.40	1.32	1.27	1.36	1.38	0.053	0.49
Short ribs	1.11	1.11	1.14	1.15	1.17	0.030	0.66

[z] SEM = pooled standard error of the mean

Table A.3 Effects of feeding wheat DDGS or corn DDGS at two inclusion levels on the yield of retail boneless boxed beef cuts from the hind end of the carcass

	Dietary Treatment						
		Wheat DDGS		Corn DDGS			
	Control	20%	40%	20%	40%	SEM[z]	*P*-value
Number of steers	20	20	20	20	20		
Left cold carcass weight (kg)	184.4	182.5	186.5	186.4	187.1	1.27	0.10
Hind cold carcass weight (kg)	82.8	82.0	83.6	84.0	84.0	0.82	0.37
Hind cuts, % of left cold carcass weight							
Inside round	5.94	5.79	5.61	5.74	5.83	0.096	0.23
Gooseneck round	6.83	6.66	6.71	6.79	6.88	0.108	0.79
Sirloin tip	3.24	3.18	3.12	3.13	3.15	0.047	0.44
Shank meat	1.35	1.33	1.35	1.33	1.38	0.027	0.75
1 X 0 striploin	3.08	3.17	3.09	3.09	3.11	0.047	0.70
Top butt	3.78	3.76	3.74	3.83	3.81	0.065	0.87
Tri tip	0.50	0.45	0.47	0.50	0.46	0.016	0.15
Ball tip	0.17	0.17	0.19	0.19	0.18	0.059	0.67
Full tenderloin	1.66	1.67	1.57	1.67	1.56	0.030	0.04
Flank steak	0.58	0.59	0.55	0.56	0.58	0.014	0.22
Inside skirt	0.94	0.91	0.86	0.91	0.91	0.040	0.72

[z] PSEM = pooled standard error of the mean

Appendix B:

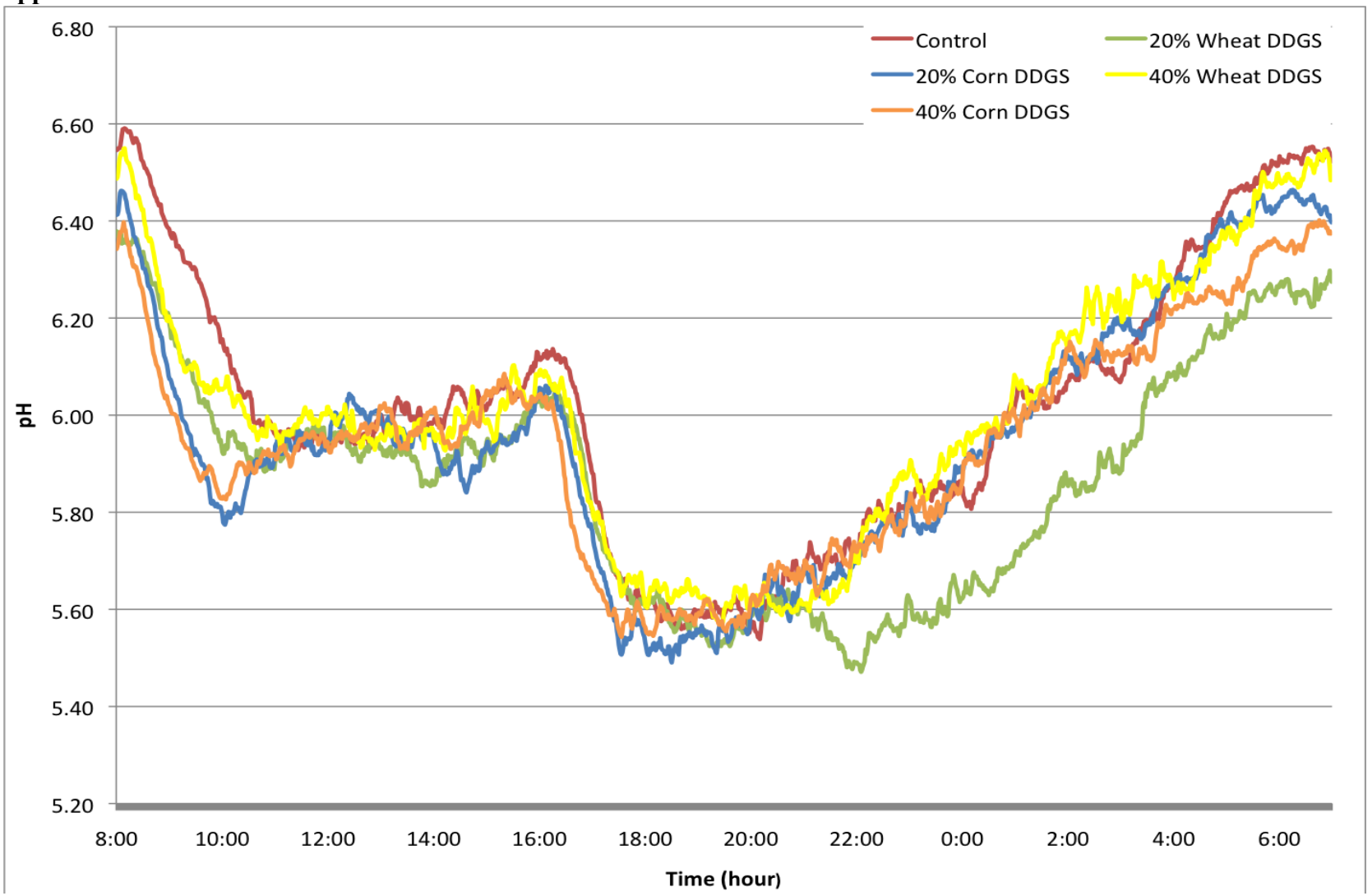

Figure B.1. Effect of feeding wheat or corn dried distillers grains with solubles (DDGS) at 20 and 40% inclusion levels on the rumen pH of heifers using in-dwelling pH probes, averaged over a 23 h feeding period

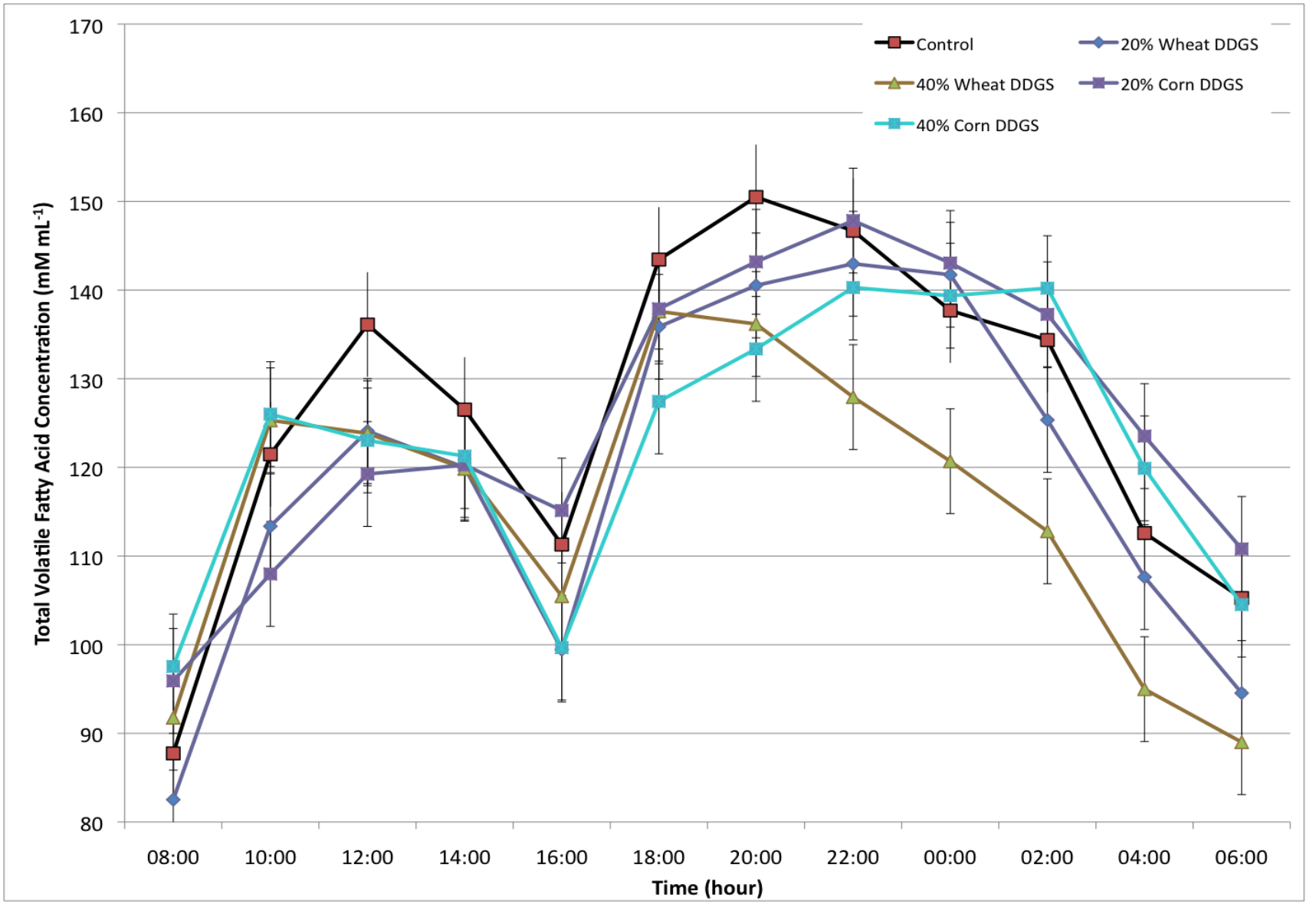

Figure B.2. Effect of feeding wheat or corn dried distillers grains with solubles (DDGS) at 20 and 40% inclusion levels on the total volatile fatty acid concentration (mmol L-1) over a 24 h feeding period

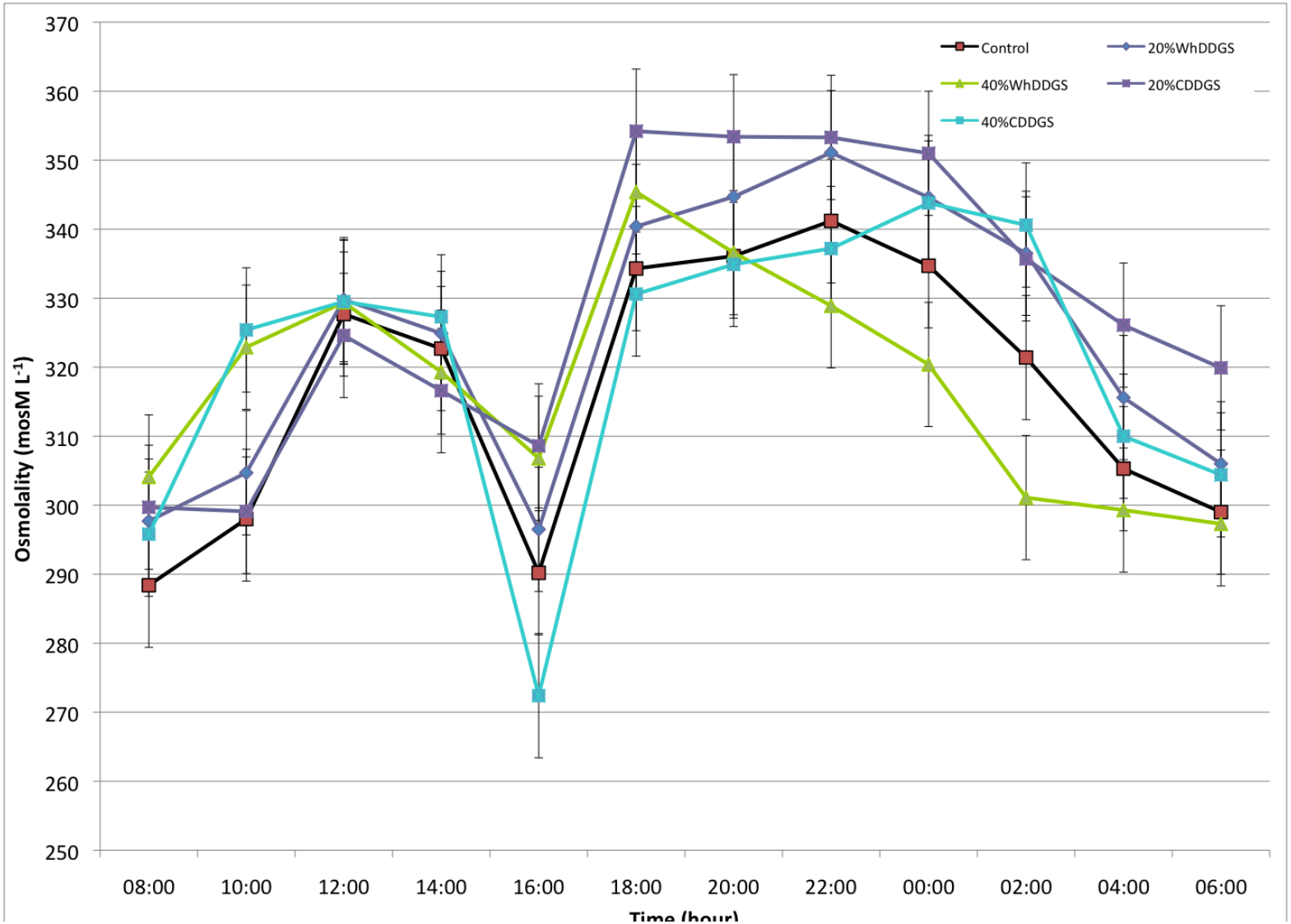

Figure B.3. Effect of feeding wheat or corn DDGS at 20 and 40% inclusion levels on the rumen osmolality over a 24 h feeding period

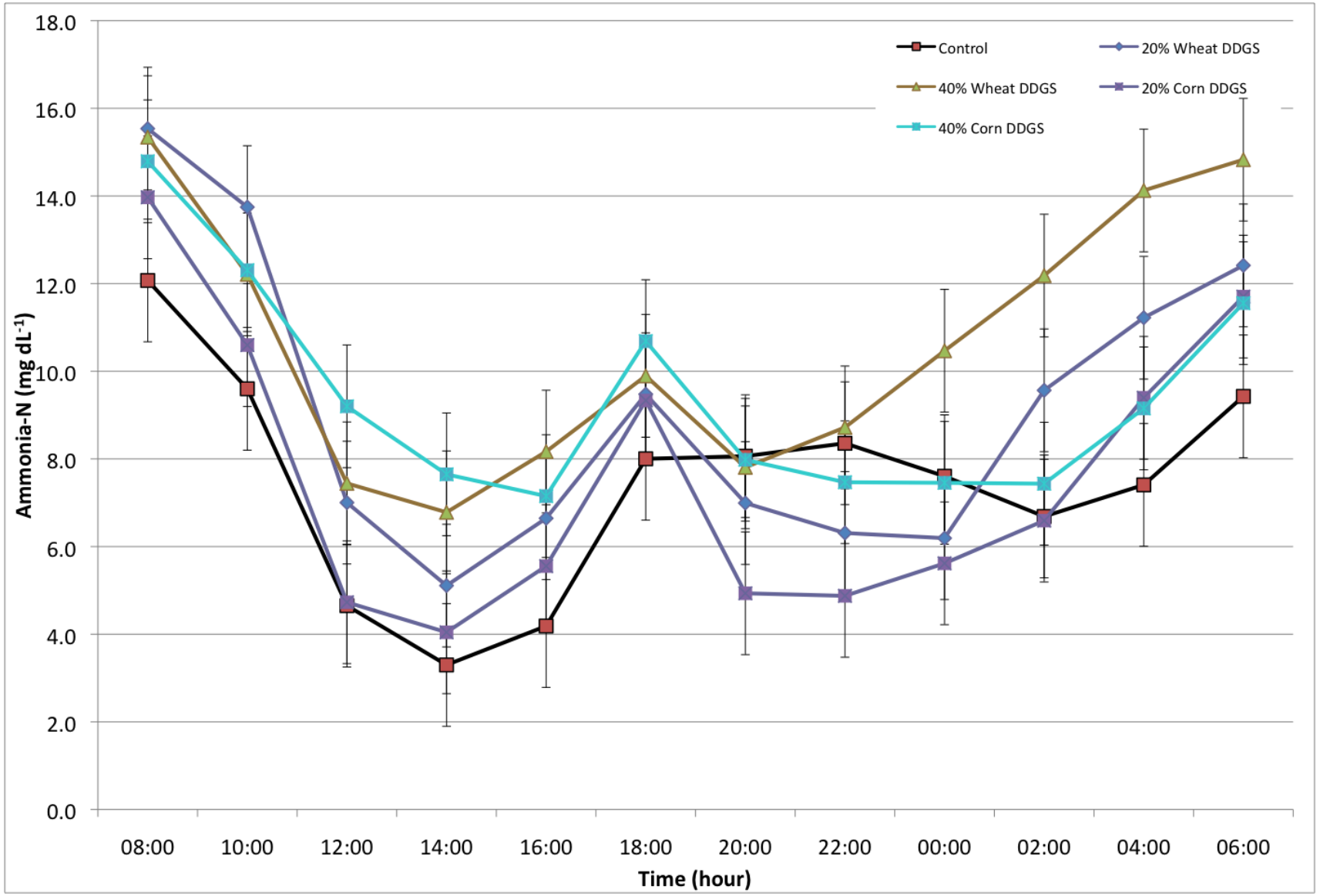

Figure B.4. Effect of feeding wheat or corn DDGS at 20 and 40% inclusion levels on rumen ammonia-N levels over a 24 h feeding period

Appendix C:

Table C.1 Effects of feeding wheat DDGS or corn DDGS at 20 and 40% inclusion levels on the feed costs of finishing ration in Trial 1[z]

	Treatment				
		Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%
Feed cost of gain ($/lb)	0.70	0.67	0.66	0.68	0.59
Total feed costs ($/animal)	421.62	398.61	387.97	405.33	352.80

[z] Prices include transport and processing (January, 2008): Barley: $200.00/tonne,Wheat DDGS: $192.00/tonne, Corn DDGS: $228.00/tonne