ALTERNATIVE FEEDS OR FEED ADDITIVES IN FEEDLOT DIETS

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ABSTRACT

Three experiments were conducted to determine effects of feeding alternative feeds or feed additives to cattle consuming feedlot diets on diet digestibility, rumen fermentation, growth performance, and carcass characteristics. In the first experiment, effects of adding a *Saccharomyces cerevisiae* product (SC) to cattle fed feedlot diets on diet digestibility and rumen fermentation were examined. Results of the first experiment suggest that feeding 1.0 g SC/hd daily may result in improved rumen acetate: propionate ratio. However, feeding 1.0 g SC/hd daily reduced rumen VFA concentrations, NH_3-N concentration, and pH. In the second experiment, effects of partially replacing steam flaked corn with soy glycerin and distillers grains on diet digestibility and rumen fermentation in cattle were examined. Feeding distillers grains resulted in increased rumen propionate, rumen branched-chain VFA, and total rumen VFA. Feeding glycerin resulted in increased rumen pH and rumen propionate, and decreased rumen acetate. Feeding distillers grains or glycerin caused a reduction in rumen acetate: propionate ratio. In the third experiment, effects of replacing dry rolled corn with either 20% full-fat distillers grains, or 20% or 47% reduced-fat distillers grains (equal fat concentration as inclusion of 20% full-fat distillers grains) on feedlot cattle growth performance and carcass characteristics were examined. Results from this experiment indicated that utilizing reduced-fat distillers grains in place of full-fat distillers grains or dry rolled corn does not impact animal growth performance or carcass characteristics.

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INTRODUCTION

Alternative feeds or feed additives can be utilized in beef cattle production to enhance feed efficiency and reduce production costs. Alternative feeds and feed additives commonly contemplated by cattle feeders for use in high-grain diets include: yeast, glycerin, and distillers grains. Yeast products have been extensively used in both human and animal nutrition for years due to perceived and proven health benefits. More recently, yeast has been used in dairy production systems to help improve the rumen environment, aid in fiber digestion, and enhance milk production (Van Soest, 1994; Newbold et al., 1996; Auclair, 2001; Fonty and Chaucheyras-Durand, 2006). However, less is known about how feeding yeast impacts feedlot cattle consuming high-grain diets. Glycerin is a high-energy, syrup-like co-product of the biodiesel industry. Its availability increased with increased biodiesel production. Glycerin can be successfully utilized in feedlot diets to improve texture, control dust, and act as an energy source (Drouillard et al., 2008). However, the impact of glycerin on the rumen environment is not fully understood at this time. Distillers grains, a co-product of the ethanol industry, has been utilized in feedlot diets for several years. However, ethanol producers are retro-fitting their plants to remove oil from distillers grains producing reduced-fat distillers grains. Most research results to date suggest that when partially replacing corn in feedlot diets, reduced-fat distillers grains generally has little impact on performance (Pritchard, 2010; Gigax et al., 2011; Jolly, 2013). However, research on feeding reduced-fat distillers grains is limited. Thus it was the aim of the following experiments to determine effects of feeding various alternative feeds or feed

additives to feedlot cattle on rumen fermentation, diet digestion, growth performance, and carcass characteristics.

REVIEW OF LITERATURE

Yeast

Yeasts, unicellular organisms belonging to the Fungi kingdom, have been used as feed additives in cattle diets (Auclair, 2001). They are proposed to exert their effect through several mechanisms of action that enhance the rumen environment, promote animal health, and lead to improved animal performance. There is evidence that yeasts may compete with lactate-producing bacteria for substrate in the rumen, while also promoting lactate utilization in the rumen (Fonty and Chaucheyras-Durand, 2006). It has also been suggested that yeast provide nutrient factors to bacteria in the rumen, increasing bacterial growth. Yeasts may also help to scavenge oxygen or promote fiber digestion (Van Soest, 1994; Newbold et al., 1996; Auclair, 2001).

Saccharomyces cerevisiae (SC) is the specific species of yeast utilized in cattle diets. The impact of feeding SC on cattle has been extensively studied at a variety of concentrations in both dairy and beef cattle diets. Yeast do not appear to proliferate once they enter the rumen, but they are able to survive for several hours (Van Soest, 1994; Kung Jr et al., 1997; Auclair, 2001). Due to their short life in the rumen, yeast is generally fed to cattle daily in order to have a long-term impact in the rumen environment.

It is known that feeding high-grain diets results in protozoa lysing as a result of extensive starch digestion (Van Soest, 1994). Therefore, it is expected that feeding diets containing high proportions of grain would lead to lower protozoa numbers. These observations were confirmed by both Carro et al. (1992) and Plata et al. (1994). However,

when feeding SC in high-grain diets rumen protozoa numbers increased (Carro et al., 1992). In fact, feeding SC to cattle fed diets containing 70% grain led to an increased number of rumen protozoa including holotrichs (Carro et al., 1992). It is possible that SC competes with protozoa for sugars and starch, removing these nutrients and thereby preventing protozoa lysing leading to stabilization of rumen protozoa numbers (Van Soest, 1994; Chaucheyras et al., 1996).

Yeast is thought to improve cellulose digestion in the rumen (Wohlt et al., 1991; Van Soest, 1994; Fonty and Chaucheyras-Durand, 2006). Interestingly, cellulolytic bacteria concentrations in the rumen were unchanged when SC was fed to cattle (Erasmus et al., 1992). However, increased cellulose digestion may be attributed to a larger protozoa population or possibly to improved action of rumen fungi (Van Soest, 1994; Fonty and Chaucheyras-Durand, 2006). Plata et al. (1994) indirectly lent support to this theory, albeit in high-forage diets, as they discovered that protozoa numbers increased when the percentage of oat straw in the diet was increased, and adding SC to the diets further increased protozoa numbers.

Saccharomyces cerevisiae appears to have no impact on rate of diet degradation in the rumen (Roa V et al., 1997). However, results from several studies demonstrated that feeding SC increased dry matter (DMD) and organic matter digestibility (OMD; (Carro et al., 1992; Mir and Mir, 1994; Miller-Webster et al., 2002; Desnoyers et al., 2009). Moreover, ADF, NDF, and cellulose digestibility were improved when SC was fed (Wohlt et al., 1991; Erasmus et al., 1992; Plata et al., 1994; Roa V et al., 1997). This could be the result of improved protozoa numbers, as indicated earlier, or it may be the result of SC

acting as a nutrient source for cellulolytic bacteria and rumen fungi (Wohlt et al., 1991; Carro et al., 1992; Plata et al., 1994; Van Soest, 1994; Fonty and Chaucheyras-Durand, 2006).

Protein digestion was enhanced in several studies when SC was fed to cattle (Wohlt et al., 1991; Erasmus et al., 1992; Mir and Mir, 1994; Roa V et al., 1997; Miller-Webster et al., 2002). In some instances, greater CP digestibility was associated with a greater concentration of rumen NH_3-N (Roa V et al., 1997; Miller-Webster et al., 2002). However, in other cases rumen NH_3-N concentration was either unchanged or reduced (Carro et al., 1992; Erasmus et al., 1992; Piva et al., 1993; Mir and Mir, 1994; Moallem et al., 2009). In studies where CP digestibility was improved, lower rumen NH_3-N is evidence of improved NH_3-N capture by rumen microbes resulting from enhanced growth by the microbial population (Carro et al., 1992; Erasmus et al., 1992; Wang et al., 2009).

Saccharomyces cerevisiae may help prevent lactic acidosis in cattle by reducing lactic acid production in the rumen (Chaucheyras et al., 1996). In support of this, lactic acid concentration in the rumen was reduced when SC was fed (Williams et al., 1991; Erasmus et al., 1992; Chaucheyras et al., 1996; Desnoyers et al., 2009). Moreover, peak lactic acid values in the rumen were reduced when SC was fed (Erasmus et al., 1992). Two factors may account for the ability of SC to lower lactic acid production in the rumen. First, SC outcompeted *S. bovis,* a common lactic acid-producing bacteria, for substrate (Van Soest, 1994; Chaucheyras et al., 1996). Second, SC stimulated lactate utilization by the rumen microbe *Megasphera elsdenii* (Chaucheyras et al., 1996).

Response by ruminal VFA concentrations to SC was variable. In several studies, SC led to an overall increase in ruminal VFA production when dietary forage to concentrate ranged from 30:70 to 50:50 (Carro et al., 1992; Roa V et al., 1997; Miller-Webster et al., 2002). However, other authors reported that feeding SC may have no impact on total rumen VFA production when dietary forage to concentrate ranged from 70:30 to 50:50 (Carro et al., 1992; Piva et al., 1993; Plata et al., 1994). Interestingly, SC was more effective in diets with areduced forage to concentrate ratio. This is contradictory to data suggesting that SC has a positive impact on cellulose digestion (Wohlt et al., 1991; Fonty and Chaucheyras-Durand, 2006). However, the positive impact observed in higher concentrate diets may be the result of SC stabilizing protozoa concentrations or SC acting as a nutrient source for rumen microbes (Van Soest, 1994). It should be noted that a meta-analysis conducted by Desnoyers et al. (2009) on research conducted on all ruminant species receiving SC revealed that SC led to an increase in rumen VFA.

Results from several studies indicated that rumen acetate concentration was reduced when SC was added to cattle diets that contained at least 40:60 forage to concentrate *in vitro* and *in vivo* (Williams et al., 1991; Carro et al., 1992; Plata et al., 1994; Miller-Webster et al., 2002). Propionate concentration was also increased *in vitro* and in cannulated Holstein steers when high forage diets were fed (Plata et al., 1994; Miller-Webster et al., 2002). As a result, the acetate: propionate ratio was reduced when SC was fed (Williams et al., 1991; Erasmus et al., 1992; Plata et al., 1994; Miller-Webster et al., 2002). It is possible that a reduction in rumen acetate indicated that yeast did not have a great impact on structural carbohydrate digestion as suggested by other research (Wohlt et

al., 1991; Fonty and Chaucheyras-Durand, 2006). It is likely that yeast had a greater impact on microbes digesting non-structural carbohydrate when included in high forage diets, possibly by acting as a nutrient source for rumen microbes (Van Soest, 1994). Due to lack of research, it is uncertain how yeast will impact VFA production when fed in high-grain diets.

Rumen pH may be altered by SC inclusion in cattle diets. On one hand, SC is expected to reduce lactic acid production in the rumen (Chaucheyras et al., 1996). On the other hand, SC may increase rumen VFA production (Desnoyers et al., 2009). Results from a meta-analysis on yeast inclusion in ruminant diets demonstrated that yeast inclusion led to an increase in rumen pH (Desnoyers et al., 2009). However, data from several other studies revealed that pH was either unchanged or reduced when SC was added to cattle diets containing 50: 50 forage to concentrate or greater (Williams et al., 1991; Piva et al., 1993; Plata et al., 1994; Roa V et al., 1997; Miller-Webster et al., 2002). The lack of consistent improvement in rumen pH is likely the result of variable changes in both rumen NH_3-N and rumen VFA production. In two studies, no change in rumen VFA or NH_3-N was observed, while two additional studies revealed an increase in both rumen VFA and rumen NH_3-N. The parallel change in rumen VFA and rumen NH_3-N would prevent a change in pH from being observed.

The majority of studies examining the impact of SC on animal performance have been conducted in dairy cattle. Several authors reported that feeding SC improved DMI when fed to lactating dairy cows consuming moderate-forage diets (Williams et al., 1991; Wohlt et al., 1991; Erasmus et al., 1992; Desnoyers et al., 2009; Moallem et al., 2009).

Moallem et al. (2009) found that SC-increased DMI led to improved feed efficiency in lactating dairy cows consuming a lactation diet with moderate-forage. Improvements in DMI in dairy cattle consuming yeast may be the result of improved diet digestibility (Wohlt et al., 1991; Erasmus et al., 1992).

No difference in DMI, ADG, feed efficiency, final BW, HCW, LM area, dressing percentage, or 12th rib fat thickness was observed by Mir and Mir (1994) when SC was fed to growing beef cattle. Dairy cattle appear to respond more favorably to SC as milk production is frequently increased (Wohlt et al., 1991; Piva et al., 1993; Kung Jr et al., 1997; Desnoyers et al., 2009; Moallem et al., 2009). Moreover, milk fat may be improved when SC is fed (Desnoyers et al., 2009; Moallem et al., 2009). Dairy cattle may respond more favorably to SC due to the fact that they consume a high forage diet which may be fermented more effectively when SC is fed.

Glycerin

Glycerin, or glycerol, is a co-product of the biodiesel industry, and has been increasing in availability as the biodiesel industry expands. It is a sugar alcohol that has the consistency of syrup. Glycerin has been successfully utilized to improve texture, control dust, and act as an energy source in cattle diets (Drouillard et al., 2008).

Biodiesel and glycerol are produced when a vegetable oil, such as soy oil, reacts with an alcohol (usually methanol) using a catalyst such as sodium or potassium hydroxide. The products of this reaction are glycerin and methyl esters which are commonly known

as biodiesel. In a typical reaction, 100 pounds of vegetable oil and 10 pounds of alcohol produce 100 pounds of biodiesel and 10 pounds of glycerin (Gerpen, 2005).

Glycerin has a low solubility in methyl esters, so it is easily removed from biodiesel using centrifugation or by settling out. After its removal from methyl esters, glycerin contains excess alcohol, catalyst, and soap from the reaction. The soap is split into free fatty acids (FFA) and salts by the addition of acid to the glycerin. Free fatty acids are not soluble in glycerin and will rise to the top where they can be removed. Some salt will precipitate out of the glycerin; however, the rest of the salt will remain in the glycerin. Alcohol can be removed from glycerin using a vacuum flash process or another type of evaporation process (Gerpen, 2005).

Glycerin is approximately 85% pure after removal of alcohol and FFA. At this point, glycerin will be sent to a glycerol refinery where it can be purified to 99.5 to 99.7% using ion exchange processes or vacuum distillation (Gerpen, 2005). When glycerin is 100% pure, it is clear. When impure, glycerin is amber in color and may contain minerals, water, FFA, and any remaining alcohol from the conversion of oil to biodiesel (Drouillard et al., 2008).

Limited research has been done to determine the impact of feeding glycerin to cattle on diet digestion and rumen fermentation. However, it has been discovered that total VFA concentration in rumen fluid tended to be greatest when glycerin was included in high grain diets at 8% of dietary DM (Mach et al., 2009). Authors suggest that this is the result of increased DMI observed in cattle consuming 8% dietary glycerin relative to cattle consuming 0, 4, or 12% dietary glycerin (Mach et al., 2009). Conversely, when glycerin

was included at 12 or 15% of dietary DM in high grain diets *in vitro*, total rumen VFA concentration were unaltered, possibly due to controlled substrate inclusion (Van Cleef et al., 2013b).

When utilized in cattle diets, propionate and butyrate concentrations in rumen fluid may be altered. Propionate and butyrate concentrations in rumen fluid *in vitro* where greater when glycerin partially replaced 15% of DRC in high grain diets (Van Cleef et al., 2013b). However, when glycerin was fed at less than 15% of diet DM to bulls receiving high-grain diets, rumen propionate and butyrate concentrations were not altered (Mach et al., 2009). It is possible that the impact of glycerin on rumen propionate and butyrate production with high-grain diets is dependent on glycerin concentration with reduced glycerin concentrations having less of an impact. Acetate concentrations in rumen fluid were unaltered by glycerin inclusion in feedlot diets (Mach et al., 2009; Wang et al., 2009; Bartoň et al., 2013; Van Cleef et al., 2013b).

Rumen NH_3-N was unchanged when glycerin was included at 5 or 10% of dietary DM in moderate-inclusion forage diets (Bartoň et al., 2013). However, 1 to 3% dietary DM glycerin inclusion in a moderate-inclusion forage diet resulted in a linear decrease in rumen NH_3-N concentrations. Authors suggest that this indicates increased NH_3-N capture by rumen microbes due to enhanced rumen microbe growth (Wang et al., 2009). This conclusion was supported by the fact the concentration of urine purine derivatives in cattle fed 2 to 3% dietary glycerin were higher than cattle receiving 0 to 1% dietary glycerin daily (Wang et al., 2009).

Dietary glycerin inclusion appears to have a negative effect on rumen pH. Mach et al. (2009) showed that 8% dietary inclusion of glycerin lowered average rumen pH from 6.07 to 5.68 . Moreover, Wang et al. (2009) discovered that rumen pH decreased linearly when dietary glycerin inclusion ranged from 1 to 3% of diet. Reduction in rumen pH may be the direct result of increased VFA or reduced NH_3-N production in the rumen.

Considerable research has been conducted to determine effects of feeding glycerin on feedlot cattle growth performance and carcass characteristics. Glycerin can be effectively utilized in feedlot diets, partially replacing grains.

Dry matter intake is generally unchanged or reduced when glycerin partially replaces grain in a feedlot diet. In two studies in which dietary grain was partially replaced with glycerin, DMI decreased linearly with increased dietary glycerin inclusion (Parsons et al., 2009; Van Cleef et al., 2013a). In addition, it was revealed by Moore et al. (2011) that 9% dietary inclusion of glycerin in a steam flaked corn-based diet led to a reduction in DMI. However, several other authors discovered no difference in DMI when glycerin was included in high-grain feedlot diets from 0 to 30% diet DM (Mach et al., 2009; Schneider et al., 2010; Gunn et al., 2011; Jaderborg et al., 2012; Françozo et al., 2013; Hales et al., 2013; van Cleef et al., 2014).

The impact of glycerin on ADG is highly variable. Average daily gain was unchanged in several studies in which glycerin partially replaced 4 to 30% of dietary grain in feedlot diets (Mach et al., 2009; Jaderborg et al., 2012; Van Cleef et al., 2013a; van Cleef et al., 2014). However, in one study, ADG decreased linearly with up to 16% dietary glycerin inclusion (Parsons et al., 2009). On the other hand, ADG was improved with

dietary glycerin inclusion in several studies. Results of a study by Moore et al. (2011) revealed that feeding 6 or 9% dietary glycerin led to improved ADG relative to a diet with no glycerin inclusion. Hales et al. (2013) discovered that 7.5% dietary inclusion of glycerin led to an improvement in ADG compared to ADG for cattle consuming a diet without glycerin, while 10% glycerin inclusion resulted in reduced ADG. Results from another study indicated that ADG may be improved with either 5 or 10% dietary glycerin inclusion relative to a corn-based diet (Françozo et al., 2013). Results of these studies suggests that low dietary inclusion of glycerin (under 10% of diet DM) in feedlot diets may lead to an improvement in ADG.

Van Cleef et al. (2013a) observed that feed efficiency linearly increased when feedlot cattle were fed 7.5 or 15% dietary glycerin. Similar results were discovered by Moore et al. (2011) when glycerin was included in feedlot diets up to 9% of dietary DM. However, additional studies revealed that feed efficiency linearly decreased with 16% dietary DM glycerin inclusion (Parsons et al., 2009; Hales et al., 2013). Moreover, several authors discovered no change in feed efficiency when glycerin partially replaced grain in feedlot diets from 0.5 to 12 percent of dietary DM (Mach et al., 2009; Schneider et al., 2010; Jaderborg et al., 2012; Françozo et al., 2013). Results of these studies suggest that glycerin inclusion above 15% dietary DM in feedlot diets may result in reduced feed efficiency.

Final BW of feedlot cattle fed glycerin is generally not improved relative to cattle not fed glycerin (Mach et al., 2009; Schneider et al., 2010; Jaderborg et al., 2012; Hales et al., 2013; Van Cleef et al., 2013a; van Cleef et al., 2014). However, in two studies final

BW was improved in feedlot cattle fed 2 to 12% dietary glycerin (Parsons et al., 2009; Moore et al., 2011; Françozo et al., 2013). This is a direct result of improved ADG in those cattle. It was revealed by Parsons et al. (2009) that 16% dietary inclusion of glycerin in feedlot diets may lead to a reduction in final BW. Hot carcass weight reflected final BW observed in past studies. In all instances, a larger final BW led to improved HCW and vice versa. Moreover, when no change in final BW was observed between control and glycerin treatments, HCW was also unchanged (Mach et al., 2009; Parsons et al., 2009; Schneider et al., 2010; Moore et al., 2011; Jaderborg et al., 2012; Van Cleef et al., 2013a; van Cleef et al., 2014).

Authors from previous studies have reported no impact of feeding glycerin on carcass dressing percentage or KPH (Parsons et al., 2009; Schneider et al., 2010; Moore et al., 2011; Jaderborg et al., 2012; Bartoň et al., 2013; Françozo et al., 2013; Van Cleef et al., 2013a; van Cleef et al., 2014). In addition, results from several studies revealed no effects of feeding glycerin on LM area, marbling score, 12th rib fat thickness, USDA Yield Grade, or USDA Quality Grade (Moore et al., 2011; Jaderborg et al., 2012; Bartoň et al., 2013; van Cleef et al., 2014).

In two studies, researchers reported that including glycerin in feedlot diets may result in poorer carcass quality. First, Parsons et al. (2009) discovered that feeding cattle glycerin had a negative impact on marbling score and 12th rib fat thickness. It was also revealed that LM area was lower when cattle consumed 12 or 16% dietary glycerin in place of corn (Parsons et al., 2009). This is likely the result of reduced DMI. In the second study, Van Cleef et al. (2013a) revealed that cattle marbling scores and 12th rib fat thickness were

also reduced with glycerin inclusion in feedlot diets. However, Van Cleef et al. (2013a) also showed that feeding glycerin to feedlot cattle led to improved USDA Yield Grades. Changes in 12th rib fat thickness may be the result of reduced acetate production when glycerin is included in feedlot diets.

Distillers Grains

Distillers grains (DG) are a co-product of dry-grind ethanol production. During dry-grind ethanol production, whole corn kernels are fermented with yeast and water. Yeast convert starch in the corn kernel to ethanol and leave the remaining corn fractions unaltered. The remaining fractions represent a solid and a semi-liquid fraction that can be identified as wet cake and thin stillage, respectively. Thin stillage can be evaporated to produce condensed distillers soluble (CDS). Wet cake can be partially dried to produce distillers wet grains (DWG) or fully dried to produce distillers dried grains (DDG). Adding CDS to distillers wet or dried grains yields either distillers wet grains with solubles or distillers dry grains with solubles (Warner and Mosier; Wheals et al., 1999; Davis, 2001; Bothast and Schlicher, 2005).

In recent years, at some plants, ethanol producers have begun to remove oil from distillers grains to produce a low- or reduced-fat product. Oil can be removed from DG using various methods and can be removed either before (front-end) or after (back-end) fermentation of corn starch to ethanol. In order to remove oil prior to fermentation, the corn kernel must be partially de-germinated (fractioned). The oil can then be removed from the germ while the rest of the corn kernel undergoes fermentation (Faulkner et al., 2012). Back-

end oil removal can be done via chemical extraction with solvents. Both methods result in DG that are not only low in oil, but also high in protein (Díaz-Royón et al., 2012). Oil can also be removed from CDS via centrifugation and columns prior to its incorporation to DWG or DDG. This method results in 30 to 70% of oil being removed from the CDS (Díaz-Royón et al., 2012). When partially de-oiled CDS is added to DWG or DDG, it results in low- or reduced-fat distillers wet grains with solubles (DWGS) or distillers dry grains with solubles (DDGS).

Feeding DG in place of corn or another grain in feedlot diets generally does not impact diet DMD or OMD. Results from several studies comparing DMD and OMD of corn- or barley-based diets in which 15 to 60% of the grain was replaced with full-fat DG indicated no difference in DMD or OMD (Depenbusch et al., 2009b; Leupp et al., 2009; May et al., 2009; Walter et al., 2012). Moreover, feeding full-fat DDG versus low-fat DDGS did not appear to impact DMD or OMD in feedlot cattle (Corrigan et al., 2008; DiCostanzo and Crawford, 2013). Rumen digestibility of full-fat DG decreased as the concentration of full-fat DG in feedlot diets increased (Leupp et al., 2009; Luebbe et al., 2012). However, this only resulted in reduction in total tract OMD with increased dietary inclusion of full-fat DG in one study (Luebbe et al., 2012).

Response by propionate, acetate, and butyrate concentrations in the rumen varied when full-fat DG partially replaced grain. In two studies, no changes in propionate, acetate, or butyrate concentrations were observed when either full-fat DWG or DDG partially replaced up to 40% dry rolled or steam flaked corn (Ham et al., 1994; May et al., 2009). Two studies were conducted to compare feeding either full-fat DWGS or DDGS versus

steam flaked corn, dry rolled corn, or barley in feedlot diets. Results from these studies demonstrated that full-fat DG caused a decrease in rumen propionate and an increase in rumen acetate and butyrate when partially replacing barley or steam flaked corn (Luebbe et al., 2012; Walter et al., 2012). Partially replacing dry rolled corn with full-fat DG led to an increase in propionate and a decrease in butyrate (Luebbe et al., 2012). Acetate was either increased or unchanged with 30 to 60% full-fat DG inclusion in dry rolled corn diets (Luebbe et al., 2012). Leupp et al. (2009) presented similar results that suggest replacing dry rolled corn with full-fat DDGS may cause rumen propionate to increase and rumen acetate to decrease. Feeding low-fat DDGS to feedlot cattle resulted in no change in propionate, acetate, or butyrate relative to a corn-based feedlot diet (DiCostanzo and Crawford, 2013). Total rumen VFA concentration was either unchanged or reduced when full-fat DG were added to feedlot diets, except when full-fat DG partially replaced 15 or 30% of dietary dry rolled corn (Ham et al., 1994; Leupp et al., 2009; Luebbe et al., 2012; Walter et al., 2012). Low-fat DDGS inclusion in a dry rolled corn diet did not lead to reduced rumen VFA production (DiCostanzo and Crawford, 2013). It can be concluded that partially replacing dry rolled corn with full-fat DG may have a positive impact on rumen VFA production. However, partially replacing other grains with full-fat DG may lead to a reduction in rumen propionate and total rumen VFA production.

The impact of DG on branched-chain VFA production is variable. In a study by Ham et al. (1994), replacing dry rolled corn with full-fat DWG resulted in increased rumen isovaleric acid concentrations. However, May et al. (2009) discovered no change in branched-chain VFA production when either dry rolled or steam flaked corn was partially

replaced with full-fat DDG. When reduced-fat DWGS was utilized at various concentrations in dairy diets, isobutyric acid decreased (Castillo-Lopez et al., 2014). In addition, replacing dry rolled corn with low-fat, high-protein DDGS reduced rumen branched chain VFA (DiCostanzo and Crawford, 2013).

Rumen NH_3-N was reduced in two studies when either full-fat DWG or DDG partially replaced dry rolled corn in feedlot diets (Ham et al., 1994; May et al., 2009). However, when low-fat DDGS partially replaced dry rolled corn in a feedlot, no change in rumen NH_3-N was observed relative to a control diet (DiCostanzo and Crawford, 2013). Data suggest that the energy content of the diet may impact rumen NH_3-N use by rumen microbes. Interestingly, research conducted by Leupp et al. (2009) and Luebbe et al. (2012) revealed that microbial efficiency was linearly improved when DDGS or DWGS were included in feedlot diets regardless if they partially replaced steam flaked or dry rolled corn.

Rumen pH was unaltered when full-fat DWGS, full-fat DDGS, or low-fat DDGS were added to feedlot diets relative to a control diet in several studies (Luebbe et al., 2012; Walter et al., 2012; DiCostanzo and Crawford, 2013). However, Leupp et al. (2009) discovered that adding DDGS to dry rolled corn-based diets led to a linear increase in rumen pH as DDGS inclusion in the diets was increased. When reduced-fat DWGS was added to dairy diets, rumen pH decreased linearly with DWGS inclusion (Castillo-Lopez et al.). The reduction in pH in this instance may have been the result of replacing dietary slow-degrading fiber with a highly digestible, low effective NDF feed.

Dry matter intake was not altered in three studies comparing a corn- or barley-based feedlot diet to diets containing up to 40% full-fat DDGS or DWGS (Buckner et al., 2008; Depenbusch et al., 2009b; Anderson et al., 2011). Results from recent research demonstrated that DMI may be improved when up to 45% DG partially replace steam flaked, dry rolled, or high-moisture corn in feedlot diets (Vander Pol et al., 2006; Depenbusch et al., 2009a; Jaderborg et al., 2012; Luebbe et al., 2012). However, when DG partially replaced over 45% of corn, DMI decreased (Vander Pol et al., 2006; Depenbusch et al., 2009a; Luebbe et al., 2012).

In several studies, ADG, feed efficiency, and BW were not impacted by DG inclusion in feedlot diets (Buckner et al., 2008; Depenbusch et al., 2009b; Jaderborg et al., 2012). However, other studies revealed that ADG, feed efficiency, and BW were improved when 45% or less DG was included in corn-based diets (Vander Pol et al., 2006; Depenbusch et al., 2009a; Anderson et al., 2011; Luebbe et al., 2012). Above 45% dietary inclusion of DG, ADG, feed efficiency, and BW were reduced (Vander Pol et al., 2006; Depenbusch et al., 2009a; Luebbe et al., 2012).

Dressing percentage, HCW, LM area, 12th rib fat thickness, KPH, marbling score, USDA Yield Grade, or USDA Quality Grade were not affected by feeding full-fat DG versus corn or barley in several studies (Buckner et al., 2008; Depenbusch et al., 2009b; Jaderborg et al., 2012). However, it was discovered by Vander Pol et al. (2006) that although partially replacing dry rolled and high moisture corn with full-fat DG led to improvements in DMI, BW, ADG, and feed efficiency, the only carcass characteristic to be improved with dietary DG inclusion was HCW. On the other hand, Anderson et al.

(2011) discovered that inclusion of 12 to 36% full-fat DG in barley-based diets resulted in improved HCW, dressing percentage, LM area, 12th rib fat thickness, KPF, marbling, USDA Yield Grade, and percentage of cattle grading USDA Choice.

Corn type substituted by DG inclusion appears to have an impact on cattle growth performance and carcass characteristics. In one study, addition of up to 40% full-fat DG to steam flaked corn-based feedlot diets improved DMI, ADG, BW, and feed efficiency; however, cattle consuming full-fat DG had lower HCW, less 12th rib fat thickness, a higher percentage of cattle grading USDA Select, and increased KPH relative to cattle on the control diet (Depenbusch et al., 2009a). In addition, a second study by Luebbe et al. (2012) revealed that replacing steam flaked corn with full-fat DG had a negative impact on ADG, BW, and feed efficiency, HCW, 12th rib fat thickness, and marbling score. On the other hand, replacing up to 45% dry rolled corn with full-fat DG in feedlot diets resulted in an increase in ADG, feed efficiency, HCW, and 12th rib fat thickness in cattle consuming full-fat DG (Luebbe et al., 2012). These data, as well as rumen fermentation data, suggest that partially replacing dry rolled corn with full-fat distillers grains has a positive impact on rumen fermentation, growth performance, and carcass characteristics.

Partially replacing grain with low-fat or reduced-fat DG in feedlot diets generally had no impact on cattle growth performance or carcass characteristics. Kelzer et al. (2011) reported that DMI was lower for cattle consuming a low-fat, high-protein DG versus cattle consuming dry rolled corn. However, in several other studies, no difference in DMI was observed for cattle consuming either low-fat or reduced-fat DG versus cattle consuming corn (Depenbusch et al., 2008; Pritchard, 2010; Gigax et al., 2011; Atkinson et al., 2012;

Jolly, 2013). In addition, partially replacing corn with low- or reduced-fat DG had no impact on ADG, feed efficiency, final BW, HCW, dressing percentage, LM area, 12th rib fat thickness, KPH, marbling, USDA Yield Grade or USDA Quality Grade in several studies (Depenbusch et al., 2008; Pritchard, 2010; Gigax et al., 2011; Kelzer et al., 2011; Atkinson et al., 2012; Jolly, 2013).

The fat content of DG may impact growth performance when DG are included in feedlot diets. Depenbusch et al. (2008) showed that DMI was greater in cattle consuming full-fat DG versus low-fat DG. Moreover, Gigax et al. (2011) revealed that ADG, final BW, and HCW were reduced in cattle consuming reduced-fat DG versus cattle consuming full-fat DG. However, no other growth performance or carcass characteristics were impacted by fat content of DG (Depenbusch et al., 2008; Pritchard, 2010; Gigax et al., 2011; Kelzer et al., 2011; Atkinson et al., 2012; Jolly, 2013).

EFFFECTS OF INCLUSION OF *SACCHAROMYCES CEREVISIAE* IN FEEDLOT DIETS ON DIGESTION AND RUMEN FERMENTATION

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SUMMARY

An experiment was conducted to determine the effects of feeding Levucell SC 20, a *Saccharomyces cerevisiae* product, on diet digestion and rumen fermentation in feedlot steers. Six ruminally cannulated Holstein steers were arranged in a replicated 3 x 3 Latin square design with 3 dietary treatments. Dietary treatments were made up of a distillers grains-based control diet (**C**) or a distillers grains-based diet top dressed with Levucell SC 20 at 0.5 g per head daily (**M**), or 1.0 g per head daily (**H**). Steers were adapted to their treatment diets for 22 d and sample collection occurred on d 23 to 26. Steers were ruminally dosed with 7.5 g chromic oxide twice daily from d 16 to 26. Rumen pH probes were inserted into the rumen on d 22, and rumen pH was recorded every 5 min through d 26. Dry matter intake was determined for each steer over the collection period. Fecal samples were collected at 0700, 1300, and 1900 h on d 23 to 26. Rumen fluid samples were collected at 0800, 1100, 1300, 1900, 2100, 0100, and 0900 h on d 26 through d 1 of the following period. Dry matter digestibility and organic matter digestibility were not different ($P > 0.86$) between dietary treatments. Average rumen pH was greater ($P = 0.02$) for cattle on the M treatment versus cattle on the H treatment. Rumen NH_3-N also differed ($P = 0.01$) between treatments with cattle on the H treatment having a reduced rumen NH_3-N concentration relative to cattle on the C and M treatments. Acetate and butyrate were lower ($P < 0.01$) for the H treatment relative to the C and M treatment. Isobutyrate was greater ($P = 0.01$) for the C treatment compared with the M and H treatments. No differences ($P > 0.12$) were observed for propionate, branched-chain VFA, or total rumen VFA

concentration between treatments. However, acetate: propionate tended (P = 0.06) to be greatest for the C treatment. The results of this experiment suggest that feeding 1.0 g Levucell SC 20 may reduce several rumen VFA, including acetate, butyrate, and isobutyrate, rumen NH_3-N concentration, and rumen pH.

Keywords: distillers grains, *Saccharomyces cerevisiae*, feedlot cattle

INTRODUCTION

Yeasts, unicellular organisms belonging to the Fungi kingdom, have been extensively used as feed additives in cattle diets (Auclair, 2001). They are proposed to have many mechanisms of action that enhance the rumen environment, promote animal health, and lead to improved animal performance. For example, it has been suggested that yeasts may compete with lactate-producing bacteria for substrate, thereby reducing the risk of lactic acidosis. It has also been suggested that yeasts provide nutrient factors to bacteria in the rumen, increasing bacterial growth. Yeasts may also help to scavenge oxygen and promote fiber digestion (Van Soest, 1994; Newbold et al., 1996; Auclair, 2001; Fonty and Chaucheyras-Durand, 2006).

Several research studies have reported positive results on diet digestibility and rumen fermentation when feeding yeast to cattle consuming moderate to high forage diets (Carro et al., 1992; Mir and Mir, 1994; Plata et al., 1994; Roa V et al., 1997; Desnoyers et al., 2009). It is expected that yeast will also improve diet digestion and rumen fermentation in cattle diets that are high in grain due to their ability to control lactic acid, provide nutrient factors to rumen microbes, and scavenge oxygen. Therefore, it was the objective of this experiment to determine the effects of feeding a *Saccharomyces cerevisiae* (SC) product to feedlot cattle on digestion and rumen fermentation.

MATERIALS AND METHODS

Animals and Sampling

All procedures involving animals were approved by the local institutional animal care and use committee. Animals were housed at the Rosemount Research and Outreach Center in Rosemount, MN.

Six Holstein steers (initial BW 665 ± 23 kg) fitted with 14-cm rumen cannulae (Bar Diamond, Inc., Parma, ID) were arranged in a replicated 3 x 3 Latin square design with 3 dietary treatments and three 26-d treatment periods (22 d adaptation). Dietary treatments consisted of a control diet (Table 1) with Levucell SC 20 (Lallemand Animal Nutrition, Blagnac, France), a *Saccharomyces cerevisiae* product, top dressed with distillers grains as a carrier. Levucell was top-dressed at a concentration of 0 g (C), 0.5 g (M), or 1.0 g (H) per animal daily. Steers were fed ad-libitum once daily at 0900 h. Steers were adapted to the treatment diet for 22 d.

On d 16 through d 26, a bolus (Torpac, Fairfield, NJ) containing 7.5 g chromic oxide (CAS #1308-38-9) was inserted into the rumen at 0700 and 1900 h. On d 22, pH probes (Omega Engineering, Inc., Stamford, CT) were inserted into the rumen, and rumen pH was recorded every 5 min throughout the sampling period. Probes were calibrated at the start of each sampling period using the probe software calibration wizard and calibration solutions with pH 4 and 7.

Dry matter intakes were recorded on d 23 through d 26. Any residual feed from d 23 to 26 was weighed, and a composite sample was collected. A composite sample of the control diet was collected on d 24 and d 25 for nutrient analysis. All samples were

transferred to a -20° C freezer immediately after sampling for storage until laboratory analyses were conducted.

Fecal samples were collected using a grab technique at 0700, 1300, and 1900 h on d 23 to 26. Fecal samples were composited by animal daily. All samples were transferred to a -20° C freezer immediately after sampling for storage until laboratory analyses were conducted.

Rumen fluid was collected at 0800, 1100, 1300, 1900, 2100, 0100, and 0900 h on d 26 through d 1 of the following period. Rumen fluid was collected via a manual transfer pump (OEM, Mineola, NY) placed through the rumen cannula. Rumen fluid pH was determined immediately after sampling using a hand-held pH probe (Acorn Series pH Probe, OAKTON, Vernon Hills, IL). All samples were transferred to a -20° C freezer immediately after sampling until laboratory analyses were conducted.

Sample Analysis

Diet and residual feed samples were dried in a drying oven (Blue M Electric, Charlotte, NC) at 60° C for 48 h. Diet samples were then ground using a 1-mm screen (Thomas Scientific, Swedesboro, NJ). Individual ingredient samples were analyzed for CP, NDF, ADF, ether extract, Ca, P, K, Mg, and S contents by methods 990.03, 2002.04, 973.18, 920.39, and 953.01 (AOAC, 2012), respectively.

Fecal samples were dried in a drying oven (Blue M Electric, Charlotte, NC) at 60° C for 48 h. Samples were then ground using a 1-mm screen (Thomas Scientific, Swedesboro, NJ). Samples were composited by animal and sampling period. Samples were

shipped to and analyzed by the University of Florida Animal Science Department (Gainesville, FL) for chromium content using atomic absorption spectrophotometry based on the procedure described by Williams et al. (1962).

Rumen fluid samples were individually analyzed for VFA content using gas chromatography (Hewlett-Packard 6890 Series, Hewlett-Packard Development Co., Palo Alto, CA) based on the methods described by Erwin et al. (1961). Volatile fatty acids analyzed included acetate, propionate, butyrate, isobutyrate, valerate, isovalerate, and 2-methylbutyrate.

Rumen fluid samples were also individually analyzed for ammonia nitrogen (NH_3-N) using a phenol-hypochlorite assay using the methods described by Broderick and Kang (1980) and Berthelot (1859). Samples were read in a spectrophotometer at 620 nm.

Average rumen pH for each h throughout the sampling period was determined by averaging all readings obtained hourly for each steer.

Data Analysis

Data were analyzed using the Mixed procedure of SAS 9.3 (SAS Institute Inc., Cary, NC). In order to normalize data, rumen VFA were converted using a $\log_{10}$ transformation, and arithmetic means are presented. Data on rumen pH, NH_3-N, and VFA were analyzed for repeated measures using h as the repeated factor. Due to unequal sampling time intervals, the spatial power covariance structure was utilized. Effects were considered significant when *P* values were less than 0.05 and were considered trends when *P* values were between 0.05 and 0.10.

RESULTS AND DISCUSSION

Treatment effects are presented in Table 2. No differences ($P > 0.86$) in dry matter digestibility (DMD) or organic matter digestibility (OMD) were observed between treatments. Results from previous research indicated variable effects of SC on DMD and OMD. Erasmus et al. (1992) discovered no difference in DMD when SC was fed to dairy cattle. However, results from other studies demonstrated improvements in DMD and OMD when SC is fed to cattle (Mir and Mir, 1994; Plata et al., 1994; Miller-Webster et al., 2002; Desnoyers et al., 2009). It was proposed that SC improved rumen cellulolytic activity possibly due to increased protozoa numbers or due to SC acting as a nutrient source for microbes which leads to improved DMD or OMD (Wohlt et al., 1991; Carro et al., 1992; Plata et al., 1994; Van Soest, 1994; Fonty and Chaucheyras-Durand, 2006).

Ruminal acetate and butyrate concentrations were lower ($P < 0.01$) for cattle fed H treatment compared with those fed C or M treatments. Propionate was not affected ($P = 0.41$) by dietary treatment. The acetate: propionate ratio also tended ($P = 0.06$) to be greater for cattle on the C treatment compared with those on M and H. Isobutyrate was lower ($P = 0.01$) for cattle on the M and H treatment compared with those on the C treatment. No differences ($P = 0.12$) were observed between treatments for rumen branched-chain or total VFA concentration. Branched-chain VFA, total VFA concentration, and acetate: propionate all differed ($P < 0.05$) over time. Interestingly, past research has revealed improvements in total rumen VFA production with SC likely due to improved NDF

fermentation (Carro et al., 1992; Miller-Webster et al., 2002; Desnoyers et al., 2009). Thus, the lack of change in total rumen VFA concentration in the current experiment may be attributed to low dietary effective NDF.

Rumen NH_3-N was lower ($P = 0.01$) for cattle fed the H treatment (8.50 mg/dL) compared with cattle on the C (12.33 mg/dL) and M (11.68 mg/dL) treatments. Rumen NH_3-N was also different ($P = 0.05$) over time. Past research revealed similar results. In several studies, rumen NH_3-N was either unchanged or reduced (Carro et al., 1992; Erasmus et al., 1992; Piva et al., 1993; Mir and Mir, 1994; Moallem et al., 2009). It has been suggested that lower rumen NH_3-N is an indicator of improved NH_3-N capture by rumen microbes (Carro et al., 1992; Erasmus et al., 1992).

Rumen pH differed ($P = 0.05$) between treatments with cattle on the H treatment having the lowest average rumen pH (5.61) and cattle on the M treatment having the highest average rumen pH (5.91). Rumen pH also differed ($P < 0.05$) over time. However, no treatment by time interaction ($P = 1.00$) was observed.

Past research has demonstrated that rumen pH is either unchanged or reduced when SC is fed to cattle (Williams et al., 1991; Piva et al., 1993; Plata et al., 1994; Miller-Webster et al., 2002; Desnoyers et al., 2009). It is likely that higher VFA production or lower rumen NH_3-N production contribute to a pH reduction when SC is fed (Carro et al., 1992; Miller-Webster et al., 2002; Desnoyers et al., 2009). Consistent with past research, the H treatment had the lowest rumen pH. Although total rumen VFA production did not differ between treatments, rumen NH_3-N was reduced in the H treatment which likely contributed to poor rumen buffering. In fact, if acetate, butyrate, and NH_3-N concentrations in the current

experiment, along with their pKa, are utilized to determine their impact on rumen pH, it can be concluded that pH would be lower for cattle on the H treatment even if all other VFA concentrations were not different, as was the case in the current experiment.

The results of this experiment suggest that SC had an impact on the rumen environment, especially when fed at 1.0 g/animal daily. Not only was rumen pH reduced with the H treatment, but several rumen VFA concentrations and rumen NH_3-N were reduced as well. It was suggested that low rumen NH_3-N is an indication of improved NH_3-N capture by rumen microbes (Carro et al., 1992; Erasmus et al., 1992). It is possible that this was the case in the current experiment, however, it is also possible that microbial growth was reduced in cattle on the H treatment and as a result VFA and NH_3-N production by microbes were reduced. It has been suggested that SC may compete for starch in the rumen (Van Soest, 1994; Chaucheyras et al., 1996). *Saccharomyces cerevisiae* outcompeting rumen microbes for starch may partially explain why a high dose of SC may have negatively impacted rumen microbes when cattle were fed the H treatment. However, more research should be conducted to confirm why SC had an impact on rumen fermentation in high grain diets.

Table 1. Dietary ingredient inclusion and nutrient profile (DM basis).

Corn earlage, %	35.0
Corn silage, %	9.0
Distillers wet grains with solubles, %	35.0
Dry rolled corn, %	15.0
Limestone, %	3.0
Vitamin and mineral premix, %	3.0
CP, %	16.5
NDF, %	25.6
ADF, %	15.3
Ether extract, %	4.4
Ca, %	0.93
P, %	0.54
S, %	0.28

Table 2. Effects of dietary treatment on digestion and rumen fermentation.

	Treatment[1]				*P*-values[3]		
	C	M	H	SEM[2]	Treatment	Time	Treatment*Time
Dry matter digestibility, %	68.60	68.18	70.14	2.71	0.86	.	.
Organic matter digestibility, %	71.95	71.58	73.24	2.63	0.89	.	.
NH_3-N, mg/dL	12.33[a]	11.68[a]	8.50[b]	2.05	0.01	0.05	0.98
pH	5.85[ab]	5.91[a]	5.61[b]	0.16	0.05	<0.0001	1.00
Acetate, m*M*	49.15[a]	47.97[a]	41.59[b]	2.02	0.001	<0.0001	0.06
Propionate, m*M*	30.30	33.55	31.45	4.86	0.41	<0.0001	0.47
Butyrate, m*M*	11.60[a]	11.49[a]	9.91[b]	0.72	0.01	<0.0001	0.70
Isobutyrate, m*M*	0.87[a]	0.77[b]	0.74[b]	0.09	0.01	0.000	0.81
Valerate, m*M*	2.00	1.98	2.00	0.46	0.99	<0.0001	0.86
Isovalerate, m*M*	1.12	1.02	1.03	0.15	0.32	0.02	0.92
2-methylbutyric, m*M*	1.53	1.56	1.48	1.56	0.82	0.15	0.51
Branched chain VFA, m*M*	3.47	3.26	3.07	0.53	0.12	0.004	0.84
Total VFA, m*M*	98.51	99.45	89.23	5.58	0.14	<0.0001	0.14
Acetate: propionate	1.61	1.43	1.35	0.22	0.06	<0.0001	0.99

[1]Treatments included control diet with 0 g Levucell SC 20 (C; Lallemand Animal Nutrition, Blagnac, France), 0.5 g Levucell SC 20 (M), or 1.0 g Levucell SC 20 (H).

[2]Highest standard error of mean reported.

[3]Effects of dietary treatment (C, M, H), time, and treatment by time interaction. *P*-values < 0.05 considered significant; *P*-values ≤ 0.10 considered a trend.

EFFECTS OF INCLUSION OF DISTILLERS WET GRAINS WITH SOLUBLES AND SOY GLYCERIN IN FEEDLOT DIETS ON DIGESTION AND RUMEN FERMENATION

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SUMMARY

An experiment was conducted to determine the effects of partially replacing steam flaked corn (SFC) with distillers wet grains with solubles and soy glycerin. Four ruminally cannulated Holstein steers were arranged in a 4 x 4 Latin square design with 4 dietary treatments. Treatments included a SFC control diet (**C**), partial replacement of SFC with 10% soy glycerin (**G**), partial replacement of SFC with 40% distillers wet grains with solubles (**DGS**), and partial replacement of SFC with 10% soy glycerin and 40% distillers wet grains with solubles on DM basis (**DGS+G**). Steers were adapted to treatment diets for 18 d and sample collection occurred on d 19 to 21. Steers were ruminally dosed with 7.5 g chromic oxide twice daily from d 11 to 21. Rumen pH probes were inserted into the rumen on d 18, and rumen pH was recorded every 5 min through d 21. Dry matter intake was determined for each steer over the collection period. Fecal samples were collected at 0700, 1300, and 1900 h on d 19 to 21. Rumen fluid samples were collected at 0800, 1100, 1300, 1900, 2100, 0100, and 0900 h on d 21 through d 1 of the following period. Average rumen pH, diet dry matter digestibility (DMD), diet organic matter digestibility (OMD), rumen fluid VFA concentration, and rumen NH_3-N were analyzed for each dietary treatment. No difference in DMD or OMD ($P > 0.20$) were observed between dietary treatments. Rumen

NH_3-N was also not different ($P > 0.12$) between treatments. Rumen pH was greater ($P = 0.04$) when soy glycerin was included in the diet. Rumen isobutyrate, isovalerate, 2-methylbutyrate, and total branched-chain VFA were lower ($P < 0.05$) in cattle consuming diets not containing distillers grains. Consuming the DGS+G diet resulted in cattle having lower ($P = 0.01$) rumen acetate relative to other treatments. Moreover, cattle consuming glycerin had lower ($P < 0.05$) rumen acetate than cattle not consuming glycerin. Rumen propionate was greater ($P < 0.03$) in cattle consuming either distillers grains or glycerin than the C treatment. Acetate: propionate was also lower ($P < 0.01$) in cattle consuming either distillers grains or glycerin than the C treatment. Finally, total rumen VFA concentration was greatest in cattle consuming distillers grains. The results of this experiment suggest that partially replacing corn with soy glycerin and distillers wet grains may increase propionate, reduce acetate, increase branched-chain VFA, reduce acetate: propionate, and increase total VFA concentration in the rumen of feedlot cattle without a negative impact on rumen pH.

Keywords: distillers grains, soy glycerin, steam flaked corn, feedlot cattle

INTRODUCTION

Cattle producers can benefit from utilizing alternative feeds in feedlot diets, especially when corn prices are high. Two alternative feeds available to producers are distillers grains (DG), a co-product of ethanol production, and glycerin, a byproduct of biodiesel production. Distillers grains are high in energy and protein, but have little starch. Glycerin is a syrup-like product that is high in energy.

A host of studies have been conducted to determine the individual and combined effects of feeding DG and glycerin on cattle growth performance and carcass characteristics. Results from these studies have revealed that DG and glycerin can partially replace corn in feedlot diets without detrimental effects on growth performance or carcass characteristics (Gunn et al., 2011; Jaderborg et al., 2012). In order to explain the effects of DG and glycerin on cattle growth performance and carcass characteristics, it is critical to understand how these alternative feeds alter the rumen environment. Results from recent research suggested that rumen VFA may be altered (Ham et al., 1994; Walter et al., 2012) when feeding these feedstuffs. Moreover, rumen NH_3-N concentrations may be reduced with the addition of glycerin or DG to feedlot diets (Ham et al., 1994; May et al., 2009; Wang et al., 2009). In addition, research has revealed that rumen pH may be reduced with

glycerin inclusion in feedlot diets (Mach et al., 2009; Wang et al., 2009). Although past research has made some discoveries regarding the impact of DG or glycerin on the rumen environment, no research has revealed how DG and glycerin will affect the rumen environment when fed concurrently. Thus, it was the objective of this study to determine the effects of inclusion of DG and soy glycerin on diet digestibility and rumen fermentation in feedlot steers.

MATERIALS AND METHODS

Animals and Sampling

All procedures involving animals were approved by the local institutional animal care and use committee. Animals were housed at the Rosemount Research and Outreach Center in Rosemount, MN.

Four Holstein steers (initial BW 810 ± 20 kg) fitted with 14-cm rumen cannulae (Bar Diamond, Inc., Parma, ID) were arranged in a 4 x 4 Latin square design with 4 dietary treatments and four 21-d treatment periods (18 d adaptation). Treatments included a corn-based control diet (C), a distillers wet grain with solubles diet (DGS), a soy glycerin diet (G), and a combination diet with both distillers wet grains with solubles and soy glycerin

(DGS+G; Tables 1 and 2). Steers were fed once daily at 0900 h. At the start of the treatment period, steers were offered their treatment diet at 1.5% of their BW on a DM basis. Feed offered was increased by 0.45 kg per d throughout the remainder of the treatment period. Steers were adapted to the treatment diet for 18 d.

On d 11 through d 21, a bolus (Torpac, Fairfield, NJ) containing 7.5 g chromic oxide (CAS #1308-38-9) was inserted into the rumen at 0700 and 1900 h. On d 18, pH probes (Omega Engineering, Inc., Stamford, CT) were inserted into the rumen, and rumen pH was recorded every 5 min throughout the sampling period. Probes were calibrated using the probe software calibration wizard and calibration solutions with pH 4 and 7.

Dry matter intakes were recorded on d 18 through d 21. Any residual feed from d 19 to 21 was weighed, and a composite sample was collected. A composite sample of each diet was collected on d 19 for nutrient analysis. All samples were transferred to a -20° C freezer immediately after sampling for storage until laboratory analyses were conducted.

Fecal samples were collected using a grab technique at 0700, 1300, and 1900 h on d 19 to 21. Fecal samples were composited by animal daily. All samples were transferred to a -20° C freezer immediately after sampling for storage until laboratory analyses were conducted.

Rumen fluid was collected at 0800, 1100, 1300, 1900, 2100, 0100, and 0900 h on d 21 through d 1 of the following period. Rumen fluid was collected via a manual transfer pump (OEM, Mineola, NY) placed through the rumen cannula. Rumen fluid pH was determined immediately after sampling using a hand-held pH probe (Acorn Series pH Probe, OAKTON, Vernon Hills, IL). All samples were transferred to a -20° C freezer immediately after sampling for storage until laboratory analyses were conducted.

Sample Analysis

Diet and residual feed samples were dried in a drying oven (Blue M Electric, Charlotte, NC) at 60° C for 48 h. Diet samples were then ground using a 1-mm screen (Thomas Scientific, Swedesboro, NJ). Individual ingredient samples were analyzed for CP, NDF, ADF, ether extract, Ca, P, K, Mg, and S contents by methods 990.03, 2002.04, 973.18, 920.39, and 953.01 (AOAC, 2012), respectively.

Fecal samples were dried in a drying oven (Blue M Electric, Charlotte, NC) at 60° C for 48 h. Samples were then ground using a 1-mm screen (Thomas Scientific, Swedesboro, NJ). Samples were composited by animal and sampling period. Samples were shipped to and analyzed by the University of Florida Animal Science Department

(Gainesville, FL) for chromium content using atomic absorption spectrophotometry based on the procedure described by Williams et al. (1962).

Rumen fluid samples were individually analyzed for VFA content using gas chromatography (Hewlett-Packard 6890 Series, Hewlett-Packard Development Co., Palo Alto, CA) based on the methods described by Erwin et al. (1961). Volatile fatty acids analyzed included acetate, propionate, butyrate, isobutyrate, valerate, isovalerate, and 2-methylbutyrate.

Rumen fluid samples were also individually analyzed for ammonia nitrogen (NH_3-N) using a phenol-hypochlorite assay using the methods described by Broderick and Kang (1980) and Berthelot (1859). Samples were read in a spectrophotometer at 620 nm.

Average rumen pH for each h throughout the sampling period was determined by averaging all readings obtained hourly for each steer.

Data Analysis

Data were analyzed using the Mixed procedure of SAS 9.3 (SAS Institute Inc., Cary, NC). In order to normalize data, rumen VFA were converted using a $\log_{10}$ transformation, and arithmetic means are presented. Data on rumen pH, NH_3-N, and VFA were analyzed for repeated measures using the repeated factor h. Due to unequal sampling

time intervals, the covariance structure spatial power was utilized. Effects were considered significant when *P* values were less than 0.05 and were considered trends when *P* values were between 0.05 and 0.10.

RESULTS AND DISCUSSION

Treatment effects are presented in Table 3. No differences in dry matter digestibility (DMD) or organic matter digestibility (OMD; $P > 0.20$) were observed for cattle on any dietary treatment. This differs from the results discovered by Wang et al. (2009). These authors discovered that diet digestibility was increased *in situ* when 1 to 3% dietary glycerin was added to moderate forage diets. It was not expected that DG would impact DMD or OMD as several experiments revealed no difference in DMD or OMD when corn was partially replaced with DG in high-grain diets (Depenbusch et al., 2009b; Leupp et al., 2009; May et al., 2009; Walter et al., 2012).

Rumen branched-chain VFA concentrations were higher ($P < 0.05$) for cattle consuming DG compared with cattle not consuming DG. Results from previous studies demonstrated variable changes in rumen branched-chain VFA when DG partially replaced corn in feedlot diets with branched-chain VFA increasing, decreasing, or exhibiting no

change (Ham et al., 1994; May et al., 2009; DiCostanzo and Crawford, 2013). However, it may be expected that the higher protein content in DG may increase amino acid availability for conversion to branched-chain VFA by microbes in the rumen.

Rumen acetate, propionate, and acetate: propionate were affected by treatment. Rumen acetate was lower ($P = 0.01$) for cattle on the DGS+G treatment versus cattle on all other treatments. Moreover, rumen acetate was reduced ($P < 0.05$) for cattle consuming glycerin. Rumen propionate was greater ($P < 0.03$) in cattle consuming DG and in cattle consuming glycerin. Moreover, acetate: propionate was lower ($P < 0.01$) in cattle consuming DG and in cattle consuming glycerin.

Leupp et al. (2009) conducted research which revealed similar results when distillers dried grains with solubles partially replaced dry rolled corn in feedlot diets. In addition, it was revealed by Wang et al. (2009) that glycerin inclusion in cattle diets led to a reduction in acetate: propionate. Interestingly, rumen acetate concentrations are generally unaltered by glycerin inclusion in cattle diets (Mach et al., 2009; Wang et al., 2009; Bartoň et al., 2013; Van Cleef et al., 2013b).

Total ruminal VFA concentration was greater ($P = 0.05$) for cattle on the DGS and DGS+G treatments than cattle on the C treatment. Moreover, DG inclusion increased ($P < 0.05$) total rumen VFA concentration. In studies by Mach et al. (2009) and Van Cleef et al.

(2013b), it was discovered that dietary glycerin inclusion did not alter total rumen VFA concentration when it was included at 12 or 15% of dietary DM . However, when glycerin was included at 4 or 8% of dietary DM, total VFA production increased (Mach et al., 2009; Van Cleef et al., 2013b). Moreover, total rumen VFA production is generally not enhanced when DG partially replace corn in cattle diets (Ham et al., 1994; Leupp et al., 2009; May et al., 2009; Luebbe et al., 2012; Walter et al., 2012).

In the current experiment, a dietary increase in CP due to DG inclusion may have enhanced microbial growth and consequently VFA concentration with the DGS and DGS+G treatments. When DG partially replaces steam flaked corn, degradable intake protein in the diet is expected to nearly double. Thus, more protein would be available for microbial use when DG partially replace steam flaked corn in cattle diets. Changes in rumen propionate concentration when DG or glycerin was fed may be attributed to the combined effects of feeding high concentrations of dietary CP with a highly fermentable, non-structural carbohydrate. The increase in dietary CP may have enhanced microbial growth and allowed for improved conversion of DG or glycerin to propionate. Furthermore, the reduction in rumen acetate concentration observed in cattle consuming either glycerin or the DGS+G treatment may have been the result of a microbial population shift from acetate- to propionate-producers.

Rumen NH_3-N did not differ ($P > 0.12$) among treatments or over time. When barley meal was partially replaced with 5 or 10% glycerin, Barton et al. (2013) obtained similar results. However, Wang et al. (2009) discovered that rumen NH_3-N decreased as glycerin was added to diets containing moderate concentrations of forage. It was suggested that the low NH_3-N concentrations with glycerin were the result of increased NH_3-N capture by rumen microbes due to enhanced microbial growth. Wang et al. (2009) also discovered an increase in urine purine derivatives with glycerin, supporting their hypothesis that microbial growth was enhanced when glycerin was added to cattle diets. It is clear that glycerin addition to moderate forage diets has a positive effect on rumen microbial growth. This effect was not observed in high grain diets. Moreover, when distillers grains with solubles were added to feedlot diets, rumen NH_3-N concentrations were unaltered or improved (Castillo-Lopez et al.; Walter et al., 2012; DiCostanzo and Crawford, 2013). Thus, it is expected that rumen NH_3-N concentrations in cattle consuming feedlot diets containing either glycerin or distillers grains with solubles would not differ or would be improved relative to cattle consuming corn-based diets.

Rumen pH was greater when cattle consumed soy glycerin ($P = 0.04$). Moreover, rumen pH tended ($P = 0.08$) to be higher in cattle consuming the DGS or DGS+G treatments versus the C treatment, while cattle consuming the G treatment had the highest

average pH. Results of this experiment are interesting because treatments in which cattle had low rumen VFA concentration also had low rumen pH. It would be expected that a low rumen pH would be associated with high rumen VFA concentration. Given that rumen NH_3-N did not differ between treatments, differences in rumen pH must be attributed to an additional factor not examined in the current experiment.

Interestingly, results from past research on glycerin inclusion in cattle diets revealed conflicting results wherein addition of glycerin to cattle diets resulted in a rumen pH decline (Mach et al., 2009; Wang et al., 2009). In addition, results from several studies indicated no change in rumen pH when DG partially replaced corn in cattle diet (Luebbe et al., 2012; Walter et al., 2012; DiCostanzo and Crawford, 2013).

In a parallel study, Jaderborg et al. (2012) revealed that 10% glycerin inclusion in feedlot diets had no impact on DMI, ADG, feed efficiency, final BW, HCW, dressing percentage, KPH, LM area, 12^{th} rib fat thickness, marbling, or USDA Yield Grade. Moreover, when distillers wet grains with solubles partially replaced steam flaked corn, DMI was improved. No differences in ADG, feed efficiency, final BW, HCW, dressing percentage, KPH, LM area, 12^{th} rib fat thickness, marbling, or USDA Yield Grade were observed when DG were fed (Jaderborg et al., 2012).

Gunn et al. (2011) compared the effects of feeding 15% glycerin and 30% distillers dried grains with solubles versus dry rolled corn in feedlot cattle on growth performance and carcass characteristics. It was demonstrated that ADG, final BW, HCW, LM area, and percentage of cattle grading USDA Prime were improved with the 15% glycerin and 30% DG treatment relative to the corn-control treatment suggesting that feeding glycerin and DG can improve growth performance and carcass characteristics (Gunn et al., 2011). Results of the current experiment suggest that the improvement observed by Gunn et al. (2011) when glycerin and DG were fed to feedlot cattle may be due to an improved rumen VFA profile or improved rumen VFA production.

In summary, partially replacing steam flaked corn with distillers wet grains with solubles and soy glycerin may lead to improved rumen branched-chain VFA production, total rumen VFA production, and reduced rumen acetate: propionate in cattle without negatively affecting rumen pH. Moreover, past research suggests that growth performance and carcass characteristics may be improved when glycerin and DG are included in feedlot diets.

Table 1. Dietary ingredient inclusion (DM basis).

	Treatment[1]			
	C	G	DGS	DGS+G
Distillers wet grains with solubles, %	0	0	40	40
Grass hay, %	10	10	10	10
Soy glycerin, %	0	10	0	10
Steam flaked corn, %	86.0	75.8	46.7	36.7
Urea, %	0.7	0.9	0.0	0.0
Vitamin and mineral premix, %	3.3	3.3	3.3	3.3

[1]Treatments included control (C), soy glycerin inclusion (G), distillers wet grains with solubles inclusion (DGS), and distillers wet grains with solubles and soy glycerin inclusion (DGS+G).

Table 2. Dietary nutrient profile (DM basis).

	Treatment[1]			
	C	G	DGS	DGS+G
CP, %	12.2	11.3	19.6	17.8
NDF, %	16.1	15.2	26.3	25.7
ADF, %	8.0	8.6	16.1	16.4
Ether extract, %	3.2	3.6	5.1	6.1
Ca, %	0.62	0.87	1.23	1.25
P, %	0.30	0.29	0.62	0.61
S, %	0.11	0.11	0.30	0.31

[1]Treatments included control (C), soy glycerin inclusion (G), distillers wet grains with solubles inclusion (DGS), and distillers wet grains with solubles and soy glycerin inclusion (DGS+G).

Table 3. Main effects of dietary treatment on digestion and rumen fermentation.

	Distillers grains		Glycerin			*P*-value[2]		
	No	Yes	No	Yes	SEM[1]	DG	Glycerin	DG*Glycerin
Dry matter digestibility, %	70.38	77.00	74.80	72.58	4.50	0.20	0.61	0.57
Organic matter digestibility, %	73.00	78.90	77.09	74.80	3.94	0.21	0.57	0.69
NH_3-N, mg/dL	7.19	8.60	7.84	7.88	1.12	0.12	0.96	0.44
pH	6.30	6.10	5.91	6.49	0.25	0.36	0.04	0.08
Acetate, m*M*	63.56	60.56	66.01	58.32	2.92	0.11	<0.0001	0.01
Propionate, m*M*	37.91	47.73	36.29	49.35	7.84	0.03	0.007	0.74
Butyrate, m*M*	4.18	4.61	4.46	4.34	0.54	0.22	0.72	0.39
Isobutyrate, m*M*	6.99	11.63	9.07	8.95	1.36	<0.0001	0.85	0.02
Isovalerate, m*M*	0.63	1.37	0.96	0.90	0.22	<0.0001	0.61	0.02
2-methylbutyrate, m*M*	4.67	6.16	5.35	5.48	1.72	<0.0001	0.69	0.15
Valerate, m*M*	1.77	1.85	1.48	2.14	0.28	0.76	0.02	0.66
Branched-chain VFA, m*M*	11.16	19.31	14.46	14.89	4.15	<0.0001	0.63	0.04
Total VFA, m*M*	118.96	133.69	123.08	129.24	7.70	0.002	0.17	0.05
Acetate: propionate	1.82	1.43	2.00	1.29	0.36	0.01	<0.0001	0.95

[1]Highest standard error of mean reported.

[2]Main effects of dietary treatment (distillers grains and glycerin), and distillers grains and glycerin interaction. *P*-values < 0.05 considered significant; *P*-values ≤ 0.10 considered a trend.

EFFECTS OF REDUCED-FAT DISTILLERS GRAINS INCLUSION IN FEEDLOT DIETS ON CATTLE GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS

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SUMMARY

An experiment was conducted to determine effects of partially replacing dry rolled corn with full- or reduced-fat distillers grains with solubles in feedlot diets on cattle growth performance and carcass characteristics. Nineteen Jersey (initial BW 455 ± 49 kg) and 29 Jersey-Limousin cross steers (initial BW 518 ± 40 kg) were utilized in a generalized randomized complete block design. Steers were individually fed using Calan gates with 4 dietary treatments (dry rolled corn control, **C**; reduced-fat distillers grains inclusion at 20% of dietary DM with corn oil, **FF**; reduced-fat distillers grains inclusion at 20% of dietary DM, **RFL**; or reduced-fat distillers grains inclusion at 47% of dietary DM, **RFH**). The latter was intended to provide similar dietary fat content as the FF treatment. Distillers grains (DG) was from a single source with reduced-fat (8.6%) to which corn oil was added during mixing to simulate full-fat DG. Cattle were implanted with Synovex-S on d -28 and were harvested on d 93. No differences were observed in cattle consuming full-fat versus reduced-fat DG. Cattle consuming DG had improved ($P < 0.05$) BW, ADG, and BW gain relative to cattle not consuming DG. Cattle consuming DG also had improved ($P < 0.02$) HCW, USDA Quality Grade, and percentage of cattle grading USDA Choice and Select. Cattle consuming 20% DG had improved ($P < 0.05$) USDA Yield Grades and percentage of cattle grading USDA Prime. In addition, cattle consuming 20% DG tended ($P < 0.10$) to have increased marbling score, 12th rib fat thickness, and USDA Quality Grade. Results from this experiment indicate that utilizing reduced-fat DG in place of full-fat DG does not impact animal growth performance or carcass characteristics. Moreover, partially replacing

dry rolled corn with DG may lead to an improvement in ADG, HCW, and USDA Quality Grade, and a reduction in USDA Select-grading carcasses

Keywords: Reduced-fat distillers grains, feedlot cattle, fat

INTRODUCTION

Distillers grains (DG), a co-product of the ethanol industry, has been utilized in feedlot diets extensively for several years. Recently, ethanol producers have attempted to increase profits by removing oil from corn or DG, thereby creating additional co-products of ethanol production.

Oil can be removed from corn prior to fermentation to ethanol by partial de-germination (Faulkner et al., 2012). Oil can also be removed from condensed distillers solubles after fermentation of corn to ethanol. This is frequently done via centrifugation (Díaz-Royón et al., 2012). When de-oiled condensed distillers solubles are added to DG, reduced-fat DG with solubles (RFDG) is produced. Generally, RFDG will contain 7 to 9% fat, while traditional full-fat DG product will contain at least 10% fat.

Full-fat distillers grains with solubles have been extensively studied in feedlot diets to determine their effect on rumen fermentation, digestion, growth performance, and carcass characteristics. However, RFDG has not been studied as extensively. With lower fat concentration, there is concern that this may translate to lower energy supply and may impact animal performance. Thus, it was the objective of this experiment to determine the effects of replacing dry rolled corn in feedlot diets with either 20% full-fat or reduced-fat DG or with 47% reduced-fat DG (at isocaloric concentrations with the 20% full-fat DG diet) on cattle growth performance and carcass characteristics.

MATERIALS AND METHODS

All procedures involving animals were approved by the local institutional animal care and use committee. Animals were housed at the Rosemount Research and Outreach Center in Rosemount, MN.

Nineteen purebred Jersey steers (initial BW 455 ± 49 kg) and 29 Jersey-Limousin cross steers (initial BW 518 ± 40 kg) were arranged in a generalized randomized complete block design. Steers were blocked by breed and allotted randomly to 1 of 4 pens.

Steers were individually fed in Calan gates (American Calan, Inc., Northwood, NH) for 93 d. Four dietary treatments were evaluated in this experiment (Table 1 and 2). A dry rolled corn-based diet served as the control treatment (C). The remaining treatments contained various concentrations of reduced-fat distillers dried grains partially replacing dry rolled corn. A single, reduced-fat DG source was used, and where necessary, corn oil was added to the diet at mixing to achieve lipid content of full-fat distillers grains. Distillers grains treatments consisted of reduced-fat distillers dried grains dietary inclusion at 20% with corn oil (FF), reduced-fat distillers dried grains dietary inclusion at 20% (RFL), or reduced-fat distillers dried grains dietary inclusion at 47% (RFH) of dietary DM. The latter was intended to provide similar dietary fat content as the FF treatment. A vitamin and mineral premix containing monensin was added to all diets; a similar premix containing urea was added to the C diet to meet cattle dietary protein requirements.

Steers were fed dietary treatments once daily at 0900 h. Steers were fed ad libitum and intakes were recorded daily. Feed refusals were removed from feed bunks and weighed daily. Samples of all feed refusals were collected for DM determination. Dietary

ingredients were sampled once weekly. All dietary and feed refusal samples were stored at -20° C until laboratory analyses. Dietary ingredients and feed refusal samples were dried in a drying oven (Blue M Electric, Charlotte, NC) at 60° C for 48 h. Ingredient samples were then ground using a 1-mm screen (Thomas Scientific, Swedesboro, NJ). Individual ingredient samples were analyzed for CP, NDF, ADF, ether extract, Ca, P, K, Mg, and S contents by methods 990.03, 2002.04, 973.18, 920.39, and 953.01 (AOAC, 2012), respectively. Metabolizable energy content of the diet was also determined using values obtained from Nutritional Requirements of Beef Cattle (NRC, 1996).

Cattle were implanted with Synovex-S (Zoetis, Florham Park, NJ) on d -28 and were harvested on d 93 at Tyson Inc. (Dakota City, NE). After harvest, carcasses were chilled for 48 h after which carcass characteristics were analyzed. Cattle growth performance and carcass characteristics evaluated included BW, BW gain, ADG, DMI, and gain: feed, HCW, dressing percentage, marbling score, LM area, 12^{th} rib fat thickness, KPH, and USDA Yield and Quality Grades.

Data were analyzed using the Mixed procedure of SAS 9.3 (SAS Institute, Inc., Cary, NC). Yield grade and quality grade frequencies were analyzed using the Genmod procedure of SAS. Pen was considered a random effect. The Reg and Robustreg procedures of SAS were used to detect and remove outliers based on DMI and gain. In total, 2 steers were removed from the RFH treatment and 1 steer was removed from the FF treatment. The Contrast statement was used to determine the effect of distillers grains inclusion, inclusion of full-fat versus reduced-fat DG, and concentration of dietary distillers

grains inclusion on data. Effects were considered significant when *P* values were less than 0.05 and were considered trends when *P* values were between 0.05 and 0.10.

RESULTS AND DISCUSSION

Dietary treatment effects on cattle growth performance and carcass characteristics are presented in Tables 3 and 4. Contrasts demonstrated no differences in any growth performance or carcass characteristics when comparing full-fat DG inclusion versus reduced-fat DG inclusion in treatment diets.

Dry matter intake tended to be higher ($P = 0.06$) when DG were included in the diet. Dry matter intake for cattle not consuming DG may have been reduced due to poor diet palatability. Furthermore, cattle not consuming DG also consumed higher dietary starch. This may have led to a reduction in rumen pH due to rapid fermentation of starch to VFA. Consequently, cattle not consuming DG may have had rumen upset due to a low rumen pH, possibly experiencing sub-acute rumen acidosis. This also may have contributed to a reduction in DMI.

Contrasts revealed that dietary DG inclusion resulted in greater ($P < 0.05$) BW, ADG, and BW gain throughout the entire study Past research has revealed that partially replacing up to 45% grain in feedlot diets with DG may lead to improvements in DMI, ADG, feed efficiency, and BW (Vander Pol et al., 2006; Depenbusch et al., 2009a; Anderson et al., 2011; Jaderborg et al., 2012; Luebbe et al., 2012). It is likely that improved

dietary energy values contribute to the improved growth performance observed in cattle consuming DG versus other grains.

Contrasts also revealed that HCW, USDA Quality Grade, and percentage of cattle grading USDA Choice and Select were improved ($P < 0.02$) when DG was included in the diet. The difference in USDA Quality Grades between cattle consuming DG and cattle not consuming DG can likely be attributed to differences in ME intake. Cattle consumed 42.8, 57.4, 54.2, and 58.5 Mcal ME daily for the C, FF, RFH, and RFL treatments respectively. Metabolizable energy intake was lower ($P < 0.05$) for cattle not consuming DG. This likely contributed to reduced adipose deposition in cattle not consuming DG and consequently an increased number of USDA Select-grading carcasses. It is likely that cattle not consuming DG were not fully finished at harvest, but would produce carcasses with similar USDA Quality Grades had they been harvested at a later date.

Including DG at 20 versus 47% of dietary DM tended ($P < 0.10$) to result in improved marbling score, 12th rib fat thickness, and USDA Quality Grade. Furthermore, 20% dietary DG inclusion led to ($P < 0.05$) an increase in percent of cattle grading USDA Prime and a reduction in cattle USDA Yield Grades. Improvements in adipose deposition observed in cattle consuming 20 versus 47% DG may be attributed to greater dietary starch intake. This may lead to improved rumen VFA production and consequently improved growth. Several studies have demonstrated that partially replacing dry rolled corn with 15 to 30% full-fat DG led to an increase in rumen VFA production (Ham et al., 1994; Leupp et al., 2009; Luebbe et al., 2012; Walter et al., 2012). Luebbe et al. (2012) revealed that partially replacing dry rolled corn with full-fat DG led to an improvement in 12th rib fat

thickness, suggesting that DG have a positive impact on adipose deposition when utilized in low concentrations in dry rolled corn based diets.

Based on the results of this experiment, replacing 20% FFDG with 20% RFDG had no impact on cattle growth performance or carcass characteristics. Moreover, increasing dietary inclusion of RFDG from 20 to 47% may lead to a reduction in USDA Prime grading cattle, but may improve USDA Yield Grade. Thus, it can be concluded that RFDG can replace FFDG in feedlot diets at the dietary inclusions investigated in this experiment. Moreover, partially replacing dry rolled corn with DG may lead to an improvement in ADG, HCW, and USDA Quality Grade, and a reduction in USDA Select-grading carcasses.

Table 1. Dietary ingredient inclusion (DM basis).

	Treatment[1]			
	C	FF	RFH	RFL
Corn oil, %	0.0	0.9	0.0	0.0
Corn silage, %	14.0	13.7	14.4	13.5
Distillers dried grains, %	0.0	19.5	46.7	19.6
Dry rolled corn, %	76.9	60.5	33.2	61.4
Preservative[2], %	0.2	0.1	0.2	0.2
Oat straw, %	3.1	2.9	3.0	3.0
Vitamin and mineral supplement, %	5.9	2.4	2.6	2.4

[1]Treatments included control diet (C), 20% reduced-fat distillers dry grains inclusion with corn oil (FF), 47% reduced-fat distillers dry grains inclusion (RFH), and 20% reduced-fat distillers dry grains inclusion (RFL).
[2]Myco CURB (Kemin, Des Moines, IA) to control mold growth in feed.

Table 2. Dietary nutrient profile (DM basis).

	Treatment[1]			
	C	FF	RFH	RFL
DM, %[2]	80.6	68.7	69.1	58.2
CP, %	12.1	13.1	20.0	13.2
NDF, %	13.6	16.8	22.0	17.0
ADF, %	7.3	9.3	12.6	9.4
Ether extract, %	3.0	5.0	5.5	4.1
Ca, %	0.67	0.63	0.68	0.63
P, %	0.39	0.50	0.74	0.50
S, %	0.14	0.18	0.28	0.19

[1]Treatments included control diet (C), 20% reduced-fat distillers dry grains inclusion with corn oil (FF), 47% reduced-fat distillers dry grains inclusion (RFH), and 20% reduced-fat distillers dry grains inclusion (RFL).
[2]Water was added to FF, RFH, and RFL treatments to mimic inclusion on distillers wet grains inclusion in diet.

Table 3. Effects of dietary treatment on growth performance.

	Treatment[1]					*P*-value[3]		
	C	FF	RFH	RFL	SEM[2]	DG vs. no DG inclusion	Full-fat DG vs. reduced-fat DG inclusion	20 vs. 47% DG inclusion
Initial BW, kg	477	490	471	507	31	0.39	0.96	0.09
d 28 BW, kg	486	533	513	534	30	0.005	0.54	0.48
d 56 BW, kg	522	565	545	564	37	0.04	0.58	0.62
d 93 BW, kg	552	593	569	604	41	0.05	0.75	0.24
ADG d 0 to 28, kg	0.32	1.53	1.49	0.94	0.48	<0.0001	0.21	0.02
ADG d 28 to 56, kg	1.27	1.13	1.12	1.07	0.47	0.45	0.89	0.81
ADG d 56 to 93, kg	0.83	0.84	0.64	1.15	0.40	0.79	0.77	0.04
Gain, kg	75	106	99	99	26	0.03	0.60	0.83
DMI d 0 to 28, kg	6.62	8.80	8.83	9.08	1.04	<0.0001	0.76	0.61
DMI d 28 to 56, kg	7.96	9.08	9.47	8.81	1.35	0.07	0.93	0.49
DMI d 56 to 93, kg	8.50	8.66	7.60	9.12	1.51	0.96	0.69	0.18
DMI d 0 to 93, kg	7.77	8.82	8.54	9.02	1.16	0.06	0.95	0.55
ADG d 0 to 93, kg	0.81	1.14	1.06	1.07	0.28	0.03	0.60	0.83
Gain: feed d 0 to 93	0.119	0.119	0.139	0.116	0.130	0.75	0.65	0.53

[1]Treatments included control diet (C), 20% reduced-fat distillers dry grains inclusion with corn oil (FF), 47% reduced-fat distillers dry grains inclusion (RFH), and 20% reduced-fat distillers dry grains inclusion (RFL).
[2]Highest standard error of mean reported.
[3]Effects of dietary distillers grains versus no dietary distillers grains inclusion, dietary full-fat versus reduced-fat distillers grains inclusion, and 20 versus 47 percentage dietary distillers grains inclusion. *P*-values < 0.05 considered significant; *P*-values ≤ 0.10 considered a trend.

Table 4. Effects of dietary treatment on carcass characteristics.

	Treatment[1]					*P*-value[3]		
	C	FF	RFH	RFL	SEM[2]	DG vs. no DG inclusion	Full-fat DG vs. reduced-fat DG inclusion	20 vs. 47% DG inclusion
HCW, kg	337	374	360	379	32	0.02	0.78	0.44
Dressing percentage, %	60.8	61.9	63.0	62.5	1.1	0.12	0.50	0.99
Marbling score[4]	424	490	466	537	30	0.19	0.73	0.09
12th rib fat thickness, cm	0.73	0.76	0.82	0.93	0.04	0.43	0.15	0.07
LM area, sq. cm	89.6	95.6	92.5	90.3	0.5	0.47	0.18	0.22
KPH, %	2.3	2.3	2.5	2.5	0.2	0.72	0.22	0.51
USDA Yield Grade	2.7	2.8	2.8	2.9	0.1	0.44	0.12	0.05
USDA Quality Grade[5]	2.5	2.1	2.2	1.8	0.1	0.004	0.49	0.06
Prime, %	0.4	0.0	0.4	18.2	0.1	0.40	0.18	0.01
Choice, %	50.1	90.0	81.5	80.9	0.1	0.02	0.57	0.75
Select, %	49.6	10.0	18.1	1.0	0.1	0.001	0.91	0.30
USDA Yield Grade 2, %	88.2	92.9	87.3	74.1	0.1	0.69	0.22	0.10
USDA Yield Grade 3, %	11.8	7.1	12.7	25.9	0.1	0.69	0.22	0.10

[1]Treatments included control diet (C), 20% reduced-fat distillers dry grains inclusion with corn oil (FF), 46% reduced-fat distillers dry grains inclusion (RFH), and 20% reduced-fat distillers dry grains inclusion (RFL).
[2]Highest standard error of mean reported.
[3]Effects of dietary distillers grains versus no dietary distillers grains inclusion, dietary full-fat versus reduced-fat distillers grains inclusion, and 20 versus 47 percentage dietary distillers grains inclusion. *P*-values < 0.05 considered significant; *P*-values ≤ 0.10 considered a trend.
[4]Marbling score 400 = low choice and 500 = average choice.
[5]USDA Quality Grade 1 = Prime, 2 = Choice, and 3 = Select.

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