University of Alberta

Feeding Value of Triticale-Based Dry Distillers' Grains plus Solubles in the Diets of Growing Lambs

by

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ABSTRACT

Nutrient profiles of distillers' grains are primarily affected by the type of grain used for ethanol production, but the feeding value of triticale-based dry distillers' grains plus solubles (TDDGS) has not been extensively studied. The first study showed that, compared to 20% corn- or wheat-based distillers' grains diets, 20% TDDGS diet increased *cis*-9 *trans*-11 linoleic acid concentration in carcass fat without affecting growth performance of lambs. In the second study, lamb growth performance was not affected by the addition of up to 60% TDDGS in the diet, but the risk of urinary calculi increased at higher inclusion levels. Lambs fed 20% TDDGS had higher cold carcass weights and grade rules than lambs fed 40 or 60% TDDGS. Increasing TDDGS decreased diet digestibility, and increased nitrogen and phosphorus excretion. In conclusion, TDDGS can be used in diets for growing ruminants, and its utilization efficiency may be optimized at 20% dietary inclusion.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fibre
ADG	Average daily gain
CDDG	Corn-based dry distillers' grains
CDDGS	Corn-based dry distillers' grains plus solubles
CLA	Conjugated linoleic acid
CP	Crude protein
DDG	Dry distillers' grains
DDGS	Dry distillers' grains plus solubles
DM	Dry matter
DMI	Dry matter intake
EE	Ether extract
FAME	Fatty acid methyl esters
FE	Feed efficiency
IVDMD	In vitro dry matter digestibility
MUFA	Mono-unsaturated fatty acid
NDF	Neutral detergent fibre
NEg	Net energy of gain
PUFA	Poly-unsaturated fatty acid
SFA	Saturated fatty acid
SMY	Saleable meat yield
TDDGS	Triticale-based dry distillers' grains plus solubles
TS	Thin stillage
TWDG	Triticale-based wet distillers' grains
VFA	Volatile fatty acid
WDDGS	Wheat-based dry distillers' grains plus solubles

WDG	Wet distillers' grains
WDGS	Wet distillers' grains plus solubles
WWDG	Wheat-based wet distillers' grains

1.0. LITERATURE REVIEW

1.1. Introduction

Distillers' grains are a co-product of the fuel ethanol industry. Using ethanol for fuel is not a new idea. Henry Fords' Model T, built in 1908, was designed to run on ethanol (Solomon et al. 2007), and information on feeding distillers' grains can be found in 'Feeds and Feeding' by Morrison, published in 1957. However, concerns over foreign oil dependency and environmental issues have re-kindled interest in the ethanol industry. Currently, the Canadian Environmental Protection Act (1999) has mandated that gasoline will have an average annual renewable fuel content of at least 5% by 2010 (Environment Canada, 2008). Presently, Canada has the capacity to produce ~1000 million liters per year and ~400 million liters per year of ethanol from corn and wheat feedstock, respectively, with provisions to produce another ~ 300 million liters per year (Canadian Renewable Fuels Association, 2009). The differences in feedstock used for ethanol production are a reflection of geographical climate. For example, corn is the primary substrate for ethanol production in eastern United States and Canada (Beliveau and McKinnon 2008), but the cooler climate in western Canada is unsuitable for growing corn, so wheat is the primary feedstock utilized for ethanol production, even though the starch content is lower (Lan et al. 2008; Alberta Agriculture and Rural Development 2007). On average, 2.5-3.0 kg of grain is needed to produce 1 L of ethanol, depending on the starch content of the grain (O'Connor 2007). The removal of the starch effectively concentrates the

remaining components of the grain, resulting in a co-product that is approximately three-fold higher in concentrations of crude protein (**CP**), fat, fibre and minerals (Klopfenstein et al. 2008). As a result, distillers' grains are being utilized as both an energy and protein source in the beef and dairy industries and to a lesser extent by the swine and poultry industries.

The objective of this chapter is to provide a comprehensive review of the production and nutritional properties of corn-, wheat-, and triticale-based distillers' grains. The effect of feeding these distillers' grains on beef cattle and sheep growth performance and carcass traits will also be discussed.

1.2. Production of Distillers' Grains

1.2.1. Overview of the Ethanol Process

There are several steps in the ethanol manufacturing process. After the grain is received at the processing plant, the grains must be pre-processed either by wet milling or dry grinding. The wet milling process separates the germ, fibre, protein and starch components of the grain by first soaking the whole grain in a weak sulfurous acid solution, then separating the components based on differences in density and particle size into dried germ, corn gluten feed, corn gluten meal and starch (Figure 1.1.; Rausch and Belyea 2006). This process is primarily used to make corn starch-based sweeteners, but the starch can also be fermented to produce ethanol (Keim 1984). If ethanol is produced, the resulting co-product is referred to as distillers' solubles (Rausch and Belyea 2006).

Extensive research has been conducted with feed co-products from the wet milling process however; it will not be discussed further in this paper.

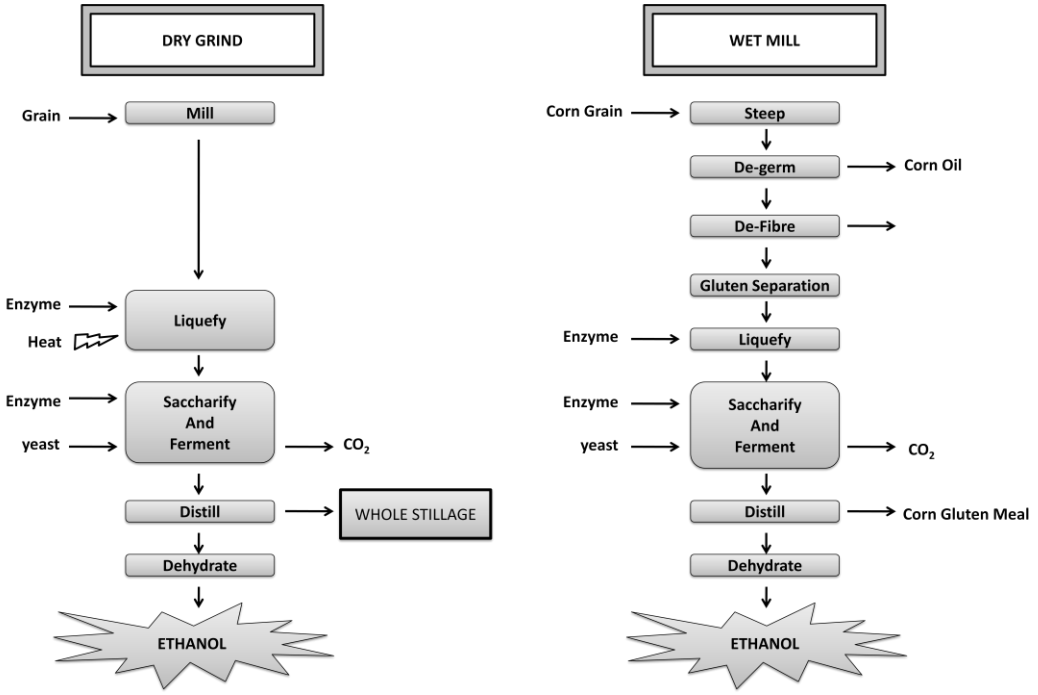

Figure 1.1. Overview of the dry grinding and wet milling process (adapted from Bothast and Schlicher 2005).

The dry grinding process does not fractionate the grain, thus less equipment is needed in the ethanol plant and only one co-product is produced. Once the grain is received in the plant, it is ground into a fine powder using either a hammer or roller mill (Figure 1.1.; Rausch and Belyea 2006). Water and α-amylase are then added to the powder at a ratio of 50-L water : 0.001-kg α-amylase : 10-kg corn, and the mixture is heated to a temperature between 120-150^{o}C (Pimentel 2003; O'Connor 2007). Heat is needed to solubilize all of the starch granules, and α-amylase hydrolyzes the starch by cleaving α-1,4-glycosidic

bonds to prevent aggregation of the long starch molecules when the mixture is cooled (Keim 1983; Vihinen and Mäntsälä 1989 as cited by Fitter et al. 2001). The next step is termed saccharification and is a 3-d process carried out at a temperature between 60-65^{o}C and pH of 4.0-4.5 (Keim 1983). In this step, glucoamylase is added to the mixture to release glucose monomers from the non-reducing end of the carbohydrate chains. Sulfuric acid is also added to acidify the mixture, with the sulfur interacting with minerals to form salts that are within the distillers' grains fraction (O'Connor 2007). After the completion of pre-processing, yeast (*Saccharomyces cerevisiae)* is added to convert the glucose monomers into ethanol and carbon dioxide. Urea is also added as a non-protein nitrogen source because the yeast cells are incapable of degrading protein in the grain (Belyea et al. 2004). Fermentation can be undertaken as individual batches, in a cascade series or in individual tanks with continuous supply and discharge (Keim 1983), and is typically carried out at ~32^{o}C for 40 to 75 h (CFIA 2009). Throughout the fermentation process, heat, vitamins, and new yeast cells are produced (Fron et al. 1996). Ethanol is then distilled off using distillation columns, a stripping column and a molecular sieve to remove any remaining water molecules (Rausch and Belyea 2006). The ethanol is then denatured and ready to be blended with gasoline. The CO_2 produced is either released to the atmosphere or collected to be used in the beverage industry. The remaining substrate, now referred to as whole stillage, is ready to be processed as the distillers' co-product.

1.2.2. Types of Distillers' Grains

Distillers' grains exist in many different forms (Figure 1.2.). Once the ethanol is distilled off, the remaining slurry is referred to as whole or spent stillage. It is a mixture of particulate material from the grain, yeast cells, chemicals added during the production process and cellular metabolites and vitamins (Fron et al. 1996; Liu 2008). Whole stillage can be subjected to either pressing or centrifugation to separate the liquid fraction from the solid fraction (Larson et al. 1993). The solid fraction is referred to as wet distillers' grains (**WDG**). Wet distillers' grains can be marketed as is, but due to the high costs of shipping and problems with spoilage, its use as feed is generally restricted to

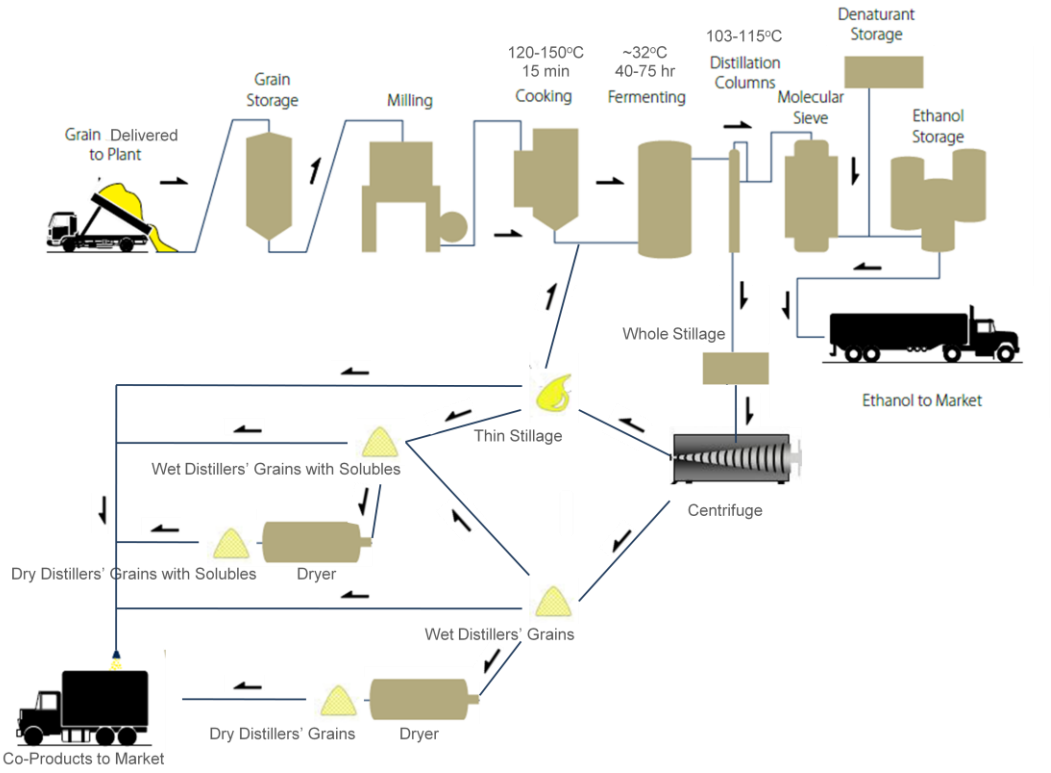

Figure 1.2. Overview of ethanol fermentation and co-product production (adapted from Husky Energy 2009 and CFIA 2009).

within close proximity to the ethanol plant (Larson et al. 1993). There has been work examining the use of ensiling WDG to stabilize it for storage (Abrams et al. 1983). Another way to extend the shelf life and reduce the cost of transport of WDG is to dry them using either a drum dryer or flash dryer to form dried distillers' grains (**DDG**; O'Connor 2007). The liquid portion that was separated off during the centrifugation process is termed thin stillage (**TS**). Thin stillage ranges between 4-8% dry matter (**DM**) and is high in protein, yeast and B-vitamins (Ojowi et al. 1996) and can be recycled in the fermentation process within the plant or fed to cattle as a drinking water replacement (Larson et al. 1993; Ham et al. 1994). The moisture content can be reduced to make condensed distillers' solubles or TS can be added back to WDG to form wet distillers' grains plus solubles (**WDGS)** and drying WDGS produces dried distillers' grains plus solubles (**DDGS**). When referring to all forms (WDG, WDGS, DDG, DDGS and TS), from one grain source, the general term 'distillers' grains' will be used.

1.2.3. Sources of Variation in Distillers' Grains

One of the drawbacks to using distillers' grains as a feed source is that the nutrient composition varies among lots. A study conducted by Spiehs et al. (2002) found that the co-efficient of variation among and within 10 Minnesota-South Dakota region ethanol plants over a three-year period was less than 10% for dry matter, CP, crude fat and crude fibre, but variation was high for amino acids and minerals (25.7 and 80.4%, respectively). Color, texture and odor also vary among lots of distillers' grains.

A large part of the nutrient variation is attributed to the feedstock used for ethanol production. Ethanol can be produced from a variety of grains including sorghum, corn, barley, wheat or triticale depending on geographic region, supply, or price. The inherent differences among the grains, such as wheat having a higher protein content than corn, are present in the distillers' grains produced. Within the same grain type, nutrient profiles may differ among different cultivars, which affect the composition of the distillers' grains. Wu et al. (1984) found that distillers' grains produced from soft wheat were lower in protein compared to those made from hard wheat, which reflected the typical difference in protein quantity between the two types of wheat. Furthermore, different varieties vary in nutrient composition. For example, within the hard wheat classification, the variety Superb has a 1% lower protein content compared to 5602HR (McKenzie et al. 2008), which could make a difference in CP content of the resulting distillers' grains due to the concentrating effect of starch removal during ethanol production. There are also structural differences in the starch-protein matrix among hybrids of corn, which will affect efficiency of ethanol fermentation and the amount of starch present in the resulting distillers' grains (Murthy et al. 2009).

Abiotic factors also affect the nutrient profile of the crop. The same crop variety will grow differently depending on the growing environment and different management factors. Gene expression controls every step of metabolism within the cell through the manufacturing of enzymes, and is differentially regulated by the environment (Stern et al. 2007). Altenbach et al. (2003) found that wheat (Butte 86) grown under various temperature, fertilizer and water management

regimes had CP contents ranging from 9.8 to 20.0%. Nutrient profiles of the soil vary depending on geographic location, crop rotation and fertilization, which in turn affect nutrient uptake and assimilation by the plant (Davidson 1940).

The other main sources of nutrient variation in distillers' grains arise from the ethanol plant itself. Although Broin and Associates (Sioux Falls, SD) market distillers' grains that are consistent in nutrient content under the brand name Dakota Gold in 10 mid-west United States ethanol plants, this consistency is not typically seen in most ethanol plants (Stein et al. 2006). The first source of variation is the nature of the grains; ethanol plants receive mainly non-food grade grains depending on supply and market price (Husky Energy 2009). Thus, the mixture of grains being fermented in a single batch can vary from 100% of a single grain type to any mixture or ratio of the grains the ethanol plant has received (Iwanchysko et al. 1999). Also, chemicals used throughout the fermentation process for pH adjustments and tank cleaning are not always added in the same proportions. These chemicals ultimately end up as minerals in the distillers' grains (Wu et al. 1984; O'Connor 2007) and can cause the co-efficient of variation in sodium, calcium and sulfur content among batches to be as high as 179% (Belyea et al. 1989). Exposure of the fermentation slurry to the copper and iron tanks and pipes also has the potential to alter the copper and iron content of the distillers' grains. Belyea et al. (1989) found that the co-efficient of variation for copper and iron content of DDGS varied by 51 and 20%, respectively, over a 10-d period from one ethanol plant. The ethanol plant may be also designed to recycle yeast cells after centrifugation, which increases ethanol plant productivity

while reducing costs, but also affects the amount of yeast remaining in the distillers' grains (Maiorella et al. 1984). Because yeast contains high concentrations of most amino acids and they cannot degrade any protein from the feedstock, the amount of yeast added back to the distillers' grains will greatly affect the protein content of the distillers' grains (Belyea et al. 2004). The drying process also affects the quality, color and odor of the distillers' grains. Currently, there are two types of dryers: rotary drum dryers and flash dryers which are usually operated between 350-400^{o}C (O'Connor 2007). A major difference between the two dryers is that grains in a flash dryer are only exposed to the heat for a few seconds, whereas the rotary drum takes 3-4 minutes to dry the grains. Another problem with the drying process is that sometimes dryers are operated above their capacity to increase throughput of grains, which is advantageous from the view point of ethanol production, but to accomplish this, a higher temperature must be used, which ultimately decreases the quality of the distillers' grains being produced (O'Connor 2007).

1.2.4. Controversies of Ethanol Production

Although there are positive aspects to the fuel ethanol industry, the use of grain for ethanol production is being criticized. The basis behind fuel ethanol production is to decrease the dependence on foreign oil and to decrease CO_2 emissions (Solomon et al. 2007), but fossil fuels are utilized in planting, harvesting, and transporting crops. In addition, CO_2 is produced when building ethanol plants (Wheals et al. 1999). There is also concern that increasing the number of acres planted with corn in order to produce ethanol (Simpson et al.

2008) will degrade water quality due to increased nitrogen runoff associated with row crop production (Schilling and Libra 2000).

There is also a major ethical concern over using a human food source for fuel production, when there are malnourished people in the world (Pimentel 2003). However, Europe and the United States are able to produce enough food for their own use and now government policies focus on storing food, rather than producing it (Bashir and Lee 1994). In this case, ethanol production provides an avenue to utilize excess feed rather than paying to store it (Bashir and Lee 1994). Also, distillers' grains can be ground into flour which has been successfully incorporated into bread and cookie recipes for human consumption, with acceptable taste and improved nutritional profiles (Tsen et al. 1982; Tsen et al. 1983), but this is not common. The 'food vs. fuel' debate has spurred research and development into cellulosic ethanol which would use fibrous wastes to produce ethanol.

Another concern is whether or not the ethanol industry would be economically sustainable without government subsidies due to high input costs and fluctuating corn prices (Pimentel 2003). Shipping ethanol is also expensive. Ethanol absorbs water present in multi-fuel pipelines which causes its separation from the gasoline, thus ethanol must be shipped by truck and blended with gasoline on site (DiPardo 2000). Furthermore, shipping ethanol by truck requires further use of fossil fuels.

Despite the drawbacks of ethanol production, fuel ethanol is still being produced throughout the world and distillers' grains continue to be produced as the co-product. While distillers' grains can be used as fertilizer or a combustion energy source, their use as feed is the most profitable (Lory et al. 2008). Therefore, the use of distillers' grain as feed for livestock warrants further investigation.

1.3. Use of Distillers' Grains as a Feedstuff for Ruminants

With the expansion of the ethanol industry, distillers' grains have been increasingly incorporated into ruminant diets. As of 2007, a survey of feeding recommendations from consulting feedlot nutritionists done throughout the United States found that 83% of the nutritionists' clients were using co-products in their rations (Vasconcelos and Galyean 2007). Of the co-products used, wet and dry distillers' grains from corn, sorghum or a mixture of both were the primary co-products used. Dietary inclusion rate ranged from 5-50% (DM basis) with 20% being the most common inclusion rate (Vasconcelos and Galyean 2007). Typically, distillers' grains are used as a protein source when added at 6-15% of the diet and as an energy source when included at > 15% of the diet DM (Klopfenstein 2008). Because of the high protein and phosphorus content of distillers' grains, these nutrients are supplied in excess when distillers' grains are used as an energy source in the diet (Klopfenstein 2008). Some regions in the United States utilize distillers' grains to such an extent that research examining the effects of distillers' grains in feedlot rations often includes distillers' grains in

their control diet to represent typical feedlot rations in the area (Homm et al. 2008).

Most of the work with distillers' grains has focused on corn-based distillers' grains. Recently, there has been an increase in the amount of work being conducted with wheat-based distillers' grains, but to date there has been little work done with triticale-based distillers' grains.

1.3.1. Nutritional Profile of Distillers' Grains

The nutrient composition of distillers' grains varies depending on the type of grain used for ethanol fermentation and the form that they are fed in. Corn-based DDGS (**CDDGS)** is typically ~90% DM (Table 1.1.; Lodge et al. 1997; Spiehs et al. 2002; NRC 2007). The CP content is ~30% (DM basis) and neutral detergent fibre (**NDF**) and acid detergent fibre (**ADF**) contents average ~46 and 19%, respectively (Lodge et al. 1997; Spiehs et al. 2002; NRC 2007). The ether extract (**EE**) content is high, typically around 10%, due to the high oil content of corn grain. Based on the analysis of Peter et al. (2000) and Al-Suwaiegh et al. (2002), nutrient profiles of corn-based DDG (**CDDG**) closely resemble that of CDDGS (generally, within 2%). Corn-based WDG (**CWDG**) contains approximately one third of the DM content of CDDGS. On a DM basis, CWDG contain similar amounts of CP and NDF, but are ~5% higher in ADF and ~2% higher in EE when compared to CDDGS (Larson et al. 1993; Lodge et al. 1997; Al-Suwaiegh et al. 2002). Corn-based TS is only ~6% DM, and on a DM basis is

Table 1.1. Chemical composition of distillers' grains (DM basis)

	Component				
Item[z]	DM (%)	CP (%)	NDF (%)	ADF (%)	Ether Extract (%)
Corn-based DDGS					
Spiehs et al. 2002[y]	88.9	30.2	44.5	16.2	10.9
Lodge et al. 1997	92.2	29.2	51.3	—	11.4
NRC 2007	90.0	29.0	42.0	21.0	10.5
Corn-based DDG					
Peter et al. 2000	87.1	29.4	45.2	12.9	—
Al-Suwaiegh et al. 2002	93.0	28.9	42.3	25.5	14.0
NRC 2007	91.0	29.0	42.0	21.0	10.5
Corn-based WDG					
Larson et al. 1993	31.4	25.0	39.4	—	13.7
Al-Suwaiegh et al. 2002	35.5	30.5	42.6	25.3	14.5
Lodge et al. 1997	31.3	29.6	51.9	—	13.7
NRC 2007	36.0	29.0	41.0	21.0	10.5
Corn-based TS					
Larson et al. 1993	5.0	16.8	11.7	—	8.1
NRC 2007	7.0	22.0	21.0	10.0	8.1
Wheat-based DDGS					
Boila and Ingalls 1994[x]	96.3	43.6	36.1	15.6	—
Beliveau and McKinnon 2008[w]	93.9	37.2	46.5	13.2	5.0
Gibb et al. 2008	91.6	45.8	28.9	19.5	4.6
McKinnon and Walker 2008	90.3	38.6	54.1	13.1	6.2
Wheat-based WDG					
Mustafa et al. 2000	—	27.5	73.9	21.6	4.4
Ojowi et al. 1997	29.4	26.4	74.9	24.1	6.6
Wheat-based TS					
Iwanchysko et al. 1999	6.3	46.6	38.4	2.0	6.9
Fisher et al. 1999[v]	6.7	40.1	36.3	7.5	7.6
Mustafa et al. 2000	—	36.6	35.2	8.5	5.9
Triticale-based DDGS					
Greter et al. 2008	87.4	30.5	36.5	15.7	10.1
Triticale-based WDG					
Mustafa et al. 2000	—	29.8	71.2	21.1	6.6
Triticale-based TS					
Mustafa et al. 2000	—	39.7	31.6	7.2	6.1

zDDGS = dry distillers' grains with solubles; DDG = dry distillers' grain; WDG = wet distillers' grains; WDDGS = wet distillers' grains with solubles; TS = thin stillage.

[y]Average of 10 new Minnesota and South Dakota ethanol plants.

[x]Sample DG3 - 100% wheat-based DDGS.

[w]Average of three batches.

[v]Average of TS used in growing and finishing period.

considerably lower in CP, NDF, ADF and EE, averaging 19, 16, 10 and 8%, respectively when compared to CDDGS (Larson et al. 1993; NRC 2007).

The DM content of wheat-based DDGS (**WDDGS**) is typically ~93% (Boila and Ingalls 1994; Beliveau and McKinnon 2008; Gibb et al. 2008; McKinnon and Walker 2008). Crude protein content of WDDGS is approximately 40%, ~10% higher than CDDGS. The NDF content of WDDGS from the four studies ranged from 28.9 to 54.1% (DM basis), but the ADF content was more consistent, averaging ~15%. Ether extract content is only ~5% which is only about half the EE content of CDDGS, due to inherent differences between wheat and corn grains. Wheat-based WDG (**WWDG**) are ~30% DM. Compared to WDDGS, WWDG only have about half of the CP content and almost twice the NDF content (Ojowi et al. 1997; Mustafa et al. 2000). Acid detergent fibre is ~5% higher in WWDG and EE contents are similar to WDDGS. Wheat-based TS is only ~6% DM, and on a DM basis, closely resembles the nutrient profile of WDDGS, except that the ADF content is only ~20% of that in WDDGS (Iwanchysko et al. 1999; Mustafa et al. 2000).

The chemical composition data on triticale-based distillers' grains are somewhat limited. Triticale-based DDGS (**TDDGS**) is approximately 87% DM (Table 1.1.; Greter et al. 2008). The CP and EE contents of TDDGS are similar to CDDGS at ~31 and ~10%, respectively. Greter et al. (2008) reported NDF and ADF values of 36.5 and 15.7%, respectively. The CP and ADF content of triticale-based WDG (**TWDG)** are similar to both WWDG and CWDG at 29.8

and 21.1%, respectively (Mustafa et al. 2000). The NDF and EE content of TWDG is similar to WWDG, but is approximately 30% higher in NDF and 7% lower in EE compared to CWDG (Mustafa et al. 2000). The composition of triticale-based TS is similar to wheat-based TS, averaging 39.7, 31.6, 7.2 and 6.1% for CP, NDF, ADF and EE, respectively (Mustafa et al. 2000).

Despite the removal of starch from the grain during ethanol fermentation, the fermentation process is not 100% efficient and some starch does remain in the distillers' grains. Stein et al. (2006) sampled CDDGS from 10 ethanol plants in the mid-west United States and found that the average starch content was 6.5% DM. Similar results were found by Greter et al. (2008) in TDDGS, which contained 7.6% starch (DM basis). However, the starch content reported by Mustafa et al. (2000) was considerably lower at 2.4 and 2.7% for WWDG and TWDG, respectively.

The mineral content of distillers' grains is also high due to the concentrating effect of starch removal. In particular, the phosphorus content of distillers' grains is typically very high, whereas the calcium content is low. The calcium content, regardless of whether corn, wheat or triticale is used as feedstock, typically ranges from 0.10 to 0.19% (DM basis; Rust et al. 1990; Gibb et al. 2008; Greter et al. 2008; McKinnon and Walker 2008). Phosphorus values are 4-8 times higher than the calcium content, ranging from 0.67-1.07% (DM) and averaging 0.87% DM (Rust et al. 1990; Gibb et al. 2008; Greter et al. 2008; McKinnon and Walker 2008). The imbalanced Ca:P ratio means that a calcium

supplement may need to be added when formulating the diet to maintain the Ca:P ratio of 2:1. The excess phosphorus in the diet also raises an environmental concern as runoff from manure can accumulate in water bodies leading to eutrophication (Rausch and Belyea 2006).

Distillers' grains can also be high in sulfur. The average sulfur content of CDDGS from 10 different ethanol plants ranged from 0.33-0.74% (Spiehs et al. 2002). Gibb et al. (2008) found that WDDGS contained 0.48% sulfur (DM basis). Incorporating a high proportion (> 50% diet DM) of distillers' grains, high in sulfur, into the diet can result in polioencephalomalacia (Buckner et al. 2008).

It must also be noted that these are only general nutrient values for distillers' grains. As discussed earlier, distillers' grains can be highly variable in their nutrient composition. Some of this variability is demonstrated by the large range of the NDF content in WDDGS (Boila and Ingalls 1994; Beliveau and McKinnon 2008; Gibb et al. 2008; McKinnon and Walker 2008). Thus, it is important to analyze distillers' grains on a regular basis and adjust the rations as needed.

1.3.2. Fermentation Characteristics of Distillers' Grains

Different fermentation characteristics of various feedstuffs alter the site and extent of digestion, and thus, affect animal performance. Some feeds are good for microbial growth, while others by-pass the rumen and are digested in the small intestine. The CP content of CDDG is relatively unavailable in the rumen. Two studies using CDDG with similar CP content found that only 40% (Batajoo and

Shaver 1998) and 58% of the CP (Peter et al. 2000) was degraded in the rumen. Mustafa et al. (2000) and Ojowi et al. (1997) found that the ruminal CP digestibility of WWDG were 45 and 69%, respectively. The 96 h in situ ruminal CP degradability of TWDG was 51.2%, which is similar to WWDG (Mustafa et al. 2000). The low ruminal CP availability to rumen microbes for DDG may be due to the formation of Maillard reaction products and thus, approximately half of the CP ingested reaches the small intestine (Batajoo and Shaver 1998). An in vitro study found the extent of NDF digestion in CDDG was 57.2% (Bhatti and Firkins 1995). However, an in situ study found that extent of NDF digestion in the rumen was 87.8 and 86.4% for CDDG and WDDGS, respectively (Al-Suwaiegh et al. 2002). The 96 h in situ effective rumen degradability of WDDGS NDF was 46%, which is lower than CDDGS (Ojowi et al. 1997; Mustafa et al. 2000). For TWDG, NDF degradability was 43.9%, similar to WWDG (Mustafa et al. 2000). The high NDF degradability found by Al-Suwaiegh et al. (2002) may be due to high rumen pH providing an optimum environment for fibrolytic activity (Grant 1994). In addition, distillers' grains NDF is potentially highly digestible.

Interestingly, Fron et al. (1996) found that rumen fluid collected from cattle fed corn-based TS had a two-fold higher in vitro lactic acid disappearance than that from cattle fed dry-rolled corn. Fron et al. (1996) found a direct correlation between the number of culturable lactilytic bacteria and the in vitro rate of lactic acid disappearance, and as lactate was metabolized, the concentration of butyrate and propionate tended to increase. Therefore, it was suggested that feeding distillers' co-products enhanced lactic acid utilization by

increasing the relative numbers of lactilytic bacteria, thus reducing the risk of lactic acidosis.

The primary volatile fatty acids (**VFA**) produced in the rumen are acetate, propionate and butyrate. The efficiencies of converting hexose to acetate, propionate and butyrate are 62, 109, and 78%, respectively (Chalupa 1977). The inefficiencies of converting hexose to acetate or butyrate are attributed to the production of two moles of CO_2 per mole of hexose, which is subsequently converted to and lost as methane (Baldwin and Allison, 1983). No carbon is lost when one mole of hexose is converted to two moles of propionate, thus animals are able to utilize more feed energy for growth (Potter et al. 1976). Although VFA profiles are not well documented for diets containing WDDGS, much work has been done with CDDGS. Kleinschmit et al. (2006) found that total VFA decreased from 65.6 to 53.8 mM when CDDGS was included at 20% of the diet, replacing soybean meal and ground shelled corn in dairy rations. However, there was no difference in the proportion of acetate and propionate produced. Anderson et al. (2006) found that including CDDGS at 10 or 20% DM replacing soybean meal and ground corn had no effect on total VFA production or proportions of acetate and propionate. Inclusion of CDDGS at 18.5% of dietary DM, in place of soybean meal and dry shelled corn in a dairy ration also did not affect total VFA concentration (Sasikala-Appukuttan et al. 2008). However, the molar proportion of acetate was 1.0% lower and propionate was 2.05% higher compared to the control (Sasikala-Appukuttan et al. 2008). On the other hand, feeding 20% CDDGS in place of cornstarch to beef cattle increased total VFA concentration, as

well as resulting in a higher proportion of acetate and a lower proportion of propionate (Peter et al. 2000).

1.3.3. Dry Matter Intake

Generally, distillers' grains are a palatable feedstuff for ruminant animals. Although Schauer et al. (2005) suggested that beyond 20% inclusion diet palatability may decrease, this does not appear to be the case. Buckner et al. (2008) fed up to 40% CDDGS in place of dry-rolled corn in a finishing diet and found no differences in dry matter intake (**DMI**), while Ham et al. (1994) found a tendency for DMI to be higher for finishing cattle fed CDDGS at 40% of dietary DM compared to cattle fed dry-rolled corn. When a cracked corn diet was supplemented with 15% CWDG, there was no difference in DMI compared to cattle fed diets supplemented with 15% modified corn fibre and 23% dried corn gluten feed (Peter et al. 2000). Rust et al. (1990) conducted an experiment examining the effect of replacing drinking water with corn-based TS, or soaking dry-rolled corn in corn-based TS before adding it to the total mixed ration. Compared to the basal diet and drinking water there was no difference in total DMI or total moisture intake between treatments (Rust et al. 1990). Similarly, when CDDGS have been fed to sheep at 40% of the diet DM in place of dry-rolled corn (Lodge et al. 1997) or 23% of the diet DM in place of a mixture of 13% corn and 10.2% soybean meal (Huls et al. 2006), DMI was not affected.

Distillers' grains derived from wheat also appear to be palatable to cattle. Beliveau and McKinnon (2008) replaced increasing amounts of dry-rolled barley

with WDDGS up to 23% of the diet DM in finishing cattle diets; and reported no differences in DMI. However, Gibb et al. (2008) found that as WDDGS was increased from 0 to 60% of the diet DM in place of steam-rolled barley, intake was 1.22 kg higher for cattle fed 60% WDDGS compared to those not receiving WDDGS in the diet. When WWDG were fed to beef cattle at 13.4% of the diet DM during the growing period and 4.7% of the diet DM in the finishing period, no difference in DMI was found compared to the barley-based control diet (Ojowi et al. 1997). When wheat-based TS was supplied from 0 to 6.7% DM in the water source, there was also no difference in total DMI, but the DMI of the basal diet decreased as TS increased (Fisher et al. 1999).

There have been few studies evaluating triticale-based distillers' grains as a feed stuff. Wierenga et al. (2009) found no difference in DMI when up to 30% TDDGS was added to the diet in place of 10% barley silage and 20% dry-rolled barley grain. Another study using dairy cows found no difference in DMI between diets containing either 21.4% TDDGS or 21.3% CDDGS on a DM basis. These studies indicate that palatability should not be a problem with TDDGS.

1.3.4. Average Daily Gain

Feeding corn-based distillers' grains to finishing cattle generally improves average daily gain (**ADG**). Ham et al. (1994) found that adding CDDGS to the diets of finishing steers at 40% of dietary DM or a combination of CWDG+TS at 40% of dietary DM improved ADG from 1.46 kg d^{-1} in cattle fed the dry-rolled corn diet, to an average of 1.69 kg d^{-1}. Larson et al. (1993) also found that ADG

increased quadratically when a mixture of CWDG and TS in a ratio of 1:1.7 was added to a dry-rolled corn based diet at 0, 5.2, 12.6 or 40% of dietary DM, replacing soybean meal and urea, and a portion of the corn for the 40% inclusion level. Average daily gain increased from 1.65 kg d^{-1} and reached a plateau at 1.76 for the 12.6 and 40% inclusion of CWDG+TS, respectively (Larson et al. 1993). Replacing 0, 25, or 50% high moisture corn with CWDG in a diet for finishing steers also increased ADG by 0.12 kg d^{-1} as CWDG was increased from 0 to 50% of diet DM (Firkins et al. 1985). Results from Al-Suwaiegh et al. (2002) also support these findings; replacing dry-rolled corn with CWDG at 30% of dietary DM in a diet for finishing steers increased ADG by 0.15 kg d^{-1}. In a cracked corn-based diet, weanling heifers fed 15% CDDGS out performed those fed other corn by-products (Peter et al. 2000). Peter et al. (2000) found that heifers fed CDDGS and dried corn gluten feed had 39 and 29% higher ADG, respectively compared to heifers fed modified corn fibre.

The aforementioned studies demonstrated that feeding corn-based distillers' grains can improve ADG, and further work has been conducted to investigate how much and how often corn-based distillers' can be fed to optimize ADG. Buckner et al. (2008) carried out an experiment to find the optimal rate of CDDGS inclusion in a finishing steer trial. Dry-rolled corn was replaced by CDDGS at 0, 10, 20, 30 or 40% of the diet DM, and a quadratic response was found where cattle fed 20% CDDGS had the highest ADG of 1.68 kg d^{-1} (Buckner et al. 2008). When calculated mathematically, the optimum dietary inclusion of CDDGS to maximize ADG was 23.5% (Buckner et al. 2008). Homm et al. (2008)

reported that ADG linearly increased from 1.51 to 1.61 kg d^{-1} as the number of days on a 40% CDDGS diet increased before cattle were switch to a high moisture corn finishing ration. Similarly, Loy et al. (2008) found that the more frequent CDDGS feeding (daily vs. 3 times per week) in place of dry-rolled corn to heifers given ad libitum access to grass hay increased ADG (0.62 vs. 0.56 kg d^{-1} for daily and thrice weekly supplementation, respectively).

Contrary to the reported increases in ADG for finishing cattle fed corn-based distillers' grains, the same results have not been found for sheep fed corn-based distillers' grains or for finishing cattle fed wheat-based distillers' grains. Replacing 40% dry-rolled corn (Lodge et al. 1997) or a mixture of 10.2% soybean meal and 13.0% corn (Huls et al. 2006) with CDDGS did not result in any differences in ADG for wethers. Schauer et al. (2005) examined the effect of replacing barley grain with 0, 10 or 20% CDDGS and found no linear or quadratic effects on ADG for wethers. Similarly, both Beliveau and McKinnon (2008) and Gibb et al. (2008) found no differences in ADG for finishing steers and heifers fed WDDGS. Beliveau and McKinnon (2008) replaced up to 23% barley grain with WDDGS and found that ADG across treatments averaged 1.85 kg d^{-1} and when Gibb et al. (2008) replaced up to 60% barley grain with WDDGS, ADG averaged 1.54 kg d^{-1} across all treatments. Feeding WWDG also did not affect ADG when supplementing a barley-based concentrate at 4.7% (DM) in a diet for finishing steers (Ojowi et al. 1997).

The higher ADG for cattle fed corn-based distillers' grains is attributed to the higher energy content of the distillers' grains compared to corn. Ham et al. (1994) found that the net energy of gain (**NEg**) of CWDG+TS was 39% higher and NEg of CDDGS was 21% higher than the NEg calculated for dry-rolled corn. However, while fat increases the NEg, Al-Suwaiegh et al. (2002) found that the lipid content of CWDG only accounted for 4.7% of the 11.7% improvement in the NEg compared to the dry-rolled corn diet. Contrarily, Gibb et al. (2008) found that adding increasing amounts of WDDGS decreased the NEg of the diets.

1.3.5. Feed Efficiency

Feeding distillers' grains causes variable responses in feed efficiency (**FE**). Some studies have found that feeding distillers' grains improves FE, whereas others found that FE tended to decrease, or is not affected. Feeding CWDGS in place of dry-rolled corn at 30% of the diet DM resulted in almost 11% higher FE in steers (Al-Suwaiegh et al. 2002). Similarly, Ham et al. (1994) found a 9% increase in FE for steers fed CDDGS and a 16% increase in FE for steers fed CWDG+TS compared to cattle finished on a dry-rolled corn diet. It was speculated that the improved FE for cattle fed WDG may be due to clumping, causing larger particle sizes, which may decrease rate of passage from the rumen and increase NDF digestion (Ham et al. 1994). This idea was supported by a decreased rate of passage and increased NDF digestion when water was added to CDDGS before feeding (Ham et al. 1994). Firkins et al. (1985) also found a tendency for FE to increase linearly as WDG were fed at 0, 25, or 50% in a high moisture corn-based ration; steers fed 50% WDG in place of high moisture corn

had a 10% higher FE compared to those fed 0% WDG diet. Both Buckner et al. (2008) and Larson et al. (1993) found a quadratic response for FE when fed up to 40% CDDGW and CWDG+TS, respectively. Buckner et al. (2008) found that steers fed CDDGS at 20% of dietary DM had the highest FE. Larson et al. (1993) found that FE improved and reached a plateau at 40% of WDG+TS dietary inclusion. They attributed improved FE to additional energy from ethanol present in the WDG+TS. Ethanol is high in gross energy and is rapidly converted to acetate in the rumen and utilized for lipogenesis. However, in a study conducted by Ham et al. (1994) supplementing sheep with 0, 5 or 10% ethanol linearly decreased FE from 0.177 to 0.167 (gain:feed). Compared to heifers supplemented with modified corn fibre in a cracked-corn based diet, heifers fed CDDG in place of corn starch at 20% of dietary DM were close to 30% more efficient (Peter et al. 2000). Improvements in FE have also been attributed to a higher rumen undegradable protein content for distillers' grains, so more feed protein reaches the small intestine and is absorbed and utilized more efficiently for growth (Firkins et al. 1985). It is also postulated that due to the removal of starch from the grain, rumen pH increases, which provides a more favorable environment for fibre digestion and reduces the risk of acidosis.

Some studies have found that FE is not affected by the addition of distillers' grains to the diet. In studies with sheep, Lodge et al. (1997) found no difference in FE in sheep fed 40% CDDGS compared to those fed dry-rolled corn. Similarly, when CDDGS was fed to sheep at 22.9% of the diet DM, in place of a mixture of soybean meal and corn (Huls et al. 2006) or up to 20% of the diet DM

in place of barley grain (Schauer et al. 2005), FE was not affected. Ojowi et al. (1997) also found no effect on FE when DDG was added to the finishing diet of steers at 4.7% of the diet DM. However, Ojowi et al. (1997) and Huls et al. (2006) had formulated their diets to be isonitrogenous and isocaloric. When WDDGS replaced barley grain up to 23% of the diet DM, FE was not affected (Beliveau and McKinnon 2008), but Gibb et al. (2008) noted that FE decreased by almost 6% for steers fed 60% WDDGS compared to those fed 0% WDDGS. McKinnon and Walker (2008) also found no additional growth response or improvement of FE for backgrounding cattle fed 50% WDDGS to those fed 25% WDDGS. This was probably because the protein requirements of cattle were met at the 25% diet inclusion of WDDGS, and there is no additional benefit in growth performance by the further increase in dietary protein content for the 50% WDDGS diet. It could also be due to the energetic cost associated with detoxifying excess nitrogen to urea (McBride and Kelly 1990) although, based on animal performance and DM digestibility, Gibb et al. (2008) noted that the energetic cost of nitrogen excretion was not evident when heifers were fed up to 60% WDDGS.

1.3.6. Carcass Characteristics

Generally, carcass traits are not affected by the addition of distillers' grains to the diet. Ham et al. (1994) observed no differences in liver abscess score, fat thickness, yield grade and quality grades of cattle fed CDDGS or CWDG+TS at 40% of dietary DM as compared to cattle fed a dry-rolled corn diet. Similarly, Larson et al. (1993) found no effect of feeding CWDG+TS to yearling steers on fat thickness, liver abscess, or quality grade compared to steers fed dry-rolled corn

diet supplemented with urea and soybean meal. Buckner et al. (2008) did find a quadratic trend for hot carcass weight at slaughter; steers fed 20% CDDGS in place of dry-rolled corn were 11 kg heavier compared to the other treatments (0-40% dietary inclusion of CDDGS). Al-Suwaiegh et al. (2002) also noted that hot carcass weights were heavier, fat cover was thicker, and yield grade tended to be higher for steers fed CWDG compared to cattle fed dry-rolled corn. In spite of this finding, Al-Suwaiegh et al. (2002) attributed the differences in carcass traits to a similar number of days on feed. No other differences in carcass composition were noted in these two studies (Buckner et al. 2008; Al-Suwaiegh et al. 2002).

When wethers were fed a 22.9% CDDGS diet, their back fat was 1 mm thinner compared to the control animals fed 10.2% soybean meal and 13% corn (Huls et al. 2006). The other carcass traits including hot carcass weight, longissimus dorsi muscle area, and USDA yield grade were not different. Replacing 0, 10 or 20% barley grain in wether diets with CDDGS also did not affect carcass traits including fat and body wall thickness or ribeye area (Schauer et al. 2005).

Feeding wheat-based distillers' grains does not consistently affect carcass characteristics. Similar to the study by Buckner et al. (2008), back fat thickness was highest for heifers fed WDDGS substituted for barley grain at 20% dietary DM and meat yield tended to decrease with higher inclusion rates of WDDGS (up to 60%, diet DM; Gibb et al. 2008). However, feeding WDDGS up to 60% diet DM did not affect carcass weight, dressing percentage or ribeye area. Likewise,

Beliveau and McKinnon (2008) and Ojowi et al. (1997) found no effect on carcass characteristics when feeding WDDGS up to 23% and WWDG at 4.7% DM in finishing diets, respectively. When increasing the wheat-based TS up to 6.7% in the drinking water for finishing steers, dressing percentage and carcass fat thickness tended to increase, but carcass weight or longissimus dorsi muscle area were not different compared to finishing steers receiving 0, 2, or 4% TS in their drinking water (Fisher et al. 1999).

1.3.7. Meat Quality

Several studies have examined the retail and eating properties of cooked beef from cattle fed distillers' grains. The appearance in the retail display is an important attribute for consumer purchases. Color is an important attribute, with the majority (72%) of consumers preferring steaks with a bright, cherry red color (Killinger et al. 2004). Marbling, fat, appearance, and palatability are also important selection criteria, but consumers looking for lean meat prefer lower marbling and those looking for highly palatable beef (i.e. lots of flavor and juice) prefer steaks with higher marbling (Killinger et al. 2004). Jenschke et al. (2007) found that quality of steaks from yearling steers fed diets including up to 25% CWDG in place of a mixture of high moisture and dry-rolled corn was not affected by treatment, but that juiciness and tenderness and occurrence of off-flavors were higher in carcasses which received a higher grade and there was a lower occurrence of perceived connective tissue. Cattle fed CWDGS had a greater number of steaks that had a higher USDA grade (Jenschke et al. 2007). Liver-like off-flavors were lowest in steaks from cattle fed 30 and 50% CWDG, therefore,

CWDG were not responsible for the liver-like off flavors (Jenschke et al. 2007). Roeber et al. (2005) set up an experiment to compare finishing Holstein steer diets containing up to 50% of WDG and CDDG in place of whole or cracked corn. Similar to the findings of Jenschke et al. (2007) tenderness and palatability of cooked beef were not affected by addition of either CWDG or CDDG to the diet, but the retail display properties varied among treatments. Steaks from animals fed the 25% CDDG diet had the greatest number of visually unacceptable steaks, which would be most likely discounted for quick sale (Roeber et al. 2005). Feeding diets containing 40 and 50% CWDG or CDDG resulted in steaks that were not as red, which made them visually less acceptable. It was concluded from this study that including 10-25% CWDG or CDDG would prolong shelf life and palatability of the cooked beef (Roeber et al. 2005). Gill et al. (2008) also conducted a study comparing meat from finishing beef steers fed CWDGS and CDDGS at 15% of dietary DM to that from steers fed sorghum-based distillers' grains and a steam flaked corn control diet. It was reported that regardless of distiller grain type, steaks were lighter and less red compared to the cattle fed steam flaked corn (Gill et al. 2008). There were no differences for juiciness or flavor, although steaks from steers fed corn distillers' grains were more tender compared to those fed sorghum distillers' grains (Gill et al. 2008). Feeding WWDG at 13.4 % of dietary DM and 4.7% of dietary DM in backgrounding and finishing diets, respectively, did not affect steak palatability and they were considered typical of unseasoned cooked beef done to a medium degree of doneness. Steaks from all treatments were similar in tenderness, juiciness,

contained very little perceivable connective tissue; flavor intensity and flavor desirability were similar (Shand et al. 1998). Aldai et al. (2009) compared steaks from steers fed CDDGS and WDDGS replacing barley grain at 20 or 40% of the diet DM. The appearance of steaks in the retail display did not differ among treatments (Aldai et al. 2009). Unlike Roeber et al. (2005) who found no difference in tenderness, Aldai et al. (2009) found that steaks from cattle fed CDDGS had higher tenderness scores and less perceived connective tissue than cattle fed either WDDGS or the barley grain diet. Also, steaks from cattle fed a 20% CDDGS diet rated better than those from animals fed a 40% CDDGS diet. Meat samples from the different dietary treatments did not differ in off-flavor intensity or juiciness (Aldai et al. 2009).

The fatty acids, *cis* 9, *trans* 11-conjugated linoleic acid (**CLA**) and its precursor, *trans* 11-18:1 have been associated with anti-carcinogenic properties (Ha et al. 1990). Interestingly, Dugan et al. (2008) found that subcutaneous fat from finishing heifers fed 0, 20, 40 or 60% WDDGS, had increased concentrations of *cis* 9, *trans* 11-CLA and *trans* 11-18:1 and decreased concentrations of *trans* 10-18:1 which has been associated with increased coronary heart disease in humans (Hodgson et al. 1996). Gill et al. (2008) found no treatment effect, compared to a steam flaked corn control diet, on *trans* 11-18:1 concentrations when either CWDGS or CDDGS were added at 15 % diet DM. Dugan et al. (2008) and Gill et al. (2008) also noted that the concentrations of saturated fatty acids (**SFA**) were not affected by addition of WDDGS or corn-based distillers' grains to the diet. However, Shand et al. (1998) found that cattle

fed WWDG had a slightly higher concentration of saturated fat in the muscle compared to control cattle.

1.4. Conclusion

As ethanol production increases, so will the amount of distillers' grains produced as they are a co-product. Geographic location of the ethanol plants and the price of grain determine the type of grain used as feedstock for ethanol production. The type of grain used, its nutritive properties, and different processing techniques used in ethanol production alter the nutritional properties of the resulting distillers' grains. Whether or not the distillers' grains are fed as WDG or DDG, and with or without solubles also affects the nutritive values of distillers' grains and thus growth performance of ruminant animals.

Currently, there have been no feeding trials done to assess the feeding value of TDDGS compared to that of CDDGS or WDDGS as a replacement for barley grain. In addition, due to environmental concerns about nitrogen and phosphorus pollution, the amount of nitrogen and phosphorus excretion should be examined and quantified for diets containing TDDGS.

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2.0. EFFECTS OF CORN-, WHEAT- OR TRITICALE DRY DISTILLERS' GRAINS PLUS SOLUBLES ON IN VITRO FERMENTATION, GROWTH PERFORMANCE AND CARCASS TRAITS OF LAMBS[1]

2.1. Introduction

Inclusion of dry distillers' grains plus solubles in ruminant diets has increased in conjunction with expansion of the ethanol industry. Corn-based DDGS is primarily produced in eastern Canada and the United States (Beliveau and McKinnon 2008), but the cooler climate in western Canada is not suitable for growing corn grain (Boila and Ingalls, 1994). Thus, the western Canadian ethanol industry generally utilizes wheat, which contributes to about one-third of Canada's total ethanol production (Gibb et al. 2008). Triticale, a cross between wheat and rye, also has potential to be used as a substrate for bio-ethanol production as ethanol yield from triticale is similar to wheat (Wang et al. 1997).

Extensive research has been conducted to examine the feeding value of corn distillers' grains. Including corn distillers' grains in the diets of feedlot cattle at up to 40% of dietary DM improved FE (Ham et al. 1994; Larson et al. 1993; Al-Suwaiegh et al. 2002). Wheat-based DDGS fed at up to 60% of dietary DM has increased (McKinnon and Walker 2008), decreased (Gibb et al. 2008), or had no effect (Beliveau and McKinnon 2008) on FE in feedlot cattle. In general, incorporating corn- or wheat-based distillers' grains into diets has not affected carcass quality (Larson et al. 1993; Ham et al. 1994; Beliveau and McKinnon

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2008), although increased back fat thickness has been reported in some studies (Al-Suwaiegh et al. 2002; Gibb et al. 2008). In vitro and in situ studies suggest that the nutrient degradability of TDDGS is similar to WDDGS (Mustafa et al. 2000). However, no feeding trials have been conducted to compare the feeding value of TDDGS to that of WDDGS or CDDGS for beef cattle.

The current study was conducted to examine the effects of feeding CDDGS, WDDGS or TDDGS in place of a mixture of barley grain and canola meal at 20% of dietary DM on in vitro fermentation, growth performance and carcass characteristics of lambs.

2.2. Materials and Methods

This experiment was conducted between June 2007 and August 2007 at the Agriculture and Agri-Food Canada Lethbridge Research Centre (Lethbridge, AB, Canada). All animals were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993).

2.2.1. Experimental Design and Dietary Treatments

For this study, CDDGS was obtained from an ethanol plant in South Dakota, TDDGS was produced at Alberta Distillers Ltd. (Calgary, AB) and WDDGS was produced at Husky Energy Inc. (Lloydminster, SK). For compositional analysis (Table 2.1.), two representative samples of each DDGS type were collected from the storage bins, immediately before diet ingredients were combined for pelleting.

Table 2.1. Chemical composition of corn-, wheat- and triticale-based dried distillers' grains plus solubles

Item	Distillers' grains plus solubles type		
	Corn (n = 2)	Wheat (n = 2)	Triticale (n = 2)
Dry matter (%)	88.8	91.5	89.3
Organic matter (% DM)	95.6	94.7	95.6
Neutral detergent fibre (% DM)	32.9	28.0	29.6
Acid detergent fibre (% DM)	15.5	16.3	13.7
Crude protein (% DM)	32.6	43.0	30.7
Ether extract (% DM)	5.7	4.4	5.4

Four experimental diets were prepared in single lots of sufficient quantity for the entire study. The control diet consisted of 55.9% milled barley grain, 16.0% sunflower hulls, 11.5% beet pulp, 10.0% canola meal, 2.5% beet molasses and 4.1% vitamin and minerals on a DM basis (Table 2.2.). Treatment diets contained 20% CDDGS, TDDGS or WDDGS on a DM basis, as a direct replacement of 10% barley grain and 10% canola meal. All diets were formulated to meet or exceed NRC requirements for growing lambs (NRC 2007) and were fed as a pelleted total mixed ration.

Sixty Canadian Arcott ram lambs were weaned at 49 ± 4 d onto a lamb grower ration for a 14-d transition period, then were assigned to receive one of four experimental diets (n = 15) commencing at 63 ± 4 d of age, at an average live weight of 22.6 ± 0.6 kg. Lambs were housed in individual pens (0.97 m × 2.82 m) bedded with straw, and had free access to water. Feed was delivered once daily in quantities to meet ad libitum intake.

Table 2.2. Ingredients and chemical composition of the diets containing corn-, wheat- or triticale-based distillers' grains with solubles (CDDGS, WDDGS, and TDDGS, respectively)

	Diet (n = 2)			
Item	Control	CDDGS	WDDGS	TDDGS
Ingredient (%, DM basis)				
Barley grain, milled	55.9	45.9	45.9	45.9
Canola meal	10.0	—	—	—
CDDGS	—	20.0	—	—
WDDGS	—	—	20.0	—
TDDGS	—	—	—	20.0
Sunflower hulls	16.0	16.0	16.0	16.0
Beet pulp	11.5	11.5	11.5	11.5
Beet molasses	2.5	2.5	2.5	2.5
Calcium carbonate	1.8	1.8	1.8	1.8
Canola oil	0.5	0.5	0.5	0.5
Sheep mineral[z]	1.3	1.3	1.3	1.3
Feed pellet binder	0.5	0.5	0.5	0.5
Vitamin A, D & E[y]	0.03	0.03	0.03	0.03
Chemical composition				
Dry matter	91.1	91.8	91.7	91.8
----------Expressed as % of DM----------				
Organic matter	91.2	91.5	90.5	91.5
Neutral detergent fibre	20.1	23.7	23.7	23.1
Acid detergent fibre	11.8	12.9	13.5	13.1
Crude protein	16.8	17.8	18.1	17.2
Ether extract	3.9	6.2	5.6	5.3
Fatty acids (% of total FAME[x])				
14:0	0.39	0.13	0.17	0.27
15:0	0.09	0.03	0.04	0.06
16:0	20.35	11.98	12.88	16.77
16:1 *c*9	0.38	0.12	0.13	0.15
17:0	0.65	0.13	0.18	0.29
18:0	7.03	4.03	4.31	5.16
*c*9-18:1	38.78	28.03	26.5	30.02
*c*11-18:1	3.75	0.83	0.94	1.18
*c*9, *c*12-18:2	24.33	51.27	50.99	42.25
*c*9, *c*12, *c*15-18:3	0.7	1.61	2.01	1.44
20:0	0.87	0.50	0.46	0.55
c11-20:1	0.91	0.50	0.56	0.73
20:4	0.08	0.07	0.06	0.11
22:0	1.68	0.76	0.76	1.03
Saturated	31.05	17.56	18.81	24.12
Unsaturated	68.95	82.44	81.19	75.88
Monounsaturated	43.84	29.48	28.13	32.08
Poly-unsaturated	25.11	52.96	53.06	43.79

[z]Containing (g kg^{-1}): NaCl (926); Dynamate® (49.7); $ZnSO_4$ (9.0); $MnSO_4$ (8.3); $CuSO_4$ (1.3); ethylenediamine dihydroiodide, 80% preparation (1.0); $CoSO_4$ (0.05); canola oil (as carrier of $CoSO_4$) (4.0); and $NaSeO_3$ (0.014; provided as a 1% premix).

[y]Conataining vitamin A (10 000 000 IU kg^{-1}), vitamin D (1 000 000 IU kg^{-1}), and vitamin E (10 000 IU kg^{-1}).

[x]Fatty acids are expressed as a percentage of total fatty acid methyl esters (FAME), c, cis.

2.2.2. In Vitro Incubation

Inoculum for the in vitro incubations was prepared from ruminal contents of three ruminally cannulated Holstein cows. The cows had *ad libitum* access to a diet that consisted of 38.3% barley silage, 56.0% concentrate and 5.7% chopped alfalfa/grass hay on a DM basis.

Ruminal contents were collected from the ventral sac and mid-dorsal feed mat of each cow 2 h after the morning feeding. The ruminal contents were combined and squeezed through two layers of cheesecloth into an insulated container and transported 0.5 km back to the laboratory, where pH was recorded.

Prior to the incubations, the pelleted diets described above were each ground to pass through a 4-mm screen, and single diets were weighed in 0.5-g quantities into 120-mL amber serum bottles (six bottles per diet). Bottles were pre-warmed to 39ºC and flushed with CO_2. Filtered ruminal content was combined with three volumes of buffer solution (Menke et al. 1979) that had been pre-warmed to 39ºC under CO_2. Inoculum was dispensed (40-mL quantities) under CO_2 to each serum bottle. Bottles were sealed immediately and placed on a rotary shaker (Lab-line Instruments Inc. Melrose Park, IL) at 150 rpm in a cabinet-style incubator (Forma Scientific, Marietta, OH) at 39ºC. Six bottles containing no substrate were also prepared as blanks to correct for gas, ammonia and VFA production that originated solely from the inoculum.

After 3, 6, 12 and 24 h of incubation, total gas production was determined for six replicates of each treatment and the six control bottles using a water

displacement technique (Fedorak and Hrudey 1983). After 24-h of incubation, pH was measured, and 1.5-mL duplicate samples were collected to determine concentrations of VFA and ammonia. Samples for VFA analysis were preserved in 300 µL of 25% (wt/vol) metaphosphoric acid, and those for ammonia analysis were mixed with 200 µL of 65% (wt/vol) trichloroacetic acid. All samples were stored at -20°C until analyzed. Contents remaining in the serum bottles were transferred to pre-weighed centrifuge tubes. After centrifugation, pellets were washed with ethanol, re-centrifuged and dried for determination of in vitro dry matter digestibility (**IVDMD**).

For in vitro incubation, VFA concentrations were quantified using gas chromatography (Hewlett Packard 5890, Agilent Technologies, Mississauga, ON) with crotonic acid as the internal standard. Ammonia concentration from in vitro samples were analyzed by the phenol hypochlorite method (Weatherburn 1967).

2.2.3. Data and Sample Collection

The amount of feed offered was recorded daily. Orts were weighed weekly to determine DMI. For each lamb, DMI was calculated from the linear regression between cumulative DMI and week, and the slope was divided by 7 to obtain daily DMI. Feed samples from each diet were collected daily and composited by month. Lambs were weighed weekly, and ADG was calculated as the linear regression between body weight and week for each lamb. The regression values for DMI and ADG were used to calculate FE (as feed consumed divided by ADG).

Once live weights of > 45 kg had been attained by approx. 60% of the lambs, the 11 heaviest individuals in each treatment group were shipped in one load (average live weight 48.1 ± 3.7 kg) to a commercial abattoir (Sunterra Meats, Innisfail, AB). Within 5 min of exsanguination, a 2-3 g fat sample was collected from the base of the tail, kept on ice, and transported back to the lab where they were snap frozen in liquid nitrogen and stored at -80 ºC until analyzed for fatty acid profiles. Hot carcass weights were measured. Muscle scores were determined for the shoulder, loin and hind leg on a scale of 1 to 5 in which 1 = extremely poor and 5 = extremely good. Grade rule (i.e., body wall thickness) was determined from the total tissue depth of the lamb carcass over the 12-13th rib at 11 cm from the carcass midline. Saleable meat yield (**SMY**) was determined from proximal cuts including shortcut semi boneless leg, sirloin, chine off rack, loin short cut, square shoulder and front shank; each trimmed to ≤ 0.64 cm subcutaneous fat as per commercial standards (Chaves et al. 2008).

2.2.4. Chemical Analysis

The DM concentration of the composited feed samples was determined by oven-drying at 135 ºC for 2 h followed by hot weighing (AOAC, 1995; method 930.15), and OM was determined by ashing samples at 550 ºC for 5 h. To determine CP (nitrogen × 6.25), feed samples were ground to a fine powder using a ball grinder (Mixer Mill MM200, Retsch inc., Newtown, PA). Nitrogen was quantified by flash combustion with gas chromatography and thermal conductivity detection (Nitrogen Analyzer 1500 series, Carlo Erba Instruments, Milan Italy). Neutral detergent fibre was determined according to Van Soest et al.

(1991) using heat-stable α-amylase and sodium sulfite. Acid detergent fiber was determined according to the procedure of AOAC (1995, method 973.18). Crude fat content was determined by extraction with ether (method 920.39; AOAC, 1990) using a Goldfisch Fat Extractor (Laconco Corporation, Kansas City, MO). Fatty acid methyl esters (**FAME**) were prepared according to a combined base/acid methylation method of Kramer et al. (1997) with modifications (He et al. 2009). The FAME were then quantified using gas chromatography (Hewlett Packard GC System 6890N; Mississauga, ON), and flame ionization detection as described by He et al. (2009), but modified so that samples were loaded on to the column via 1 μL splitless injections.

Adipose tissue samples were freeze-dried and methylated with sodium methoxide, and the FAME were analyzed using gas liquid chromatography and silver ion high performance liquid chromatography as described by Cruz-Hernandez et al. (2004) with minor modifications as two complementary gas liquid chromatography temperature programs were used for *trans*-18:1 analysis (Dugan et al. 2007; Kramer et al. 2008). Reference standards are described by Aldai et al. (2008). The *trans*-18:1 and CLA isomers not included in the standard mixtures were identified by their retention times and elution orders as reported previously (Dugan et al. 2007).

2.2.5. Statistical Analyses

2.2.5.1. Growth Study

Growth performance and carcass trait data were analyzed as a completely randomized design using the proc MIXED procedure of SAS (SAS Inc., 2009 SAS Online Doc® 9.1.3. Cary, NC, USA). The model included treatment as a fixed effect, lamb as a random effect, and residual error as the error term. One lamb from the control treatment was removed from the statistical analysis for carcass trait data because it was condemned at slaughter for reasons unrelated to treatment. Least square means were separated using the Bonferroni t-test. Significance was declared at $P \leq 0.05$ and a tendency was declared at $0.05 < P \leq 0.10$.

2.2.5.2. In Vitro Incubation

All in vitro data were analyzed as a completely randomized design using the proc MIXED procedure of SAS (SAS Inc., 2009 SAS Online Doc® 9.1.3. Cary, NC, USA), with individual vial as an experimental unit. The model included treatment as a fixed effect, and residual error was used as the error term. Measurements conducted at each time point were analyzed independently. Least square means were separated using the Bonferroni t-test. Significance was declared at $P \leq 0.05$ and a tendency was declared at $0.05 < P \leq 0.10$.

2.3. Results

2.3.1. In Vitro Incubations

Inclusion of CDDGS, WDDGS or TDDGS in the diets did not affect (P = 0.12) in vitro pH, which averaged 6.5 ± 0.05 across treatments (Table 2.3.).

Ammonia concentration at 24 h was approximately 60% higher ($P < 0.05$) for the WDDGS diet compared to the CDDGS and TDDGS diets, but did not differ from that of the control diet. Gas production among the four diets varied over time. Total gas production was higher ($P < 0.05$) from the control diet than from WDDGS and CDDGS diets, with TDDGS intermediate. In vitro dry matter digestibility was lower ($P < 0.05$) for the WDDGS diet compared to the other diets. Although total VFA concentrations did not differ ($P = 0.14$) among the four diets (averaging 67.3 ± 0.72 mM), the proportion of individual VFA differed among treatments. Concentration of acetate was higher ($P < 0.05$) in incubations with WDDGS than with TDDGS, and neither of these diets differed from control or CDDGS. Propionate accumulation was lower ($P < 0.05$) with WDDGS than the other DDGS diets, and numerically lower than with control diet. These factors resulted in higher ($P < 0.05$) acetate:propionate ratios with WDDGS and control than with CDDGS or TDDGS. Butyrate production was higher ($P < 0.05$) with TDDGS and control than with CDDGS and WDDGS.

Table 2.3. In vitro fermentation characteristics of diets containing corn-, wheat-, or triticale-based dry distillers' grains plus solubles (CDDGS, WDDGS and TDDGS, respectively) in place of 10% barley grain and 10% canola meal

	Experimental diet[z]					
Item[y]	Control	CDDGS	WDDGS	TDDGS	SEM	*P* value
pH	6.5	6.5	6.5	6.4	0.05	0.12
Ammonia (mM)	7.7*ab*	6.1*b*	9.9*a*	6.3*b*	0.72	<0.01
Gas production (mL g DM incubated^{-1})						
3 h	41.6*c*	43.2*bc*	48.7*a*	46.6*ab*	0.53	<0.01
6 h	63.0*a*	59.6*b*	56.7*c*	58.6*bc*	0.27	<0.01
12 h	54.6*a*	48.5*b*	45.7*c*	49.8*b*	0.41	<0.01
24 h	51.3*a*	46.8*b*	49.5*a*	50.5*a*	0.25	<0.01
Total gas production	210.6*a*	198.1*b*	200.6*b*	205.5*ab*	0.99	<0.01
IVDMD[x] (%)	77.7*a*	76.8*a*	72.9*b*	78.2*a*	1.38	0.05
Corrected total VFA production (mM)	68.75	66.65	66.54	67.3	0.72	0.14
Volatile fatty acids (molar %)						
Acetate	62.21*ab*	62.41*ab*	62.85*a*	61.85*b*	0.186	0.01
Propionate	19.27*b*	20.00*a*	19.05*b*	19.94*a*	0.077	<0.01
Butyrate	13.33*a*	12.77*b*	12.85*b*	13.33*a*	0.105	<0.01
Isobutyrate	1.05*a*	0.94*b*	0.96*b*	0.93*b*	0.010	<0.01
Isovalerate	1.67*a*	1.60*ab*	1.61*ab*	1.53*b*	0.019	<0.01
Valerate	2.05*b*	1.89*c*	2.26*a*	2.00*b*	0.020	<0.01
Caproic	0.42*a*	0.39*b*	0.43*a*	0.41*ab*	0.009	0.04
Acetate:Propionate	3.23*a*	3.12*b*	3.30*a*	3.10*b*	0.020	<0.01
Total VFA concentration (mM)[w]	68.75	66.65	66.54	67.3	0.72	0.14

[z]In each case, DDGS replaced 10% barley grain and 10% canola meal in the control diet.
[y]All measurements were conducted after 24 h of incubation, except gas production as indicated.
[x]IVDMD: In vitro dry matter digestibility.
[w]Total VFA concentrations were corrected using values measured in the substrate-free controls (i.e., production solely from the inoculum).
a,b: Within a row, means lacking a common letter differ ($P < 0.05$).

2.3.2. Growth Performance and Carcass Characteristics

Including CDDGS, WDDGS or TDDGS in the diets did not affect ($P \geq 0.05$) DMI or ADG, which averaged 1.45 kg d^{-1} and 0.39 kg, respectively (Table 2.4.). Numerically greater intake and slower gain by lambs fed WDDGS led to their having less efficient ($P < 0.05$) gain compared to those fed the control and CDDGS diets.

Table 2.4. Effect of replacing 10% barley grain and 10% canola meal with corn-, wheat- or triticale-based dried distillers' grains plus solubles (CDDGS, WDDGS and TDDGS, respectively) in the diet on performance of lambs

	Experimental diet					
	Control (n = 15)	CDDGS (n = 15)	WDDGS (n = 15)	TDDGS (n = 15)	SEM	P value
Dry matter intake (kg d^{-1})	1.39	1.47	1.51	1.43	0.057	0.52
Average daily gain (kg d^{-1})	0.38	0.40	0.37	0.39	0.015	0.51
Feed efficiency (feed:gain)	3.65*b*	3.63*b*	4.08*a*	3.71*ab*	0.109	0.02

a,*b*: Within a row, means lacking a common letter differ ($P < 0.05$).

Feeding DDGS did not affect ($P \geq 0.39$) carcass traits (hot carcass weight, body wall thickness, or muscle scores of the leg, shoulder and loin (Table 2.5.). Saleable meat yield and the weights of individual cuts of meat were not affected by treatment ($P \geq 0.26$) except for front shank ($P = 0.02$). The front shanks of lambs fed control and CDDGS diets were heavier ($P < 0.05$) than those of lambs fed WDDGS and TDDGS.

Table 2.5. Effect of replacing 10% barley grain and 10% canola meal with corn-, wheat- or triticale-based dried distillers' grains plus solubles (CDDGS, WDDGS and TDDGS, respectively) in the diet on carcass characteristics of lambs

	Experimental diet					
	Control (n = 10)	CDDGS (n = 11)	WDDGS (n = 11)	TDDGS (n = 11)	SEM	P value
Hot carcass weight (kg)	25.3	25.4	24.6	24.3	0.67	0.61
Grade rule (mm)[z]	17.1	15.5	15.5	15.6	0.80	0.47
Muscle scores[y]						
Leg muscle	3.4	3.4	3.1	3.4	0.14	0.39
Shoulder muscle	3.1	3.1	3.2	3.2	0.11	0.89
Loin muscle	3.3	3.2	3.2	3.2	0.13	0.90
Salable meat yield (kg)[x]	14.7	14.9	14.3	14.2	0.42	0.60
Weight of meat cuts (kg)						
Short cut semi-boneless leg	4.72	4.85	4.46	4.63	0.137	0.26
Sirloin, cap on	0.61	0.60	0.61	0.57	0.030	0.70
Short loin, bone in	1.70	1.74	1.76	1.76	0.057	0.90
Chine off rack	2.04	1.97	1.94	1.99	0.079	0.87
Square cut shoulder	4.97	5.04	4.90	4.64	0.171	0.37
Front shank	0.70*a*	0.71*a*	0.63*b*	0.63*b*	0.023	0.02
Waste (kg)[w]	3.21	3.05	3.12	2.98	0.131	0.64

[z]Body wall thickness between the 12th and 13th rib, 11 cm from the carcass midline.

[y]Scored on a subjective scale from 1 (extremely poor) to 5 (extremely good).

[x]Determined from proximal cuts including short cut leg, sirloin, chine off rack, loin short cut, square shoulder and front shank.

[w]Amount of tissue trimmed from meat cuts to reduce subcutaneous fat to ≤ 0.64 cm, in accordance with commercial standards.

a,b: Within a row, means lacking a common letter differ ($P < 0.05$).

Although differences among treatments in the proportions of several individual fatty acids were observed (Table 2.6.), proportions of total SFA, mono-unsaturated and Poly-unsaturated fatty acids (**MUFA** and **PUFA**, respectively) in subcutaneous adipose tissues were not affected by treatment ($P \geq 0.13$). Individual

concentrations of 10:0 and 12:0 fatty acids were higher ($P < 0.05$) in lambs fed TDDGS than in the controls. Lambs fed CDDGS had higher ($P < 0.05$) concentration of 17:0 in subcutaneous fat tissue than did those fed TDDGS. The concentration of *cis* 11-18:1 was highest in tail fat of lambs fed the control diet. Feeding TDDGS increased ($P < 0.05$) tail fat concentrations of *trans* 16-18:1 and of *cis* 9-18:1 compared to feeding the other three diets, whereas *trans* 10-18:1 concentration was 31.4% lower ($P < 0.05$) in lambs fed TDDGS compared to those fed the other diets. Lambs fed TDDGS had a higher proportion of *cis* 9, *trans* 11-CLA and a lower proportion of *trans* 10, *trans* 12-CLA compared to those fed CDDGS. Ratios of *n*-6/*n*-3 fatty acids and PUFA/SFA, which averaged 10.1 ± 0.81 and 0.18 ± 0.012 across treatments, respectively, were not affected by treatment ($P \geq 0.16$).

Table 2.6. Effect of replacing 10% barley grain and 10% canola meal with corn-, wheat- or triticale dried distillers' grains (CDDGS, WDDGS and TDDGS, respectively) in the diet on in the diet on fatty acid profiles in subcutaneous tail fat of lambs

Component[z]	Experimental diet				SEM	*P* value
	Control (*n* = 11)	CDDGS (*n* = 11)	WDDGS (*n* = 11)	TDDGS (*n* = 11)		
Saturated fatty acids (SFA)						
10:0	0.17*b*	0.20*ab*	0.19*ab*	0.25*a*	0.021	0.05
12:0	0.16*b*	0.21*ab*	0.26*ab*	0.29*a*	0.031	0.03
14:0	3.31	3.62	4.12	4.04	0.233	0.06
15:0	1.12	1.16	0.98	0.89	0.082	0.10
15:0 iso	0.23	0.23	0.2	0.2	0.030	0.86
15:0 ai	0.22	0.22	0.2	0.21	0.011	0.43
16:0	21.71	22.10	22.83	22.5	0.571	0.54
16:0 iso	0.29	0.28	0.26	0.27	0.026	0.86
17:0	2.67*ab*	2.80*a*	2.21*ab*	2.12*b*	0.170	0.01
17:0 iso	0.47	0.45	0.47	0.46	0.018	0.79
17:0 ai	0.82	0.8	0.7	0.74	0.049	0.31
18:0	12.05	12.16	11.3	12.38	0.877	0.83
18:0 iso	0.18	0.17	0.16	0.17	0.011	0.62
19:0	0.11	0.12	0.12	0.12	0.004	0.53
20:0	0.08	0.08	0.08	0.08	0.006	0.88
Total SFA	43.59	44.59	44.08	44.72	0.750	0.70
Mono-unsaturated FA (MUFA)						
*c*9-14:1	0.14	0.15	0.16	0.17	0.019	0.53

Table 2.6. Con't. Effect of replacing 10% barley grain and 10% canola meal with corn-, wheat- or triticale dried distillers' grains (CDDGS, WDDGS and TDDGS, respectively) in the diet on in the diet on fatty acid profiles in subcutaneous tail fat of lambs

Component[z]	Experimental diet				SEM	*P* value
	Control (*n* = 11)	CDDGS (*n* = 11)	WDDGS (*n* = 11)	TDDGS (*n* = 11)		
*c*7-16:1	0.37	0.35	0.36	0.38	0.012	0.42
*c*9-16:1	1.48	1.46	1.6	1.73	0.114	0.32
*c*9-17:1	1.22	1.24	1.05	1.09	0.124	0.61
*c*9-18:1	29.67*b*	29.73*b*	29.55*b*	32.94*a*	0.914	0.03
*c*11-18:1	1.15*a*	0.99*ab*	0.95*b*	0.90*b*	0.050	0.01
*c*12-18:1	0.34	0.42	0.45	0.4	0.061	0.62
*c*13-18:1	0.11	0.11	0.11	0.11	0.008	0.90
*c*14-18:1	0.04	0.05	0.04	0.05	0.004	0.57
*t*6, *t*8-18:1	0.55	0.72	0.72	0.57	0.070	0.19
*t*9-18:1	0.52	0.66	0.66	0.55	0.055	0.16
*t*10-18:1	8.96*a*	8.91*a*	9.01*a*	6.15*b*	0.829	0.05
*t*11-18:1	1.94	1.04	1.20	1.23	0.368	0.33
*t*12-18:1	0.26	0.29	0.28	0.32	0.039	0.75
*t*13, *t*14-18:1	0.41	0.42	0.42	0.45	0.059	0.98
*t*15-18:1	0.13	0.09	0.11	0.14	0.015	0.07
*t*16-18:1	0.06*b*	0.07*b*	0.06*b*	0.10*a*	0.011	0.05
*t*11-20:1	0.21	0.20	0.20	0.17	0.009	0.07
Total MUFA	47.44	46.79	46.81	47.31	0.671	0.87
Conjugated linoleic acid (CLA)						
*c*9, *t*11-CLA	0.39*ab*	0.35*b*	0.41*ab*	0.50*a*	0.035	0.04
*t*7,*c*9-CLA	0.19	0.22	0.22	0.19	0.017	0.42
*t*8, *c*10-CLA	0.02	0.02	0.02	0.02	0.001	0.79
*t*9, *c*11-CLA	0.12	0.10	0.10	0.09	0.013	0.27
*t*10, *c*12-CLA	0.12*ab*	0.13*a*	0.13*a*	0.09*b*	0.012	0.03
*t*11, *c*13-CLA	0.01	0.01	0.01	0.01	0.001	0.21
Total CLA	0.86	0.84	0.90	0.90	0.048	0.76
Poly-unsaturated FA (PUFA)						
18:2 *n*-6	6.57	6.29	6.60	5.47	0.351	0.10
20:2 *n*-6	0.07	0.06	0.06	0.05	0.004	0.17
20:3 *n*-6	0.05	0.04	0.04	0.04	0.003	0.16
20:4 *n*-6	0.17	0.15	0.18	0.15	0.010	0.09
22:4 *n*-6	0.05	0.05	0.04	0.04	0.005	0.39
18:3 *n*-3	0.49	0.49	0.54	0.59	0.048	0.37
20:5 *n*-3	0.02	0.02	0.01	0.01	0.003	0.29
22:5 *n*-3	0.11	0.10	0.11	0.11	0.010	0.80
22.6 *n*-3	0.02	0.02	0.03	0.02	0.004	0.26
Total PUFA	7.53	7.22	7.62	6.47	0.370	0.13
PUFA/SFA	0.19	0.18	0.19	0.16	0.012	0.16
n-6 / *n*-3	10.88	10.65	10.25	8.70	0.807	0.23

[z]Fatty acids are expressed as a percentage of total fatty acid methyl esters, *c*, cis; *t*, trans; ai, anteiso.

2.4. Discussion

Similar to our findings, previous research feeding sheep 22.9% CDDGS in place of a mixture of soybean meal and corn (Huls et al. 2006) and 40% CDDGS in place of dry rolled corn (Lodge et al. 1997) found no effect of CDDGS on FE. The less efficient gains for lambs fed WDDGS compared to those fed the control diet differs from previous studies in which feed efficiencies were unaffected when finishing cattle were fed up to 23% WDDGS (Beliveau and McKinnon 2008) or were improved when backgrounding steers were fed 25% WDDGS (McKinnon and Walker 2008). McKeown et al. (2009) reported that feed efficiencies were not affected when lambs were fed increasing amounts of TDDGS up to 60% of diet DM.

Poorer FE of lambs fed WDDGS compared to those fed CDDGS may have been attributable in part to the higher EE content of the CDDGS diet. In a more detailed study, Ham et al. (1994) found greater energy availability for growth in diets containing distillers' co-products with higher fat content compared with dry-rolled corn. Previous in vitro work in which ground grass hay substrate was amended with up to 10% corn oil determined that propionate concentration was increased, with no change in acetate concentration, which led to a decrease in the acetate to propionate ratio (Jenkins 1987). The corn oil present in CDDGS may be one explanation for the increased propionate production from the fermentation of CDDGS.

The efficiencies of converting hexose to acetate, propionate and butyrate are 62%, 109% and 78%, respectively, due to carbon losses as CO_2 in the production of acetate and butyrate (Chalupa, 1977). This is further supported by the lower total gas production from the CDDGS diet compared to other dietary treatments. Factors other than EE content could also be involved in improving FE, however, given that feed conversion ratios of lambs fed the control diet were similar to those fed the CDDGS diet, even though the EE content was lowest for the control diet.

Although Jenkins (1987) observed depressed fibre digestibility in response to corn oil supplementation, IVDMD in the present study was not reduced for the CDDGS diet, nor was total VFA production, indicating that the greater fat content of the CDDGS diet did not negatively affect microbial fermentation. However, the lower acetate:propionate ratio associated with the CDDGS diet compared to the control and the WDDGS diets may indicate that fibre digestion was reduced (Getachew et al. 2004).

Greater ammonia concentration for the WDDGS treatment compared to the CDDGS treatment indicated that protein degradability may differ among diets, which possibly led to the inefficient gains for lambs fed the WDDGS diet compared to those fed the CDDGS diet. There is a large variation among ethanol plants as to the amount of TS, commonly referred to as solubles (Rust et al. 1990), that are added back to the distillers' grains (Spiehs et al. 2002). The CP in wheat TS is rapidly degraded (Iwanchysko et al. 1999) and rapid degradation of protein

leads to an increase in ammonia production (McDonald 1948). Increased ammonia concentration may result in nitrogen being utilized less efficiently for bacterial protein production, thus reducing the amount of metabolizable protein available to the animal (McDonald 1952). In addition, animals require additional energy to detoxify absorbed ammonia via urea synthesis (McBride and Kelly 1990). Lower IVDMD for the WDDGS diet would have also contributed to lower feed efficiencies.

2.4.1. Carcass Traits

Our findings that feeding CDDGS, WDDGS or TDDGS did not affect carcass traits, with the exception of the front shank, are in agreement with results found by Beliveau and McKinnon (2008) who fed finishing cattle up to 23% WDDGS and Ham et al. (1994) who fed 40% CDDGS to finishing cattle. Similarly, McKeown et al. (2009) reported hot carcass weight and SMY were not affected by inclusion of up to 60% of TDDGS in lamb diets. No differences in hot carcass weights among the diets are consistent with no treatment effect on ADG. Although front shanks were heavier for lambs fed the control and CDDGS diets, the difference was not enough to affect overall SMY.

2.4.2. Fatty Acid Composition

Overall, the diets fed in the present experiment led to relatively high levels of *trans* 10-18:1. This *trans* isomer has been linked to an increased risk for coronary heart disease in humans (Hodgson et al. 1996). The high levels of *trans* 10-18:1 likely relate to a lack of dietary forage (Palmquist et al. 2004) which

created a rumen environment unsuitable for growth of the bacteria that biohydrogenate PUFA using the *trans* 11-18:1 pathway (Klieve et al. 2003). Feeding TDDGS produced some improvement in the *trans*-18:1 composition, however, with lambs fed TDDGS fed lambs yielding lower tail fat *trans* 10-18:1 concentrations (P = 0.05) than did those fed any of the other three diets. Moreover, the concentration of *cis* 9, *trans* 11-CLA, the fatty acid associated with anti-carcinogenic properties (Ha et al. 1990), was slightly increased by feeding TDDGS, although there was no difference in the amount of its precursor, *trans* 11-18:1.

Our results from feeding WDDGS contrast those from an earlier study in which feeding up to 60% WDDGS to finishing cattle decreased the concentration of *trans* 10-18:1 and increased the concentration of *cis* 9, *trans* 11-CLA (Dugan et al. 2008). In the present study, however, feeding TDDGS did produce these results. These results suggest that adding higher levels of TDDGS to lamb diets may have a positive impact on the fatty acid profile of carcass fat. However, the PUFA/SFA ratios in lamb carcass fat were not affected by diet and were similar to the PUFA/SFA ratios reported by Enser et al. (1996), which are below 0.7. A ratio greater than 0.7 is recommended by health advisors to reduce the risk of heart disease or cancer (Raes et al. 2004; Wood et al. 2003). The n-6/n-3 fatty acid ratio was also not affected by diet, but was more than twice that of the ratio (4.0 or less) recommended to reduce the onset of coronary heart disease and stroke (Connor 2000; Wood et al. 2003).

Proportions of total SFA, MUFA and PUFA are within 5% of those found by Webb and Casey (1995) in wethers. Elevation of PUFA in adipose tissue can alter the shelf life and flavor of the meat (Wood et al. 2003). As there were no differences in the concentration of PUFA, they would not be expected to alter the shelf life or flavor of the meat harvested from lambs in this study. Shand et al. (1998) and Jenschke et al. (2007) fed 13.4% wet wheat distillers' grain or up to 50% wet corn distillers' grains in the diet of beef cattle, respectively, and did not find diet effects on tenderness, juiciness, or flavor of the meat. The higher concentration of 17:0 in subcutaneous tissue for lambs fed CDDGS is also indicative of a higher energy feed diet (Casey and Webb 1995).

2.5. Conclusion

This study indicates that feeding up to 20% of CDDGS, WDDGS or TDDGS in place of a mixture of barley grain and canola meal does not adversely affect DMI, ADG, or carcass traits of lambs. Feeding WDDGS to lambs may decrease feed conversion ratio (feed:gain), and feeding TDDGS may improve the fatty acid profile of the meat possibly increasing the human health properties of lamb.

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3.0. EFFECTS OF REPLACING BARLEY GRAIN WITH TRITICALE-BASED DRIED DISTILLERS' GRAINS PLUS SOLUBLES ON NUTRIENT DIGESTIBILITY, LAMB GROWTH PERFORMANCE AND CARCASS TRAITS[2]

3.1. Introduction

Distillers' grains are a co-product of ethanol production, and the use of DDGS in livestock feed is increasing as the ethanol industry expands. In eastern Canada and the United States, corn is utilized extensively for ethanol production (Beliveau and McKinnon 2008). However, in western Canada, the cooler climate is unfavorable for growing corn (Boila and Ingalls 1994) and consequently, wheat plays a more prominent role in ethanol production (Lan et al. 2008). Triticale, a cross between wheat and rye, is another potential substrate for ethanol production, as its fermentation efficiencies are similar to those of wheat (Wang et al. 1999). Compared to wheat, triticale has many desirable properties as a potential biorefinery crop, such as its ability to grow in water-deficient soils (Giunta and Motzo 2004), lower susceptibility to *Fusarium culmorum* (Miedaner et al. 2001), and high grain yield (Rosenberger et al. 2002).

Numerous feeding trials have been conducted with CDDGS and to a lesser extent with WDDGS. Previous experiments have reported increased FE when beef cattle were fed finishing diets with CDDGS included at up to 40% in place of dry rolled corn (Larson et al. 1993; Ham et al. 1994; Al-Suwaiegh et al. 2002).

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Feed efficiency has generally remained the same or been improved when the proportion of WDDGS is less than 50% DM in growing (McKinnon and Walker 2008) or finishing (Beliveau and McKinnon 2008) diets for beef cattle, but it may decline when DDGS is included at 60% DM or higher (Gibb et al. 2008). In general, distillers' grains are used as a protein source when included at 6 to 15% of diet DM and as an energy source when included above 15% diet DM (Klopfenstein 2001). However, distillers' grains are high in both protein and phosphorus, thus these nutrients are supplied in excess when DDGS are included as an energy source in the diet (Klopfenstein et al. 2008). Given the higher concentrations of nitrogen and phosphorus in distillers' grains compared with more traditional feed ingredients, concerns over including them in significant quantities in diets for cattle, also arise with regard to the potential negative effects of these excess nutrients on the environment and the consequent increase in manure disposal costs (Rausch and Belyea 2006).

Currently, very little research has been conducted with TDDGS. Mustafa et al. (2000) found that in vitro and in situ degradabilities of TDDGS were comparable to those of WDDGS, but there is no information on the effects of feeding TDDGS on growth performance of ruminants. The objective of this study was to determine the effects of replacing barley grain with TDDGS at 0, 20, 40 or 60% of dietary DM on feed intake, growth, nutrient digestibility and carcass traits of growing lambs.

3.2. Materials and Methods

This experiment was conducted between November 2007 and March 2008 at the Lethbridge Research Centre (Lethbridge, AB, Canada). All animals were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993).

3.2.1. Dietary Treatments

One lot of TDDGS was purchased from Alberta Distillers Limited (Calgary, AB) and used in both experiments (Table 3.1.). The control diet

Table 3.1. Chemical composition of triticale-based dried distillers' grains plus solubles

Item	% (DM basis) (*n = 2*)
Dry matter	89.3
Neutral detergent fibre[z]	29.6
Acid detergent fibre	13.7
Crude protein	30.7
Ether extract	5.4
Ash	4.4
Organic matter	95.6
Minerals	
Calcium	0.07
Phosphorus	0.78
Sodium	0.01
Potassium	0.99
Sulfur	0.32
Magnesium	0.33

[z]Value not corrected for N.

consisted of (DM basis) 72.5% barley grain, 10% beet pulp, 9.0% sunflower hulls, 3.0% alfalfa meal, 2.5% molasses, 1.2% calcium carbonate, 0.03% mineral vitamin pre-mix, 1.4% salt, and 0.4% feed pellet binder (Table 3.2.). Treatment

Table 3.2. Ingredients and chemical composition of the diets containing increasing amounts of triticale-based dried distillers' grains plus solubles (TDDGS)

	Diet			
Item	Control	20% TDDGS	40% TDDGS	60% TDDGS
Ingredient (%, DM)				
Barley grain, milled	72.5	52.2	31.9	11.3
TDDGS	0.0	20.0	40.0	60.0
Beet pulp	10.0	10.0	10.0	10.0
Sunflower hulls	9.0	9.0	9.0	9.0
Alfalfa meal	3.0	3.0	3.0	3.0
Molasses	2.5	2.5	2.5	2.5
Calcium carbonate	1.125	1.45	1.80	2.30
Sheep mineral[z]	1.35	1.35	1.35	1.35
Vitamin mix[y]	0.025	0.025	0.025	0.025
Feed pellet binder	0.4	0.4	0.4	0.4
Chemical composition				
DM (%)	97.3	97.1	96.6	95.8
----------Expressed as % of DM----------				
NDF	22.2	26.5	27.7	30.6
ADF	11.8	14.3	15.5	17.7
CP	13.0	17.0	20.7	24.5
Starch	41.1	30.6	22.0	13.3
Ether extract	2.5	4.3	5.3	6.8
Ash	7.6	7.6	8.0	9.1
Calcium	0.9	0.9	0.9	1.1
Phosphorus	0.2	0.4	0.5	0.6
Sodium	0.8	0.7	0.6	0.7
Potassium	0.6	0.7	0.9	1.0
Sulfur	0.2	0.2	0.3	0.3
Magnesium	0.2	0.2	0.3	0.3
Fatty acids (% of total FAME[x])				
14:0	0.41	0.23	0.12	0.09
15:0	0.09	0.06	0.04	0.04
16:0	24.1	18.1	14.4	13.6
16:1 *c9*	0.18	0.15	0.14	0.14
17:0	0.20	0.43	0.05	0.12
18:0	7.63	4.57	2.81	2.52
18:1 *c9*	30.4	26.8	23.4	23.5
18:1 *c11*	1.33	1.04	0.74	0.61
18:2 *c9, c12*	30.7	44.7	54.2	55.3
18:3 *c9, c12, c15*	1.30	1.99	2.82	2.90
20:0	0.64	0.43	0.31	0.29
20:1 *t11*	1.31	0.66	0.50	0.46
20:4	0.60	0.28	0.21	0.17
22:0	1.08	0.66	0.31	0.25
Saturated	34.2	24.4	18.0	16.9
Unsaturated	65.8	75.6	82.0	83.1
Mono-unsaturated	33.2	28.6	24.8	24.7
Poly-unsaturated	32.7	47.0	57.2	58.3

[z]Containing (g kg^{-1}): NaCl (926); Dynamate® (49.7); $ZnSO_4$ (9.0); $MnSO_4$ (8.3); $CuSO_4$ (1.3); ethylenediamine dihydroiodide, 80% preparation (1.0); $CoSO_4$ (0.05); canola oil (as carrier of $CoSO_4$) (4.0); and Na_2SeO_3 (0.014; provided as a 1% premix).
[y]Containing vitamin A (10 000 000 IU kg^{-1}), vitamin D (1 000 000 IU kg^{-1}), and vitamin E (10 000 IU kg^{-1}).
[x]FAME: Fatty acid methyl esters.

diets included 20, 40 or 60% TDDGS, which was substituted on a DM basis for barley grain (Table 3.2.). To maintain the Ca:P ratio at 2:1 or above, calcium carbonate content was increased as dietary TDDGS content increased (from 1.13% in control diet to 2.30% in the 60% TDDGS diet). All diets were completely pelleted. For analysis, feed samples from the growth trial were collected daily and composited by month; those from the metabolic trial were collected daily and composited for each 5-d collection period.

3.2.2. Growth Study

3.2.2.1. Animals and Experimental Design

Sixty Canadian Arcott lambs (26.6 ± 3.6 kg average body weight ± SD), were weaned at 84 ± 3 days of age, stratified by body weight and randomly assigned to one of the four treatment groups, with feeding of experimental diets commencing at 14 wk of age. Lambs were housed in individual pens (0.97 m × 2.82 m) bedded with straw, fed at 0900 h daily, and weighed weekly. All lambs had ad libitum access to water and cobalt-iodized salt blocks throughout the study. Feed deliveries were recorded daily, and orts were weighed weekly for determination of weekly DMI. Daily dry matter intake of each lamb was estimated by summing the weekly intake for each lamb over the experimental period and dividing by the number of days on feed. Average daily gain of each lamb over the experimental period was calculated by regression body weight against time. Feed conversion was calculated as feed:gain.

3.2.2.2. Slaughter and Sample Collection

At a live weight of ≥ 50 kg, lambs were slaughtered at a commercial abattoir (Sunterra Meats Ltd., Innisfail, AB). At slaughter, a fat sample (2-3 g) from the base of the tail was collected from each lamb. The samples were kept on ice and transported back to the lab where they were snap-frozen in liquid nitrogen and stored at –80 ºC until analyzed for fatty acids. Hot and cold carcass weights were determined. Saleable meat yield was estimated from proximal cuts including short cut semi-boneless leg, sirloin, chine off rack, loin short cut, square shoulder and front shank; with each cut trimmed to ≤0.64 cm subcutaneous fat as per commercial standards (Chaves et al. 2008). Muscle scores were determined for the shoulder, loin and hind leg on a scale of 1 to 5, with 1 being very poor and 5 being very good. Body wall thickness was estimated as grade rule measurement, i.e., total tissue depth of the lamb carcass over the 12-13th rib, 11 cm from the carcass midline.

3.2.3. Metabolism Study

3.2.3.1 Animals and Experimental Design

Twelve Canadian Arcott ram lambs (196 ± 4 days of age; initial BW 49.7 ± 2.0 kg) were used in a metabolism study designed as a replicated 4 × 4 Latin Square (n = 3). The same four diets used in the growth experiment were fed in four periods, each comprising 21 d. For the first 14 d of each period, the lambs were housed in individual pens (0.97 m × 2.82 m) and provided with free access to feed and water. Feed was delivered at 0900 h daily. For determination of daily

DMI, orts were collected and weighed each day prior to feeding. Immediately prior to feeding on d 15, the lambs were fitted with strap-on canvas fecal collection bags and moved into individual metabolism crates. Feed offered in the crates was restricted to 90% of the *ad libitum* intake determined over the preceding 4 d, but lambs had free access to water. The lambs were allowed 2 d to adapt to the metabolism crates before total fecal and urine collections (for 5 d) commenced on d 17. On the morning of d 22, fecal bags were removed and lambs were returned to the floor pens.

3.2.3.2. Sample Collection

Urine was filtered through wire mesh and collected into a plastic container beneath each metabolism crate. Urine pH was maintained at ≤ 2 through daily additions of 4 N sulfuric acid to each container. Total urine volume was recorded daily, with acid volumes subtracted from daily totals. Each day, a 10% aliquot of urine was filtered through one layer of cheesecloth, and added to 5-d composite samples stored at –20°C for each lamb in each period.

The canvas fecal collection bags were lined with a pre-weighed plastic bag which was changed daily at 0900 h. Feces collected each day were weighed, mixed thoroughly by hand and duplicate subsamples representing 10% of daily fecal production from each lamb were retained. Samples from each lamb were combined over the 5-d period and stored at –20°C until analyzed. One of the duplicates was used for wet analysis and the other for dry analysis.

3.2.4. Chemical Analyses

Analytical DM was determined by oven-drying at 135 ºC for 2 h followed by hot weighing (AOAC, 1990; method 930.15) and organic matter was determined by ashing at 550 ºC for 5 h. To determine CP (nitrogen × 6.25), samples were ground using a ball grinder (Mixer Mill MM200, Retsch Inc., Newtown, PA). Nitrogen was quantified by flash combustion with gas chromatography and thermal conductivity detection (Nitrogen Analyzer 1500 series, Carlo Erba Instruments, Milan, Italy). Ammonia concentration in urine samples was analyzed by the phenol hypochlorite method (Weatherburn 1967). Total phosphorus, calcium, sulfur, magnesium, sodium and potassium were determined for dried feed and fecal samples using nitric acid digestion prior to analysis with inductively coupled plasma mass spectrometry (Method 3050B; EPA 1996). Water extractable phosphorus was determined by mixing the wet equivalent of 1 g DM of feces with 200 mL of H_2O, shaking for 1 h followed by centrifugation (Kleinman et al. 2005) and analysis by inductively coupled plasma mass spectrometry. Neutral detergent fibre was determined according to Van Soest et al. (1991) with heat-stable α-amylase and sodium sulfite included. Acid detergent fibre was determined according to the procedure of AOAC (1990, method 973.18). Crude fat content was determined by extraction with ether (method 920.39; AOAC, 1990) using a Goldfisch Fat Extractor (Laconco Corporation, Kansas City, MO).

From each treatment group, five of the tail fat samples collected at slaughter were selected randomly and freeze-dried. Fatty acids were methylated

with sodium methoxide and the FAME were analyzed using gas liquid chromatography and silver ion high performance liquid chromatography (Ag^+-HPLC) as outline by Cruz-Hernandez et al. (2004). However, two complementary gas liquid chromatography temperature programs were used for *trans*-18:1 analysis (Dugan et al 2007; Kramer et al. 2008); for the identification of FAME by gas liquid chromatography, reference standard 463 from Nu-Chek Prep Inc. (Elysian, MN) was used. Branched-chain FAME were identified by using gas liquid chromatography reference standard BC-Mix1 (Applied Science, State College, PA). Reference standards were BC-Mix1 (Applied Science, State College, PA) for branched-chain FAME, and UC-59M (Nu-Chek Prep Inc., Elysian, MN), for CLA. The *trans*-18:1 and CLA isomers not included in the standard mixtures were identified by their retention times and elution orders as reported previously (Dugan et al. 2007).

3.2.5. Statistical Analyses

3.2.5.1. Growth Study

Growth performance data, slaughter traits and fatty acid profiles were analyzed as a completely randomized design using the Proc Mixed procedure of SAS (SAS Inc., 2009 SAS OnlineDoc® 9.1.3. Cary, NC) with individual lamb as the experimental unit. The model included the random effect of lamb and the fixed effect of treatment and the residual error was used as the error term. One lamb from the 40% TDDGS diet and one from the 60% TDDGS diet were removed from the growth performance data due to the development of urinary

calculi. A second lamb from the 40% TDDGS treatment was removed from the carcass trait data because it was condemned at slaughter for reasons unrelated to treatment. Planned orthogonal contrasts were made to determine linear and quadratic effects of feeding increasing amount of TDDGS in the diets of lambs. Significance was declared at $P \leq 0.05$ and a tendency was reported if $0.05 < P \leq 0.10$.

3.2.5.2. Metabolism Study

Dry matter intake, digestibility data and nutrient excretion were analyzed as a replicated 4 × 4 Latin Square design accounting for the effect of carryover, using the MIXED model of SAS (SAS Inc., 2009 SAS OnlineDoc® 9.1.3. Cary, NC). One lamb in period 3 (20% TDDGS) and two additional lambs (Control and 60% TDDGS) in period 4 exhibited symptoms of urinary calculi, and therefore were excluded from all statistical analyses. Another lamb in period 3 (60% TDDGS) was treated for urinary calculi using ammonium chloride, hence data from this individual were excluded from all analysis related to nitrogen metabolism. The model included the random effect of period and lamb nested within square and the fixed effects of treatment and residuals from period 1, 2 and 3. Planned orthogonal contrasts were made to determine linear and quadratic effects of feeding increasing amount of TDDGS in the diets of lambs. Significance was declared at $P \leq 0.05$ and a tendency was reported if $0.05 < P \leq 0.10$.

3.3. Results

3.3.1. Growth Study

Dietary TDDGS level did not affect DMI, ADG or FE, which averaged 1.29 ± 0.04 kg d^{-1}, 0.29 ± 0.01 kg d^{-1} and 4.58 ± 0.19, respectively (Table 3.3.).

Table 3.3. Effect of increasing concentration of triticale-based dried distillers' grains plus solubles (TDDGS) in the diet on performance of lambs

	Experimental diet (TDDGS content)					*P* value	
	Control (*n* = 15)	20% (*n* = 15)	40% (*n* = 14)	60% (*n* = 14)	SEM	Linear	Quadratic
Dry matter intake (kg d^{-1})	1.20	1.35	1.28	1.33	0.04	0.12	0.22
Average daily gain (kg)	0.27	0.31	0.28	0.29	0.01	0.95	0.22
Feed efficiency (feed:gain)	4.48	4.41	4.61	4.81	0.19	0.14	0.48

No linear or quadratic effects on hot carcass weight (26.0 ± 0.4 kg; Table 3.4.) were observed, but cold carcass weight and grade rule responded quadratically (*P* = 0.04) to increasing levels of TDDGS. There were no effects of TDDGS on carcass shrink, muscle scores of the leg, shoulder or loin, SMY, or on weights of individual cuts of meat.

The proportion of *cis* 18:2 *n-6* in subcutaneous tail fat increased linearly (*P* = 0.04) with dietary TDDGS level (Table 3.5.). Similarly, *trans 10, cis 12*-CLA also increased with TDDGS (linear; *P* = 0.02), from 0.06 to 0.11% of total fatty acids. In contrast, no linear or quadratic TDDGS effects were observed for proportions of *cis9, trans11*-CLA, *trans11*-18:1 or *t10*-18:1. Proportions of total

SFA and MUFA in total fatty acids were unrelated to dietary TDDGS content. However, the proportion of PUFA in total fatty acids increased linearly ($P = 0.03$)

Table 3.4. Effect of increasing concentration of triticale-based dried distillers' grains with solubles (TDDGS) in the diet on carcass characteristics of lambs

	Experimental diet (TDDGS content)					*P* value	
	Control (*n* = 15)	20% (*n* = 15)	40% (*n* = 13)	60% (*n* = 14)	SEM	Linear	Quadratic
Hot carcass weight (kg)	25.1	26.8	25.8	26.2	0.4	0.39	0.11
Cold carcass weight (kg)	24.6*b*	26.1*a*	25.5*ab*	25.4*ab*	0.4	0.41	0.04
Shrink (%)	2.24	2.48	2.26	2.90	0.39	0.38	0.61
Grade rule (mm)[z]	15.7*b*	18.6*a*	18.2*a*	17.6*a*	0.8	0.18	0.04
Muscle scores[y]							
Leg muscle	3.1	3.3	3.1	3.1	0.1	0.90	0.47
Shoulder muscle	3.1	3.1	3.2	3.1	0.1	0.72	0.65
Loin muscle	3.1	3.3	3.2	3.1	0.1	0.45	0.28
Saleable meat yield (kg)[x]	15.8	16.5	16.1	16.2	0.3	0.54	0.34
Weight of meat cuts (kg)							
Short cut semi-boneless leg	5.10	5.28	5.08	5.22	0.09	0.87	0.84
Sirloin, cap on	0.70	0.73	0.72	0.71	0.02	0.70	0.32
Short loin, bone in	1.86	2.00	1.97	2.00	0.06	0.22	0.37
Chine off rack	2.14	2.24	2.19	2.19	0.07	0.80	0.48
Square cut shoulder	5.17	5.46	5.24	5.29	0.13	0.99	0.39
Front shank	0.78	0.76	0.81	0.81	0.04	0.37	0.80
Waste[w]	3.25	3.42	3.50	3.38	0.14	0.48	0.30

[z]Body wall thickness between 12th and 13th rib, 11 cm from the carcass midline.
[y]Scored on a subjective scale from 1 (very poor) to 5 (very good).
[x]Determined from proximal cuts including short cut leg, sirloin, chine off rack, loin short cut, square shoulder and front shank.
[w]Amount of tissue trimmed from meat cuts to reduce subcutaneous fat to ≤ 0.61 cm, in accordance with commercial standards.
a,b: Within a row, means lacking a common letter differ ($P < 0.05$).

Table 3.5. Effect of increasing concentration of triticale-based dried distillers' grains plus solubles (TDDGS) in the diet on fatty acid profiles in subcutaneous tail fat of lambs

	Experimental diet (TDDGS content)					*P* value	
Component[z]	Control (n = 5)	20% (n = 5)	40% (n = 5)	60% (n = 5)	SEM	Linear	Quadratic
Saturated fatty acids (SFA)							
10:0	0.22	0.20	0.25	0.22	0.019	0.67	0.87
12:0	0.22	0.21	0.32	0.33	0.063	0.17	0.99
14:0	3.73	3.79	3.80	3.89	0.405	0.78	0.97
15:0	1.39	0.89	1.18	1.00	0.150	0.22	0.30
15:0 iso	0.23	0.31	0.33	0.26	0.095	0.81	0.48
15:0 ai	0.24	0.26	0.23	0.20	0.028	0.24	0.39
16:0	22.9	22.9	21.4	21.6	0.898	0.19	0.94
16:0 iso	0.34	0.40	0.39	0.32	0.071	0.80	0.41
17:0	3.55	2.92	2.87	2.07	0.411	0.03	0.83
17:0 iso	0.51	0.50	0.53	0.53	0.032	0.51	0.84
17:0 ai	1.01	0.93	0.90	0.76	0.133	0.22	0.83
18:0	10.3	10.0	11.3	10.3	1.321	0.83	0.83
18:0 iso	0.24	0.21	0.22	0.20	0.017	0.17	0.84
19:0	0.13	0.09	0.11	0.11	0.011	0.56	0.06
20:0	0.06	0.06	0.07	0.09	0.008	0.52	0.90
Total SFA	45.1	43.6	43.9	43.9	1.792	0.25	0.88
Monounsaturated FA (MUFA)							
14:1 *c9*	0.19	0.22	0.20	0.21	0.054	0.92	0.88
16:1 *c7*	0.35	0.33	0.36	0.35	0.032	0.93	0.88
16:1 *c9*	1.92	1.85	1.53	1.65	0.186	0.19	0.61
17:1 *c9*	1.89	1.81	1.37	1.16	0.364	0.12	0.86
18:1 *c9*	32.2	30.9	30.8	30.5	1.720	0.50	0.79
18:1 *c11*	1.33	1.12	0.99	0.88	0.083	<0.01	0.59
18:1 *c12*	0.42	0.39	0.38	0.48	0.061	0.59	0.32
18:1 *c13*	0.14	0.12	0.12	0.14	0.022	0.9	0.44
18:1 *c14*	0.04	0.34	0.05	0.06	0.005	0.04	0.09
18:1 *t6-t8*	0.28	0.39	0.58	0.57	0.023	0.01	0.48
18:1 *t9*	0.28	0.40	0.58	0.56	0.016	<0.01	0.39
18:1 *t10*	6.11	8.55	7.69	9.09	0.085	0.20	0.70
18:1 *t11*	1.08	0.90	0.97	1.22	0.067	0.51	0.20
18:1 *t12*	0.29	0.27	0.30	0.39	1.343	0.15	0.29
18:1 *t13-t14*	0.42	0.40	0.47	0.53	0.164	0.20	0.51
18:1 *t15*	0.12	0.11	0.12	0.13	0.030	0.84	0.76
18:1 *t16*	0.10	0.07	0.09	0.10	0.048	0.92	0.31
20:1 *t11*	0.18	0.20	0.21	0.21	0.066	0.15	0.83
Total MUFA	47.3	47.9	46.7	48.0	1.635	0.88	0.84
Conjugated linoleic acid (CLA)							
c9, t11-CLA	0.5	0.37	0.45	0.55	0.032	0.55	0.20
t7,c9-CLA	0.12	0.16	0.20	0.22	0.002	<0.01	0.72
t8, c10-CLA	0.02	0.02	0.02	0.23	0.014	0.03	0.31
t9, c11-CLA	0.11	0.15	0.12	0.16	0.084	0.48	0.97
t10, c12-CLA	0.06	0.07	0.09	0.11	0.002	0.02	0.88
t11, c13-CLA	0.01	0.01	0.01	0.01	0.024	0.84	0.75
Total CLA	0.82	0.79	0.89	1.07	0.105	0.09	0.33
Polyunsaturated FA (PUFA)							
18:2 *n*-6	5.29	6.07	6.63	7.28	0.655	0.04	0.92
20:2 *n*-6	0.05	0.06	0.07	0.07	0.009	0.05	0.49

Table 3.5. Con't. Effect of increasing concentration of triticale-based dried distillers' grains plus solubles (TDDGS) in the diet on fatty acid profiles in subcutaneous tail fat of lambs

	Experimental diet (TDDGS content)					*P* value	
Component[z]	Control	20%	40%	60%	SEM	Linear	Quadratic
20:3 *n*-6	0.03	0.04	0.03	0.04	0.005	0.61	0.89
20:4 *n*-6	0.14	0.14	0.15	0.14	0.016	1.00	0.78
22:4 *n*-6	0.03	0.03	0.04	0.04	0.008	0.35	0.77
18:3 *n*-3	0.61	0.62	0.76	0.72	0.073	0.18	0.72
20:5 *n*-3	0.01	0.02	0.02	0.02	0.004	0.28	0.39
22:5 *n*-3	0.09	0.08	0.13	0.12	0.015	0.04	0.83
22.6 *n*-3	0.02	0.02	0.04	0.02	0.006	0.60	0.09
Total PUFA	6.27	7.07	7.87	8.43	0.697	0.03	0.86
PUFA/SFA	0.22	0.20	0.25	0.22	0.019	0.67	0.87
n-6 / *n*-3	7.49	8.91	7.25	7.96	1.346	0.97	0.80

[z]Fatty acids are expressed as a percentage of total fatty acid methyl esters, *c*, cis; *t*, trans; ai, anteiso.

with TDDGS, from 6.27% in lambs fed the Control diet to 8.43% in those fed 60% TDDGS. A linear trend (P = 0.09) toward increased total CLA with increasing TDDGS (from 0.82 to 1.07 ± 0.11% of total FA) was observed, but ratios of *n*-6/*n*-3 FA and PUFA/SFA, were unaffected by level of TDDGS in the diet.

3.3.2 Metabolism Study

3.3.2.1. Digestibility

Dry matter intake of lambs increased linearly (P < 0.01) with increasing TDDGS content (Table 3.6.). Overall, there was a quadratic (P < 0.01) decrease in DM digestibility with increasing TDDGS content, but DM digestibilities were similar among the diets containing TDDGS. Thus, increased DMI resulted in a linear increase (P = 0.02) in the amount of DM digested (g d^{-1}). A linear increase (P < 0.01) in ADF digestibility with increasing TDDGS content was also observed. In contrast, NDF digestibility and amount of NDF digested were not

influenced by dietary TDDGS content. A quadratic response (P = 0.03) in CP digestibility was observed, with lower CP digestibility in TDDGS diets (P < 0.05 for 40% and 60% TDDGS), compared with Control. Amounts of CP digested also tended (P = 0.06) toward a quadratic response, although numerically more CP was digested from the 60% TDDGS diet (221 *vs.* 184 g d^{-1}) than from the Control. Starch digestibility and the amount of starch digested decreased linearly (P < 0.01) with TDDGS addition. Lower (P < 0.05) fat digestibility in the 40% TDDGS diet than in all the others was reflected as a quadratic response (P = 0.02), but amount of fat digested (g d^{-1}) increased linearly (P < 0.01) with increasing TDDGS fed.

Table 3.6. Effect of increasing concentration of triticale-based dried distillers' grains plus solubles (TDDGS) in the diet on nutrient digestibility in lambs

	Experimental diet (TDDGS content)					*P* value	
	Control	20%	40%	60%	SEM	Linear	Quadratic
DM intake (kg d^{-1})	1.1	1.2	1.4	1.5	0.09	<0.01	0.98
Digestibility (%)							
DM	76.4*a*	69.7*b*	68.0*b*	69.1*b*	1.71	<0.01	<0.01
NDF	41.6	31.5	37.6	35.0	4.06	0.50	0.29
ADF	29.9	26.7	39.2	44.6	4.42	<0.01	0.30
Crude protein	79.7*a*	72.3*ab*	67.9*b*	69.8*b*	2.93	<0.01	0.03
Starch	99.0	98.4	96.6	95.2	0.43	<0.01	0.06
Fat	92.4*ab*	94.1*a*	89.2*b*	95.9*a*	0.97	0.51	0.02
Digested (g d^{-1})							
DM	841	855	986	1044	79.2	0.02	0.74
NDF	131	97	153	146	22.7	0.15	0.49
ADF	52	42	85	105	13.3	<0.01	0.24
Crude protein	184	157	186	221	22.4	0.03	0.06
Starch	436	365	318	242	52.6	<0.01	0.92
Fat	33	36	56	66	3.72	<0.01	0.38

a,*b*: Within a row, means lacking a common letter differ (P < 0.05).

Excretion of nitrogen in urine and feces both increased linearly ($P < 0.01$) with increasing TDDGS content in the diet (Table 3.7.), which more than doubled total nitrogen excretion (from 17.1 to 39.1 g d^{-1}) when TDDGS was increased from 0 to 60%. Ammonia excretion showed a quadratic tendency ($P = 0.07$) with increasing level of TDDGS. Excretion of allantoin linearly increased ($P = 0.02$) from 0.19 to 0.39 mmol d^{-1} as amounts of TDDGS in the diet increased. Total phosphorus increased linearly whereas soluble phosphorus excretion increased quadratically ($P < 0.01$) with increasing level of TDDS in the diet.

Table 3.7. Effect of increasing concentration of triticale-based dried distillers' grains plus solubles (TDDGS) in the diet on nutrient excretion by lambs

	Experimental diet (TDDGS content)					*P* value	
Excretion component	Control	20%	40%	60%	SEM	Linear	Quadratic
N in urine (g d^{-1})	10.5	13.1	16.8	24.4	2.51	<0.01	0.31
N in feces (g d^{-1})	6.5	7.7	13.7	14.9	0.88	<0.01	0.97
Total N excreted (g d^{-1})	17.1	20.7	30.5	39.1	3.00	<0.01	0.41
Ammonia (g d^{-1})	0.82	0.76	0.64	1.44	0.25	0.12	0.07
Allantoin (mmol d^{-1})	0.19	0.25	0.22	0.39	0.05	0.02	0.27
Soluble P (g d^{-1})	0.12*c*	0.61*c*	2.00*a*	0.96*b*	0.24	<0.01	<0.01
Total P (g d^{-1})	1.17	2.33	4.11	3.53	0.59	<0.01	0.12

a–*c*: Within a row, means lacking a common letter differ ($P < 0.05$).

3.4. Discussion

3.4.1. Growth Performance

Increasing levels of TDDGS in the diet tended to increase DMI in the growth study and increased DMI in the digestibility experiment. Intake by lambs

fed 40% TDDGS in the present study was similar to that of lambs fed diets containing 40% CDDGS substituted for dry-rolled corn (Lodge et al. 1997). Others have found that dietary inclusion of CDDGS up to 40% DM (Buckner et al. 2008) and WDDGS up to 60% DM (Gibb et al. 2008) did not alter DMI of beef cattle. Although palatability of TDGGS did not appear to be a factor in the present study, Schauer et al. (2005) proposed that palatability issues may reduce the intake of CDDGS when it exceeds more than 20% of the diet. Palatability of DDGS may be reduced when excessive heat is applied during the drying process, resulting in DDGS of dark brown color due to the formation of Maillard products (Cromwell et al. 1993). The TDDGS used in our study was a golden color and exhibited no signs of heat damage.

The lack of effect of TDDGS on ADG by the lambs in this study was consistent with other reports in which rates of gain by lambs (n = 15) fed 40% CDDGS did not differ from lambs fed dry-rolled corn (Lodge et al. 1997), and in which gain by lambs (n = 40) fed 22.9% CDDGS in place of the soybean meal (10.2%) plus 13% of the corn in the control diet was unaffected by diet (Huls et al. 2006). Average daily gain by lambs in these two trials was similar to ADG of lambs in the current study. In contrast to findings with lambs, CDDGS has been shown to increase ADG when fed to cattle. A trend toward a quadratic response in ADG was observed by Buckner et al. (2008) when steers were fed CDDGS in place of dry-rolled corn at 0, 10, 20, 30 or 40% of diet DM, with ADG highest at 20% CDDGS. Other researchers have reported that replacing dry-rolled corn with

CDDGS at 30% (Al-Suwaiegh et al. 2002) or 40% (Ham et al. 1994) of diet DM increased ADG of finishing cattle.

The observation that dietary TDDGS did not affect FE in the present study was consistent with earlier reports of studies in which CDDGS (Huls et al. 2006) or CWDGS (Lodge et al. 1997) were fed to lambs, in which no effects on FE were observed. Diets formulated by Huls et al. (2006), were balanced to be isonitrogenous and isoenergetic with the control diet, thus comparable gain was not unexpected.

As with observations of ADG, several studies have found that feeding corn- or wheat-based distillers' grains to cattle improves FE, even though this is not seen in lambs. Firkins et al. (1985) fed 132 steers diets containing 0, 25 or 50% CWDGS replacing a mixture of 4.2% soybean meal and high moisture corn, and found FE improved by 1.2 and 9.9%, respectively. Similarly, Ham et al. (1994) found that FE was improved by 8.7% when steers were fed 40% CDDGS for 99 d compared to those fed only dry-rolled corn. However, cattle fed CDDGS were 7.8% less efficient than steers fed CWDGS, which suggests that the feeding value of DDGS is reduced by the drying process.

The higher oil content of CDDGS as compared to TDDGS and WDDGS likely contributes to improved FE as oil contains about three times the energy of corn grain. However, Al-Suwaiegh et al. (2002) found that lipid content of wet corn distillers' grains accounted for only 4.7% of the 11.7% improvement in NEg and suggested that yeast by-products in DDGS contained unidentified nutrients that contributed to the improved performance. Mustafa et al. (2000) found that the

ether extract content of TDDGS was 2.2% higher than WDDGS. In the present trial, the ether extract content of the TDDGS was similar to or only slightly lower than other previously reported values for WDDGS (Beliveau and McKinnon 2008; McKinnon and Walker 2008). It appears that TDDGS can be used in diets in place of barley grain at levels up to 60% with no adverse effects on growth performance.

3.4.2. Carcass Traits

The quadratic response in cold carcass weight and grade rule measurements associated with increasing levels of TDDGS is consistent with the observations of Gibb et al. (2008) who reported a quadratic response in back fat thickness in cattle fed WDDGS at 0, 20, 40 and 60%. A higher grade rule measurement indicates a fatter carcass (Stanford et al. 1998), which is associated with reduced shrink either as a consequence of reduced water content of fat compared to muscle, or through the effectiveness of adipose tissue serving as a moisture barrier (Smith and Carpenter 1973). Overall, there were no differences in the weight of individual cuts of meat, indicating that TDDGS can be included in lamb diets without adversely affecting SMY.

3.4.3. Protein Metabolism

As the amount of TDDGS in the diet increased, so did the amount of protein supplied to the lambs and the amount of nitrogen excreted in urine and feces. This was to such an extent that even though the digestibility of the protein decreased with increasing TDDGS, the amount of protein digested increased. In

our study, urinary and fecal nitrogen excretion was lowest in lambs fed the control diet and linearly increased in both fractions as more TDDGS was added to the diet. Others have reported that addition of 23% CDDGS to lamb diets did not alter urine or fecal nitrogen excretion as compared to a diet in which the majority of protein in the diet was supplied by soybean meal (Waller et al. 1980). However, unlike in our study, diets in this study were balanced to be isonitrogenous (12%) and to not exceed the protein requirements of lambs. Our objective was to examine the extent to which TDDGS could be used to replace barley grain as an energy source in the diet. Consequently, at the highest level of TDDGS the diet exceeded the protein requirements of the lambs by at least 8 percentage units, leading to a dramatic increase in nitrogen excretion. Furthermore, allantoin excretion also linearly increased with TDDGS, suggesting that heightened microbial protein synthesis may have also contributed to higher levels of absorbed protein and nitrogen excretion. Allantoin is an end production of the degradation of nucleotides that arise primarily from microbial cells (Pérez et al. 1998). Undoubtedly, increased metabolizable energy would be required for the liver to synthesize urea from the heightened levels of ammonia absorbed from the intestinal tract due to the excessive levels of CP in the diet. However, in our study, partitioning of this energy towards urea synthesis was not sufficiently high to adversely affect the growth of lambs even when TDDGS comprised 60% of the dietary DM. However, it is clear that the practice of including this high of level of TDDGS in lamb diets will result in a considerable increase in the excretion of nitrogen into the environment.

3.4.4. Fatty Acid Composition

The fatty acid *trans 10*-18:1 has been linked to increased coronary heart disease in humans (Hodgson et al. 1996). In the present study, adding TDDGS to the diets did not affect the concentration of *trans 10*-18:1 in subcutaneous fat of lambs, nor did it affect the concentrations of *cis 9, trans 11*-CLA or its precursor, *trans 11*-18:1, which has been associated with anti-carcinogenic properties (Ha et al. 1990). These results are contrary to Dugan et al. (2008) who found that *trans 10*-18:1 decreased and *cis 9, trans 11*-CLA and *t11*-18:1 increased when cattle were fed increasing levels of WDDGS up to 60% of diet DM. The level of *trans 10*-18:1 was, however, the most variable of the fatty acid among individual cattle and the limited number of observations may have precluded the finding of a significant increase with increasing WDDGS. In the present study, the level of the immediate precursor to *trans 10*-18:1; *trans 10, cis 12*-CLA did linearly increase with increasing TDDGS in the diet.

As TDDGS had more PUFA than barley grain, the PUFA content of the diet also increased with increasing TDDGS, a factor that also likely accounted for the higher level of PUFA in the subcutaneous fat of lambs fed TDDGS. However, the PUFA/SFA ratios in lamb carcass fat were not affected by dietary TDDGS in this study, but in each treatment group, the ratios were considerably higher than the PUFA/SFA ratio reported for lamb adipose tissue by Enser et al. (1996), possibly because these researchers examined a less complete fatty acid profile. Even at the elevated level, however, the ratios are still below the > 0.7 ratio recommended by health advisors (Raes et al. 2004). The n-6/n-3 fatty acid

ratio was also unaffected by inclusion of TDDGS in the diet and was lower than the recommended ratio of < 4 (Wood et al. 2003).

Elevation of PUFA in adipose tissue can alter the shelf life and flavor of the meat (Wood et al. 2003). In the present study, however, increases in PUFA were relatively modest, thus they would not be expected to have significantly altered the shelf life or flavor of the meat harvested from these lambs. Shand et al. (1998) found that including 13.4% WWDG in a diet for beef cattle did not affect tenderness, juiciness or flavor of beef. Subjective retail display properties of steaks over a 6-d period were also unaffected when cattle were fed 15% corn- or sorghum-based distillers' grains in place of steam-flaked corn (Gill et al. 2008).

3.4.5. Occurrence of Urinary Calculi

Taking into account the high phosphorus content of the TDDGS, diets were formulated to include sufficient calcium carbonate to maintain Ca:P ratios above 2:1 in an effort to avoid urinary calculi (Vipperman et al. 1968). This approach was obviously not fully successful, as there were six cases of urinary calculi over the course of the growth and metabolism trials. Pelleting the diets to reduce sorting of the ingredients may have contributed to the occurrence of urinary calculi, in that pelleting can reduce mastication (Hay 1990; Huls et al. 2006) and saliva production and increase the amount of phosphorus excreted in the urine, which may also increase the risk of urinary calculi (Khorasani et al. 1997). Increasing dietary allocation of TDDGS also increased the potassium content of the diet, which can also reduce the solubility of phosphorus in the urine (Vipperman et al. 1968). These factors plus observations of calculi in lambs

suggests that feeding excess amounts of TDDGS may increase the risk of urinary calculi in lambs.

3.4.6. Phosphorus Excretion

The high concentration of phosphorus in distillers' grains results in increased fecal excretion of this nutrient as dietary DDGS increases. Even at 20% TDDGS, the diet in this study exceeded recommended dietary phosphorus requirements for growing lambs (NRC, 2007). Interestingly, excretion of soluble phosphorus was related quadratically to increasing dietary TDDGS. Possibly, the higher calcium content of the 60% TDDGS diet led to increased phosphorus in the insoluble fraction of feces (Chapuis-Lardy et al. 2004). Increasing fecal excretion of phosphorus, especially the soluble fraction, by increasing the amount of TDDGS in the diet could pose an environmental concern. Phosphorus applied to the land can be lost due to run off and accumulate in water bodies resulting in eutrophication (Rausch and Belyea 2006).

3.5. Conclusion

This study indicates that TDDGS can be included at up to 60% in diets for lambs with no detrimental effects on growth, feed intake or FE. However, feeding TDDGS increases nitrogen and phosphorus excretion, and at higher levels, may increase the incidence of urinary calculi in lambs. On the basis of these observations, it is recommended that caution be exercised when including TDDGS at levels greater than 20% in diets for lambs.

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4.0. GENERAL DISCUSSION

4.1. Summary of Findings

Two studies were conducted to evaluate the feeding value of CDDGS, WDDGS and TDDGS in lamb diets. The first experiment compared growth performance and carcass traits of 60 ram lambs fed 20% (DM basis) CDDGS, WDDGS or TDDGS in place of 10% barley grain and 10% canola meal (Control diet), as well as examining the in vitro fermentation characteristics of the four diets. Lambs fed WDDGS exhibited less efficient gain compared to lambs fed the other three diets, but there was no effect of treatment on ADG or DMI. The decreased FE for lambs fed WDDGS was attributed to higher ammonia and acetate production and lower propionate production during in vitro fermentation. Adding distillers' grains to the diets did not affect carcass traits, with the exception of the individual cut weight of the front shank. Front shanks were heavier for lambs fed the Control and CDDGS diets compared to those fed WDDGS or TDDGS, but overall SMY was not affected by treatment. Interestingly, lambs fed TDDGS had numerically lower concentrations of *trans* 10-18:1; a fatty acid associated with coronary heart disease, and higher concentrations of *cis* 9, *trans* 11-18:2-CLA, a fatty acid with anti-carcinogenic effects, compared to lambs fed the other three diets. It was concluded that 20% CDDGS, WDDGS or TDDGS could replace a mixture of barley grain and canola meal without adversely affecting DMI, ADG or carcass characteristics of lambs.

Addition of 20% TDDGS may possibly improve the fatty acid profile of the meat of lambs.

The second study was conducted to determine how much TDDGS could be added to lamb diets. When 60 lambs were fed diets containing TDDGS in place of barley grain at 0, 20, 40 or 60% of the diet, there was no treatment effect on DMI, ADG or FE. However, one lamb fed 40% TDDGS and one fed the 60% TDDGS diet succumbed to urinary calculi. At slaughter, cold carcass weight and grade rule responded quadratically, peaking at 20% TDDGS inclusion, but carcass traits were otherwise not affected by addition of TDDGS to the diet. In this study, concentrations of *trans* 10-18:1 and *cis* 9, *trans* 11-CLA were not affected by the addition of TDDGS to the diet. To determine the treatment effect on nutrient digestibility, 12 ram lambs were used in a 4 × 4 replicated Latin square design. Dry matter intake increased linearly with increasing TDDGS in the diet, however apparent total tract digestibility of DM, CP and fat responded quadratically. Dry matter digestibility was highest for control animals compared to all three TDDGS diets, CP digestibility was lowest for 40 and 60% TDDGS, and fat digestibility was lowest for lambs fed 40% TDDGS. Apparent starch digestibility decreased and ADF digestibility in the total tract increased linearly, but there was no treatment effect on NDF digestibility. In addition, because distillers' grains are high in protein and P, as more TDDGS was added to the diet, total nitrogen and phosphorus excretion increased linearly. From this experiment it was concluded that although up to 60% TDDGS could be fed to lambs without affecting growth performance or SMY, due to increased nitrogen and phosphorus excretion to the

environment and risk of lambs developing urinary calculi, it was recommended that inclusion of TDDGS not exceed 20-30% of dietary DM.

4.2. Future Research

Although these studies provided us with valuable information on the feed value of TDDGS, further research is warranted in some areas. Firstly, we did not evaluate the effect of substituting barley grain with distillers' grains on ruminal acidosis, a common problem leading to reduced performance of feedlot cattle. Distillers' grains are typically high in fibre and low in starch, which could reduce the risk of acidosis even though the particle size of this feedstuff is small. In the second experiment, as TDDGS increased in the diets, DMI tended to increase, which may be attributable to a reduction in sub-clinical acidosis due to the lower starch content of complete diets that contained TDDGS (Firkins et al. 1985). A reduction in rumen pH often reduces feed intake or causes a fluctuation in feed intake, and reduces FE. Feed efficiency tended to be lower as TDDGS in the diet increased in this study, but this is most likely explained by the increase in DMI with no change in ADG. Unfortunately, changes in DMI and FE could not be attributed to possible changes in rumen pH, because neither rumen pH nor feeding behavior was evaluated in this study. Furthermore, the lambs in this experiment were bedded on straw. While it is likely that all animals, regardless of treatment, consumed some straw (Kertz 2007), the amount of straw consumption and its effects on rumen pH are unknown. It could be speculated that lambs fed the Control diet consumed more straw to offset any occurrence of acidosis, which would confound any effect of diet on rumen pH. Also, as pelleted diets were used

there was no negative control treatment providing traditional long stem fibre, so as a result it is hard to determine if feed intake for the Control treatment was depressed due to low fibre intake and subsequent sub-clinical acidosis (Huls et al. 2006). Data on liver abscess scores at slaughter could have also provided possible insight into the occurrence of acidosis.

Secondly, feeding trials should be conducted with finishing cattle to verify the results found with lambs. While sheep are a good model for beef cattle, there are some differences between the two species. There was some discrepancy in the literature pertaining to the results of ADG between sheep and beef cattle. While results in this study are consistent with previous research that found no differences in ADG for sheep fed CDDGS (Lodge et al. 1997; Huls et al. 2006), ADG is generally improved when corn-based distillers' grains are added to finishing feedlot cattle diets up to 40% of the dietary DM (Al-Suwaiegh et al. 2002; Ham et al. 1994). Also, disease susceptibility may be different between the two species. It was recommended from this study that TDDGS not exceed 40% of DM inclusion due to the possible risk of urolithiasis. However, there have been no reported cases of urinary calculi in cattle fed up to 60% distillers' grains, although cases of polioencephalomalacia have been reported. Buckner et al. (2008) reported 6 cases of polioencephalomalacia when 40 feedlot cattle were fed 50% CDDGS for 22 d. One possible explanation for the occurrence of urolithiasis in sheep is that their narrow urinary tract is prone to obstruction from urinary calculi (Church 1988), whereas the cow may have a wider urinary tract that is less prone to obstruction. Wool is also high in sulfur, indicating a higher sulfur requirement

for wool sheep compared to hair sheep (NRC 2007). As cattle do not have wool, it is expected that there are differences in sulfur metabolism between the two species which may explain the susceptibility of cattle to polioencephalomalacia.

Distillers' grains are a highly variable co-product due to differences among grain type and ethanol plants. Because there is such a large variation in the nutrient profiles among different lots of distillers' grains, regardless of grain type, it is important to analyze the nutrient profiles of the distillers' grains prior to feeding (Spiehs et al. 2002). Differences in the nutrient composition among lots of distillers' grains may expose animals to toxic levels of some minerals. For example, high phosphorus and potassium content of the diets in this study may have promoted the occurrence of urolithiasis (Vipperman et al. 1968) when higher levels of TDDGS were included in the diet. Also, in the study by Buckner et al. (2008), the sulfur content of the 50% CDDGS diet exceeded the toxic level for beef cattle and resulted in polioencephalomalacia.

The retail display, tenderness and palatability qualities of the meat would have also been worthwhile to investigate. Feeding WWDG at 13.4% of the diet DM (Shand et al. 1998) or CWDG at 50% of the diet DM (Jenschke et al. 2007) did not affect tenderness, juiciness or flavor of the meat. Roeber et al. (2005) compared steaks from steers fed CWDG and CDDG up to 50% of the diet, and found that steaks from cows fed 25% CDDG had a greater number of visually unacceptable steaks in the retail display and thus were likely to be discounted for quick sale. As both WDG and DDG increased to 40 and 50% of dietary DM

inclusion, steaks were not as red and were considered visually less acceptable compared to steaks from steers fed distillers' grains at 10 and 25% of the diet. However, neither form of distillers' grain influenced tenderness or palatability of the meat. Thus, Roeber et al. (2005) concluded that including distillers' grains at 10 – 25% of diet DM was optimal to maintain the shelf life of meat, without affecting its palatability after cooking. Currently, there have been no studies examining the effect of including up to 60% DDGS, or using TDDGS on the eating quality of beef. It would be also interesting to evaluate the meat from animals fed dry distillers' grains because Roeber et al. (2005) found differences between wet and DDG. Triticale grain, silage or distillers' grains are not commonly fed to feedlot cattle, which may also affect sensory and palatability properties.

The fatty acid profiles of subcutaneous fat tissues were altered by the addition of TDDGS to the diet. However, this fat can be easily removed prior to human consumption, so the analysis of the intramuscular fatty acids may have been more meaningful to the health conscience consumer (Raes et al. 2004). In addition, we analyzed five fat samples per treatment for fatty acid profile in the second experiment and we did not detect a significant treatment effect. The lack of a treatment effect on fatty acid profiles may be attributed to insufficient experimental units for each treatment, and more samples per treatment to increase statistical power would be warranted for future studies.

Future research must also account for the dynamic nature of the ethanol industry as it becomes more efficient and addresses consumer concerns such as whether or not we should be using food for fuel. Grains that are developed specifically for ethanol production will be selected for carbohydrate content. Greater carbohydrate content would decrease the amount of grain needed to produce the same amount of ethanol, but selection for carbohydrate content may negatively affect protein quantity and/or quality (Rosenberger et al. 2002). Also, fractionating the grains prior to fermentation will also alter the quality of co-products from the ethanol industry. Fractionation would separate the parts of the grain into the bran, germ and endosperm, as a means of increasing the efficiency of ethanol production and diversifying the co-products produced in an effort to tap additional markets and add value to the overall production process. In this case, bran could become another ruminant feed but would also have the potential to be included in human food or used to replace natural gas as a fuel source in ethanol plants. Germ could also be fed as an oil source to cattle as well as being used for the production of bio-diesel and cooking oil. The distillers' grains produced after these fractionation processes would be a more uniform product, lower in oil and fibre content, and potentially more suitable for the swine industry (Watkins 2008).

To address the ethical issue of converting human food to fuel, research is also being conducted in the area of cellulosic ethanol production. For this approach, ethanol would be fermented from fibrous materials such as (but not limited to) straw, dirty diapers, or garbage (Motavalli 2009). In addition to ethanol, cellulosic ethanol production will yield lignin, which will most likely be

burned to produce energy for the ethanol plant, ultimately resulting in the production of ash (Lynd 1996). Although there are no co-product feeds directly produced in these scenarios, using ash as fertilizer may impact nutrient profiles of crops fed to livestock. Also, it is possible to produce ethanol from algae, which yields ethanol and leftover proteins that can potentially be fed to livestock, and its feeding values require investigation (Bullis 2007).

As the ethanol industry continues to grow and evolve, it will present many new research opportunities. Addressing the suggestions made above in future research will be important to ensure that the livestock industry utilizes co-products effectively in order to maximize production and reduce costs.

4.3. General Conclusion and Industry Perspective

Distillers' grains are not a new feed ingredient, but the growing ethanol industry has resulted in more extensive use of distillers' grains as a feed ingredient. Thus, assessment of their feeding value for ruminants is important. The objective of these two studies were to a) determine the effect of replacing a mixture of canola meal and barley grain with CDDGS, WDDGS or TDDGS at 20% dietary DM on in vitro ruminal fermentation, lamb growth performance and carcass traits and b) to determine the effect of replacing barley grain with TDDGS at 0, 20, 40 or 60% of dietary DM on nutrient digestibility, growth and carcass traits of lambs. Results from this study suggest that distillers' grains resulting from using corn, wheat or triticale for ethanol production can be included at up to 20% of diet DM without negatively affecting growth performance or carcass traits

of lambs. The second study also suggests that inclusion of TDDGS up to 60% of diet DM to replace barley grain, will not negatively affect growth, FE, intake or SMY, but will increase the occurrence of urinary calculi as well as increased nitrogen and phosphorus excretion to the environment.

The results of these studies indicate that distillers' grains can be incorporated into ruminant rations, and provide additional feed options allowing producers to formulate diets at lower cost. But, due to the variation in nutrient profiles of various batches of distillers' grains, it is important to analyze the distillers' grains produced locally and formulate diets accordingly. Other factors, such as water quality also need to be considered. For example, areas with high sulfur content in the water may not benefit from using distillers' grains as they are also high in sulfur which can lead to polioencephalomalacia (Gould et al. 2002). As the ethanol industry continues to become more efficient and environmentally sustainable, future research will be needed to optimize feeding strategies of these new co-products.

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