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Evaluation of Distillers Grains Components for Finishing Beef Cattle

Jordan E. Burhoop
University of Nebraska-Lincoln, jordanburhoop_28@hotmail.com

EVALUATION OF DISTILLERS GRAINS COMPONENTS FOR FINISHING BEEF CATTLE

by

Jordan E. Burhoop

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EVALUATION OF DISTILLERS GRAINS COMPONENTS FOR FINISHING BEEF CATTLE

Jordan Ethan Burhoop, M. S.

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Advisor: Galen E. Erickson

With the large expansion of the ethanol industry in previous years, there has been an increase in supply of distillers grains plus solubles (DGS) for the feedlot industry. Distiller's grains are a common byproduct used in feedlot diets for added protein or energy. Recently, ethanol companies have been using different extraction techniques to remove various parts of the DGS to sell separately, such as corn oil and fiber. Previous research trials have tried to determine the contribution of individual nutrients in distillers grains that improve performance in order to predict the impact of removing certain components. In previous studies, fiber has shown the greatest contribution; however, no sole nutrient has been identified that contributes to providing equal performance to distillers grains. Therefore, a study was conducted to determine the value of the fiber in modified distillers grains plus solubles for finishing cattle performance. In that study, the conclusion was made that the isolated fiber component does not give equal performance to feeding MDGS due to a reduction in G:F and feeding value if only the fiber components replaced corn, which means the energy in MDGS is provided by other components to make it better than corn. Some producers are concerned that feeding de-oiled DGS will have a negative impact on finishing cattle performance. Currently, some feedlots have been adding corn oil back to diets to ensure they are getting the best

performance possible. Although corn oil has been added to diets in the past and experiments have been done to evaluate de-oiled versus normal DGS, there has never been a study that evaluated the removal of corn oil from distillers grains compared to adding corn oil back to de-oiled distillers grains. Therefore, two finishing studies were completed to determine the effects of the removal of corn oil from modified distillers grains plus solubles and replacement with supplemental corn oil on finishing cattle performance and total tract digestibility. When corn oil was added back to MDGS, there was a negative impact on digestibility of OM and NDF as well as lower DE (Mcal/kg) compared with de-oiled MDGS or full fat MDGS. When 2% corn oil was added back to de-oiled MDGS, there was a 4.9% improvement in F:G compared to de-oiled MDGS. There was a numerical improvement in F:G by 3.7% for MDGS + Oil compared to FF MDGS.

Key words: By-products, Corn oil, Digestion, Distillers grains plus solubles, Fiber, Finishing cattle,

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INTRODUCTION

With the large expansion of the ethanol industry in previous years, there has been an increase in supply of distillers grains plus solubles (DGS) for the feedlot industry. In 2016, there was approximately 59 billion liters of ethanol produced (RFA Pocket Guide to Ethanol, 2016). According to the RFA Pocket Guide to Ethanol (2016), one bushel of corn yields 10.6 liters of ethanol, 7.5 kg of livestock feed, and 0.3 kg of corn oil. In 2016, ethanol plants produced a new record of feed for the livestock industry at nearly 42 million metric tons (RFA, 2017). Distillers grains are a common byproduct used in feedlot diets for added protein or energy. Recently, ethanol companies have been using different extraction techniques to remove various parts of the DGS to sell separately. This review will provide background information regarding ethanol production and DGS, how fiber plays an important role in the diet, and finally a discussion on oil extraction and fat in ruminant diets.

ETHANOL PRODUCTION

The main source of starch for ethanol production in the United States is from corn, with 91.5% of production being from plants utilizing only corn and 7.9% of production being from plants utilizing a blend of corn and some other cereal grain (EPA, 2010). When looking at the components of a corn kernel, it can be broken down into three main areas, which are the pericarp, the endosperm, and the germ. The pericarp is the outer layer of the kernel and contains a large amount of fiber. The endosperm contains gluten that is high in protein and starch. The germ is located inside the endosperm and is where oil can be found. The end goal is to convert the starch portion

into ethanol. This can occur by two different processes, either dry milling or wet milling. In dry milling, the entire corn kernel is ground and processed, while in wet milling the kernel is broken down into its individual components before being processed.

DRY MILLING

PROCESS

The dry milling process is very diverse in the type of grain that can be fermented, such as corn, grain sorghum, wheat, barley, or a mixture of any of these grains (Stock et al., 2000). However, the most common grain is usually U.S. No. 2 grade yellow dent corn that is 85 percent dry matter (DM) or more. The receiving of shelled corn is the first step in the process (OSHA, 2015). Next, the corn is sent through a series of screens to remove any foreign material such as cobs, husks, sticks, rocks, etc. After removal of the foreign material, the kernels are processed through a hammer mill to break down the outer seed coat to help make the starch more easily available. Particles leaving the hammer mill are generally 3.2 to 4.8 millimeters in diameter, which makes mixing with water and further steps down the chain much easier.

In the liquefaction step, the milled corn is mixed with water and alpha-amylase in a jet-cooker to produce what is now called slurry. Alpha-amylase is added to break down the starch into shorter carbohydrate chains known as dextrins. This process can take several hours and once completed the mixture of corn solubles and insolubles is now called mash. The mash is cooled to 30° C and mixed with glucoamylase, which breaks down starch into simple sugars, or glucose. The optimal performance of this process occurs between a pH of 4.0 to 5.5 so sulfuric acid is added to lower the pH from previous steps (OSHA, 2015).

The mash is then sent to fermentation tanks where yeast is added to convert glucose into ethanol and carbon dioxide. The mixture is agitated over 40 to 60 hours of fermentation time to ensure as much ethanol is produced as possible. The fermentation process yields a mixture made up of yeast, bran, gluten, and liquids of which 8 to 12 percent is ethanol (OSHA, 2015). Now that the glucose has been fermented to ethanol, the ethanol needs to be separated from other components of the mixture. To do this, the mixture is pumped through a continuous, multicolumn distillation system, which uses the different boiling points of the liquids to separate them into ethanol, water, and whole stillage. The ethanol still contains some water so it is sent through a molecular sieve to produce a product that is over 99 percent pure ethanol. The ethanol is then denatured by adding gasoline so it cannot be used for human consumption.

The stillage is centrifuged to separate the product into thin stillage and wet cake, also called distillers grains which is 35 percent DM. Thin stillage is water that contains 5 to 10 percent solids, which can either be used in the liquefaction process or evaporated to produce condensed distillers solubles (CDS), which is normally 25 to 40 percent solids (OSHA, 2015). The CDS can either be marketed as a feed ingredient or it can be added back to the distillers grains to produce wet distillers grains plus solubles (WDGS). This co-product can either be marketed or sent through a dryer to produce modified distillers grains plus solubles (MDGS) or further drying produces dry distillers grains plus solubles (DDGS).

NUTRIENT COMPOSITION

Following the removal of starch during the dry milling process, the remaining nutrients have increased concentrations by approximately three times, which shows that

DGS has a greater feeding value compared to corn (Klopfenstein et al., 2008). Buckner et al. (2011a) looked at the nutrient concentrations of WDGS from four different ethanol plants and MDGS from two different plants. For WDGS, they found the CP to be 31.0% and ranged from 30.1 to 32.2%, fat content was 11.9% and ranged from 10.9 to 13.0%, P was 0.84% and ranged from 0.78 to 0.91%, and S was 0.77% and ranged from 0.71 to 0.84%. These values can change depending on the ethanol plant that the WDGS came from or over time at the same plant. It is important for producers to be aware of the analysis of their product before feeding, especially values of DM, fat, and sulfur. Depending on inclusion level in the diet and amount of drying that has taken place, distillers grains can be used as either an energy source or a protein source. At levels of 15-20% of diet DM, distillers grains are included as a protein source, while at levels above 15-20%, the distillers become a protein and energy source due to replacing larger amounts of corn (Corrigan et al., 2006). Larson et al. (1993) reported the feeding value of WDGS is 177% that of corn at 12.6% of diet DM and 155% at 40% of diet DM for yearlings and 146% at 12.6% of diet DM and 135% at 40% of diet DM for calves. Bremer et al. (2011) summarized performance results from 20 finishing studies evaluating WDGS, four studies evaluating MDGS, and four studies evaluating DDGS in a meta-analysis to update equations that predict performance of feedlot cattle fed 0 to 40% of diet DM as DGS. Bremer reported feeding values of WDGS and MDGS when fed at 20-40% inclusion levels to be 130-143% and 117-124%, respectively. The improved feeding values compared to corn are not due to increased digestibility, but instead from factors such as acidosis control, improved energy utilization, and presence of yeast end products (Stock et al., 2000). Numerous studies have observed lower

digestibility of diets containing DGS compared to the corn that it replaced (Corrigan et al., 2009; Vander Pol et al., 2009; May et al., 2010; Luebbe et al., 2012; Hales et al., 2012, 2013b). It is not clear why drying of distillers grains lowers feeding value, but could be due to heat damage or from the loss of volatile compounds. Since there is no drying associated with WDGS, it has the greatest feeding value relative to corn. Nuttelman et al. (2011) compared the effect of WDGS, MDGS, and DDGS all fed in the same study at 20%, 30%, or 40% of diet DM. The authors observed average feeding values across all inclusion levels of 45.7%, 26.5% and 9.3% more than corn, respectively.

OPTIMUM INCLUSION

There have been numerous studies that have evaluated increasing inclusion levels of DGS in finishing diets to determine the point where optimum performance is met. Nuttelman et al. (2011) compared the effect of three types of distillers grains at three inclusion levels on feedlot performance. For the main effect of inclusion level, there were no differences in final BW, DMI, or ADG between 20, 30, or 40% DGS inclusion level. Cattle fed 40% DGS were more efficient than cattle fed 20% DGS. Watson et al. (2014) also evaluated the effects of dietary inclusion of WDGS or MDGS on finishing cattle performance and carcass characteristics. In the first experiment, dietary treatments were 0, 10, 20, 30, 40, or 50% DM inclusion of WDGS. There were quadratic responses for DMI, final BW, ADG, and G:F as WDGS inclusion increased. Results show that maximum ADG would occur at 30% of diet DM and maximum G:F would occur at 40% of diet DM. The second experiment was similar to the first experiment, but used MDGS instead of WDGS. There were quadratic responses observed for final BW, ADG, and

DMI, while G:F increased linearly as dietary inclusion of MDGS increased. The greatest ADG was observed at 20% of diet DM, while G:F was maximized at 50% of diet DM.

WET MILLING

PROCESS

The receiving and removal of foreign material from shelled corn is the same for wet milling as dry milling. The first step that is different from the dry milling process is steeping to soften the corn kernels. The steep tanks contain water and about 0.1 percent sulfur dioxide, which helps break the waxy layer of the kernel. The steep tanks are connected in series and water is recycled through each tank. Fresh water is added to the tank that has been steeping the longest and the excess water is recycled back through the series until it reaches the tank with the fresh corn. The tanks are kept at approximately 52°C, where the corn is soaked for 28 to 48 hours, to yield steeped corn kernels and heavy steepwater. Heavy steepwater can be added back to gluten feed later in the process or it can be sold as an ingredient. The steeped corn is sent through a coarse grind that puts a crack in the kernel to allow for separation of the germ (Jansen, 2009). The germ is separated, dried, and goes through an extraction process to remove the corn oil, which is sold to outside markets. The remaining portion of the germ can be sold as corn germ meal or can be added to gluten feed.

The remaining kernel is sent through a finer grind, which decreases the particle size of the endosperm but leaves the fiber portion intact (Jansen, 2009). The fiber portion, or wet bran, can be pressed to produce dry bran and is a major component of gluten feed. The remaining portion of the kernel without the bran still contains starch and gluten. These components are centrifuged to separate the lower density gluten from the starch

(Corn Refiners, 2017). The gluten that has been removed can be dried to produce corn gluten meal that can be sold as an ingredient for pet foods or the poultry industry. The starch component is washed to remove any remaining protein, and can then be directed many different ways. The starch can either be dried and sold to the food industry or used to produce dextrose. Dextrose can be processed to form high fructose corn syrup or fermented to ethanol similar to the dry milling process (Stock et al., 2000). The fermentation process yields products for outside industries, ethanol, and condensed distillers solubles that can be added to gluten feed. Condensed distillers solubles from the wet milling industry contain a lesser amount of fat compared to the CDS from the dry milling industry due to removal of oil from the germ. The main co-product produced from the wet milling industry is wet corn gluten feed (WCGF), which traditionally contains dry bran, corn germ meal, condensed distillers solubles, and heavy steepwater (Blanchard, 1992). The process of combining ingredients to make corn gluten feed varies widely between plants so there is not a consistent nutrient profile. The DM, amount of bran, heavy steepwater, condensed distillers solubles, germ meal, cracked corn screenings, and end products from other microbial fermentations can all vary among plants producing CGF.

FIBER IN FINISHING DIETS

Fiber is the plant cell wall that is made up of cellulose, hemicellulose, and lignin. These components make up approximately 40-70% of the dry matter in forages (Van Soest, 1994). The fiber portion of diets will stimulate rumination, salivation, and reticuloruminal motility, all of which help to elevate ruminal pH (NASEM, 2016). According the Nutrient Requirements of Beef Cattle, the consumption of fiber to

stimulate normal digestive function is the key to long-term health and productivity of the animal. The source of fiber, in the diet as roughage, has an impact on extent of digestion, rate of passage, and rate of digestibility. High quality forages will have a high digestibility and faster passage rate, which will increase intakes, while low quality forages have lower digestibility and slower passage rate, which will depress intakes (Mertens, 1994). When feeding distillers grains in the diet, producers are able to use a lower quality, fibrous, otherwise unpalatable forage source. The DGS increases palatability, allows for better mixing of the diet, and will help prevent cattle from sorting components of the diet. Since starch is not present in distillers grains and there is a high proportion of fiber, it was hypothesized that the addition of distillers grains in the diet could help prevent ruminal acidosis (Krehbiel et al., 1995; Farran et al., 2006; Klopfenstein et al., 2008). Felix et al. (2012) concluded that DGS in the diet does not help prevent ruminal acidosis, and with the low pH of DGS, could actually increase the risk of acidosis, which means that roughage is still needed in the diet. Benton et al. (2015) evaluated the effects of roughage source and inclusion level by comparing alfalfa hay, corn silage, or corn stalks at low or standard inclusion levels. The corn silage and corn stalk diets were formulated to be equal in NDF to 4 or 8% alfalfa hay. There were no differences in DMI, ADG, or G:F due to roughage source; however, cattle fed a standard inclusion had greater DMI and ADG than cattle fed a low inclusion. Benton concluded that reducing or eliminating roughage when including WDGS in the diet is not beneficial. Hales et al. (2013a) fed four inclusion levels of alfalfa hay to determine optimum inclusion to maximize performance. The authors concluded that the ideal alfalfa

inclusion for finishing diets that include DRC and WDGS, is 3% for optimal G:F and 7% for optimal ADG.

CORN FRACTIONATION

Changes have been made recently to the dry milling process, such as prefractionation and post fractionation. Prefractionation is broken down into either wet or dry technologies (Berger and Singh, 2010). In wet fractionation, also referred to as the enzymatic dry grind (E-mill) corn process, the corn is soaked for approximately six to 12 hours and then coarsely ground. Protease and starch degrading enzymes are incubated with the corn kernels to increase specific gravity, which will help separate the different components. The germ and pericarp fiber are separated out in hydrocyclones and endosperm fiber is screened either before or after fermentation (Berger and Singh, 2010). The degermed and defibered slurry is then fermented. When comparing the nutrient composition of DDGS from the E-mill process to the conventional dry grind process, there is an increase in protein content from 28 to 58%, fat content is decreased from 12.7 to 4.5%, ADF decreased from 10.8 to 2.0%, and ash content was not changed (Berger and Singh, 2010).

Dry fractionation, also referred to as dry degerm defiber (3D) process, is similar to wet fractionation, but does not involve the soaking step. With this process, corn is subjected to hot water or steam for approximately five to 10 minutes, followed by removal of germ and pericarp from the corn endosperm (Duensing et al., 2003). The endosperm is broken into smaller pieces called grits during grinding. The grits and germ are separated using density separation, while pericarp fiber is removed from grits using air. The remaining grits are what is processed to produce ethanol and DGS. The bran, or

fiber, can be combined with distillers solubles to create a by-product feed called Dakota Bran (Poet Nutrition, Sioux Falls, SD). Buckner et al. (2011b) completed a finishing study to evaluate increasing levels of Dakota Bran and to compare Dakota Bran to DDGS. Dietary treatments consisted of a corn control, 15% Dakota Bran, 30% Dakota Bran, 45% Dakota Bran, and 30% DDGS. The nutrient composition of Dakota Bran was 52% DM, 14.7% CP, 32.0% NDF, 10.9% fat, and 0.82% S, while the nutrient composition of DDGS was 90% DM, 29.5% CP, 29.0% NDF, 10.8% fat, and 1.24% S. As inclusion of Dakota Bran increased, carcass adjusted final BW and ADG increased linearly. There was a quadratic increase in DMI as inclusion of Dakota Bran increased in the diet, with DMI decreasing at the highest inclusion level. A linear improvement in G:F was observed when Dakota Bran was included in the diet compared to CON. There were no significant differences reported for any performance or carcass characteristics between 30% inclusion of Dakota Bran or DDGS. The authors concluded that wet Dakota Bran has a similar feeding value to DDGS.

Fiber can also be removed from distillers grains at the end of the process, using a technology called elusieve. In this process, the DGS are separated into four different sizes and fiber is removed from the three largest sizes through air separation (Loar et al., 2009). In the air separation process, the DGS goes through a sifter into an aspirator with one aspirator for each size category. When air is blown through the DGS, the lighter fiber portion is moved into a separate area of the aspirator. The resulting product has increased protein content from 28 to 41%, increased fat content from 12 to 14%, and reduced NDF content from 32 to 19% (Berger and Singh, 2010). Currently, research only exists evaluating DGS from the elusieve process in poultry and swine diets.

CELLERATE

There has been recent interest in using alternative products besides corn to produce ethanol, which has led to the adoption of cellulosic ethanol production. Instead of using cellulose from trees, plants or grasses, a new process utilizes fiber from the corn kernel to produce ethanol in a secondary fermentation process (Cellerate; Syngenta, Wilmington, DE and Cellulosic Ethanol Technologies, LLC, Galva, IA). Before centrifugation that yields distillers grains and corn condensed distillers solubles (CCDS), cellulosic enzymes and yeast are added to the whole stillage. The enzymes and yeast help to remove the residual starch and fiber that is left in the kernel. This process results in a different distillers product than is typically fed, called cellulosic wet distillers grains. Lundy et al. (2015) evaluated the impact of cellulosic wet distillers grains on steer growth performance and carcass characteristics during the finishing period. Dietary treatments consisted of a corn-based control with 13% traditional WDG, 30% traditional WDG, 30% cellulosic wet distillers grains, or 18% cellulosic wet distillers grains and 12% CCDS. The nutrient composition of the traditional WDG was 32.5% DM, 34.1% CP, 32.2% NDF, and 7.7% ether extract, while cellulosic wet distillers grains was 34.0% DM, 39.1% CP, 32.7% NDF, and 7.3% ether extract. When comparing the control and 30% traditional WDG, there was no difference in DMI, while cattle on the 30% traditional WDG treatment had a higher ADG, which led to improved G:F. When comparing 30% cellulosic wet distillers grains and 30% traditional WDG, there were no differences in ADG, FBW, HCW, LM area, or marbling score. Steers fed 30% cellulosic wet distillers grains had increased DMI, and in turn decreased G:F compared to 30% traditional WDG. The calculated feeding value of 30% traditional WDG was 138% the value of corn and

30% cellulosic wet distillers grains was 111% the value of corn. When comparing 30% cellulosic wet distillers grains and 18% cellulosic wet distillers grains and 12% CCDS, cattle fed 18% cellulosic wet distillers grains and 12% CCDS had a lower DMI and ADG; however, G:F was not different. The authors concluded that feeding distillers grains from a secondary fermentation process to cattle will result in similar performance as feeding traditional WDG; however, their conclusion appears to be incorrect due to poorer feed efficiency and lower feeding value observed with cellulosic wet distillers grains.

FEEDING ISOLATED COMPONENTS OF WET MILLING INDUSTRY

There have been numerous studies that have evaluated the effects of DGS on finishing cattle performance, but it has been unclear what contribution each individual nutrient plays in improving performance. Lodge et al. (1997) evaluated the effect of a composite of feed ingredients formulated to be similar in nutrient composition to wet distillers byproducts on finishing cattle performance. The authors evaluated a DRC control, WCGF, WDGS composite that contained 65.7% WCGF, 26.3% corn gluten meal, and 8.0% tallow, the composite minus tallow, or the composite minus corn gluten meal. There were no treatment differences observed for ADG. Cattle fed the composite treatment were 10% more efficient than steers fed WCGF or DRC control, while cattle fed the composite minus tallow or corn gluten meal were 7% more efficient than WCGF or DRC control. The authors concluded that the composite was similar in nutrient content and resulted in similar performance; however, they were not able to identify how the interactions between fat, fiber, and protein contribute to the increase in performance. Conroy et al. (2016) conducted a finishing experiment to determine the nutrient values of

isolated components of WDGS. Dietary treatments consisted of a corn-based control with no WDGS, 40% WDGS diet, 10% CCDS diet, 14% corn gluten meal and 10% CCDS diet to mimic the protein content of WDGS, 4.2% full-oil germ and 10% CCDS diet to mimic the fat content of WDGS, and 14% dry corn bran, 3% solvent extracted meal (SEM) and 10% CCDS diet to mimic the fiber content of WDGS. When comparing the control to 40% WDGS, results were similar to previous research, with steers fed 40% WDGS having similar DMI, increased ADG, and higher G:F than the control. Steers fed 14% corn gluten meal and 10% CCDS (protein diet) or 4.2% full-oil germ and 10% CCDS (fat diet) ate more than the control, 40% WDGS, and 10% CCDS, while 14% dry corn bran, 3% SEM and 10% CCDS (fiber diet) was intermediate. The greatest ADG was observed for cattle fed 40% WDGS, intermediate for the protein diet or fat diet, with the fiber diet being greater than both the control and 10% CCDS. Cattle fed 40% WDGS had the greatest G:F value. The fiber diet treatment led to improved G:F when compared to the fat diet, with all other treatments being intermediate. The authors were not able to determine a sole nutrient component that was responsible for the increased performance observed when feeding distillers grains. However, it was concluded that there were numeric improvements from the fiber component compared to protein and fat.

Since there was no determination of a specific nutrient responsible for the increased performance, another study was completed to determine the nutritional energy value of the fiber, protein, fat, and solubles and their interactions in WDGS (Oglesbee et al., 2016). Ten dietary treatments were evaluated consisting of a 1) corn-based control, 2) 20% WDGS diet, 3) 40% WDGS diet, 4) 7% corn bran and 1.5% solvent extracted germ meal diet to mimic the fiber portion of 20% WDGS, 5) 14% corn bran and 3% solvent

extracted germ meal diet to mimic the fiber portion of 40% WDGS, 6) 17.5% corn gluten meal was added to the fiber diet to mimic the crude protein in 40% WDGS, 7) 7.5% whole fat germ was added to the fiber diet to mimic the fat portion, solubles were then added to each of the 3 fiber diets at 8% of diet DM. Final BW, HCW, DMI, and ADG increased quadratically for WDGS compared to the control. Feed efficiency was improved due to ADG increasing at a greater magnitude than DMI. Results of final BW, HCW, ADG, 12th rib fat, marbling score, and yield grade were greater for cattle fed 20% WDGS and 40% WDGS compared to cattle fed the respective fiber diet. Feeding WDGS resulted in improved G:F compared to fiber due to similar DMI and greater ADG. The calculated feeding value of 7% corn bran and 1.5% solvent extracted germ meal was 119%, 14% corn bran and 3% solvent extracted germ meal decreased to 83%, and 40% WDGS was greatest at 130%. These results indicate that the fiber portion alone only contributes a portion of the positive performance seen with feeding WDGS. When including solubles in diets, there was a significant increase in final BW, HCW, DMI, ADG, 12th rib fat, marbling score, and yield grade; however, there was no effect on G:F. The addition of protein led to an increase in the feeding value; however, feeding values of 117% for the 14% corn bran, 3% solvent extracted germ meal, and 17.5% corn gluten meal treatment and 121% for 14% corn bran, 3% solvent extracted germ meal, 17.5% corn gluten meal, and 8% CCDS treatment were not as high as the 130% observed with 40% WDGS. When fat was added to the diet, DMI decreased and G:F increased, and the feeding value was increased 2 to 8%. When all components were added together, the feeding value was 127%, which almost matched the feeding value of 130% for 40% WDGS. The observed results show that the fiber portion alone does not account for the

increased performance from feeding WDGS and that the interactions between fiber, protein, fat, and solubles are all important.

OIL REMOVAL

Another nutrient component of DGS that has received attention lately is the fat content and how fat impacts rumen fermentation, and digestion of nutrients such as fiber. There are two strategies in place for removing the corn oil from DGS at the ethanol plant. The first is done prior to the fermentation step by front-end fractionation, which separates the endosperm, germ, and bran using hexane. The germ is where the fat is contained in the kernel, so the germ is targeted for corn oil removal (Winkler-Moser, 2011). Depenbusch et al. (2008) fed diets consisting of a control with no DGS, 13% dried corn DGS from traditional dry-grind process (12% fat), and 13% dried corn DGS from a partial fractionation dry-grind process (4% fat). Dry matter intake, ADG, and feed efficiency were not different for cattle fed the control diet compared to either DGS treatment. Cattle fed traditional DGS had a greater DMI than those on the fractionated diet, but ADG and feed efficiency were not different for cattle fed either DGS treatment. Depenbusch et al. (2008) concluded that performance was not different for cattle fed DGS from either processing method if the fractionated DGS was at a low level. To show performance characteristics of fractionated DGS fed at a greater dietary concentration, Gigax et al. (2011) fed a control diet with no WDGS, pre-fractionated WDGS at 35% (6.7% fat), and normal WDGS at 35% (12.9% fat) of diet DM. The normal WDGS had a greater final BW and HCW compared to pre-fractionated and control. The ADG followed the same trend as final BW and HCW with normal WDGS having the greatest ADG. The

authors concluded that pre-fractionated WDGS had a reduced energy value than normal WDGS and was comparable to a normal corn-based diet (Gigax et al., 2011).

The other method used is removing the oil after fermentation from thin stillage by simply putting it through a centrifuge (Winkler-Moser, 2011). This product can be fed or added back to the grains to make lower fat content DGS. To determine the effects of cattle performance fed CDS that has gone through the post-fractionation process, Jolly et al. (2013) completed three different studies. The first experiment completed by Jolly et al. (2013) looked at replacing a DRC:HMC blend with 27% de-oiled (6.0% fat) or full fat CDS (21.1% fat) to 40% de-oiled (9.2% fat) or full fat MDGS (11.8% fat). There were no interactions between fat content and byproduct type (CDS vs MDGS). As expected, the CDS and MDGS diets both showed an improved G:F over the control diet. Surprisingly, there were no significant differences observed for G:F between de-oiled and full fat CDS or MDGS, although the de-oiled CDS treatment was numerically more efficient than the full fat CDS treatment. There were no significant differences for DMI, ADG, or G:F when comparing CDS to MDGS. The second experiment by Jolly et al. (2013) looked at how de-oiled or full fat CDS or MDGS affected total tract digestibility. Treatments consisted of 27% de-oiled (8.7% fat) or full fat (15.4% fat) CDS and 40% de-oiled (9.2% fat) or full fat (12.3% fat) MDGS. No differences between de-oiled or full fat CDS or MDGS were observed for DM and OM intake or digestibility. Intake of NDF was greater in full fat CDS treatments compared to de-oiled CDS diets, and was greater in full fat MDGS diets compared to de-oiled MDGS diets. Total tract NDF digestibility was greater in full fat CDS treatments compared to de-oiled CDS treatments, and was not different between de-oiled and full fat MDGS. The final finishing trial by Jolly evaluated de-oiled

or normal WDGS at 35, 50, or 65% inclusion levels. The fat concentration of de-oiled WDGS was 7.9%, while normal WDGS was 12.4%. There were no linear or quadratic interactions observed for ADG or G:F. Jolly observed no statistical differences for final BW, ADG, or G:F when comparing de-oiled to normal WDGS, which suggests feeding de-oiled by-products will give similar performance to feeding normal by-products. Bremer et al. (2014) completed two finishing experiments that also evaluated the effects of de-oiled versus normal distillers grains on finishing cattle performance. In the first experiment, they fed de-oiled MDGS (7.2% fat) at 0, 15, 30, 45, or 60% of diet DM or full fat MDGS (12.0% fat) at 15 or 30% of diet DM. The results presented here will be from the 2×2 factorial of inclusion level and amount of fat. There were no significant differences reported for final BW, DMI, or ADG for cattle fed de-oiled or full fat MDGS at either inclusion level. There was a tendency for an interaction between fat content and inclusion level on G:F. There was no difference in G:F between de-oiled and full fat MDGS at 15%; however, there was a tendency for a difference at the 30% inclusion level, with cattle fed full fat MDGS being 3.3% more efficient than cattle fed de-oiled MDGS. The second experiment conducted by Bremer et al. (2014) was a 2×2 factorial to compare 35% full fat (11.3% fat) or de-oiled (7.9% fat) WDGS in DRC or SFC based diets. No corn processing method by WDGS fat content interactions were observed. For the main effect of WDGS fat content, there were no statistical differences in DMI, ADG, or G:F. Numerically, cattle fed full fat WDGS were 2.7% more efficient than their de-oiled counterparts in DRC based diets, and numerically 5.2% more efficient in SFC based diets.

NEGATIVE IMPACTS OF FAT

Fat is normally fed and wanted in diets to increase the energy density since it has approximately 2.25 times the energy of carbohydrates from cereal grains (Hess et al., 2008). However, supplementing fat at high concentrations in the diet can have negative impacts on performance and fiber digestibility. A brief understanding of fiber digestion in the rumen is needed to understand the negative impacts of fat on fiber digestion. Once in the rumen, fibrolytic microbes attach to forage particles and enzymes are released from the microbes. Thin cell walls are digested by the enzymes released from the microbe, while thicker cell walls are adhered to in order for the microbes to digest them. This breakdown by microbes produces VFA, carbon dioxide, and methane in the rumen. There are thought to be two main reasons that fat has a negative impact on fiber digestion. The first is the coating theory, which says that fat particles coat forage particles, which leads to a decrease in attachment by microbes. The second reason is that fat can be toxic to fiber digesting microbes. Doreau and Chilliard (1997) showed that there was a decrease in the acetate:propionate ratio in the rumen of animals fed supplemental fat at greater than 6% of diet DM, along with a lower digestibility of the fibrous fraction of OM. Leupp et al. (2006) offered steers switch grass hay and canola seeds to provide 4% of diet DM as crude fat and found that forage intake and diet digestibility were not affected. To show that increased levels could have a negative impact on performance and digestibility, Pavan et al. (2007) supplemented corn oil to steers grazing fescue pasture at 0, 0.75, or 1.5 g/kg of BW and reported decreased forage DMI and total DE intake. From the interpretation of many different studies, it was concluded that the optimal level of supplementation of fat in a high forage diet is 3% of DM if you want to maximize DMI

of the forage. Fat supplementation should be limited to 2% of DM if replacement of forage intake with fat is not beneficial (Hess et al., 2008). However, fat can be supplemented up to 9.4% of DM in a high-concentrate finishing diet without affecting the digestibility of other feedstuffs in the diet (Hess et al., 2008).

WDGS vs. SUPPLEMENTAL FAT

Fat in distillers grains is bound in the germ and unavailable to microbes in the rumen. Thus, it is able to pass through the rumen undegraded and does not have a negative impact on fiber digestion. Corn oil removed from CDS is considered free oil, which means that it is available to microbes in the rumen and thus impacts fiber digestion in the rumen. Vander Pol et al. (2009) conducted three different experiments to determine the effect of feeding WDGS or supplemental fat on performance, rumen metabolism, and digestibility. Dietary treatments for the first experiment were 0, 20, or 40% WDGS or 0, 2.5, or 5.0% corn oil in a finishing diet based on HMC and DRC. In the first experiment, the authors observed that as supplemental corn oil increased, ADG decreased linearly, but as WDGS increased, there was no effect on ADG. Feed efficiency showed similar results with G:F decreasing linearly as corn oil in the diet increased. Al-Suwaiegh et al. (2002) concluded that the fat in distillers grains improved NE_g by 42%, while the remaining 58% increase was due to addition of yeast, excess protein used for energy, added moisture, cofactors, differences in nonfiber carbohydrate fraction, or a reduction in subacute acidosis. In summary, fat from distillers grains had an impact on performance, but there were also many other factors that contributed to the improved performance (Al-Suwaiegh et al., 2002). Vander Pol et al. (2009) concluded that 20% DGS and 40% DGS diets provided 2.5 and 6.8% more NEg, respectively, than the 0% DGS diet.

The second experiment conducted by Vander Pol et al. (2009) looked at DDGS vs. tallow and different levels of fat (1.3 or 2.6% added fat). There were no significant differences found for any performance characteristics that were observed. The energy and nutrient density of DDGS is less than WDGS, as WDGS fed in Exp 1 resulted in improved performance relative to control; however, the comparison is hard to make since the results were from different studies. The overall conclusion of this study was that providing similar quantities of supplemental fat through added tallow is similar to feeding DDGS.

Vander Pol et al. (2009) conducted a digestion study that utilized five cannulated Holsteins to evaluate the effects of feeding WDGS, a composite (corn bran and corn gluten meal), or supplemental corn oil on various aspects of feeding behavior, digestion, duodenal fatty acid profile, and metabolism. Average ruminal pH was the lowest for the WDGS treatment and greatest for the composite + oil treatment, along with time below pH 5.6 being the least for the composite + oil treatment. The acetate:propionate ratio was least for the WDGS treatment stemming from less acetate and more propionate being produced. Since the corn bran treatment had a greater acetate:propionate ratio, it is thought that there was increased fiber digestion. Cattle fed the control plus oil diet had a decreased starch and fat intake, which was a direct correlation to a lower DMI for that treatment. The reason for the reduction was thought to be due to an interaction between corn oil and additional DRC in the diet. According to values observed for total tract DM, OM, and NDF digestibility, the authors concluded that supplemental corn oil might impede total tract starch digestion relative to similar fat supplied by WDGS. Vander Pol et al. (2009) concluded that WDGS appears to have a positive effect on total-tract starch

digestion along with no negative impact on starch digestion from the fat content of WDGS, while supplemental corn oil can negatively impact starch digestion. Feeding high-concentrate diets can negatively impact biohydrogenation, meaning more unsaturated fatty acids making it to tissue and milk (Atkinson et al., 2006). In Vander Pol's study, supplemental corn oil had larger amounts of 18:0 reaching the duodenum, while cattle fed WDGS had the least. The opposite was seen for proportions of 18:1 trans, 18:1, and 18:2 reaching the duodenum with WDGS having greater numbers and supplemental corn oil having lower numbers. This shows that the fatty acids in WDGS are not hydrogenated to the same extent as fatty acids in corn oil, and in turn since unsaturated fats are absorbed more efficiently, the fat in WDGS is more digestible than corn oil.

LIPOLYSIS AND BIOHYDROGENATION

There is a large difference in the composition of fat in the tissues and milk of ruminant animals compared to that of non-ruminants (Banks and Hilditch, 1931). The difference is that the fats are more saturated in ruminant tissues even though the feed that they have consumed is unsaturated. This shows that there is some process going on in the rumen to be making the conformational change. Some of the unsaturated fatty acids that are present in the feed are α-linolenic acid (cis-9, cis-12, cis-15-18:3) and linoleic acid (cis-9, cis-12-18:2) (Jenkins et al., 2008). In these descriptions, the cis refers to the orientation of hydrogen (both on the same side) around a double bond, the 18:2 or :3 refers to the number of carbons present in the chain and the number of double bonds, respectively. There are also triglycerides, phospholipids, and galactolipids present in the feed (Jenkins et al., 2008). The first way that fats are transformed in the rumen is by

lipolysis, which is a process that uses microbial lipases to hydrolyze ester linkages of triglycerides to release fatty acids (Jenkins et al., 2008). The microorganism in the rumen that is responsible for producing two enzymes to help with lipolysis of fat is *Anaerovibrio lipolytica*. Lipolysis leaves a glycerol backbone that can be fermented to produce volatile fatty acids (VFAs) (Doreau and Ferlay, 1994). After lipolysis, there is a process that changes polyunsaturated fatty acids to saturated fatty acids by microorganisms in the rumen, which is called biohydrogenation. The process of biohydrogenation is needed because unsaturated fatty acids are toxic to rumen bacteria if they are allowed to accumulate in large quantities (Lock, 2006). A study done by Reiser (1951) demonstrated that biohydrogenation is taking place as the linolenic acid (18:3) present in linseed oil decreased substantially while the concentration of 18:2 increased. Another study looked at the conversion of linolenic acid to 18:2 and 18:1 intermediates and an end product of stearic acid (18:0; Shorland et al., 1955). In this study, they observed that 93% of the linolenic acid was converted to stearic acid as the end product, with a small portion in the trans 18:1 configuration. Going from the cis configuration to the trans configuration in intermediates is commonly how biohydrogenation takes place. To support the thought of going through a trans intermediate, Wilde and Dawson (1966) completed a study where they infused linolenic acid into sheep ruminal contents. They found that the cis-12 bond was isomerized to the C_{11} or C_{13} position, and then one of the double bonds was hydrogenated to produce a fatty acid with the composition of 18:2. Following this step there were two more steps of hydrogenation to produce an 18:1 and then finally stearic acid as the final product.

After biohydrogenation in the rumen, the next site of activity is the small intestine, and more specifically the jejunum, where most fatty acid absorption occurs (Hess et al., 2008). Approximately 80-90% of the free fatty acids that have entered the SI are attached to feed particles (Doreau and Chilliard, 1997). Before the feed reaches the jejunum, bile and pancreatic juice have been added to aid in solubilizing the fat. The bile supplies bile salts and lecithin, while pancreatic juice supplies enzymes to convert lecithin to lysolecithin and bicarbonate to raise the pH. These two secretions separate the fatty acids from the feed and bacteria they are attached to. In order for absorption to occur, the fatty acids have to form micelles, with micelles coming from unsaturated fatty acids being more efficiently utilized (Vander Pol et al., 2009). The micelle is needed to dissolve water-insoluble fatty acids so they can cross the unstirred water layer of intestinal epithelial cells of the jejunum (Lock et al., 2005). Once the fatty acids make it into the cell, they are re-esterified into triglycerides to be packaged into chylomicrons for transport in the blood.

CONJUGATED LINOLEIC ACID

One positive important impact of biohydrogenation in ruminant animals is the fact that an intermediate conjugated linoleic acid (CLA) is produced by altering the conformation around the double bonds of linoleic acid. This intermediate makes it to the SI following incomplete biohydrogenation. The process of forming CLA is isomerization of linoleic acid to form cis-9, trans-11, which is followed by hydrogenation of the cis-double bond to a trans-monoenoic acid (Grinari et al., 1999). Another idea on how CLA is produced is that Δ^9-desaturase converts trans-11 octadecenoic acid from the rumen to CLA (Grinari et al., 1999). The authors believe that incomplete biohydrogenation could

not provide large enough numbers of CLA levels in tissue and milk, so they developed the second hypothesis. There are many positive impacts of having cis-9, trans-11 and trans-10, cis-12 present in the tissue and milk of ruminant animals (Mir et al., 2004). Some of the health benefits mentioned by Mir et al. (2004) are anticarcinogenesis in mice, enhancement of immunity, alleviation of allergies and asthma, decreased blood cholesterol in hamsters, antiatherosclerotic effects in rabbits, decreased obesity in mice, and enhanced insulin sensitivity in Zucker obese rats. There are CLA's present in milk and beef but the concentrations depend on pasture vs. feedlot finished, diet in the feedlot, and presence of oil or oilseed in the diet (Mir et al., 2004). Some methods that could be used to increase the amount of CLA found in beef would be to provide a source of dietary linoleic acid, use a dietary forage to establish micro flora that enhance the formation and deposition of CLA in tissues, and to provide modest amounts of grain compared to high levels of grain.

CONCLUSION

The large increase in ethanol production in the last few years has left producers with a great byproduct that can either be used as a protein or energy source. Producers need to be aware of the price that they are paying for DGS and decide if it is economical for their operation to be using the byproduct as an energy source or if they should just use it as a protein source. Feeding distillers grains has been very common due to the increased value compared to a corn-based diet, which has been shown in numerous different studies. Recently, ethanol companies have been further processing DGS, so producers need to be aware of the nutrient composition of the product that they are receiving and need to stay up to date on current research to know the best way to utilize

the byproduct that they are feeding. Therefore, three experiments were conducted to address several objectives:

1. Determine the value of the fiber in modified distillers grains plus solubles for finishing cattle
2. Evaluate the effects of the removal of corn oil from modified distillers grains plus solubles and the impact of supplemental corn oil on finishing cattle performance
3. Evaluate the effects of the removal of corn oil from modified distillers grains plus solubles and the impact of supplemental corn oil on finishing cattle nutrient digestion

LITERATURE CITED

Al-Suwaiegh, S., K. C. Fanning, R. J. Grant, C. T. Milton, T. J. Klopfenstein. 2002. Utilization of distillers grains from the fermentation of sorghum or corn in diets for finishing beef and lactating dairy cattle. J. Anim. Sci. 80:1105-1111.

Atkinson, R. L., E. J. Scholljegerdes, S. L. Lake, V. Nayigihugu, B. W. Hess, D. C. Rule. 2006. Site and extent of digestion, duodenal flow, and intestinal disappearance of total and esterified fatty acids in sheep fed a high-concentrate diet supplemented with high-linoleate safflower oil. J. Anim. Sci. 84:387-396.

Banks, A., T. P. Hilditch. 1931. The glyceride structure of beef tallows. Biochemical Journal 25:1168-1182.

Benton, J. R., A. K. Watson, G. E. Erickson, T. J. Klopfenstein, K. J. Vander Pol, N. F. Meyer, M. A. Greenquist. 2015. Effects of roughage source and inclusion in beef finishing diets containing corn wet distillers grains plus solubles. J. Anim. Sci. 93:4358-4367.

Berger, L., V. Singh. 2010. Changes and evolution of corn coproducts for beef cattle. J. Anim. Sci. 88(Suppl.):143-150.

Blanchard, P. H. 1992. Technology of corn wet milling and associated processes. Industrial Chemistry Library Vol. 4. New York: Elsevier.

Bremer, M. L. 2014. Energy value of de-oiled distillers grains plus solubles in beef cattle diets. Masters theses. Univ. of Nebraska- Lincoln.

Bremer, V. R., A. K. Watson, A. J. Liska, G. E. Erickson, K. G. Cassman, K. J. Hanford, T. J. Klopfenstein. 2011. Effect of distillers grains moisture and inclusion level in livestock diets on greenhouse gas emissions in the corn-ethanol-livestock life cycle. The Prof. Anim. Scientist. 27:449-455.

Buckner, C. D., M. F. Wilken, J. R. Benton, S. J. Vanness, V. R. Bremer, T. J. Klopfenstein, P. J. Kononoff, G. E. Erickson. 2011a. Nutrient variability for distillers grains plus solubles and dry matter determination of ethanol by-products. The Prof. Anim. Scientist. 27:57-64.

Buckner, C. D., V. R. Bremer, T. J. Klopfenstein, G. E. Erickson, K. J. Vander Pol, K. K. Karges, M. L. Gibson. 2011b. Evaluation of a prefermentation-fractionated by-product corn grain dry milling ethanol process in growing and finishing cattle diets. The Prof. Anim. Scientist. 27:295-301.

Conroy, B. B., M. K. Luebbe, G. E. Erickson, J. C. MacDonald, J. A. Hansen. 2016. Impact of feeding distillers grains or isolated components in distillers grains on feedlot performance and carcass traits. Neb. Beef Cattle Rep. 122-123.

Corn Refiners Association. 2017. What is corn refining. https://corn.org/what-is-corn-refining/. Accessed: May 12, 2017.

Corrigan, M. E., G. E. Erickson, T. J. Klopfenstein, M. K. Luebbe, K. J. Vander Pol, N. F. Meyer, C. D. Buckner, S. J. Vanness, K. J. Hanford. 2009. Effect of corn processing method and corn wet distillers grains plus solubles inclusion level in finishing steers. J. Anim. Sci. 87:3351-3362.

Corrigan, M. E., G. E. Erickson, V. R. Bremer, T. J. Klopfenstein. 2006. Effect of corn processing in finishing diets containing grain milling byproducts. Oklahoma State University Ext. Cattle Grain Processing Symposium. pp. 173-182.

Depenbusch, B. E., E. R. Loe, M. J. Quinn, M. E. Corrigan, M. L. Gibson, K. K. Karges, J. S. Drouillard. 2008. Corn distillers grains with solubles derived from a traditional or partial fractionation process: Growth performance and carcass characteristics of finishing feedlot heifers. J. Anim. Sci. 86:2338-2343.

Doreau, M., A. Ferlay. 1994. Digestion and utilisation of fatty acids by ruminants. Animal Feed Science and Technology. 45:379-396.

Doreau, M., Y. Chilliard. 1997. Digestion and metabolism of dietary fat in farm animals. British Journal of Nutrition. 78:S15-S35.

Duensing, W. J., A. B. Roskens, R. J. Alexander. 2003. Corn dry milling: Processes, products and applications. Pages 407-447 in Corn: Chemistry and Technology. P. J. White and L. A. Johnson, ed. Am. Assoc. Cereal Chem., St. Paul, MN.

Environmental Protection Agency. 2010. Renewable Fuel Standard Program. https://www.epa.gov/renewable-fuel-standard-program. Accessed May 10, 2017.

Farran, T. B., G. E. Erickson, T. J. Klopfenstein, C. N. Macken, R. U. Lindquist. 2006. Wet corn gluten feed and alfalfa hay levels in dry-rolled corn finishing diets: Effects on finishing performance and feedlot nitrogen mass balance. J. Anim. Sci. 84:1205-1214.

Felix, T. L., T. A. Murphy, S. C. Loerch. 2012. Effects of dietary inclusion and NaOH treatment of dried distillers grains with solubles on ruminal metabolism of feedlot cattle. J. Anim. Sci. 90:4951-4961.

Gigax, J. A., B. L. Nuttelman, W. A. Griffin, G. E. Erickson, T. J. Klopfenstein. 2011. Performance and carcass characteristics of finishing steers fed low-fat and normal-fat wet distillers grains. Neb. Beef Cattle Rep. 44-45.

Grinari, J. M., D. E. Bauman. 1999. Biosynthesis of conjugated linoleic acid and its incorporation into meat and milk in ruminants. Advances in conjugated linoleic acid research 1.1.

Hales, K. E., H. C. Freetly, S. D. Shackelford, D. A. King. 2013a. Effects of roughage concentration in dry-rolled corn-based diets containing wet distillers grains with solubles on performance and carcass characteristics of finishing beef steers. J. Anim. Sci. 91:3315-3321.

Hales, K. E., N. A. Cole, J. C. MacDonald. 2012. Effects of corn processing method and dietary inclusion of wet distillers grains with solubles on energy metabolism, carbon-nitrogen balance, and methane emissions on cattle. J. Anim. Sci. 90:3174-3185.

Hales, K. E., N. A. Cole, J. C. MacDonald. 2013b. Effects of increasing concentration of wet distillers grains with solubles in steam-flaked corn-based diets on energy metabolism, carbon-nitrogen balance, and methane emissions of cattle. J. Anim. Sci. 91:819-828.

Hess, B. W., G. E. Moss, D. C. Rule. 2008. A decade of developments in the area of fat supplementation research with beef cattle and sheep. J. Anim. Sci. 86:188-204.

Jansen, R., J. Kerr, P. Lloyd-Jones, R. Tanner. 2009. Corn wet milling process. United States Patent Application Publication. US 2009/0238918 A1.

Jenkins, T. C., R. J. Wallace, P. J. Moate, E. E. Mosley. 2008. Board-invited review: Recent advances in biohydrogenation of unsaturated fatty acids within the rumen microbial ecosystem. J. Anim. Sci. 86: 397-412.

Jolly, M. L. 2013. Evaluation of oil extraction on corn dry-milling byproducts in growing and finishing cattle diets. Masters theses. Univ. of Nebraska-Lincoln.

Klopfenstein, T. J., G. E. Erickson, V. R. Bremer. 2008. BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86:1223-1231.

Krehbiel, C. R., R. A. Stock, D. W. Herold, D. H. Shain, G. A. Ham, J. E. Carulla. 1995. Feeding wet corn gluten feed to reduce subacute acidosis in cattle. J. Anim. Sci. 73:2931-2939.

Larson, E. M., R. A. Stock, T. J. Klopfenstein, M. H. Sindt, R. P. Huffman. 1993. Feeding value of wet distillers byproducts for finishing ruminants. J. Anim. Sci. 71:2228-2236.

Leupp, J. L., G. P. Lardy, S. A. Soto-Navarro, M. L. Bauer, J. S. Caton. 2006. Effects of canola seed supplementation on intake, digestion, duodenal protein supply, and microbial efficiency in steers fed forage-based diets. J. Anim Sci. 84:499-507.

Loar, R. E., R. Srinivasan, M. T. Kidd, W. A. Dozier, A. Corzo. 2009. Effects of elutriation and sieving processing (Elusieve) of distillers dried grains with solubles on the performance and carcass characteristics of male broilers. J. Appl. Poult. Res. 18:494-500.

Lock, A. L. B. M. Teles, J. W. Perfield II, D. E. Bauman, L. A. Sinclair. 2006. A conjugated linoleic acid supplement containing trans-10, cis-12 reduces milk fat synthesis in lactating sheep. J. Dairy Sci. 89:1525-1532.

Lock, A. L., K. J. Harvatine, I. Ipharraguerre, M. Van Amburgh, J. K. Drackley, D. E. Bauman. 2005. The dynamics of fat digestion in lactating dairy cows: what does the literature tell us. Proc. Cornell Nutr. Conf. 83-94.

Luebbe, M. K., J. M. Patterson, K. H. Jenkins, E. K. Buttrey, T. C. Davis, B. E. Clark, F. T. McCollum, N. A. Cole, J. C. MacDonald. 2012. Wet distillers grains plus solubles concentration in steam-flaked corn based diets: Effects on feedlot cattle performance, carcass characteristics, nutrient digestibility, and ruminal fermentation characteristics. J. Anim. Sci. 90:1589-1602.

Lodge, S. L., R. A. Stock, T. J. Klopfenstein, D. H. Shain, D. W. Herold. 1997. Evaluation of wet distillers composite for finishing ruminants. J. Anim. Sci. 75:44-50.

Lundy, E. L., D. D. Loy, S. L. Hansen. 2015. Influence of distillers grains resulting from a cellulosic ethanol process utilizing corn kernel fiber on nutrient digestibility of lambs and steer feedlot performance. J. Anim. Sci. 93:2265-2274.

May, M. L., J. C. DeClerck, M. J. Quinn, N. DiLorenzo, J. Leibovich, D. R. Smith, K. E. Hales, M. L. Galyean. 2010. Corn or sorghum wet distillers grains with solubles in combination with steam-flaked corn: Feedlot performance, carcass characteristics, and apparent total tract digestibility. J. Anim. Sci. 88:2433-2443.

Mertens, D. R. 1994. Regulation of forage intake. Forage quality, evaluation, and utilization. 450-493.

Mir, P. S., T. A. McAllister, S. Scott, J. Aalhus, V. Baron, D. McCartney, E. Charmley, L. Goonewardene, J. Basarab, E. Okine, R. J. Weselake, Z. Mir. 2004. Conjugated linoleic acid–enriched beef production. The American journal of clinical nutrition. 79:1207S-1211S.

National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient Requirements of Beef Cattle, Eighth Revised Edition. The National Academies Press, Washington, DC.

Nuttelman, B. L., W. A. Griffin, J. R. Benton, G. E. Erickson, T. J. Klopfenstein. 2011. Comparing dry, wet, or modified distillers grains plus solubles on feedlot cattle performance. Neb. Beef Cattle Rep. 50-52.

Oglesbee, R. A., C. J. Bittner, F. H. Hilscher, G. E. Erickson, J. C. MacDonald, M. K. Luebbe. 2016. Evaluation of distillers grains components singly or in combination in a calf fed feedlot study. Neb. Beef Cattle Rep. 124-127.

Occupational Safety and Health Administration. 2015. Section II: Ethanol industry and process descriptions. https://www.osha.gov/dts/osta/otm/otm_iv/descriptions.pdf. Accessed: May 10, 2017.

Pavan, E., S. K. Duckett, J. G. Andrae. 2007. Corn oil supplementation to steers grazing endophyte-free tall fescue. I. Effects on in vivo digestibility, performance, and carcass traits. J. Anim. Sci. 85:1330-1339.

Reiser, R. 1951. Hydrogenation of polyunsaturated fatty acids by the ruminant. Federation Proceedings. Federation of American Societies for Experimental Biology. 10:236.

Renewable Fuels Association. 2016. Pocket guide to ethanol. http://www.ethanolrfa.org/wp-content/uploads/2016/02/10823-RFA.pdf. Accessed: June 15, 2017.

Renewable Fuels Association. 2017. Co-products. http://www.ethanolrfa.org/resources/industry/co-products. Accessed: June 15, 2017.

Shorland, F. B., R. O. Weenink, A. T. Johns. 1955. Effect of the rumen on dietary fat. Nature. 175.4469:1129-1130.

Stock, R. A. 2017. Personal Communication. UNL Feedlot Nutrition and Management. Accessed: January 23, 2017.

Stock, R. A., J. M. Lewis, T. J. Klopfenstein, C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. J. Anim. Sci. 77:1-12.

Vander Pol, K. J., M. K. Luebbe, G. I. Crawford, G. E. Erickson, T. J. Klopfenstein. 2009. Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts, or supplemental corn oil. J. Anim. Sci. 87:639-652.

Van Soest, P. J. 1994. Nutritional ecology of the ruminant. Cornell University Press.

Watson, A. K., K. J. Vander Pol, T. J. Huls, M. K. Luebbe, G. E. Erickson, T. J. Klopfenstein, M. A. Greenquist. 2014. Effect of dietary inclusion of wet or modified distillers grains plus solubles on performance of finishing cattle. The Prof. Anim. Scientist. 30:585-596.

Wilde, P. F., R. M. C. Dawson. The biohydrogenation of α-linoleic and oleic acid by rumen microorganisms. Biochemical Journal. 98:469–475.

Winkler-Moser, J. K., L. Breyer. 2011. Composition and oxidative stability of crude oil extracts of corn germ and distillers grains. Industrial Crops and Products. 33: 572-578.

CHAPTER II. EVALUATION OF THE VALUE OF FIBER IN DISTILLERS GRAINS PLUS SOLUBLES ON PERFORMANCE OF FINISHING CATTLE

J. E. Burhoop, L. J. Schneider, C. J. Bittner, F. H. Hilscher, J. C. MacDonald, R. A. Moxley, D. R. Smith, G. E. Erickson

ABSTRACT

A finishing experiment was conducted to determine the value of the fiber in distillers grains plus solubles for cattle. The experiment utilized 800 crossbred yearling steers (initial BW = 415 kg; SD = 24 kg) fed in 100 pens (8 steers/pen and one of 5 treatments; n=20 pens/treatment). Cattle were split into four blocks by starting blocks each week for four consecutive weeks. Cattle were limit fed 5 d prior to starting experiment and were weighed on day 0 and 1 for an accurate initial BW. The five treatments consisted of a corn control diet (CON), 20 (20MDGS) or 40% (40MDGS) modified distillers grains plus solubles (MDGS), and two diets containing corn germ meal and corn bran balanced to equal the fiber content of the two MDGS diets (20FIB and 40FIB). Performance data were based on 134 d (blocks 1, 2, 3) or 148 d (block 4) with carcass data being collected at slaughter and following a 48 hr chill. Initial BW (P = 0.63) was not influenced by treatment. Intakes were impacted by treatment ($P < 0.01$) and DMI increased quadratically ($P < 0.01$) as MDGS increased with steers fed 20MDGS having the greatest DMI. Steers fed 40MDGS or 40FIB had similar DMI (P = 0.76), whereas steers fed 20MDGS consumed more ($P < 0.01$) than steers fed 20FIB. When 20FIB and 40FIB were fed, DMI increased linearly (P = 0.01) relative to CON. Dietary treatment impacted ADG ($P < 0.01$) with ADG increasing quadratically (P = 0.02) as MDGS inclusion increased, and equal ADG between 20MDGS and 40MDGS (P = 0.96). Feeding 20FIB and 40FIB numerically reduced ADG but not statistically, ($P > 0.14$) compared to CON. As a result of increased ADG, G:F increased linearly ($P < 0.01$) for steers fed MDGS. When steers were fed 20FIB or 40FIB, G:F decreased linearly ($P <$ 0.01) due to an increase in DMI and numerical decrease in ADG compared to CON. The

feeding value (change in G:F due to MDGS inclusion) of MDGS was 107 to 108% of corn that was replaced in CON, while the isolated fiber treatments had feeding values that were lower than the control at 83% for 20FIB and 90% for 40FIB. The isolated fiber component does not give equal performance to feeding MDGS due to a reduction in G:F and feeding value if only the fiber components replaced corn, which means the energy in MDGS is provided by other components to make it better than corn.

Key words: Distillers grains plus solubles, Fiber, Finishing cattle

INTRODUCTION

Distillers grains are commonly fed in finishing diets. The ethanol industry has recently started removing components of distillers grains, such as fiber components, which changes the nutrient content of distillers grains plus solubles (DGS) that are available to be fed. Previous research trials have tried to determine the contribution of individual nutrients in distillers grains that improve performance in order to predict the impact removal of certain components would have. Lundy et al. (2015) examined WDGS from secondary cellulosic ethanol fermentation that removes a portion of the fiber and reported poorer feed efficiency compared to traditional WDGS. Feeding the fiber diet (FIB) which consisted of 14% dry corn bran and 3% solvent extracted meal resulted in the closest performance to the DGS diet in one study (Conroy et al., 2016). Oglesbee et al. (2016) fed either 20 or 40% WDGS, 20% fiber that contained 7% corn bran and 1.5% solvent extracted germ meal (SEM) to mimic the fiber content of 20% WDGS, or 40% fiber that contained 14% corn bran and 3% SEM to mimic the fiber content of 40% WDGS. The fiber portion alone did not improve G:F; however, when protein was added G:F was increased and when fat and solubles were added separately, G:F continued to improve. Oglesbee concluded that feeding individual components did not mimic performance of WDGS, but including fiber, protein, fat and solubles combined together gave the same performance as feeding WDGS. Oglesbee's findings demonstrate that the interactions between fiber, protein, fat, and solubles in WDGS are important, and have a similar feeding value to WDGS. The objective of this study was to determine the value of the fiber in modified distillers grains plus solubles for finishing cattle performance.

MATERIALS AND METHODS

All animal care and management procedures were approved by the University of Nebraska- Lincoln Institution of Animal Care and Use Committee (IACUC #902).

A finishing experiment conducted at the Eastern Nebraska Research and Extension Center utilized 800 crossbred yearling steers (initial BW = 415 kg ± 24 kg). For five days prior to the start of the trial, cattle were limit-fed a diet of 50% alfalfa and 50% Sweet Bran (DM Basis) at 2% of BW to reduce variation in gastrointestinal fill (Watson et al., 2013). Cattle were weighed on day 0 and 1 to establish an accurate initial BW (Stock et al., 1983). Steers were split into four blocks according to their initial BW with each block consisting of 200 head. A new block was started each week for four consecutive weeks, with the heaviest block being started first. A total of 100 pens were used for the study with 8 steers per pen. Pens were assigned randomly to treatment with five treatments and 20 pens per treatment. The replication was needed as a food safety study was being performed simultaneously to evaluate these diets. The objective of that study was to determine whether the level of fiber or source of fiber in the diet affects the probability of detecting seven serogroups of Enterohemorrhagic Escherichia coli (EHEC) in rectoanal mucosa swabs and hides of feedlot steers (Schneider et al., 2017). All cattle were adapted to the finishing treatments over a five-step adaptation process by replacing alfalfa with dry-rolled-corn (DRC).

On arrival, cattle were vaccinated with a modified live virus to protect against infectious bovine rhinotracheitis virus, bovine viral diarrhea virus Types 1 and 2, parainfluenza virus, and bovine respiratory syncytial virus (Bovi-shield Gold 5, Zoetis Animal Health, Parsippany, NJ), administered an injectable dewormer (Dectomax

Injectable, Zoetis Animal Health), and vaccinated to protect against clostridium chauvoei-septicum-novyi-sordellii-perfringens types C and D (Ultrabac 7, Zoetis Animal Health). Cattle were revaccinated 14-21 d later to protect against BVD types 1 and 2, IBR, BRSV, PI_3, and *Manheimia haemolytica* (Bovi-shield Gold One Shot, Zoetis Animal Health) and *Histophilus somni* (Somubac, Zoetis Animal Health). Blocks 1, 2, and 3 were implanted with Revalor-200® (200 mg trenbolone acetate and 20 mg estradiol, Merck Animal Health, Summit, NJ) 99 days prior to harvest and block 4 was implanted 113 days prior to harvest.

The five treatments consisted of a corn control diet (CON), 20% (20MDGS) or 40% (40MDGS) modified distillers grains plus solubles, and two diets formulated with corn germ meal and corn bran to equal the fiber content of 20MDGS (20FIB) or 40MDGS (40FIB; Table 2.1). Watson et al. (2014) reported that ADG was maximized at 20-30% DM inclusion of MDGS and G:F was maximized at 40-50%, so they concluded that 20-40% inclusion of MDGS is optimum. The inclusion levels in the current study were chosen to evaluate this common range for inclusion. To mimic the nutrient composition of the 20MDGS treatment, the 20FIB treatment contained 1.5% solvent extracted germ meal (SEM) and 7% wet corn bran from the wet milling industry (Cargill Corn Milling, Blair, NE). Likewise, the 40FIB treatment was formulated to mimic 40MDGS by adding 3% SEM and 14% wet corn bran. Lab analysis of NDF indicated values of 16.7% for 20MDGS and 16.6% for 20FIB, and 22.0% for 40MDGS and 22.2% for 40FIB. We can conclude the fiber diets mimicked the MDGS diets and were formulated correctly. On a DM basis, all diets contained 12% high moisture corn (HMC), 8% corn silage, 3% alfalfa hay, and supplement fed at either 5% or 8%. The control,

20FIB, and 40FIB had a greater inclusion of supplement because 3% soybean meal was fed in addition to urea to meet RDP requirements (NRC, 1996). The supplement also provided Tylan-40® (Elanco Animal Health, Indianapolis, IN) at 90 mg per steer daily and Rumensin-90® (Elanco Animal Health) at 33.1 g per metric ton DM.

Feed bunks were assessed at approximately 0600 h and managed to contain trace amounts (≤ 0.2 kg) of feed remaining in the morning at time of feeding. Refused feed was removed as needed, weighed, and dried in a forced air oven for 48 h at 60°C for DM determination (AOAC, 1999; Method 930.15) to calculate accurate DMI. Diets were mixed and delivered daily at approximately 0800 h using a truck-mounted feed mixer and delivery unit (Roto-Mix model 274, Roto-Mix, Dodge City, KS). Individual ingredient samples were collected weekly and analyzed for DM content. Weekly ingredient samples were composited by month for the entire feeding period and analyzed for DM, OM, NDF, ADF, lignin, and CP. Ash and OM were determined by placing samples in a muffle furnace for 6 h at 600°C (AOAC, 1999; method 4.1.10). The procedure for determining NDF is outlined by Van Soest et al. (1991) with modifications to the analysis of corn and byproducts described by Buckner et al. (2010). Acid detergent fiber and lignin content were determined using the procedure described by Van Soest et al. (1963). Determination of CP was completed by using a combustion type N analyzer (TruSpec N Determinator, Leco Corporation, St. Joseph, MI; AOAC, 1999; method 990.03).

Cattle in the three heavier blocks were fed for 134 days and the light block was fed for 148. Steers were shipped to a commercial abattoir (Greater Omaha Packing, Omaha, NE) for slaughter, and carcass data were recorded. On day of harvest, hot carcass weight and liver score were collected. Following a 48-hour chill, USDA marbling score,

LM area, and 12th rib fat thickness were captured by cameras within the plant and recorded at time of grading. Calculated final BW, ADG, and G:F were calculated using HCW adjusted to a common dressing percentage of 63%. Feeding values were calculated using the following equation: [((compared treatments G:F- CON G:F) / CON G:F) / compared treatments byproduct inclusion rate * 100 + 100]. Dietary NEm and NEg values were calculated for each treatment based on intake and performance of steers. The data were analyzed as dietary NE for each pen, similar to performance data using equations from the NRC (1996) as described by Vasconcelos and Galyean (2008).

Animal performance and carcass characteristics were analyzed as an unstructured treatment design using a protected F-test, where block was included as a fixed effect. Treatment design was also analyzed as a 2 × 2+1 with two feed sources (MDGS or Fiber) and two inclusion levels (20 or 40%) plus a control. Interactions for the 2 × 2 factorial design were evaluated. Linear and quadratic orthogonal contrasts were used to evaluate inclusion of MDGS or fiber in the diet with the control being the 0% inclusion level. Data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc. Cary, N.C.), where pen was the experimental unit. Treatment differences were declared significant at $P \leq 0.05$. One steer from the control treatment died on day 147 and a steer from the 40MDGS treatment was removed on day 86 due to repeated bloating. These two steers were removed from performance data.

RESULTS AND DISCUSSION

Initial BW ($P = 0.63$; Table 2.2) was not influenced by treatment, based on allocation. Intakes were impacted by treatment ($P < 0.01$) and DMI increased with MDGS inclusion, with steers fed 20MDGS having the greatest DMI (12.2 kg). Steers fed

40MDGS or 40FIB had similar DMI (12.0 and 11.9 kg, respectively; $P = 0.76$). Steers fed 20MDGS consumed more ($P < 0.01$) than steers fed 20FIB (12.2 vs. 11.8 kg, respectively). When 40FIB was fed, DMI increased linearly ($P = 0.01$) relative to CON. Dietary treatment impacted ADG ($P < 0.01$), as ADG was improved with MDGS inclusion compared to FIB; however, ADG was similar for cattle fed 20MDGS and 40MDGS (1.84 and 1.83 kg, respectively; $P = 0.96$). Feeding 20FIB and 40FIB (1.69 and 1.70 kg, respectively) slightly reduced ADG but not statistically ($P > 0.14$) compared to CON (1.73 kg). As a result of increased ADG, G:F improved linearly ($P < 0.01$) for steers fed MDGS (0.151 for 20MDGS and 0.153 for 40MDGS). When steers were fed 20FIB or 40FIB, G:F decreased linearly ($P < 0.01$) due to an increase in DMI and numerical decrease in ADG compared to CON (0.148). The cattle on the MDGS treatments were more efficient than their counterparts on the FIB treatments. Conroy et al. (2016) reported similar results between 40% WDGS and fiber for all performance characteristics when compared to the current study; however, performance was slightly poorer in the current study.

The feeding value of MDGS relative to corn (difference between test G:F and control G:F divided by control G:F, then divided by by-product inclusion level) was 107% for 20MDGS and 108% of corn for 40MDGS. Bremer et al. (2011) reported feeding values of MDGS when fed at 20-40% inclusion levels to be 117-124%. Nuttelman et al. (2011) compared the effect of three types of distillers grains at three inclusion levels on feedlot performance. For the main effect of inclusion level, there were no differences in final BW, DMI, or ADG between 20, 30, or 40% DG inclusion level ($P > 0.24$). Cattle fed 40% DG were more efficient than cattle fed 20% DG ($P = 0.05$).

Nuttelman et al. (2011) observed a feeding value of 126% for MDGS relative to corn. Conroy et al. (2016) observed a feeding value of 136% for 40% WDGS relative to corn. In the current study, the isolated fiber treatments had feeding values that were lower than the control at 83% for 20FIB and 90% for 40FIB. Oglesbee et al. (2016) observed a feeding value of 119% for 20% Fiber and 83% for 40% Fiber, while 40% WDGS was 130%. From feeding value results, it was concluded that just the fiber portion in WDGS does not account for all of the performance increase seen with feeding WDGS. When comparing WDGS to MDGS, it is evident that the two products do not give equal performance, which can be seen by decreased feeding values for MDGS (Bremer et al., 2011; Nuttelman et al., 2011). It is not clear why drying of distillers grains lowers feeding value, but could be due to heat damage or from the loss of volatile compounds. The cattle performed as expected when comparing MDGS to fiber, with the MDGS treatments showing the best performance and the fiber treatments having reduced performance.

The values observed for NEm and NEg followed the same trend with the 40MDGS (1.94 and 1.29 Mcal/kg, respectively) having the greatest NEm and NEg values ($P < 0.01$), while all other treatments were lower and similar to each other (1.89- 1.90 Mcal/kg and 1.25- 1.26 Mcal/kg, respectively; $P > 0.21$).

Steers on the MDGS treatments had the greatest HCW ($P < 0.01$) and fat thickness ($P < 0.01$) compared to the other three treatments. Oglesbee et al. (2016) reported that feeding WDGS at 20 and 40% resulted in greater HCW, ADG, fat thickness, and marbling score when compared to the fiber diets, which is similar to results in the current study, except marbling score. Cattle fed 20MDGS had the highest marbling ($P < 0.01$), with the other four treatments being lower and not significantly

different from each other. Dietary treatment had no impact on LM area ($P = 0.42$). The total number of liver abscesses were not statistically different between treatment groups ($P = 0.59$). There were only two steers from the entire trial that had a severe (A+) liver score.

The results from the current study illustrate that G:F was poorer if only the fiber components that typically comprise distillers grains replace corn. These data suggest that the isolated fiber component does not give equal performance to feeding MDGS. It is unclear what impact removal of a portion of the fiber from distillers may have, if other components are concentrated. These data are based on fiber isolated from the wet milling process, but presumably applies for fiber from distillers grains plus solubles, as both are isolated from corn grain.

LITERATURE CITED

AOAC. 1999. Official method of analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Bremer, V. R., A. K. Watson, A. J. Liska, G. E. Erickson, K. G. Cassman, K. J. Hanford, T. J. Klopfenstein. 2011. Effect of distillers grains moisture and inclusion level in livestock diets on greenhouse gas emissions in the corn-ethanol-livestock life cycle. Prof. Anim. Sci. 27:449-455.

Buckner, C. D. 2010. Ethanol byproduct feeds: nutrient composition and variability, determining accurate fiber content, storing with low-quality forages, and fiber utilization in finishing diets. Ph.D. dissertation. Univ. of Nebraska-Lincoln.

Conroy, B. B., M. K. Luebbe, G. E. Erickson, J. C. MacDonald, J. A. Hansen. 2016. Impact of feeding distillers grains or isolated components in distillers grains on feedlot performance and carcass traits. Neb. Beef Cattle Rep. 122-123.

Lundy, E. L., D. D. Loy, S. L. Hansen. 2015. Influence of distillers grains resulting from a cellulosic ethanol process utilizing corn kernel fiber on nutrient digestibility of lambs and steer feedlot performance. J. Anim. Sci. 93:2265-2274.

National Research Council. 1996. Nutrient Requirements of Beef Cattle. Seventh Edition. National Academy Press, Washington, D.C.

Nuttelman, B. L., W. A. Griffin, J. R. Benton, G. E. Erickson, T. J. Klopfenstein. 2011. Comparing dry, wet, or modified distillers grains plus solubles on feedlot cattle performance. Neb. Beef Cattle Rep. 50-52.

Oglesbee, R. A., C. J. Bittner, F. H. Hilscher, G. E. Erickson, J. C. MacDonald, M. K. Luebbe. 2016. Evaluation of distillers grains components singly or in combination in a calf fed feedlot study. Neb. Beef Cattle Rep. 124-127.

Schneider, L. G., T. J. Klopfenstein, Z. R. Stromberg, G. L. Lewis, G. E. Erickson, R. A. Moxley, D. R. Smith. 2017. A randomized controlled trial to evaluate the effects of dietary fiber from distillers grains on enterohemorrhagic *Escherichia coli* detection from the rectoanal mucosa and hides of feedlot steers. Zoonoses and Public Health (submitted).

Stock, R. A., T. J. Klopfenstein, D. Brink, S. Lowry, D. Rock, S. Abrams. 1983. Impact of weighing procedures and variation in protein degradation rate on measured performance of growing lambs and cattle. J. Anim. Sci. 57:1276-1285.

Watson, A. K., B. L. Nuttelman, T. J. Klopfenstein, L. W. Lomas, G. E. Erickson. 2013. Impacts of a limit-feeding procedure on variation and accuracy of cattle weights. J. Anim. Sci. 91:5507-5517.

Watson, A. K., K. J. Vander Pol, T. J. Huls, M. K. Luebbe, G. E. Erickson, T. J. Klopfenstein, M. A. Greenquist. 2014. Effect of dietary inclusion of wet or modified distillers grains plus solubles on performance of finishing cattle. Prof. Anim. Sci. 30:585-596.

Van Soest, P. J. 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. Journal of A.O.A.C. 46:830.

Van Soest, P. J., J. B. Robertson, B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583.

Vasconcelos, J. T., M. L. Galyean. 2008. Technical note: Do dietary net energy values calculated from performance data offer increased sensitivity for detecting treatment differences? J. Anim. Sci. 86:2756-2760.

Table 2.1. Composition (% of diet DM) of dietary treatments fed to yearling steers

	Treatment[1]				
Ingredient	CON	20MDGS	40MDGS	20FIB	40FIB
Dry-rolled corn	68.5	51.5	31.5	60	51.5
High-moisture corn	12	12	12	12	12
MDGS[2]	-	20	40	-	-
SEM[3]	-	-	-	1.5	3
Wet Corn Bran	-	-	-	7	14
Corn Silage	8	8	8	8	8
Alfalfa hay	3.5	3.5	3.5	3.5	3.5
Supplement[4]	-	-	-	-	-
Fine Ground Corn	1.228	2.635	2.899	1.361	1.856
Limestone	1.615	1.599	1.585	1.633	1.604
Tallow	0.2	0.125	0.125	0.2	0.2
Urea	1.377	0.25	-	1.2	0.75
SBM	3	-	-	3	3
Potassium Chloride	0.189	-	-	0.215	0.199
Salt	0.3	0.3	0.3	0.3	0.3
Beef Trace Minerals	0.05	0.05	0.05	0.05	0.05
Vitamin A-D-E	0.015	0.015	0.015	0.015	0.015
Rumensin-90®[5]	0.017	0.017	0.017	0.017	0.017
Tylan-40®[6]	0.009	0.009	0.009	0.009	0.009
Nutrient Composition, % of DM					
CP	14.1	15.1	19.8	14.1	13.3
NDF	11.0	16.7	22.0	16.6	22.2
ADF	4.5	6.6	8.6	6	7.5
Lignin	1.7	2.3	2.9	1.9	2.2

[1]Treatments included CON-control; 20MDGS-20% modified distillers grains plus solubles; 40MDGS-40% modified distillers grains plus solubles; 20FIB-fiber fed from concentrated ingredients to mimic fiber provided by 20MDGS; 40FIB-fiber fed from concentrated ingredients to mimic fiber provided by 40MDGS.
[2]MDGS: Modified distillers grains plus solubles,
[3]SEM: solvent extracted germ meal
[4]Supplement fed at 8% of dietary DM for CON, 20FIB, and 40FIB and 5% of dietary DM for 20MDGS and 40MDGS
[5]Formulated to supply Rumensin-90® (Elanco Animal Health) at 30 g per ton DM
[6]Formulated to supply Tylan-40® (Elanco Animal Health) at 90 mg per steer daily

Table 2.2. Effect of feeding modified distillers grains plus solubles (MDGS) at 20 or 40% of diet DM compared to fiber to mimic NDF provided by 20 or 40% MDGS on feedlot performance and carcass characteristics

	Treatment[1]						*P*-values[2]		
	CON	20MDGS	40MDGS	20FIB	40FIB	SEM	F-TEST	INT	SOURCE	INCLUSION
Feedlot Performance										
Initial BW, kg	415	415	415	415	415	0.4	0.63	0.53	0.26	0.89
Final BW, kg[3]	653^{b}	668^{a}	668^{a}	648^{b}	648^{b}	2.5	<0.01	0.90	<0.01	0.96
DMI, kg/d	11.7^{c}	12.2^{a}	12.0^{b}	11.8^{bc}	11.9^{b}	0.1	<0.01	0.03	0.01	0.54
ADG, kg	1.73^{b}	1.84^{a}	1.83^{a}	1.69^{b}	1.70^{b}	0.02	<0.01	0.93	<0.01	0.98
G:F	0.148^{b}	0.151^{ab}	0.153^{a}	0.143^{c}	0.142^{c}	0.0005	<0.01	0.09	<0.01	0.47
Feeding Value[4]	-	107	108	83	90	-	-	-	-	-
NEm, Mcal/kg[5]	1.90^{b}	1.90^{b}	1.94^{a}	1.89^{b}	1.90^{b}	0.009	<0.01	0.05	<0.01	0.02
NEg, Mcal/kg[5]	1.26^{b}	1.26^{b}	1.29^{a}	1.25^{b}	1.25^{b}	0.008	<0.01	0.06	<0.01	0.02
Carcass Characteristics										
HCW, kg	411^{b}	421^{a}	421^{a}	408^{b}	409^{b}	1.6	<0.01	0.90	<0.01	0.96
LM area, cm^{2}	88.4	88.4	87.1	87.7	87.7	0.6	0.42	0.12	0.73	0.45
Marbling[6]	477^{b}	496^{a}	476^{b}	465^{b}	476^{b}	6.0	<0.01	0.01	0.01	0.45
12th rib fat, cm	1.35^{b}	1.47^{a}	1.50^{a}	1.32^{b}	1.40^{b}	0.03	<0.01	0.27	<0.01	0.12
Liver Abscess (n)[7]	10	7	15	12	9	-	0.59	0.14	0.99	0.54

[a-c]Means with different subscripts differ ($P < 0.05$)

[1]Treatments included CON-control; 20MDGS-20% modified distillers grains plus solubles; 40MDGS-40% modified distillers grains plus solubles; 20FIB-fiber fed from concentrated ingredients to mimic fiber provided by 20MDGS; 40FIB-fiber fed from concentrated ingredients to mimic fiber provided by 40MDGS.

[2]INT=interaction between fiber source and inclusion, SOURCE = P-value for main effect of fiber source, INCLUSION = main effect of fiber or MDGS inclusion.

[3]Calculated from HCW/common dressing percentage (63%)
[4]Feeding Value Calculation: [((compared treatments G:F – CON G:F) / CON G:F) / compared treatments by-product inclusion rate*100 + 100]
[5]Dietary NE equations from the NRC (1996) as described by Vasconcelos and Galyean (2008)
[6] Marbling score: 400 = Slight^{00}, 450 = Slight^{50}, 500 = Small^{00}, 550 = Small^{50}
[7]Liver Abscess Score: total number of A-, A, or A+ liver scores per treatment (159 or 160 steers per treatment group). Only two steers were observed with A+ abscesses.

CHAPTER III. IMPACT OF CORN OIL REMOVAL FROM MODIFIED DISTILLERS GRAINS PLUS SOLUBLES AND SUPPLEMENTAL CORN OIL ON FINISHING CATTLE PERFORMANCE AND NUTRIENT DIGESTION

J. E. Burhoop*, C. J. Bittner*, F. H. Hilscher*, M. K. Luebbe*, J. C. MacDonald*, G. E. Erickson*

*Department of Animal Science, University of Nebraska, Lincoln, NE 68583

ABSTRACT

Two experiments evaluated the effects of added corn oil in distillers grains plus solubles on finishing cattle performance and nutrient digestion. Experiment 1 utilized 320 steers (initial BW = 413 kg; SD = 25 kg) fed in 32 pens (10 steers / pen) and one of 4 treatments (n = 8 pens / treatment). The four treatments consisted of a corn control diet (CON), 40% de-oiled modified distillers grains plus solubles (DO MDGS), 38% de-oiled modified distillers grains plus solubles plus 2% corn oil (MDGS+Oil), and 40% full fat modified distillers grains plus solubles (FF MDGS). The de-oiled MDGS product contained 8.9% fat while the full fat MDGS product was 11.6% fat. Intakes were impacted by treatment ($P < 0.01$) with steers fed DO MDGS having the greatest DMI ($P < 0.05$) and steers fed CON, MDGS+Oil, and FF MDGS having lower but similar DMI ($P > 0.15$). Dietary treatment had a tendency to impact ADG ($P = 0.06$) and HCW ($P = 0.05$) with the three modified distillers treatments all having similar gains ($P > 0.23$) but DO MDGS and MDGS+Oil were greater than CON ($P < 0.04$) while FF MDGS was similar to CON ($P = 0.14$). As a result of increased ADG, G:F was improved ($P < 0.03$) for cattle fed treatments containing MDGS compared to CON. The greatest G:F was observed for cattle fed MDGS+Oil ($P < 0.05$) while FF MDGS was similar to MDGS+Oil ($P = 0.15$) and DO MDGS ($P = 0.55$). Feeding MDGS improved G:F by 6 to 11% compared to feeding corn; however, G:F was increased 4.9% when 2% dietary oil was added back to de-oiled MDGS whereas only a 1.2% increase in G:F was observed for FF MDGS compared to DO MDGS. Experiment 2 was a 5 × 4 unbalanced Latin rectangle digestion trial with four diets, five ruminally cannulated steers, and five periods that utilized the same treatments as Exp. 1. Dietary fat was 4.2% for CON, 6.0% for

DOMDGS, 7.9% for MDGS+Oil, and 7.1% for FFMDGS. Intake of DM, OM, and energy as well as total tract fat digestibility and DE (Mcal/d) were not impacted by dietary treatment ($P > 0.46$). Cattle fed all 3 treatments containing MDGS had similar ($P > 0.10$) DM excreted, OM excreted, NDF intake, NDF excreted, fat excreted, and fecal energy excretion but greater than steers fed CON ($P < 0.03$). Fat intake was greatest and similar for MDGS+Oil and FFMDGS ($P = 0.47$) and intermediate for DOMDGS ($P = 0.08$), whereas fat intake was least for CON ($P < 0.01$). Total tract OM digestibility was greatest for cattle fed CON ($P < 0.01$), whereas DOMDGS and FFMDGS were intermediate and similar ($P > 0.39$), and MDGS+Oil was lowest but similar to FFMDGS ($P = 0.10$). Total tract digestibility of NDF was greater for FFMDGS compared with CON and MDGS+Oil ($P < 0.04$) but not compared with DOMDGS. There was a tendency for DE (Mcal/kg; $P = 0.13$) to be different among treatments. Feeding FFMDGS resulted in a greater DE (Mcal/kg; $P < 0.04$) compared to CON. The DOMDGS treatment was similar to both FFMDGS ($P = 0.40$) and CON ($P = 0.17$). The MDGS+Oil diet had the lowest DE ($P < 0.01$). When corn oil was added back to MDGS, there was a negative impact on digestibility of OM and NDF as well as lower DE (Mcal/kg) compared with DOMDGS or FFMDGS.

Key words: By-products, Digestion, Distillers grains plus solubles, Finishing cattle, Corn oil

INTRODUCTION

Distillers grains are commonly fed in finishing diets as either a protein or energy source depending on inclusion level. The ethanol industry has recently started removing components of distillers grains, such as corn oil, which changes the nutrient composition of distillers grains plus solubles (DGS) that are available to be fed. Some producers are concerned that feeding de-oiled DGS will have a negative impact on finishing cattle performance. Currently, some feedlots have been adding corn oil back to diets to ensure they are getting the best performance possible.

When comparing de-oiled versus normal fat MDGS at 40% inclusion, there were no significant differences in any performance trait due to the fat content of MDGS (Jolly, 2013). Another study compared de-oiled versus normal WDGS at increasing concentrations, and observed an increase in DMI when de-oiled WDGS was fed (Jolly et al., 2014). For the main effect of oil content, there were no differences for final BW, ADG, or G:F; however, G:F was improved 2.6% for normal WDGS compared to de-oiled WDGS. Cattle consuming normal MDGS at 30% inclusion level were numerically 3.4% more efficient than cattle consuming de-oiled MDGS; however, at the 15% inclusion level the difference was only 1.4%. Vander Pol et al. (2009) fed WDGS (0, 20, or 40%) or corn oil at three different inclusions (0, 2.5, or 5%). Cattle fed 5.0% corn oil had lower overall performance than cattle fed other diets. Their results showed that fat from WDGS improves performance, while G:F was poorer for cattle fed corn oil, which suggests that the fat in the two products is different. A metabolism experiment was conducted to evaluate the digestibility of WDGS compared with corn fiber and corn oil in finishing diets (Vander Pol et al., 2009). Cattle fed WDGS had lower rumen pH, greater

propionate, lower acetate:propionate, and greater total tract fat digestion. Bremer (2010) concluded that cattle fed WDGS had the lowest total tract DM and fat digestibility, while cattle fed corn oil had the lowest total tract NDF digestibility. A third metabolism trial was conducted to determine the effects of corn oil removal from MDGS on nutrient digestibility and ruminal pH (Jolly, 2013). Oil removal had no impact on DM, OM, or NDF digestibility, and average ruminal pH was lower for steers fed de-oiled MDGS than for steers fed normal MDGS.

Although corn oil has been added to diets in the past and experiments have been done to evaluate de-oiled versus normal DGS, there has never been a study that evaluated the removal of corn oil from distillers grains compared to adding corn oil back to de-oiled distillers grains. The objectives of these studies were to determine the effects of the removal of corn oil from MDGS and replacement with supplemental corn oil on finishing cattle performance and total tract digestibility.

MATERIALS AND METHODS

All animal care and management procedures were approved by the University of Nebraska- Lincoln Institution of Animal Care and Use Committee (IACUC #902).

Experiment 1

A 134 d finishing experiment conducted at the Eastern Nebraska Research and Extension Center utilized 320 crossbred yearling steers (initial BW = 413 kg ± 25 kg) in an unstructured treatment design.

Cattle were previously utilized in a receiving study that evaluated different BRD vaccinations (Jones et al., 2017). Initial processing included vaccination with a modified

live viral vaccine (Titanium 5 or Titanium 5 PH-M, Elanco Animal Health, Greenfield, IN), if cattle received Titanium 5, they were given a *Mannheimia haemolytica* vaccine to provide a similar immune response to Titanium 5 PH-M (Nuplura PH, Elanco Animal Health). All cattle received a *Histophilus somni* vaccine (Somnu Shield, Elanco Animal Health), and were administered an injectable dewormer (Dectomax Injectable, Zoetis Animal Health, Parsippany, NJ). Cattle were revaccinated 33 d later with a modified live viral vaccine (Titanium 5, Elanco Animal Health) and a vaccine for prevention of seven clostridial diseases (Ultrabac 7, Zoetis Animal Health). Cattle were implanted with Component TE-200® (200 mg trenbolone acetate, 20 mg estradiol USP, and 29 mg tylosin tartrate, Elanco Animal Health) 104 days prior to harvest.

For five days prior to the start of the trial, cattle were limit-fed a diet of 50% alfalfa hay and 50% Sweet Bran (DM Basis) at 2% of BW to reduce variation in gastrointestinal fill (Watson et al., 2013). Cattle were weighed on day 0 and 1 to establish an accurate initial BW (Stock et al., 1983). Steers were split into three blocks according to their initial BW and assigned randomly to pen within block. There were three blocks, with block one having two reps, block two having five reps, and block three having one rep. A total of 32 pens were used on the study with 10 steers per pen. Pens were assigned randomly to treatment with four treatments and eight pens per treatment. All cattle were adapted to their respective finishing treatment diet over a five-step adaptation process by replacing alfalfa with dry-rolled-corn (DRC) and high moisture corn (HMC). The three treatments that contained MDGS included it at respective inclusion levels throughout the step-up period and corn oil was included in the MDGS+Oil treatment throughout the step-up period as well.

The four treatments consisted of a corn control diet (CON), 40% de-oiled MDGS (DO MDGS), 40% full fat MDGS (FF MDGS), or 38% de-oiled MDGS plus 2% corn oil (MDGS + Oil) formulated to equal the fat content of FF MDGS (Table 3.1). The de-oiled MDGS contained 8.9% fat, while the full fat MDGS contained 11.6% fat. All byproducts utilized in the trial were sourced from the same plant (E Energy Adams, Adams, NE). Although the MDGS + Oil and FF MDGS treatments were formulated to have equal fat content, actual analysis showed the MDGS + Oil treatment contained 7.78% dietary fat and the FF MDGS treatment contained 7.10% dietary fat. On a DM basis, all diets contained 3.5% alfalfa hay, 4% sorghum silage, 5% supplement, and a 50:50 blend of DRC:HMC to make up the remainder of the diet. The control treatment supplement contained 2% Empyreal corn protein concentrate (Cargill, Blair, NE) for days 1-50 then 1% Empyreal for days 51-85 to meet metabolizable protein requirements (NRC, 1996). Empyreal is 75% CP and 65% RUP (% of CP), so it was used because it is an excellent source of RUP, which would ensure any performance improvement from the MDGS treatments was not due to a protein response over the control treatment. Empyreal was removed from the supplement after day 85 as the need for RUP supplementation decreases as cattle grow. Urea was included in the control diet at 1.52% of DM. The supplement also provided Tylan-40® (Elanco Animal Health) at 90 mg per steer daily and Rumensin-90® (Elanco Animal Health) at 33.1 g per metric ton DM.

Feed bunks were assessed at approximately 0600 h and managed to contain trace amounts ($\leq$ 0.2 kg) of feed remaining in the morning at time of feeding. Refused feed was removed as needed, weighed, and dried in a forced air oven for 48 h at 60°C for DM determination (AOAC International, 1997; Method 930.15) to calculate accurate DMI.

Diets were mixed and delivered daily at approximately 0800 h using a truck-mounted feed mixer and delivery unit (Roto-Mix model 274, Roto-Mix, Dodge City, KS). Individual ingredient samples were taken weekly and analyzed for DM content. Experiment 2 was conducted during part of the same time period as Experiment 1, so ingredient samples from Exp. 2 were used for Exp. 1 nutrient analysis. Ingredient samples were taken on days nine and 12 of each period in Exp. 2 and composited by period, lyophilized, ground through a 1-mm screen of a Wiley Mill (Thomas Scientific, Swedesboro, NJ), and analyzed for DM, OM, NDF, fat, and CP. Experiment 1 was longer than Exp. 2, so for the three extra months, weekly ingredient samples were composited by month, lyophilized, ground through a 1-mm screen of a Wiley Mill (Thomas Scientific, Swedesboro, NJ), and analyzed for DM, OM, NDF, fat, CP, and sulfur. Ash and OM were determined by placing samples in a muffle furnace for 6 h at 600°C (AOAC, 1999; method 4.1.10). Ether extract was determined by performing a biphasic lipid extraction procedure (Bremer, 2010). Samples were heated in a 1:1 mixture of hexane and diethyl ether for 9 h, dilute HCl was added, and samples were centrifuged to separate the lipid layer from other liquid. The lipid layer was pipetted off, heated to drive off remaining solvent, and weighed. The procedure for determining NDF is outlined by Van Soest et al. (1991) with modifications described by Buckner (2010). Determination of CP and S were completed by using a combustion type N and S analyzer (TruSpec N Determinator and TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI; AOAC, 1999; method 990.03).

Steers were shipped to a commercial abattoir (Greater Omaha Packing, Omaha, NE) for slaughter, and carcass data were recorded. On day 134, cattle were fed 50% of

the previous days feed call and shipped to the abattoir at approximately 1700 h. On day of harvest, hot carcass weight (HCW) and liver score were collected. Following a 48-hour chill, USDA marbling score, LM area, and 12th rib fat thickness were captured by cameras within the plant and recorded at time of grading. Calculated final BW, ADG, and G:F were calculated using HCW adjusted to a common dressing percentage of 63%. Feeding values were calculated using the following equation: [((compared treatments G:F- CON G:F) / CON G:F) / compared treatments byproduct inclusion rate * 100 + 100]. Yield grade was calculated (USDA, 1997) from the following formula: 2.50 + (0.98425*fat thickness, cm) + (0.2*2.5 [KPH, %]) + (0.00837*HCW, kg) – (0.0496*LM area, cm^2). Dietary NEm and NEg values were calculated for each treatment based on intake and performance of steers. The data were analyzed as dietary NE for each pen, similar to performance data using equations from the NRC (1996) as described by Vasconcelos and Galyean (2008).

Animal performance and carcass characteristics were analyzed as an unstructured treatment design using a protected F-test, with block included as a fixed effect. Data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc. Cary, N.C.), with pen as the experimental unit. Treatment differences were declared significant at $P \leq 0.05$. Three steers from the FF MDGS treatment died on day 52, 121, and 125 due to heat stress and bad lungs, and a steer from the MDGS + Oil treatment died on day 130 due to heat stress. One steer from the FF MDGS treatment and one steer from the DO MDGS treatment were removed on day 95 and 101, respectively, due to injuries. These six steers were removed from the performance data.

Experiment 2

A 70-day metabolism experiment utilized five ruminally fistulated crossbred yearling steers (initial BW = 542 kg ± 40 kg) in a 5 × 4 unbalanced rectangle design with five periods and four treatments, at the University of Nebraska Metabolism Lab (Lincoln, NE). Steers were assigned randomly to one of four treatments, with a different one of the four treatments having two steers each period.

Dietary treatments were similar to those fed in Exp. 1 (Table 3.2). All byproducts utilized in the trial were sourced from the same plant (E Energy Adams, Adams, NE) and had the same fat concentrations as Exp. 1. Although the MDGS + Oil and FF MDGS treatments were formulated to have equal fat content, actual analysis showed the MDGS + Oil treatment contained 7.86% dietary fat and the FF MDGS treatment contained 7.09% dietary fat. The control treatment supplement contained 1% Empyreal corn protein concentrate (Cargill Corn Milling) to meet metabolizable protein requirements. Empyreal was used because it is an excellent source of RUP, with 75% CP and 65% RUP (% of CP). The supplement also provided Tylan-40® (Elanco Animal Health) at 90 mg per steer daily and Rumensin-90® (Elanco Animal Health) at 30 g per ton DM. Steers were previously on a high grain diet, so they were adapted to treatments by blending the two diets over a four-step process across 4-d (old diet, new diet; 3/4, 1/4, 1-d; 1/2, 1/2, 2-d; 1/4, 3/4, 1-d; 0, 1).

Steers were housed in individual concrete slatted pens that were 2.1 × 3.7 m where they had ad libitum access to feed and water. Cattle were fed once daily at 0800 with refused feed being removed prior to feeding. Refused feed was collected from d 10-13, was frozen at -20°C, and later a subsample was dried for 48 h in a 60°C forced air

oven to determine DM and adjust intakes. Ingredient samples were taken on days 9 and 12 of each period and composited by period. Samples were lyophilized, ground through a 1-mm screen of a Wiley Mill (Thomas Scientific, Swedesboro, NJ), and analyzed for DM, OM, NDF, fat, CP, and energy through bomb calorimetry to calculate nutrient composition of dietary treatments (Table 3.2). Nutrient analysis was completed with the same lab procedures as outlined in Exp. 1.

Each period was 14-d, which consisted of a 10-d adaptation phase and 4-d collection phase. Titanium dioxide, an indigestible marker, was dosed intraruminally twice daily at 0800 and 1600 h throughout the entire period to provide a total of 10 g/d for use as an estimate of fecal output (Myers et al., 2004). On d 10 to 13, fecal grab samples were collected four times/d at 0800, 1200, 1600, and 2000 h, and immediately frozen at -20°C. At the end of each period, fecal samples were composited by day (wet basis), lyophilized, and ground through a 1-mm screen of a Wiley Mill (Thomas Scientific), and composited by period. Fecal sample analysis consisted of DM, OM, NDF, fat, energy through bomb calorimetry, and titanium dioxide using the procedure described by Myers et al. (2004), then plated, and analyzed using a SpectraMAX 250 (Harlow Scientific, Arlington, MA).

Submersible wireless pH probes (Dascor, Inc., Escondido, CA) were placed in the rumen for the entire period; however, ruminal pH was only analyzed from d nine to d 12. Ruminal pH measurements were recorded every minute (1,440 measurements/d) and downloaded after whole rumen contents were collected on d 14 of each period. Probes were attached to a weight to ensure the electrode remained submerged in the rumen contents. All probes were calibrated prior to placement in the rumen and after removal by

submersing them in pH 4 and 7 standard solutions. Measurements were adjusted using the beginning and ending calibration values. Measurements for pH include average ruminal pH, minimum and maximum pH, and magnitude.

In-situ bags (ANKOM Technology; 5 cm × 10 cm, 50 µm pore size) were used to determine DM digestibility and NDF digestibility at 20 and 30 h. The two time points were utilized to be able to form a slope to predict digestibility values at other time points than what was measured. For DM digestibility, 1.25 g of 6-mm masticate grind DRC was placed in the bag. For NDF digestibility, 1.25 g of either dry corn bran or solvent extracted germ meal were utilized. There were four bags per feed for each steer at each time point. Two additional bags each for dry corn bran and SEM were not incubated and were analyzed to determine initial NDF. Bran and SEM were chosen because they represent the sources of fiber present in DGS. By using these ingredients to mimic the fiber in DGS, the impact of dietary treatment diets on DGS fiber digestibility can be determined. In-situ bags were placed in mesh bags containing weights to keep them submerged in rumen contents and then placed in the rumen on d 13 at 0700 and 1700 h, and removed on d 14 at 1300 h. After removal from the rumen, all in-situ bags were placed in a washing machine and rinsed five times (one minute of agitation and two minutes of spin for each rinse; Whittet et al. (2002). They were then frozen and at the end of the trial, bags containing dry corn bran or solvent extracted germ meal (SEM) were refluxed with NDF solution in an ANKOM 2000 Automated Fiber Analyzer (ANKOM Technology, Macedon, NY) to determine NDF. After the NDF procedure, bags were dried in a 60°C forced-air oven for 16 hours and weights were used to calculate NDF digestibility. Digestibility of NDF was calculated with the equation 1 – NDFout/NDFin.

The bags that contained DRC were not analyzed for NDF and were only dried in the 60°C forced-air oven for 16 hours to determine DM digestibility. At the time of in-situ bag removal, contents were mixed in the rumen and sampled. Approximately 2 kg were collected and immediately frozen at -20°C and later used to determine DM of whole rumen contents.

Approximately 250-300 g of whole rumen contents were collected on d 14 at 1300 h from each of the five steers on trial. Contents were placed in 1000 mL ANKOM RF Gas Production System bottles (ANKOM Technology, Macedon, NY) and weights were recorded. Two gas production bottles were used for each steer. Gas production modules were placed on the bottles and the bottles were put into a 39°C water bath. The pressure, in psi, was measured every 30 minutes for six hours, and measurements were automatically recorded. Pressure measurements were adjusted for pressure of an empty bottle that was used as a blank, DM of whole rumen contents, and amount of DM that was put into the bottles. Total mL gas produced per g of DM was calculated, which was then ran through the NLIN procedure of SAS to determine treatment means for total gas produced and rate in %/h. Treatment means were then analyzed using the MIXED procedure of SAS to determine treatment differences.

Production of VFA was calculated over the six-hour gas production period. Two 250 mL bottles (0 h) were filled with whole rumen contents when other rumen samples were taken and frozen in liquid nitrogen. After the gas run, contents of ANKOM bottles were emptied into 250 mL bottles (6 h) and frozen in liquid nitrogen. Concentration of VFA's were measured on the zero and six hour bottles. The difference in VFA

production between the two time points was calculated and then divided by six hours to get VFA production rate in mM/hr.

Dietary NEm and NEg values were calculated for each treatment based on DE (Mcal/d) values using equations from Nutrient Requirements of Beef Cattle (NASEM, 2016). First, metabolizable energy (ME; Mcal/d) was calculated from DE, with the following equation: ME = DE × 0.82. Concentration of ME (Mcal/kg) was calculated with the following equation: [ME] = ME / DMI (kg/d). Dietary NEm (Mcal/kg) was calculated as $NEm = 1.37 \times [ME] - 0.138 \times [ME]^2 + 0.0105 \times [ME]^3 - 1.12$. Dietary NEg (Mcal/kg) was calculated as $NEg = 1.42 \times [ME] - 0.174 \times [ME]^2 + 0.0122 \times [ME]^3 - 1.65$.

Digestibility, intakes, and in-situ data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc. Cary, N.C.). The fixed effects in the model were treatment and period, while steer was a random effect. Ruminal pH data were summarized by hour and analyzed using the GLIMMIX procedure of SAS (SAS Institute, Inc.) to get an overall period treatment average for each parameter. Slope of VFA production was analyzed using the MIXED procedure of SAS, with steer being a random effect. Treatment effects were evaluated using the F-test statistic and assessed as significant at $P \leq 0.05$. If significant, then treatments were separated and compared using a t-test.

RESULTS AND DISCUSSION

Experiment 1

Initial BW ($P = 0.43$; Table 3.3) was not influenced by treatment, based on allocation. Intake was impacted by treatment ($P < 0.01$) with steers fed DO MDGS having the greatest DMI (10.8 kg) and all other treatments being similar to (10.0- 10.2

kg; $P > 0.15$). Dietary treatment impacted ADG ($P < 0.06$), with DO MDGS and MDGS + Oil having the greatest ADG (1.68 and 1.65 kg, respectively). Cattle fed the FF MDGS treatment had intermediate ADG (1.61 kg), while CON was lowest (1.52 kg). Jolly (2013) observed greater ADG for cattle fed de-oiled WDGS compared to full fat WDGS ($P < 0.01$). Results of DMI and ADG do not agree with Bremer (2014) who observed no difference between de-oiled and full fat MDGS. Vander Pol et al. (2009) observed a decrease in DMI and ADG as supplemental corn oil increased in a corn based diet. As a result of increased ADG, G:F in the current study was impacted by treatment ($P < 0.01$). Feed conversion was numerically the best for MDGS + Oil (0.165). The FF MDGS treatment (0.159) had similar G:F to both MDGS + Oil (0.165) and DO MDGS (0.157), while CON was the poorest (0.148). There was a numerical improvement in G:F of 1.2% observed for FF MDGS compared to DO MDGS. Bremer (2014) reported that cattle fed full fat MDGS at 30% of diet DM were 3.4% more efficient than steers fed 30% de-oiled MDGS. In this study, when 2% corn oil was added back to de-oiled MDGS, there was a 4.9% improvement in G:F compared to DO MDGS. There was a numerical improvement in G:F by 3.7% for MDGS + Oil compared to FF MDGS. In the current study, the feeding value of DO MDGS was calculated to be 115% of corn and FF MDGS was 119% of corn. The current study results do not agree with Jolly (2013) who reported a feeding value of 130% of corn for both de-oiled and normal MDGS at 40% inclusion. Bremer (2014) observed a feeding value of 117% of corn for de-oiled MDGS at 30% inclusion level, which is similar to the current study; however, they observed 129% for full fat MDGS, which is higher than the current study. Dietary treatment impacted NEm and NEg ($P < 0.01$), with MDGS+Oil having the greatest NE values and CON being lowest.

When comparing DO MDGS and FF MDGS, NEm and NEg tended ($P = 0.07$) to be higher for FF MDGS. Bremer (2014) also reported tendencies for NEm and NEg to be higher for full fat MDGS compared to de-oiled MDGS at 30% inclusion level. However, the values in the current study were higher than what Bremer (2014) observed. The NEm value tended to be higher for MDGS+Oil compared to FF MDGS ($P = 0.06$), and NEg was significantly higher for MDGS+Oil ($P = 0.05$).

Steers on the DO MDGS and MDGS + Oil treatments had the greatest HCW (406 and 404 kg, respectively; $P = 0.05$), with FF MDGS being intermediate (401 kg) and CON having the lowest HCW (393 kg). Cattle on all treatments had similar LM area (86.5- 88.4 cm^2; $P = 0.52$) and marbling (446-467; $P = 0.64$). Fat thickness was greatest ($P < 0.01$) and similar for all treatments containing MDGS (1.37- 1.42 cm), while CON was lowest (1.19 cm). Calculated YG was greatest ($P = 0.02$) and similar for all treatments containing MDGS (3.34- 3.44), while CON was least (3.10). Calculated YG results were observed because the MDGS treatments had greater fat thickness and HCW compared to the control treatment, while LM area was similar for all treatments. No differences in carcass characteristics between de-oiled and full fat DGS agree with previous studies (Jolly, 2013; Bremer, 2014).

With the removal of corn oil from DGS, there has been concern as to whether adding corn oil back to diets is economical from a price and performance standpoint. Total revenue and total expense calculations were used to analyze total profit/loss of de-oiled MDGS diets versus de-oiled MDGS diets containing corn oil. If MDGS is priced at 90% of the price of corn (currently $140/metric ton) and corn oil is $0.66/kg, it is not economical to add corn oil to the diet. The improvement in feed efficiency is not large

enough to offset the increased cost of the added corn oil. The price of MDGS would have to increase to 118% of the price of corn or corn oil would have to decrease to less than $0.55/kg to make adding corn oil to the diet economical.

Experiment 2

No treatment differences were observed for DMI ($P = 0.94$; Table 3.5) with intake ranging from 8.9 to 9.4 kg/d. This does not agree with Vander Pol et al. (2009) and Bremer et al. (2010), who observed a decrease in DMI when corn oil was added to diets. Intake observed in Exp. 2 were numerically lower than what was observed in Exp. 1 (8.9 vs. 10.3 kg for CON, 9.3 vs. 10.8 kg for DO MDGS, 9.0 vs. 10.0 kg for MDGS+Oil, 9.4 vs. 10.2 kg for FF MDGS). Dietary treatment had an impact on total tract DM digestibility ($P < 0.01$). The greatest digestibility was observed for the control treatment, DO MDGS was next, MDGS + Oil was lowest, with FF MDGS being similar to both DO MDGS and MDGS + Oil. Total tract DM digestibility results agree with Corrigan et al. (2009), Vander Pol et al. (2009), and Bremer et al. (2010), who showed that feeding DGS diets decreased digestibility compared to corn control diets. They also noted that DM digestibility is decreased when corn oil is added to the diet. Results of OM intake and total tract digestibility followed the same trend as DM, with intakes ranging from 8.6 to 9.0 kg/d and OM digestibility having the same ranking as DM digestibility. Jolly (2013) reported similar results when comparing de-oiled and normal MDGS, with no differences in DM or OM intake and total tract digestibility. Jolly also reported no differences between MDGS diets and the corn control for DM and OM digestibility.

A treatment effect was observed for NDF intake ($P < 0.01$), with MDGS treatments having greater NDF intake than the control. Greater NDF intake is due to

greater NDF concentration in diets with DGS. There was a tendency ($P = 0.07$) for total tract NDF digestibility to be different among treatments. The greatest NDF digestibility was observed for FF MDGS and lowest for CON and MDGS + Oil, with DO MDGS being intermediate and similar to all other treatments. The control treatment had a lower NDF digestibility compared to FF MDGS ($P = 0.02$). The control treatment was statistically similar to DO MDGS and MDGS+Oil ($P > 0.11$), but had numerically lower digestibilities. Corrigan et al. (2009) and Bremer et al. (2010) also reported numerically lower NDF digestibility for CON compared to MDGS treatments. Digestibility of NDF was greater for FF MDGS compared to MDGS + Oil ($P = 0.04$). Results from this study agree with Jolly (2013), where NDF intake was greater for MDGS diets compared to the control and there was no difference between de-oiled and normal MDGS for NDF digestibility.

The current study results suggest that corn oil may have a negative impact on NDF digestibility, which could be because corn oil is considered free oil, which is available for biohydrogenation, or feed particles could be coated with oil (Zinn et al., 2000). Free oil impacts fiber digestion in the rumen, while the fat in distillers grains is bound in the germ so it will pass through the rumen and not negatively impact rumen fiber digestion. There was no interaction between incubation time and dietary treatment ($P = 0.31$) for in-situ NDF digestibility in the current study, so only main effects of incubation will be discussed. When looking at in-situ NDF digestibility, values for corn bran were approximately half of what was observed for total tract NDF digestibility (26.6 to 28.6%); however, values for SEM were greater than total tract (60.1 to 64.7%). Cattle fed MDGS + Oil had the greatest corn bran NDF digestion whereas NDF digestion was

least in steers fed CON, with DO MDGS and FF MDGS being intermediate and similar to all other treatments (Table 3.6). Similarly, Corrigan et al. (2009) saw no difference in NDF digestibility of corn bran between a corn control diet and 40% WDGS with 22 h ruminal in-situ incubation. Values reported by Vander Pol et al. (2009) were greater than the current study, and values reported by Bremer et al. (2010) were lower than the current study. Sayer et al. (2013) reported similar values as the current study for in-situ NDF digestibility of corn bran at 24-h. At 24-h, Sayer did not observe a difference between treatments for NDF digestibility and treatments did not separate until after this time point, which explains why treatments had numerically similar values in the current study. Cattle fed FF MDGS resulted in the greatest NDF digestibility of SEM whereas NDF digestion was least in steers fed DO MDGS, with CON being intermediate and MDGS + Oil being similar to both FF MDGS and CON. Results of in-situ NDF digestibility for FF MDGS and MDGS + Oil do not mimic results of total tract NDF digestibility. The impact of corn oil decreased total tract NDF digestibility at a much greater magnitude than was observed for in-situ NDF digestibility. Results of total tract NDF digestibility are more valid than in-situ NDF digestibility due to the use of titanium dioxide as a marker for digestibility in-vivo. When looking at DM digestibility with DRC, DO MDGS and FF MDGS had the greatest digestibility, MDGS + Oil was intermediate, and CON was least.

Fat intake was different among treatments ($P < 0.01$), with MDGS + Oil being greatest, DO MDGS being intermediate, CON being least, and FF MDGS being similar to both MDGS + Oil and DO MDGS. There was no treatment effect observed for total tract fat digestibility ($P = 0.83$), with an observed range of 81.1 to 83.3%. Bremer et al. (2010) observed values greater than 90% for total tract fat digestibility for all treatments,

which is greater than what was observed in the current trial. Jolly (2013) also reported values around 90% for total tract fat digestibility, but there was no difference between de-oiled and normal MDGS, which agrees with results from the current study.

Energy intake (Mcal/d) and digestible energy (Mcal/d) were not impacted by treatment (P = 0.46 and 0.76, respectively). Energy intake ranged from 38.6 to 45.0 Mcal, while DE ranged from 30.97 to 34.31 Mcal/d. There was a tendency for DE (Mcal/kg) to be different among treatments (P = 0.13). The greatest DE (Mcal/kg) was observed for FF MDGS and lowest for CON, with DO MDGS and MDGS + Oil being intermediate. Hamilton (2016) reported a DE (Mcal/kg) value of 3.68 for a 40% WDGS diet, which was similar to the current study. Hamilton concluded that there was an additional supply of DE when diets contain DGS compared to a corn based diet, which is likely due to the higher protein and fat content of DGS. The results of increased supply of DE in diets containing DGS is a new concept and has not been studied heavily. This concept could help explain the increase in performance due to feeding DGS. Results of DE do not match performance results from Exp. 1, where cattle fed MDGS+Oil were numerically the most efficient and had the greatest ADG.

Dietary NE values that were calculated from equations in Nutrient Requirements of Beef Cattle using DE from Exp. 2 were very similar to values calculated from performance characteristics in Exp. 1, except for values for the MDGS + Oil treatment (Table 3.4). The difference seen between the NE values in the MDGS + Oil treatment is proposed to be due to a difference in the previously assumed 82% conversion of DE to ME. Through back calculations, a DE to ME conversion of 87% was calculated for the MDGS + Oil treatment. Although NE values from Exp. 1 are assumed to be more correct

than values from Exp. 2, there is confidence that DE values from Exp. 2 are correct due to the similarity between NE values.

Average, maximum, minimum, and magnitude of change for ruminal pH were not impacted by dietary treatment (Table 3.7; $P > 0.14$). Jolly (2013) found that average ruminal pH was greater for normal MDGS than de-oiled MDGS. Bremer (2010) reported that ruminal pH was greatest for cattle fed a diet containing corn oil, which is similar to results in the current study.

Total VFA production rate (mM/hr) was greatest for DO MDGS (Table 3.8; $P < 0.01$). There was a tendency ($P = 0.08$) for CON and FF MDGS to be different, while MDGS + Oil was similar to both CON and FF MDGS ($P = 0.40$ and 0.34, respectively). Production rate of acetate and butyrate were not statistically different among treatments ($P \geq 0.40$). Propionate production was greatest for DO MDGS ($P < 0.01$), intermediate for CON, and lowest for FF MDGS, while MDGS + Oil was similar to both CON and FF MDGS ($P > 0.10$). Total VFA production agrees with observed pH data, where MDGS + Oil and FF MDGS had numerically greater pH and the lower rate of production, while CON and DO MDGS had numerically lower pH with a greater rate of VFA production. There were no hour × treatment interactions for molar proportion of VFA ($P \geq 0.96$). Molar proportion of acetate was greatest for FF MDGS ($P = 0.01$), while DO MDGS and MDGS + Oil were lowest and similar to each other ($P = 0.88$), and CON was intermediate and similar to all other treatments ($P > 0.09$). Molar proportion of propionate was impacted by dietary treatment ($P = 0.06$). Propionate was similar and greatest ($P = 0.70$) for DO MDGS and MDGS + Oil, and lowest for FF MDGS, while CON was similar to all other treatments ($P > 0.09$). There was no dietary treatment effect

observed for molar proportion of butyrate ($P = 0.57$). The A:P molar proportion was greatest for FF MDGS ($P = 0.07$), least in cattle fed DO MDGS and MDGS + Oil, which were similar to each other ($P = 0.79$), while CON was intermediate and similar to all other treatments ($P > 0.18$). When Carlson (2017) fed a corn based control or 40% inclusion of MDGS, they observed no statistical differences in any VFA molar proportion, which agrees with the current study. Ham et al. (1994) fed a DRC based control or 40% inclusion of WDGS and observed no differences in amount (m*M*) of acetate, propionate, butyrate, or acetate:propionate.

Total gas production was greatest and similar for MDGS + Oil and FF MDGS (Table 3.8; $P = 0.55$), CON was intermediate and similar to all other treatments ($P > 0.10$), while DO MDGS was least ($P = 0.02$). Rate of gas production (%/hr) was greatest for MDGS+Oil, CON was intermediate and similar to all other treatments ($P > 0.12$), while DO MDGS and FF MDGS were lowest and similar to each other ($P = 0.85$).

Vander Pol et al. (2009) observed that total tract DM, OM, and NDF digestibility were less ($P < 0.10$) for cattle fed the composite and composite plus oil diets compared to WDGS, control, and control plus oil. The composite diet consisted of corn bran and corn gluten meal. The authors concluded that equal amounts of fat provided from WDGS or corn oil do not result in similar animal performance. Bremer et al. (2010) fed diets containing 8.5% lipid from different sources and concluded that diets containing distillers grains to supply up to 8% of diet DM as lipid can be fed without having a negative impact on performance; however, 8% dietary lipid as corn oil will have a negative impact. This concept is due to the difference in rumen biohydrogenation between corn oil and WDGS from the physical protection of lipid in the germ in distillers grains. Digestion

data from OM and DE are not consistent with observed performance in Exp. 1 between full fat and adding corn oil back to de-oiled MDGS. Cattle on the FF MDGS treatment had numerically greater OM digestibility and numerically greater DE in the diet than MDGS + Oil; however, steers fed FF MDGS had a numerically lighter final BW, gained less numerically, and in turn had a poorer feed conversion. Digestibility values from feeding DGS relative to corn control diets do not follow the same trend, which is illustrated when comparing digestible energy and OM digestibility. Digestible energy increases with DGS feeding, but OM digestibility decreases with DGS feeding. Adding corn oil decreased fiber digestibility compared to de-oiled or full fat MDGS; however, decreased fiber digestibility was not observed with in-situ incubations when corn oil was added to the diet.

LITERATURE CITED

AOAC. 1997. Official method of analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

AOAC. 1999. Official method of analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Bremer, M. L. 2014. Energy value of de-oiled distillers grains plus solubles in beef cattle diets. Masters theses. Univ. of Nebraska- Lincoln.

Bremer, V. R. 2010. Distillers grains with solubles for feedlot cattle- Finishing performance, lipid metabolism, and ethanol greenhouse gas balance. Ph.D. dissertation. Univ. of Nebraska- Lincoln.

Bremer, V. R., K. M. Rolfe, C. D. Buckner, G. E. Erickson, T. J Klopfenstein. 2010. Metabolism characteristics of feedlot diets containing different fat sources. Neb. Beef Cattle Rep. 80-82.

Buckner, C. D. 2010. Ethanol byproduct feeds: nutrient composition and variability, determining accurate fiber content, storing with low-quality forages, and fiber utilization in finishing diets. Ph.D. dissertation. Univ. of Nebraska-Lincoln.

Carlson, Z. E. 2017. Evaluation of protein and fiber from distillers grains plus solubles in finishing beef cattle diets. Masters theses. Univ. of Nebraska- Lincoln.

Cooper, R. J., T. J. Klopfenstein, R. A. Stock, C. T. Milton, D. W. Herold, J. C. Parrott. 1999. Effects of imposed feed intake variation on acidosis and performance of finishing steers. J. Anim. Sci. 77:1093-1099.

Corrigan, M. E., G. E. Erickson, T. J. Klopfenstein, M. K. Luebbe, K. J. Vander Pol, N. F. Meyer, C. D. Buckner, S. J. Vanness, and K. J. Hanford. 2009. Effect of corn processing method and corn wet distillers grains plus solubles inclusion level in finishing steers. J. Anim. Sci. 87:3351-3362.

Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, R. P. Huffman. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. 72:3246-3257.

Hamilton, H. C. 2016. Validating laboratory techniques that influence estimates of intake and performance in beef cattle. Masters theses. Univ. of Nebraska- Lincoln.

Jolly, M. L. 2013. Evaluation of oil extraction on corn dry-milling byproducts in growing and finishing cattle diets. Masters theses. Univ. of Nebraska- Lincoln.

Jolly-Breithaupt, M. L., B. L. Nuttelman, D. B. Burken, C. J. Schneider, T. J. Klopfenstein, G. E. Erickson. 2014. Effects of increasing inclusion of wet distillers grains plus solubles with and without oil extraction on finishing performance. Neb. Beef Cattle Rep. 81-82.

Jolly-Breithaupt, M. L., B. L. Nuttelman, D. B. Burken, C. J. Schneider, T. J. Klopfenstein, G. E. Erickson. 2013. Effects of modified distillers grains plus solubles and condensed distillers solubles with and without oil extraction on finishing performance. Neb. Beef Cattle Rep. 64-65.

Jones, R. M., C. J. Bittner, F. H. Hilscher, M. F. Wilken, R. A. Stock, G. E. Erickson. 2017. Comparison of Titanium 5 PH-M versus Titanium 5 plus NUPLURA PH with the presence or absence of monensin on health and performance of newly received feedlot calves fed RAMP. Neb. Beef Cattle Rep. 79-80.

Myers, W. D., P. A. Ludden, V. Nayigihugu, and B. W. Hess. 2004. Technical note: A procedure for the preparation and quantitative analysis of samples for titanium dioxide. J. Anim. Sci. 82:179-183.

National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient Requirements of Beef Cattle, Eighth Revised Edition. The National Academies Press, Washington, DC.

National Research Council. 1996. Nutrient Requirements of Beef Cattle. Seventh Edition. National Academy Press, Washington, D.C.

NRC. 1996. Nutrient Requirements of Beef Cattle. Natl. Aca. Press, Washington, DC.

Sayer, K. M., C. D. Buckner, G. E. Erickson, T. J. Klopfenstein, C. N. Macken, T. W. Loy. 2013. Effect of corn bran and steep inclusion in finishing diets on diet digestibility, cattle performance, and nutrient mass balance. J. Anim. Sci. 91:3847-3858.

Stock, R. A., T. J. Klopfenstein, D. Brink, S. Lowry, D. Rock, S. Abrams. 1983. Impact of weighing procedures and variation in protein degradation rate on measured performance of growing lambs and cattle. J. Anim. Sci. 57:1276-1285.

USDA. 1997. Official United States standards for grades of carcass beef. Agric. Marketing Serv. USDA, Washington, DC.

Vander Pol, K. J., M. K. Luebbe, G. I. Crawford, G. E. Erickson, and T. J. Klopfenstein. 2009. Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts, or supplemental corn oil. J. Anim. Sci. 87:639-652.

Van Soest, P. J., J. B. Robertson, B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583.

Vasconcelos, J. T., M. L. Galyean. 2008. Technical note: Do dietary net energy values calculated from performance data offer increased sensitivity for detecting treatment differences? J. Anim. Sci. 86:2756-2760.

Watson, A. K., B. L. Nuttelman, T. J. Klopfenstein, L. W. Lomas, G. E. Erickson. 2013. Impacts of a limit-feeding procedure on variation and accuracy of cattle weights. J. Anim. Sci. 91:5507-5517.

Whittet, K. M., C. W. Creighton, K. J. Vander Pol, G. E. Erickson, T. J. Klopfenstein. 2002. Influence of rinsing technique and sample size on in situ protein degradation of protein sources. Abstract #1610. 2002 American Society of Animal Science Joint National Meeting. Vol. 80, Supp 1.

Zinn, R. A., S. K. Gulati, A. Plascencia, J. Salinas. 2000. Influence of ruminal biohydrogenation on the feeding value of fat in finishing diets for feedlot cattle. J. Anim. Sci. 78:1738-1746.

Table 3.1. Composition (% of diet DM) of dietary treatments fed to yearling steers (Exp.1)

	Treatment[1]			
Ingredient	CON	DO MDGS	MDGS + Oil	FF MDGS
Dry-rolled corn	43.75	23.75	23.75	23.75
High-moisture corn	43.75	23.75	23.75	23.75
MDGS De-oiled[2]	-	40	38	-
MDGS Full Fat[3]	-	-	-	40
Corn Oil	-	-	2	-
Alfalfa hay	3.5	3.5	3.5	3.5
Sorghum Silage	4	4	4	4
Supplement[4]	-	-	-	-
Fine Ground Corn	0.773	2.787	2.787	2.787
Limestone	1.729	1.697	1.697	1.697
Tallow	0.125	0.125	0.125	0.125
Urea	1.517	-	-	-
Potassium Chloride	0.465	-	-	-
Salt	0.3	0.3	0.3	0.3
Beef Trace Minerals	0.05	0.05	0.05	0.05
Vitamin A-D-E	0.015	0.015	0.015	0.015
Monensin premix[5]	0.017	0.017	0.017	0.017
Tylosin premix[6]	0.009	0.009	0.009	0.009
Analyzed Nutrient Composition, % of DM				
OM	96.0	95.2	93.3	95.3
CP	12.1	17.0	16.4	16.7
NDF	11.1	22.7	22.0	22.8
Fat	3.89	5.96	7.78	7.10
Sulfur	0.15	0.45	0.43	0.48

[1]Treatments included CON-control; DO MDGS-40% de-oiled modified distillers grains plus solubles; MDGS + Oil-38% de-oiled modified distillers grains plus solubles plus 2% corn oil; FF MDGS-40% full fat modified distillers grains plus solubles.
[2]DO MDGS: de-oiled modified distillers grains plus solubles containing 8.9% fat.
[3]FF MDGS: full fat modified distillers grains plus solubles containing 11.6% fat.
[4]Supplement fed at 5% of dietary DM
[5]Premix contained 198 g of monensin/kg (Rumensin-90®; Elanco Animal Health)
[6]Premix contained 88 g of tylosin/kg (Tylan-40®; Elanco Animal Health)

Table 3.2. Composition (% of diet DM) of dietary treatments fed to yearling steers (Exp. 2)

	Treatment[1]			
Ingredient	CON	DO MDGS	MDGS + Oil	FF MDGS
Dry-rolled corn	43.75	23.75	23.75	23.75
High-moisture corn	43.75	23.75	23.75	23.75
MDGS De-oiled[2]	-	40	38	-
MDGS Full Fat[3]	-	-	-	40
Corn Oil	-	-	2	-
Alfalfa hay	3.5	3.5	3.5	3.5
Sorghum Silage	4	4	4	4
Supplement[4]	-	-	-	-
Fine Ground Corn	0.773	2.787	2.787	2.787
Limestone	1.729	1.697	1.697	1.697
Tallow	0.125	0.125	0.125	0.125
Urea	1.517	-	-	-
Potassium Chloride	0.465	-	-	-
Salt	0.3	0.3	0.3	0.3
Beef Trace Minerals	0.05	0.05	0.05	0.05
Vitamin A-D-E	0.015	0.015	0.015	0.015
Monensin premix[5]	0.017	0.017	0.017	0.017
Tylosin premix[6]	0.009	0.009	0.009	0.009
Analyzed Nutrient Composition, % of DM				
DM	78.5	67.0	68.0	67.3
CP	12.1	17.0	16.4	16.7
NDF	11.0	22.7	22.0	22.6
Fat	4.16	6.04	7.86	7.09
Sulfur	0.17	0.44	0.44	0.48

[1]Treatments included CON-control; DO MDGS-40% de-oiled modified distillers grains plus solubles; MDGS + Oil-38% de-oiled modified distillers grains plus solubles plus 2% corn oil; FF MDGS-40% full fat modified distillers grains plus solubles.
[2]DO MDGS: de-oiled modified distillers grains plus solubles containing 8.9% fat.
[3]FF MDGS: full fat modified distillers grains plus solubles containing 11.6% fat.
[4]Supplement fed at 5% of dietary DM
[5]Premix contained 198 g of monensin/kg (Rumensin-90®; Elanco Animal Health)
[6]Premix contained 88 g of tylosin/kg (Tylan-40®; Elanco Animal Health)

Table 3.3. Effect of feeding 40% de-oiled MDGS, 40% full fat MDGS, or 38% de-oiled MDGS plus 2% corn oil on feedlot performance and carcass characteristics (Exp. 1)

	Treatment[1]					
	CON	DO MDGS	MDGS + Oil	FF MDGS	SEM	F-TEST
Feedlot Performance						
Initial BW, kg	419	420	420	420	0.5	0.43
Final BW, kg[2]	624[b]	645[a]	640[a]	636[ab]	5.6	0.04
DMI, kg/d	10.3[b]	10.8[a]	10.0[b]	10.2[b]	0.15	0.01
ADG, kg	1.52[b]	1.68[a]	1.65[a]	1.61[ab]	0.041	0.06
G:F	0.148[c]	0.157[b]	0.165[a]	0.159[ab]	0.0028	<0.01
Feeding Value[3]	-	115	-	119	-	-
NEm/kg[4]	1.96[c]	2.00[bc]	2.09[a]	2.05[ab]	0.019	<0.01
NEg/kg[4]	1.31[c]	1.34[bc]	1.43[a]	1.38[b]	0.017	<0.01
Carcass Characteristics						
HCW, kg	393[b]	406[a]	404[a]	401[ab]	3.5	0.05
Marbling[5]	463	458	446	467	12.9	0.64
LM area, cm^2	87.7	88.4	88.4	86.5	1.29	0.52
12th rib fat, cm	1.19[b]	1.42[a]	1.37[a]	1.40[a]	0.051	0.01
Calculated YG[6]	3.10[b]	3.43[a]	3.34[a]	3.44[a]	0.086	0.02

[a-c]Means with different subscripts differ ($P < 0.05$)
[1]Treatments included CON-control; 20MDGS-20% modified distillers grains plus solubles; 40MDGS-40% modified distillers grains plus solubles; 20FIB-fiber fed from concentrated ingredients to mimic fiber provided by 20MDGS; 40FIB-fiber fed from concentrated ingredients to mimic fiber provided by 40MDGS.
[2]Calculated from HCW/common dressing percentage (63%)
[3]Feeding Value Calculation: [((compared treatments G:F – CON G:F) / CON G:F) / compared treatments by-product inclusion rate*100 + 100]
[4]Dietary NE equations from the NRC (1996) as described by Vasconcelos and Galyean (2008)
[5] Marbling score: 400 = Slight^{00}, 450 = Slight^{50}, 500 = Small^{00}, 550 = Small^{50}
[6]Calculated YG = 2.50 + (0.9843*fat thickness, cm) + (0.2*KPH,%) + (0.0084*HCW, kg) – (0.0496*LM area, cm^2)

Table 3.4. Effect of feeding 40% de-oiled MDGS, 40% full fat MDGS, or 38% de-oiled MDGS plus 2% corn oil on dietary NE values

	Treatment[1]					
	CON	DO MDGS	MDGS + Oil	FF MDGS	SEM	F-TEST
NEm/kg[2]	1.96[c]	2.00[bc]	2.09[a]	2.05[ab]	0.019	<0.01
NEm/kg[3]	1.92	1.99	1.94	2.03	-	-
NEg/kg[2]	1.31[c]	1.34[bc]	1.43[a]	1.38[b]	0.017	<0.01
NEg/kg[3]	1.28	1.34	1.29	1.37	-	-

[a-c]Means with different subscripts differ ($P < 0.05$)

[1]Treatments included CON-control; 20MDGS-20% modified distillers grains plus solubles; 40MDGS-40% modified distillers grains plus solubles; 20FIB-fiber fed from concentrated ingredients to mimic fiber provided by 20MDGS; 40FIB-fiber fed from concentrated ingredients to mimic fiber provided by 40MDGS.

[2]Dietary NE equations from the NRC (1996) as described by Vasconcelos and Galyean (2008)

[3]Dietary NE calculated from DE using equations from the NASEM (2016)

Table 3.5. Effect of feeding 40% de-oiled MDGS, 40% full fat MDGS, or 38% de-oiled MDGS plus 2% corn oil on digestible energy and intake and total tract digestibility of DM, OM, NDF, and fat (Exp.2)

	Treatment[1]					
	CON	DO MDGS	MDGS + Oil	FF MDGS	SEM	F-TEST
DM						
Intake, kg/d	8.9	9.3	9.0	9.4	0.88	0.94
Total Tract Digestibility, %	81.7^{a}	77.2^{b}	73.8^{c}	75.9^{bc}	1.28	<0.01
OM						
Intake, kg/d	8.6	8.8	8.6	9.0	0.84	0.96
Total Tract Digestibility, %	83.6^{a}	79.1^{b}	76.1^{c}	78.1^{bc}	1.43	<0.01
NDF						
Intake, kg/d	0.98^{b}	2.14^{a}	1.99^{a}	2.17^{a}	0.174	<0.01
Total Tract Digestibility, %	50.5^{b}	55.3^{ab}	51.3^{b}	57.7^{a}	2.19	0.07
Fat						
Intake, kg/d	0.37^{c}	0.56^{b}	0.71^{a}	0.67^{ab}	0.056	<0.01
Total Tract Digestibility, %	82.9	81.1	81.8	83.3	1.91	0.83
Energy						
Intake, Mcal	38.6	43.3	43.0	45.0	4.08	0.46
DE, Mcal/d	30.97	33.27	31.70	34.31	2.920	0.76
DE, Mcal/kg	3.50^{b}	3.60^{ab}	3.52^{ab}	3.66^{a}	0.067	0.13

[a-c]Means with different subscripts differ ($P < 0.05$)

[1]Treatments included CON-control; DO MDGS- 40% de-oiled MDGS, FF MDGS- 40% full fat MDGS, or MDGS + Oil- 38% de-oiled MDGS plus 2% corn oil

Table 3.6. Effect of feeding 40% de-oiled MDGS, 40% full fat MDGS, or 38% de-oiled MDGS plus 2% corn oil on in-situ NDF and DM digestibility (Exp. 2)

	Treatment[1]							
	CON	DO MDGS	MDGS + Oil	FF MDGS	SEM	Int[2]	Trt[3]	Sample[4]
NDFD								
Corn Bran	26.6[e]	27.6[de]	28.6[d]	27.7[de]	0.55	<0.01	<0.01	<0.01
Germ Meal	62.2[b]	60.1[c]	63.2[ab]	64.7[a]				
DMD								
DRC	49.1[c]	56.3[a]	53.4[b]	56.5[a]	1.64	-	<0.01	-

[a-c]Means with different subscripts differ ($P < 0.05$)
[1]Treatments included CON-control; DO MDGS- 40% de-oiled MDGS, FF MDGS- 40% full fat MDGS, or MDGS + Oil- 38% de-oiled MDGS plus 2% corn oil
[2]Int is the interaction between incubation time and sample type in in-situ bag
[3]Trt is the overall effect of dietary treatment on digestibility
[4]Sample is the overall effect of sample type on digestibility

Table 3.7. Effect of feeding 40% de-oiled MDGS, 40% full fat MDGS, or 38% de-oiled MDGS plus 2% corn oil on ruminal pH (Exp. 2)

	Treatment[1]					
	CON	DO MDGS	MDGS + Oil	FF MDGS	SEM	Trt
Average pH	5.64	5.70	5.88	5.83	0.138	0.14
Maximum pH	6.46	6.53	6.66	6.66	0.150	0.38
Minimum pH	5.03	5.06	5.22	5.18	0.120	0.36
pH magnitude	1.43	1.47	1.45	1.49	0.112	0.97

[a-c]Means with different subscripts differ ($P < 0.05$)

[1] Treatments included CON-control; DO MDGS- 40% de-oiled MDGS, FF MDGS- 40% full fat MDGS, or MDGS + Oil- 38% de-oiled MDGS plus 2% corn oil

Table 3.8. Effect of feeding 40% de-oiled MDGS, 40% full fat MDGS, or 38% de-oiled MDGS plus 2% corn oil on VFA production (mM/hr), VFA molar proportion, amount of ruminal gas produced, and rate of production (%/hr) (Exp. 2)

	Treatment[1]						
	CON	DO MDGS	MDGS + Oil	FF MDGS	SEM	Trt	Hr*Trt
VFA Production							
Total	13.6^{b}	17.2^{a}	12.5^{b}	11.2^{b}	1.74	<0.01	-
Acetate	5.4	6.8	5.4	5.1	0.88	0.40	-
Propionate	5.7^{b}	7.7^{a}	4.8^{bc}	3.8^{c}	0.87	<0.01	-
Butyrate	1.7	1.9	1.8	1.8	0.35	0.99	-
VFA molar %							
Acetate	48.1^{ab}	45.4^{b}	45.1^{b}	51.6^{a}	1.49	0.01	0.98
Propionate	35.1^{ab}	38.3^{a}	37.0^{a}	29.7^{b}	2.30	0.06	0.99
Butyrate	12.1	12.1	13.9	13.7	1.21	0.57	0.98
A:P	1.6^{ab}	1.3^{b}	1.3^{b}	1.9^{a}	0.23	0.07	0.96
Gas Production							
Total	8.52^{ab}	7.31^{b}	9.19^{a}	9.61^{a}	0.813	0.02	-
Rate (%/hr)	54.92^{ab}	51.52^{b}	59.14^{a}	50.98^{b}	2.880	0.03	

$^{a\text{-}c}$Means with different subscripts differ ($P < 0.05$)

[1] Treatments included CON-control; DO MDGS- 40% de-oiled MDGS, FF MDGS- 40% full fat MDGS, or MDGS + Oil- 38% de-oiled MDGS plus 2% corn oil