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**ENERGY VALUE OF DE-OILED DISTILLERS GRAINS PLUS SOLUBLES IN
BEEF CATTLE DIETS**

by

Meredith L. Bremer

A THESIS

Presented to the faculty of

The Graduate College at the University of Nebraska

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Under the Supervision of Professors

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Lincoln, Nebraska

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ENERGY VALUE OF DE-OILED DISTILLERS GRAINS PLUS SOLUBLES IN BEEF CATTLE DIETS

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University of Nebraska, 2014

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Ethanol plants are centrifuging off oil from the thin stillage stream as it has added market value currently. The impact of oil removal on cattle performance has been minimally researched. Thus four trials, one growing, one digestion, and two feedlot, were designed to determine the energy and feeding value of de-oiled distillers grains in beef cattle diets.

In growing cattle diets, diet concentration of modified distillers grains plus solubles (MDGS) impacted cattle performance more than oil content. Ending BW, ADG, and G:F did not differ between cattle fed de-oiled or full fat MDGS, however cattle fed de-oiled MDGS had lower DMI than those fed full fat MDGS. No significant differences in fiber digestibility were observed between de-oiled and full fat MDGS treatments. The energy value of de-oiled MDGS in growing cattle diets was calculated to be 124% the value of corn.

In finishing steer diets, increasing diet concentrations of de-oiled MDGS increased G:F. However, decreasing MDGS fat content from 12.0% to 7.2% decreased steer performance by 3.4%. No significant interactions were observed when increasing concentrations of de-oiled wet distillers grains plus solubles (WDGS) were fed with steam flaked (SFC) or dry rolled corn (DRC). Comparison of steer performance when

de-oiled and full fat WDGS are fed in SFC and DRC diets resulted in no significant differences also.

In growing and finishing diets small differences in cattle performance have been observed. Energy values for distillers grain in growing diets are still high with no improvements in fiber digestibility being observed. In finishing diets where distillers grains were fed at 30-35%, de-oiled distillers grains have 89% the feeding value of full fat distillers grain.

Key Words: corn processing, digestion, de-oiled, finishing, growing

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Chapter I

REVIEW OF LITERATURE

Introduction

Starting in the mid-1970s ethanol production increased significantly. Events such as the oil embargo of 1973, the Iranian revolution of 1978, and the initiation of Federal gasoline standards promoted oil prices to increase rapidly (Shapouri et al., 2002). A concern over the security of national energy supplies developed and resulted in a push for fuel ethanol to be used as a gasoline extender (Shapouri et al., 2002). Also during this time, the Environmental Protection Agency (EPA) was looking for an alternative to lead fuel additives. Due to ethanol's high octane content, it was selected to be a standard octane enhancer (Shapouri et al., 2002). As we fast forward into the twenty-first century, U.S. ethanol production increased by 9 billion gallons between 2000 and 2009 (Wallander et al., 2011).

Ethanol is produced from the fermentation of starch in cereal grains such as wheat, sorghum, corn and barley. In the United States however, corn is the predominant grain of choice for 98% of the ethanol plants due to its energy efficiency of 134% energy output per input (RFA Ethanol Pocket-Book, 2014). Evidence of the increase in demand of corn for ethanol production can be seen in the roughly 10 percent increase in acres planted to corn from 2000-2009 (Wallander et al., 2011). The dry milling process by which ethanol is produced is also favorable to livestock producers in that ethanol byproducts can be fed to livestock as either a high quality protein or energy source (Klopfenstein, 2007). Cattle producers have found value in feeding distillers grain to both growing and finishing cattle. In 2011, U.S. ethanol refineries used 5 billion bushels of corn to yield 13.9 billion gallons of ethanol and 39 million metric tons of livestock

feed (RFA, 2014c). Of that livestock feed, 35.7 million metric tons were distillers grains with the remainder in the form of gluten feed and gluten meal (RFA, 2014c). From each bushel of corn (56 lbs.), there are 2.8 gallons of ethanol and 17-18 pounds of livestock feed produced (RFA Ethanol Pocket book 2014). Today there are approximately 200 ethanol plants that in total produce 15 billion gallons of ethanol (RFA Ethanol Pocket book 2014).

Currently over half of Nebraska's ethanol plants are finding added market value in removing a portion of the oil from distillers grains via centrifugation of the thin stillage and selling this oil to non-ruminant feed companies and the biodiesel industry. Not surprisingly, cattle feeders were concerned that removing oil from distillers grain would decrease its energy value and its subsequent feeding value in beef cattle diets. To address these concerns, Jolly et al., (2013) conducted two metabolism trials, a growing trial, and two feedlot studies to evaluate the effects of de-oiled condensed distillers solubles and distillers grains on cattle performance and carcass characteristics. Prior to oil removal via centrifugation of the thin stillage, numerous studies had been conducted on the optimal inclusion level, energy value, digestibility, and associative effects of feeding distillers grains in beef cattle diets. This review will focus on rumen lipolysis and biohydrogenation, distillers grains fed to growing and finishing cattle, and the associate effects of distillers grains and processed corn.

Fermentation of the starch comprising cereal grains to produce ethanol occurs by two primary milling procedures; wet milling or dry milling. Approximately 90% of the industry uses the dry milling process to produce ethanol (RFA Ethanol Pocket book 2014). Both the wet milling and the dry milling industries have byproducts that are used

in the livestock industry as feed resources. Distillers grains plus solubles (DGS) and condensed distillers solubles (CDS) are the primary feed byproducts of the dry milling industry, whereas corn gluten feed is the feed byproduct of the wet milling industry (Erickson et al, 2007).

Dry Milling

Introduction.

Wheat, grain sorghum, barley, corn, or mixtures of these grains are sources of starch used for fermentation to ethanol in the dry milling process. Portions of the cereal grains utilized may be of lower quality without being detrimental to the end-product (Stock et al., 2000). Corn, the primary cereal grain utilized in distillers grain production, (RFA Pocketbook-2014) is high in zein protein. Zein protein is high in ruminally undegradable protein (RUP), thus distillers grains are an excellent source of RUP as each gram of distillers grains is about 63% RUP (Castillo-Lopez et al., 2013).

Process.

As the process begins, the grain is screened, removing debris and then ground to a flour-like consistency by a hammermill (ICM, 2013). The floury grain is mixed with water and the mixture's pH is adjusted to 5.8. Alpha-amylase is then added, creating what is now called slurry. Heating of the slurry to 82-88°C for 30-45 minutes occurs next to reduce the slurries viscosity (ICM, 2013). Next, the primary liquefaction phase of the dry milling process begins. During this phase, the slurry is pumped through a pressurized jet cooker at 105°C for five minutes and then cooled using a vacuum flash condenser (ICM, 2013). The secondary liquefaction phase requires that the slurry mixture set for 1-2 hours

at 82-87°C to allow alpha-amylase the time to break down starch molecules down into short chain dextrans (ICM, 2013). Slurry pH and temperature are again adjusted as another enzyme, glucoamylase, is added. After the addition of the second enzyme, the mixture, now referred to as mash, is pumped into fermentation tanks where the glucoamylase breaks down the dextrans into glucose (ICM, 2013). Yeast is then added to the mash converting the sugar to ethanol and carbon dioxide. Fermentation of the mash is allowed to continue for 50-60 hours, with the products of this process being 15% ethanol, solids from the corn, and yeast (ICM, 2013). Fermented mash is then pumped into a multi-column distillation system and heat is added. The distillation process utilizes the differing boiling points of ethanol and water to separate off the ethanol. When the resulting product leaves the distillation columns it is 95% ethanol by volume (190 proof). At the bottom of the distillation columns lie the remaining residues from the grains. Non-fermentable solids and water are what comprises the residue, and this is referred to as whole stillage. Whole stillage is then pumped out of the columns into centrifuges whereas the distilled ethanol is pumped to a molecular sieve system still at 190-proof strength (ICM, 2013). The molecular sieve system contains specialized sieve beads that absorb water molecules while letting ethanol molecules pass through. Ethanol at the conclusion of this step is 100% ethanol by volume or 200-proof. From here ethanol goes to on-site storage tanks where it will be denatured (ICM, 2013). The whole stillage that have been pumped to the centrifuge, and removed from the ethanol, are then separated into a wet cake and thin stillage. Wet cake is 30-35% DM and thin stillage is 5% DM (Erickson et al., 2007) at this point in the production process. Wet cake can be dried down to produce modified distillers grains (MDG) at 45-50% DM or dried down even

further producing dry distillers grains (DDG) at roughly 91% DM (Erickson et al., 2007). Thin stillage is pumped to evaporators where water is removed producing condensed distillers solubles (CDS) or syrup that is 30-35% DM (Erickson et al., 2007). Condensed distillers solubles can be added back to the WDG, MDG, or DDG at varying proportions to wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), or dry distillers grains plus solubles (DDGS). Throughout the remainder of this review, the preceding notations of the three main distillers byproducts will be used. As water is removed from distillers grains, the feeding value decreases. When WDGS, MDGS, and DDGS are included at 20-40% concentrations in the diet (DM-basis) their feeding value in comparison to corn is 143-130% for WDGS, 124-117% for MDGS, and a constant 112% for DDGS. As moisture content of distillers grains decreases, so does the feeding value in comparison to corn. The feeding value also decreases as the concentration of distillers grains in the diet increases for both WDGS and MDGS, but remains constant with increasing inclusions of DDGS (Bremer et al., 2011).

Distillers Grains Nutrient Composition

Introduction.

Though starch from many grain sources can be fermented to produce distillers grain, corn is the primary grain utilized (Wallander et al., 2011). Corn is comprised of approximately two-thirds starch, thus when removed, the remaining nutrients increase approximately three-fold in the DGS byproduct (Stock et al., 2000). To illustrate this, crude protein (CP) content of corn is roughly 8.0-9.0% and increases to a little over 30.0% in DGS. The same is true for phosphorus (P) which increases from 0.30% in corn to 0.90% in DGS and NDF which increases from 9.0% to approximately 35% (Stalker et

al., 2010). Sulfur, however, does not increase three-fold due to sulfuric acid being added during dry milling to control pH (Erickson et al., 2007). The sulfur concentration in corn is 0.10-0.15% (NRC, 1996), whereas distillers grains contain 0.70% (Erickson et al., 2007 and Buckner et al., 2011).

Benton et al. (2010) reviewed numerous published articles to summarize the nutrient composition of DG. The authors found that the average nutrient composition for distillers grains was 31.5% CP, 10.5% fat, 6% starch, 43.2% NDF, 0.51% P, and 0.57% S. In this review there was low variation observed for CP, NDF, and P and S with CV 10.7, 10.5, 8.4, and 6.3%, respectively. The authors observed a higher CV for fat and starch content of DG with CV of 31.4 and 36.3%, respectively. They attributed the greater variations in fat and starch content to the amount of CDS added back to wet, modified, and dry distillers grains (Erickson et al., 2007). If all of the CDS is added back to the distillers grains, then 20% of the byproduct is CDS and 80% is distillers grains (Corrigan et al. 2008).

Nebraska plants are currently also finding added market value in removing a portion of oil from the thin stillage constituent via centrifugation, thus the concentration of fat in DGS is variable from plant to plant. Prior to centrifugation from the thin stillage, the fat content increased from 4% in corn to 12% in the DG (Stalker et al., 2010). Currently the fat content of DGS are 7-8% (Jolly et al., 2013). As there is plant to plant variability in DGS feeds and their nutrient contents, it is crucial for cattle feeders to know the nutrient content of the feed they are purchasing before feeding it to their cattle.

Variability.

Buckner et al., (2011) conducted a study where the nutrient composition of wet DGS and modified DGS produced at six different Nebraska ethanol plants was compared in their variability to one another. Distillers grain samples were taken from four to five locations of the byproduct pile during loading for 10 loads being taken out by semi-trucks from the plant each sampling day. Samples were collected for five consecutive days, and across four months. Fifty samples were collected per period per plant for a total of 200 samples being collected per plant across 4 months. Samples were analyzed for DM, CP, P, S, and fat contents. Mean crude protein concentrations ranged from 31.0 to 32.2% and mean P concentrations ranged from 0.78 to 0.91% in DGS across all plants with low variability. Fat and sulfur values were more variable between plants in this experiment. Average sulfur concentrations were the most variable during period one of the study where plant averages ranged from 0.71-1.06%. These highly variable values were reported to the individual plants allowing the plants to make adjustments that were evident in the final three periods of this study. Following the adjustment phase, mean sulfur concentrations were 0.71 to 0.84%. Spiehs et al., (2002), sampled ten plants throughout South Dakota and Minnesota and found sulfur values to range from 0.33 to 0.74% with high variability. These authors also found average DM, CP, P, and fat concentrations to be 89.3, 30.2, 0.89, and 10.9%, respectively, for plants in these two states. Finally the determination of the average fat content of DGS across the six plants sampled was determined to range from 10.3 to 13.0%. Buckner et al., (2011) reported that the nutrient values of DGS produced in Nebraska was on average 31.0% CP, 0.84% P, 0.77% S, and 11.9% fat.

Belyea et al.(2004) conducted a five year study from 1997 to 2001 in which the nutrient composition of corn prior to dry mill processing was compared to the distillers byproduct. Corn was sampled from storage bins one day each month of the trial. On this day, samples were collected every two hours of the twenty-four hours and samples were composited and analyzed for DM, CP, fat content, crude fiber content, and starch content. Nutrient values found for corn were similar to those reported in the 1996 NRC: $9.18 \pm 0.09\%$ CP, $4.21 \pm 0.06\%$ fat, and $71.4 \pm 0.32\%$ starch. Samples of dry DGS differed in their nutrient content when compared to values reported in the 1996 NRC. The nutrient content of dry DGS was found to be: $31.30 \pm 0.21\%$ CP, $11.90 \pm 0.11\%$ fat, and $5.10 \pm 0.26\%$ starch. This study showed no significant correlations in nutrient content between corn and dry DGS. Variations in dry DGS looked to be attributed to dry milling processing methods and most likely to the composition of distillers solubles (DS) and the proportion of DS added back to the distillers grains.

Holt and Pritchard (2004) conducted a study where the nutrient composition of corn co-products produced in four dry milling ethanol plants was compared. Plant averages were also compared to values in the 1996 NRC and the cracked corn utilized for byproduct production. Four corn co-products sampled were; dry DGS, modified DGS, Blended DGS (dry DGS blended with wet DGS), wet DGS, and CDS. Overall the lowest variations in nutrient composition were observed in the cracked corn used for ethanol production suggesting that the dry milling process between plants caused variation in the byproducts produced. Mean nutrient values for dry DGS were 90.0% DM, 33.3% CP, 42.7% NDF, 13.2% ADF, 95.9% OM and 13.1% fat. Mean nutrient values of modified DGS were 58.9% DM, 29.7% CP, 34.9% NDF, 10.9% ADF, 94.7% OM, and 16.7% fat.

Solubles were 23.4% DM 19.8% CP, 90.5% OM, and 32.1% fat on average. The wet DGS was 31.4% DM, 35.5% CP, 42.3% NDF, 12.1% ADF, 96.2% OM, and 12.1% fat. Dry matter content of dry DGS varied slightly between plants ($P < 0.05$) and ranged from 89.80% to 90.91%. Crude protein and NDF content varied between plants ($P < 0.05$) and ranged between 30.68% and 36.71% for CP and from 37.34% and 48.91% for NDF. The ADF and OM values also significantly differed in DDGS produced from the four plants ($P < 0.05$). Acid detergent fiber values ranged from 10.94% to 16.00% and the OM content of DDGS ranged from 96.12% to 95.77%. Three plants produced WDGS and the DM content between each plant differed significantly ($P < 0.05$) and ranged from 29.52% to 36.48%. Crude protein, NDF, and ADF values varied significantly between the three plants also ($P < 0.05$). Crude protein values ranged from 34.39% to 36.18%, NDF values ranged from 36.10% to 48.18%, and ADF values ranged from 9.81% to 16.93%. Organic matter content significantly differed between plants as did fat content ($P < 0.05$) and ranged from 97.25% to 95.77% for OM and ranged from 11.04% to 13.12% for fat content. Changes to DG are continually being made and thus cattle feeders need to be diligent in knowing the nutrient content of the product that they are buying and feeding.

Feeding Ethanol Byproducts (Distillers Grains) to Beef Cattle

Introduction.

Fermenting cereal grains to produce alcohol has been a technology employed for many years, however not until the mid-19th century did grain byproducts from the alcohol fermentation process begin to be utilized as a livestock feed source (Klopfenstein et al., 2007). In 1945, the Distillers Feed Research Council, later renamed the Distillers Grain

Technology Council, was started with the purpose of conducting research on distillers grains as a livestock feed (Distillers Grain Technology Council, 2014). Distillers grains were initially fed to beef cattle as a source of protein. Corn distillers grains have a three-fold increase in crude protein after starch removal, making it an excellent source of protein for the beef animal (Klopfenstein et al., 1978). In the 1990s, ethanol production increased and so did the amount of distillers grains available to cattle feeders. This increase in availability resulted in a shift in the approach cattle feeders took when feeding distillers grains. As availability increased so did the concentration of distillers grains in the diet.

Optimal Concentrations and Feeding Value.

Feeding distillers grains at concentrations between 15-20% on a DM basis is a strategy to provide supplemental protein to the beef animal (Erickson et al., 2007). Zein is the primary protein found in corn and thus is the primary protein constituent found in DG as well. Approximately 60% of zein protein consumed by a ruminant is rumen undegradable protein (McDonald, 1954). Distillers grains protein is approximately 63% (Castillo-Lopez et al., 2013) and when fed as a protein source will need to have a source of ruminally degradable intake protein (RDP) supplemented also in order to meet the metabolizable protein (MP) requirements of the animal (Erickson et al., 2007).

Ruminally undegradable protein is more efficiently used by the ruminant as it bypasses VFA production allowing the energy from protein (when fed in excess of requirements) to be used primarily by the animal itself (Owens and Zinn, 1988). When DGS are fed at concentrations greater than 15%, it is supplying both protein and energy to the ruminant animal (Klopfenstein, 2007). As there are three main types of DGS based on DM content

(dry, modified, or wet), titration experiments and meta-analysis have been conducted in order to determine the optimal inclusion concentrations and feeding values of each of the types. Each of the trials included in this review are based upon feed ingredients commonly used in commercial feedyards in Nebraska.

DDGS.

As discussed previously, dry DGS are roughly 90% DM. Wet grains are dried during production, resulting in increasing concentrations of acid detergent insoluble nitrogen (ADIN), a measure of heat damage. Ham et al., (1994) conducted a trial to determine the effects of drying DGS on finishing cattle performance and found no differences in performance or carcass characteristics were observed as ADIN concentration increased in the finishing diet.

To determine the optimal concentration of dry DGS on finishing cattle performance, Buckner, et al. (2007) fed dry DGS at 0, 10, 20, 30, 40, or 50% on a DM basis replacing DRC in a finishing trial. The remainder of all diets consisted of 7.5% forage (10% corn silage + 2.5% ground alfalfa hay) and 6% supplement. As dry DGS increased in the diet, final BW responded quadratically ($P = 0.04$) and cattle tended to respond quadratically for DMI ($P = 0.08$), with greatest values for cattle consuming 20% dry DGS diets. Feed efficiency tended to improve linearly as dry DGS concentration increased in the diet ($P = 0.08$). Feeding value of dry DGS in the diet tended to respond quadratically ($P = 0.07$). The feeding value of DDGS at 10 and 20% concentrations in the diet was 124%, whereas when the diet concentration increased to 30 or 40%, the feeding value of dry DGS dropped to 108% the value of corn. Hot carcass weight tended to respond quadratically to increasing concentrations of dry DGS in the diet ($P = 0.07$),

following the trend of final BW where cattle consuming 20% dry DGS had the heaviest carcasses. Marbling score, REA, fat depth, and calculated yield grade were not significantly different between treatments ($P \geq 0.24$). This study agrees nicely with what Benson et al., (2005) observed when they fed 0, 15, 25, or 35% DDGS and observed that DMI responded quadratically and was greatest at 15% concentration of DDGS in the diet ($P = 0.05$). Daily gains tended to increase with increasing concentrations of DDGS ($P = 0.11$); whereas HCW, fat depth, and yield grade did increase with increasing DDGS diet concentrations ($P \leq 0.05$). Similarly, Gordon et al., (2002) fed DDGS at 0, 15, 30, 45, 60, or 75% of the diet to feedlot heifers and observed that DMI, ADG, and G:F were greatest in heifers consuming 15% dry DGS but decreased as dry DGS was increasingly added to the finishing diet ($P < 0.05$). Feeding 30% dry DGS resulted in performance similar to feeding no dry DGS at all.

Bremer et al., summarized 4 trials conducted at the University of Nebraska-Lincoln (UNL) where dry DGS was fed to finishing cattle at 0-40% concentrations in the diet. The authors reported that DMI increased quadratically ($P = 0.03$) and was greatest in cattle fed 30-40% dry DGS. Daily gains and G:F increased linearly ($P < 0.01$) with increasing concentrations of dry DGS and were 1.83 and 0.162, respectively, when dry DGS was fed at 40% of the diet DM. The feeding value of dry DGS was calculated to be 112% the value of corn when included at 10-40% of the finishing diet.

MDGS.

Huls et al., (2008) fed modified DGS at 0, 10, 20, 30, 40, 50% of the diet DM replacing a 1:1 blend of HMC/DRC with increasing modified DGS inclusions. The

authors found that increasing the concentration of modified DGS in the diet caused a quadratic increase in final BW ($P < 0.01$) with cattle consuming 20% modified DGS in the diet being the heaviest. Dry matter intake decreased quadratically ($P = 0.01$) and ADG increased quadratically ($P < 0.01$) when modified DGS concentration increased from 10 to 50% of the diet. Cattle fed 20% modified DGS diets, gained the greatest at 1.80 kg/d. A decrease in DMI and an increase in daily gains caused a linear improvement in G:F ($P < 0.01$). Cattle consuming 50% modified DGS were numerically the most efficient (G:F = 0.172). Carcass weights increased quadratically with increasing concentrations of modified DGS, and cattle consuming the 20% modified DGS diets had the heaviest carcasses ($P < 0.01$). Marbling scores tended to linearly increase ($P = 0.10$) and fat depth tended to quadratically increase ($P = 0.12$) as MDGS was increasingly added to the diet. Calculated yield grade did respond with a quadratic increase ($P = 0.04$) as cattle consuming 20% MDGS offered the most lean product. Replacing the HMC:DRC blend with MDGS, resulted in a feeding value for MDGS of 123% when included at 10% of the diet DM and decreased to 109% when included at 50% of the diet. Optimal cattle performance was observed between 20 and 40% inclusion of MDGS in the diet, but MDGS could be fed to a concentration of 50% of the diet DM with improvement in that observed above the HMC/DRC blend.

Bremer et al., (2011) conducted a meta-analysis of 4 UNL finishing trials (Adams et al., 2008; Huls et al., 2008; Luebbe et al., 2008; Nuttelman et al., 2010) in which modified DGS was fed from 0 to 40% of the diet DM. Authors reported that DMI and ADG responded quadratically to increasing concentrations of modified DGS in the diet ($P < 0.01$) and were maximized at 20-30% concentrations in the diet. Feed efficiency

increased linearly with increasing concentrations ($P < 0.01$) and was 0.165 at 40% modified DGS diet concentrations. The feeding value of modified DGS was calculated to be 128% that of corn when included at 10% of the diet DM and decreased to 117% the value of corn when modified DGS diet concentration increased to 40%.

WDGS.

Bremer et al., (2011) conducted a meta-analysis of University of Nebraska-Lincoln (UNL) feedlot trials (Larson et al., 1993; Ham et al., 1994; Al-Suwaiegh et al., 2002; Vander Pol et al., 2005; Godsey et al., 2008a,b; Luebbe et al., 2008; Meyer et al., 2008; Wilken et al., 2008; Corrigan et al., 2009; Rich et al., 2009; Vander Pol et al., 2009; Loza et al., 2010; Moore et al., 2010; Nuttelman et al., 2010; Rich et al., 2010; Sarturi et al., 2010) where wet DGS replaced DRC or HMC in the diet. Authors reported that a quadratic decrease in DMI ($P = 0.01$) and a quadratic increase in ADG ($P < 0.01$) resulted in a linear improvement in G:F ($P < 0.01$) as wet DGS concentration increased. Dry matter intake was lowest in finishing diets where WDGS was included at 50% of the diet DM, ADG was greatest at 20%, and G:F was increased up to 50% inclusion in the diet. Fat depth increased linearly ($P < 0.01$) and marbling scores quadratically ($P = 0.05$) with increasing concentrations of WDGS in the diet. Feeding value of WDGS responded cubically to increasing concentrations ($P = 0.05$). Concentrations of 10% in the diet resulted in the highest feeding values, 151% of corn, and decreased to 113% the feeding value of corn as the concentration of WDGS increased to 50%.

Ham et al., (1994) compared feeding 40% wet DGS or dry DGS to finishing cattle fed 85% DRC and supplement. The authors reported that feeding a corn byproduct of either moisture type resulted in greater gains and higher G:F ($P < 0.05$) compared to

cattle fed DRC alone. Comparing wet DGS to dry DGS resulted in similar gains ($P > 0.10$), however cattle fed wet DGS had lower DMI ($P < 0.05$) and thus were more efficient ($P < 0.05$).

Nuttelman et al., (2011) conducted the first trial where dry DGS, modified DGS, and wet DGS were all fed and compared within the same study. The three distillers grains types were fed at 20, 30, or 40% of the diet on a DM basis replacing at 60:40 blend of HMC:DRC. A negative corn-based control diet was fed for energy value comparisons. No interactions were reported for distillers grain type and level, thus the main effects will be discussed. Final BW and ADG did not differ between distillers grains types ($P = 0.51$ and $P = 0.30$, respectively). However, DMI between type did differ ($P < 0.01$) in that cattle consuming dry DGS ate 12.3 kg/d, cattle fed modified DGS ate 12.0 kg/d, and cattle fed wet DGS diets ate 11.2 kg/d. With significant differences in DMI and no changes in ADG, an improvement in G:F resulted from increasing the moisture content of the distillers grain ($P < 0.01$). Cattle fed WDGS, MDGS, and DDGS, had feed efficiencies of 0.165, 0.158, and 0.150, respectively. The authors reported that the feeding value of wet DGS, modified DGS, and dry DGS in comparison to the HMC:DRC, was 145.7, 126.5, and 109.3%, respectively and the feeding value of wet DGS was 136.0% and 117.9% greater than DDGS and MDGS, respectively. On average DGS were 130% the feeding value of corn when fed to finishing cattle. A tendency for fat depth differences between treatments was reported ($P = 0.15$) but HCW, marbling score, and LM area did not differ between distillers grain treatments ($P \geq 0.50$). As the concentration of distillers grains increased in the diet, no significant differences were reported for final BW, DMI, or ADG ($P \geq 0.24$). A linear increase in G:F did occur as

the concentration of distillers grains in the diet increased from 20 to 40%. A tendency for linear improvement in fat depth did occur ($P = 0.12$) as distillers grain inclusion increased, otherwise no other carcass characteristics differed as concentration of distillers grains increased ($P > 0.18$). When comparing the control to 20, 30 or 40% distillers grain in the diet, final BW ($P = 0.05$), ADG ($P = 0.04$), G:F ($P = 0.04$) improved quadratically. Dry matter intake decreased linearly ($P = 0.01$) in comparison to the control and HCW weight ($P < 0.01$) and fat depth ($P < 0.01$) increased linearly. No significant differences between the control and distillers grains diets were found when reporting marbling score or LM area ($P > 0.63$).

Distillers Grains in Forage-Based Diets

Introduction.

Prior to entering the feedlot as calf-feds or yearlings, beef cattle typically consume high-forage diets either prior to weaning or in a backgrounding system. Forage diets common to Nebraska beef cattle consist of low- or high-quality harvested forages, meadows, range, or corn residue. Distillers grains can be supplemented as a source of protein, energy, and phosphorus (Stalker et al., 2010) in these forage diets. As Loy et al., (2007) and Morris et al., (2005) have reported, supplementing DDG in low- or high-quality forage diets increases ADG. Wilken et al., (2009) reported that when comparing DDGS and MDGS in forage diets, DMD and NDFD are similar between DDGS and MDGS, thus type of DGS isn't what affects cattle performance, but rather forage type. As starch is removed during ethanol production, dietary fiber contained within distillers grains is increased that does not illicit a negative associated response when fed with a

higher fiber diet because distillers grains contain a highly-digestible fiber source (Klopfenstein, 2001; Stalker et al., 2010).

Low Quality-Forages.

Distillers grains can be a source of protein and energy for these growing cattle. When DDGS was supplemented to cattle consuming low- and high-quality forage diets, forage intake decreased and ADG increased (Morris et al., 2005 and Loy et al., 2008). Determining why distillers grain supplementation in high forage diets results in increases in ADG was addressed by MacDonald et al., (2007) when the authors supplemented heifers on smooth bromegrass pastures with DDG, corn gluten meal (CGM) or corn oil (OIL). Corn gluten meal was a source of RUP, which is low in rapidly growing forages, and OIL was a source of fat. Both CGM and OIL were added into the diet at concentrations that caused the CGM diet to be equal in RUP to the DDGS diet and the OIL diet was equal in fat to the DDGS diet. The authors reported that DDGS caused an increase in ADG ($P < 0.01$), and CGM tended to cause an increase in ADG ($P = 0.14$) but at a rate that was 39% of gains exhibited in DDGS supplemented cattle. This value of 39% suggests that supplemental RUP accounts for approximately one-third of the increase in ADG for cattle supplemented DDGS. Corn oil supplementation did not increase ADG ($P = 0.25$) and tended to result in lower gains than cattle fed CGM ($P = 0.09$). The additive effect of fat and RUP contained within DDG appears to be the cause of favorable gains when supplemented in forage diets.

Increasing stocking rates and reducing the use of harvested forages are of economic importance to cattle producers. Loy et al., (2007) conducted a digestion study to determine the energy value and effect on forage intake when DRC or DDGS were

supplemented to cattle fed ad-libitum chopped grass hay (CP = 8.9%). Steers were either supplemented (DRC or DDGS) daily or on alternate days at 0.40% BW or 0.80% BW, respectively. A control diet of grass hay with no supplementation was also evaluated. The authors found that control heifers consumed more kg per day of grass hay than those heifers being supplemented (1.88 vs. 1.66% BW/d) with either DRC or DDGS ($P < 0.01$). Total DMI (grass hay and supplement) was lower for the control cattle versus those supplemented ($P < 0.01$). Dry matter intake did not differ between cattle supplemented DRC or DDGS ($P = 0.45$) and tended to be lower in cattle supplemented on alternate days compared to those heifers supplemented daily ($P = 0.08$). Heifers supplemented on alternate days consumed fewer and larger meals ($P < 0.01$), and spent less time feeding ($P < 0.01$) than those heifers supplemented daily. Average rumen pH was greater in the control heifers over those who were supplemented (6.30 vs. 6.18, $P = 0.05$). Control heifers also had greater rates and extents of NDF disappearance than supplemented heifers ($P = 0.04$), and rate of hay NDF disappearance was slower in DRC supplemented heifers compared to DDGS supplemented heifers ($P = 0.02$).

In another study conducted by Loy et al., (2008) DRC, DRC + corn gluten meal (CGM), or DDGS was supplemented at 0.21 or 0.81% of BW, daily or 3 times a week to growing heifers consuming an ad libitum grass hay diet. The authors reported that DMI of grass hay decreased as the concentration of supplement increased ($P < 0.01$), but that total DMI over the length of the trial was greater in cattle supplemented at high levels over those receiving low levels of supplementation. Comparing DDGS, DRC, and DRC+CGM, supplementation strategies showed no significant differences in DMI ($P = 0.27$) and was 4.67, 4.70, and 4.83 kg/d, respectively. A supplementation type by

concentration interaction was observed for ADG and G:F ($P < 0.01$). At low concentrations of supplementation, heifers gained more and were more efficient when fed DDGS compared to the DRC and DRC+CGM supplemented heifers that performed similarly to one another. At the high supplementation level, heifers fed DDGS or DRC+CGM had similar ADG and G:F ($P = 0.85$) and both outperformed those heifers supplemented DRC alone ($P < 0.01$). At the low concentration of supplementation, DDGS had 130% the energy value of DRC, and at the high concentration of supplementation the energy value decreased to 118% that of DRC. This decline in energy value as DDGS supplementation concentration increased may be due to the fat content of the diet and thus the hindrance of fiber digestion by rumen microorganisms. Fat concentrations greater than 5% have been shown to hinder fiber digestion in the rumen (Corrigan et al., 2009), and in the Loy et al., (2008b) study, the fat content of the high DDGS diet was 5.2%.

To continue, Ahern et al., (2014) fed increasing concentrations (0, 0.33, 0.67, or 1.0% of BW) WDGS, DDGS, or a MIX (67% WDGS + wheat straw) to cattle fed decreasing concentrations of a 60% sorghum silage, 40% alfalfa forage diet. The authors observed no concentration by supplementation, type interactions except for DMI. As the concentration of WDGS, MIX, or DDGS increased in the diet, a linear increase in DMI also occurred ($P < 0.01$). Cattle fed MIX and WDGS diets consumed similar amounts of forage ($P = 0.94$), however both were less than that consumed by cattle fed DDGS diets ($P < 0.01$). No significant treatment differences were reported for ending BW, ADG, or G:F for the main effect of supplementation type ($P \geq 0.12$). As the main effect of

concentration of supplement increased, ending BW, ADG, and G:F increased linearly ($P < 0.01$).

In a meta-analysis conducted by Griffin et al., (2012), 20 studies (13 pasture grazing and 7 confinement) were compiled and analyzed, utilizing 790 steers and heifers to determine the response to varying levels of DDGS in forage-based diets on gain and forage intake. The authors reported linear responses in ending BW and ADG for pasture fed cattle ($P < 0.01$) and quadratic response for these two measurements in confinement cattle studies ($P < 0.01$). They attributed these differences between pasture and confinement cattle to the metabolizable protein requirements of the animals utilized. Confinement cattle were lighter than pasture-grazed cattle and thus their requirements for metabolizable protein were higher.

Furthermore, Nuttelman et al., (2010) conducted a trial to evaluate the energy value of WDGS compared to DRC in high forage diets. DRC was fed at 22.0, 41.0, or 60.0% concentrations in the diet (DM-basis) and WDGS was fed at 15.0, 25.0, or 35.0% concentrations of the diet DM. The remainder of all diet consisted of 30.0% sorghum silage and decreasing concentrations of grass hay with increasing concentrations of either DRC or WDGS. Dry matter intake was held constant between treatments. Ending BW was numerically greater in cattle consuming WDGS ($P = 0.13$). With equal DMI and greater ADG ($P < 0.01$), cattle fed WDGS were more efficient than those fed DRC ($P < 0.01$). At 15.0, 25.0, and 35.0% concentrations in the diet, the energy value of WDGS was calculated to be 146, 149, and 142%, respectively, the energy value of DRC.

Nebraska also has an abundant forage source in corn residue. Distillers grains high energy (108% TDN in forage-based diets) and protein (~30%) make it an excellent

protein and energy source to beef cattle grazing corn residue. Gustad et al., (2006) supplemented steer calves grazing corn residue for 95 d with 1.5, 2.5, 3.5, 4.5, 5.5, or 6.5 lb/hd/d of DDGS that contained 12.4% fat and 30.1% CP. The authors reported a quadratic increase in ADG with increasing concentrations of supplementation ($P < 0.01$). Gains ranged from 0.90 to 1.80 lb/d and were maximized at 5.5 lb/hd/d of DDGS. Thirty steers were utilized as a control in this study and were supplemented with the aforementioned levels of DDGS when fed a diet consisting of 70.9% brome hay and 29.1% sorghum silage. Forage intake decreased by 27% as DDGS supplementation increased from 1.5 to 6.5 lb/hd/d. In a study by Jones et al., (2014) steers grazing irrigated or non-irrigated corn residue were supplemented with MDGS or DDGS at 0.3, 0.7, or 1.1% of BW. The authors observed no distillers grain type, irrigation type, and diet inclusion interactions ($P = 0.12$). Jones et al., (2014) did report however that average daily gains increased quadratically ($P = 0.01$) with increasing levels of supplementation for calves grazing irrigated or non-irrigated corn residue. Calves gained 1.55, 2.02, and 2.12 lb/day when supplemented at 0.3, 0.7, and 1.1% of BW, respectively. The authors noted that feed refusals were observed for steers supplemented at 0.7 and 1.1% MDGS or DDGS of BW and correlated refusals to their quadratic responses to gain. Jones et al., (2014) then deemed the optimal inclusion for steers grazing irrigated corn residue to be 1.0% of BW and 0.9% of BW for steers grazing non-irrigated corn residue and supplemented with either MDGS or DDGS. Steers supplemented MDGS gained 1.92 lb/d whereas DDGS supplemented steers gained 1.88 lb/d thus gains were not statistically different between treatments ($P = 0.51$). Steers grazing non-irrigated corn residue gained more (2.02 lb/d, $P < 0.01$) than steers grazing irrigated corn residue (1.77 lb/d).

Corn Processing and Distiller Grains

Introduction.

Feeding corn to beef cattle increases efficiency in the feedlot (Hale, 1973; Theurer, 1986). As starch comprises approximately two-thirds of the corn kernel (Huntington et al, 1997), the feedlot cattle's ability to utilize starch is crucial (Theurer et. al, 1986). To increase the availability of starch for ruminal digestion, corn is often processed. In a survey of nutritionists conducted by Vasconcelos and Galyean in 2007, the three most common corn processing methods are steam-flaking corn (SFC), ensiling high moisture corn (HMC), and dry rolling corn (DRC). For the purpose of this review, DRC and SFC processing methods will be more heavily focused on as they were the methods used for experimentation.

Corn Processing.

Owens et al., (1997) conducted a review where data were compiled from 183 DRC studies, 117 HMC trials, and 53 trials where SFC was fed. A total of 16, 228 head of cattle were included in the review. Dry matter intake significantly decreased as the intensity of corn processing increased from DRC to HMC to SFC ($P < 0.05$). Daily gains were similar between DRC and SFC diets (1.45 and 1.43 kg/d, respectively) but cattle consuming HMC diets gained significantly less (1.37 kg/d, $P < 0.05$). Feed efficiency was statistically similar between DRC and HMC diets (0.152 and 0.156, respectively, $P > 0.05$), however when cattle were fed SFC diets they were significantly more efficient (0.170, $P < 0.05$). The authors found that when compared to DRC diets, HMC diets had 102% the feeding value, whereas SFC diets had a feeding value of 112% compared to

DRC diets. Cooper et al., (2002a) fed DRC, HMC, and SFC to finishing feedlot steers within the same trial. The authors observed that when comparing feed efficiency across diets, cattle fed HMC were 102% more efficient than those consuming DRC diets, whereas the SFC fed cattle were 113% more efficient than the DRC fed cattle. These values agreed with the review that Owens et al., (1997).

As the intensity of corn processing increases, the susceptibility of starch for rumen digestion also increases. Galyean et al., (1976) observed starch digestibilities of 78, 89, and 83% for DRC, HMC, and SFC based diets, respectively. In a review of 14 experiments conducted from 1986 to 1995, Huntington et al., (1997) reported starch digestibilities of 76.2, 89.9, and 84.8% for DRC, HMC, and SFC based diets, respectively. Cooper et al., (2002b) observed ruminal starch digestibilities of 76.2, 91.7, and 89.6%, for DRC, HMC, and SFC based diets, respectively. When comparing to the results of Owens et al., (1997) and Cooper et al., (2002a) trials, cattle fed SFC based diets were more efficient, and as Galyean et al., (1976), Huntington et al., (1997), and Cooper et al., (2002b) trials all showed that more starch is being digested in the rumen when HMC is fed.

Another factor to consider when increasing the intensity of corn processing, is the increase in RDP requirements for beef cattle (Erickson and Klopfenstien, 2002), due to the increase in energy in the rumen (NRC, 1996). Microbial production of protein is limited by the amount of energy the microbes are receiving, or the amount of protein that is degradable in the rumen and thus available to the microbes (Erickson and Klopfenstein, 2002). When RDP is limiting, starch digestion is hindered and animal performance declines (Erickson and Klopfenstein, 2002). Therefore, RDP requirements need to

account for the amount of energy microbes will be utilizing along with the RDP content of ration ingredients. Shain et al., (1998) estimated the DIP requirements for cattle fed DRC based diets. The authors found that supplementing 0.9% urea, or 6.5% DIP as a percent of DM was sufficient to meet the DIP requirements of the animal. Cooper et al., (2002a) evaluated the DIP requirements for cattle fed DRC, HMC, or SFC-based diets by conducting three finishing trials. Authors observed that DIP requirements were 6.3, 10.0, and 8.3% on average for DRC, HMC, and SFC-based diets, respectively.

Feeding Processed Corn with Distillers Grains.

As the intensity of corn processing increases, the effect of distillers grains inclusion with corn processing needs to be evaluated. In a study conducted by Vander Pol et al., (2008) various corn processing methods were compared. Dry rolled corn, HMC, a 1:1 blend of DRC and HMC, or SFC were fed in feedlot finishing diets containing 30% wet DGS. Final BW, DMI, and ADG were greatest for cattle fed DRC diets, lowest for SFC fed cattle, and intermediate for cattle fed the HMC only and DRC:HMC blend ($P < 0.01$). Intermediate DMI and ADG allowed cattle fed the HMC only and DRC:HMC blend with 30% wet DGS to be the most efficient (0.182 and 0.185) followed by DRC treatments (0.179) and SFC fed cattle (0.176, $P < 0.01$). Hot carcass weights, fat depth measurement, and marbling scores also followed performance data trends in that DRC fed cattle were heavier, fatter, and had greater marbling than DRC:HMC blend cattle followed by SFC treatments ($P < 0.01$).

Corrigan et al., (2009a) saw similar results to Vander Pol et al., (2008) in a study conducted to evaluate the effects of increasing concentrations of wet DGS (0, 15, 27.5, and 40% on a DM basis) replacing DRC or SFC. An interaction was observed between

corn processing method and level of wet DGS for final BW, ADG, and G:F. Final BW and ADG increased linearly as WDGS increased in DRC fed cattle ($P < 0.10$). A quadratic response was observed when WDGS was added to SFC diets ($P < 0.05$) with gains being greatest when WDGS was included at 15% of the diet DM. Just as Vander Pol et al. (2008) observed, Corrigan et al., (2009a) observed a decrease in DMI as wet DGS concentration in the diet increased resulting in an improvement in G:F ($P < 0.01$). Corrigan et al., (2009a) observed a linear increase in HCW for DRC fed cattle ($P < 0.01$) and a quadratic increase in SFC fed cattle ($P < 0.05$). Fat depth was greater at lower concentrations with increasing intensity of corn processing as were marbling scores ($P \leq 0.04$). Conversely Luebke et al., (2011) found that when WDGS replaced either DRC or SFC at 15, 30, 45, or 60% on a DM basis, no interactions were observed. Cattle fed SFC had greater final BW, ADG, and G:F than DRC fed cattle ($P < 0.01$). Carcass characteristics of HCW and fat depth also followed these performance trends and were greater in SFC fed cattle over DRC fed cattle ($P \leq 0.05$). Calculated YG also tended to be greater in SFC fed cattle ($P = 0.07$), but no differences in dressing percentage, LM area, KPH, or marbling scores were detected between corn processing methods ($P \geq 0.48$). A linear decrease was reported for final BW, ADG, and G:F for the main effect of WDGS concentration in the diet ($P < 0.01$). These aforementioned measurements were greatest for cattle fed 15-30% WDGS. Dry matter intake also decreased as WDGS was increased in the diet ($P < 0.01$). The authors suggested that this decrease in intake could be due to high sulfur and fat contents of diets with increasing concentrations of WDGS (Klopfenstein et al, 2008). Fat content of the 45% WDGS diet was 7.05% fat and increased to 8.25% fat in the 60% WDGS diet. This increased in fat content resulted in a

7.9% reduction in DMI. Calculated dietary NE_m and NE_g values decreased quadratically with increasing concentrations of WDGS ($P \leq 0.02$). Furthermore, HCW, fat depth, calculated YG, marbling score, and dressing percentage decreased with increased WDGS inclusion ($P \leq 0.05$), whereas no significant treatment differences were observed for LM area or KPH measurements ($P \geq 0.20$).

Furthermore, Buttrey et al., (2012) evaluated the effects of corn processing method (DRC vs. SFC) at low concentrations of DGS in the diet (0 or 20% on a DM basis) on cattle performance. The authors observed no interactions between corn processing method and WDGS inclusion at this low concentration ($P \geq 0.34$), the main effects were reported. Final BW and ADG were not significantly different between corn processing methods ($P \geq 0.62$), however, DMI was significantly greater for DRC fed cattle as has been reported previously (Vander Pol et al. 2008, Corrigan et al. 2009a, and Bremer et al. 2011) compared to SFC. The decrease in DMI, and no effect on ADG resulted in a 9.0% improvement in feed efficiency for SFC fed cattle ($P < 0.03$). Dietary NE_m and NE_g were also greater for SFC fed cattle over those fed DRC ($P < 0.01$). Final BW, ADG, G:F, NE_m , and NE_g were not statistically different between treatments for the main effect of wet DGS concentration ($P \geq 0.14$). Overall it appears as corn processing intensity increases DMI decreases when distillers grains are included in the diet. Including distillers grains in the diet resulted in greater overall performance over 0% inclusion of distillers, and though data has been variable in terms of Final BW, ADG, G:F, and carcass characteristics, it seems that less distillers grains need to be included in the diet when replacing SFC compared to DRC. Optimum inclusion of wet DGS fed with DRC is 40%.

Nichols et al., (2012) fed 0 or 35% wet DGS with a increasing ration of SFC:DRC (0:100, 25:75, 50:50, 75:25, and 100:0) to finishing steers. The authors reported that significant interaction was observed for G:F ($P = 0.03$). When wet DGS was not included in the diet, feeding 100% SFC resulted in 11.2% improvement in feed efficiency over DRC. When wet DGS concentration increased to 35% in the diet, the 100% SFC only improved G:F by 2.1% over the 100% DRC diet. This study further solidifies the point that less DGS need to be fed in finishing diets with increasing intensity of corn processing.

Fat Removal

Introduction.

Cereal grains, cereal grain byproducts, and minimal forages are common feed ingredients comprising beef feedlot rations. Lipids comprise a portion of each of these ingredients and provide a source of energy for the ruminant animal (Zinn et al., 1994). Forages are comprised primarily of galactolipids and the poly unsaturated fatty acid (PUFA) linolenic acid (cis-9, cis-12, cis-15-18:3), whereas triglycerides and linoleic acid (cis-9, cis-12-18:2) are more abundant in cereal grains and their byproducts (Lock et al., 2004). Triglycerides are compounds containing a single glycerol comprised of three carbons combined via ester linkages to three fatty acid molecules. A galactolipid is a three carbon glycerol molecule attached to two fatty acids and one galactose molecule. Phospholipids are the third source of lipids in the ruminant's diet and they are similar to galactolipids except that the galactose molecule is replaced with a phosphate group (Jenkins, 2007). Both linoleic and linolenic are classified as unsaturated fatty acids. Unsaturated fatty acids possess at least one double bond, where hydrogen atoms have been eliminated. Ruminants consume feeds abundant in unsaturated fatty acids, but

produce meat and milk that are more concentrated with saturated fatty acids, or fatty acids devoid of double bonds (Pavan et al., 2007 and Duckett et al., 2009). Lipid composition of non-ruminant meat products is similar to the feed resources that they consume (Lock et al., 2004), so it appears logical that events occurring within the rumen result in the conversion of unsaturated fatty acids contained in feed materials to saturated fatty acids comprising ruminant meat and milk products. The microorganisms inhabiting the rumen are responsible for the conversion of poly unsaturated fatty acids (PUFA) to saturated fatty acids(SFA) (Jenkins, 2007). This process of transforming PUFA to SFA is known as biohydrogenation.

Dietary fat content can affect the digestibility of various feed ingredients. Dietary fat concentrations should not exceed 3% of DM in forage-based diets (Moore et al., 1986, Gilbrey et al., 2006, and Hess et al., 2008) as greater concentration in the diet suppresses fiber digestion in the rumen. In concentrate-based diets, dietary fat concentrations can be as high as 9.4% of DM inclusion before deleterious effects on ruminal digestion occur (Kucuk et al., 2004; Atkinson et al., 2006).

Rumen digestion of lipids occurs via two main processes; lipolysis and biohydrogenation. In short, lipolysis is the hydrolysis of ester linkages of glycerol and fatty acids to produce VFAs from glycerol and liberated free fatty acids, and biohydrogenation is the process of hydrating the double bonds of unsaturated fatty acids so as to saturate them. Rumen metabolism of lipids is dependent upon rumen pH and ruminal fat concentration (Van Nevel and Demeyer, 1996).

Lipolysis and Biohydrogenation.

As triglycerides and galactolipids enter the rumen, microbial lipases hydrolyze the ester linkages of the complex fatty acids as lipolysis occurs. Free fatty acids, glycerol, and galactose are the products of lipolysis (Garton et al., 1961; Dawson et al., 1977). Following lipolysis, glycerol and galactose are rapidly fermented to volatile fatty acids (VFAs) (Van Soest, 1994). Upon the completion of lipolysis, liberated unsaturated fatty acids are biohydrogenated. Biohydrogenation is the process of saturating the double bonds of unsaturated fatty acids with hydrogen atoms to produce single bonded saturated fatty acids. Beam et al. (2000) conducted an in vitro experiment where soybean oil (esterified triglyceride) was added to ground grass hay at 0, 2, 4, 6, 8, or 10% wt/wt concentrations to determine the extent of lipolysis and biohydrogenation of the forage. At 2% concentration of soybean oil, the rate of lipolysis was 41.4%/h. Rate of lipolysis significantly linearly decreased ($P < 0.05$) to 22.6%/d as the concentration of soybean oil increased up to 10%. This trend was also observed for rate of biohydrogenation of C_{18:2} as the concentration of soybean oil increased from 2 to 10% ($P < 0.05$). Van Nevel and Demeyer (1996) conducted an in vitro experiment in which HCl was added to incubation flasks of soybean oil in order to obtain pH values of 6.8, 6.3, 5.9, 5.6, and 5.2. The concentration of soybean oil in each flask was either 40 or 80 mg. It was observed that at $\text{pH} \leq 6.0$, lipolytic activity was significantly inhibited and that this inhibition was magnified when the concentration of soybean oil was increased. In order to see a 50% reduction in lipolytic activity, a pH of 5.5 was needed. Ruminal pH values do not typically drop this dramatically unless cattle are consuming a high-concentrate diet. Biohydrogenation activity on fatty acids was influenced by a low pH to a lesser extent than lipolysis. Thus ruminal depressions in microbial biohydrogenation activity are

probably due more to reduced substrates coming from lipolysis rather than reductions in biohydrogenation itself (Van Nevel and Demeyer, 1996).

Ruminal breakdown of lipids is driven by microbial enzymatic activity (Dawson 1977). Ciliated protozoa, anaerobic bacteria, and anaerobic fungi are the three primary inhabitants of the rumen (Jenkins et al., 2008). Bacteria have been found to be the main contributors to rumen biohydrogenation. These bacteria are classified into one of two groups; Group A or Group B (Kemp and Lander, 1984). Group A bacteria, which have a greater presence within the rumen, are bacteria with the ability to biohydrogenate PUFA to *trans* 18:1 fatty acids. Group B bacteria, which are fewer in number, are able to biohydrogenate *trans*18:1 or other intermediates to stearic acid (Harfoot and Hazlewood, 1997). The duties performed by Group A and B bacteria contribute to a large concentration of *trans* 18:1 intermediates in the rumen rather than stearic acid fatty acids. *Butyrivibrio fibriosolvens*, a species of bacteria, have been identified to biohydrogenate fatty acids producing conjugated fatty acids and *trans*-11-18:1 intermediates in the biohydrogenation of linoleic acid (Polan et al., 1964 and Kepler et al., 1966). Unsaturated fatty acids are toxic to rumen bacteria in large quantities, thus ruminal transformation is crucial to survival of certain bacterial species (Lock , 2006). Identifying the microbial species responsible for conversion of intermediates to stearic acid (18:0) has proved more difficult. The Rowett Research Institute has more recently worked to identify the bacterial species needed for conversion of *trans*-11-18:1 to stearic acid (Jenkins et al., 2008). They found that eleven of the twenty-six most prominent bacterial species found in the rumen had the ability to metabolize linoleic acid. Three different strains of *Butyrivibrio* and two strains of *Clostridium proteoclasticum* were

identified as producers of *trans*-11-18:2. *Clostridium proteoclasticum* was also identified as being able to biohydrogenate *trans*-11-18:2 to stearic acid (Jenkins et al., 2008).

Clostridium proteoclasticum is closely related to *Butyrivibrio* as found in research published by Attwood et al., (1996), Kopečný et al., (2003), and Paillard et al., (2007).

Ciliated protozoa comprise approximately half of the rumen's microbial biomass (Williams, 1989). Protozoa have a negative associative relationship with bacteria in that they ingest large quantities of bacteria as their energy source. Protozoal fatty acids are known to be highly unsaturated in comparison to bacterial fatty acids, thus could be a source of unsaturated fatty acids in ruminant meat and milk products (Harfoot and Hazlewood, 1997). This fact has led some to conclude that both bacteria and protozoa have the ability to biohydrogenate fatty acids (Wright et al., 1959 and 1960). Bacterial consumption by protozoa has led others to doubt this theory. Dawson and Kemp (1969) looked at how defaunation affected biohydrogenation of lipids. They found that biohydrogenation only decreased slightly and concluded that protozoa were not essential to biohydrogenation.

Degree of ruminal biohydrogenation is significant when looking at the fatty acid profile entering the duodenum. Lock et al., (2005) conducted a review discussing the significance of this concept. The authors stated that linoleic acid concentration in dairy diets is high due to the amount of forage consumed. Linoleic acid, however, is only absorbed at the small intestine at approximately 21% of that which is consumed. Stearic acid, though ingested in smaller quantities in high forage diets, is absorbed at a rate of almost 800% of that which is consumed. The high concentration of steric acid entering

the small intestine illustrates how active bacteria are in ruminal biohydrogenation of PUFA.

Intestinal Digestion of Fatty Acids.

Absorption of fatty acids occurs in the jejunum. Lipid composition, available for absorption in the jejunum, is similar to that flowing from the rumen (Moore and Christie, 1984). Of the fatty acids entering the duodenum, 80 to 90% are attached to feed particles with the remainder being in the form of microbial phospholipids. Prior to absorption, however, the hydrophobic fatty acid needs to be solubilized in order to cross the unstirred water layer (Baumen et al., 2003). For this to occur, a micelle needs to be formed. As fatty acids enter the duodenum, secretions from the gall bladder and pancreas flow into the small intestine to provide the necessary supplies for micelle formation (Baumen et al., 2003). Bile from the gall bladder supplies bile salts and lecithin which precipitate fatty acids from feed components and bacteria (Baumen et al., 2003). From the pancreas, enzymes essential for the conversion of lecithin to lysolecithin, are secreted. The combination of bile salts, fatty acids, and lysolecithin form a micelle (Baumen et al., 2003). When the micelle enters the epithelial cells of the jejunum, the fatty acids and lecithin are absorbed and the bile salts are removed and recycled back through the system (Lock, 2006). Triglycerides combine with cholesterol, phospholipids and protein to form a chylomicron that transports fat to the body via the lymphatic system to large body veins. Once at the veins, the chylomicron adheres to the endothelium of the capillary. Here it is hydrolyzed by lipoprotein lipases freeing the fatty acids from the monoacylglycerol. The remainder of the chylomicron is now referred to as the

chylomicron remnant and upon hydrolysis is transported back to the liver in the circulatory system (Lock, 2004).

Fat in Beef Cattle Diets.

Fat is supplemented in cattle diets increase the energy density of the diet (NRC, 1996). Compared to the typical carbohydrates cattle consume, those found in forages and cereal grains, supplemental fat has a little over 2 times the energy value of carbohydrates (Hess et al., 2007), which is why fat is added to diets to improve performance. Popular supplemented fat sources found in beef cattle diets are rendered beef tallow and pork grease fat byproducts (tallow or grease), poultry fat, mixed feed grade fat (blends of tallow, grease, poultry fat, and restaurant grease), feed grade vegetable oil (canola oil, soybean oil, and soap stocks), and oil seeds without fat extraction (canola seeds); (Lock et al., 2004). Another excellent source of fat for cattle diets is condensed distillers solubles which is often added back to DGS as well as the energy from fat found in DGS themselves.

Fat Supplementation and Cattle Performance.

Up until the 1980's, it was reported that fat supplementation over 5% of the diet DM hindered gains in feedlot cattle (Zinn, 1989a). However, these depressions appear to be dependent upon the grain source that comprises the basis of the diet as well as the source of fat being supplemented. Fat supplemented to barley, sorghum, or wheat-based diets has been shown to improve ADG and G:F in feedlot diets (Brethour et al., 1986; Zinn, 1989a; Brandt and Anderson, 1990). By contrast, when supplemental fat was included in corn-based diets, the results are variable (Haaland et al., 1981; Gramlich et al., 1990; Huffman et al., 1992). Haaland et al. (1981) found that adding 5% protected

tallow to steam-flaked corn diets maximized DMI, ADG, and G:F ($P < 0.05$). Gramlich et al. (1990) found that when tallow was added to a dry-rolled corn (DRC) based diet at 4% on DM-basis, ADG was maximized and feed efficiency was the greatest. Huffman et al., (1992) conducted two experiments utilizing DRC-based diets with differing levels and types of supplemental fat. The authors found that when bleacheable fancy tallow was fed at 0, 2, 4, or 6% (DM basis) with 0 or 7.5% forage, there was no effect on ADG or G:F in the 7.5% forage diet, but that in the all concentrate diet, ADG and G:F decreased linearly ($P < 0.01$, and $P = 0.08$, respectively). When Huffman et al. (1992) fed 0% fat, 4% bleacheable tallow, or 4% blended animal-vegetable fat with 0 or 7.5% forage, the authors found that across both forage levels the addition of supplemental fat to the DRC-based diet increased ADG and G:F ($P < 0.01$). Zinn, (1989a) noted that the greatest responses to feeding fat are seen in diets where acidosis control is maximized.

Condensed distillers solubles fed alone or when added back to distiller grains provide an excellent source of energy in growing or finishing beef cattle diets. Supplementation of these two corn byproducts in forage-based diets increase ADG and decreases forage intake (Morris et al., 2005). Decreased forage intake and increased gains appear to be caused by the additive effects of supplemental RUP and fat in the forage diet. MacDonald et al., (2007) conducted an experiment to determine the magnitude of contribution both supplemental protein and energy in the form of fat had on forage fed cattle. Dry distillers grain, corn gluten meal (CGM), and corn oil were supplemented to cattle on smooth brome pasture. The authors reported that feeding dry DGS increased ADG ($P < 0.01$) and CGM tended to increase gains ($P = 0.14$) but at a rate that was 39% that of exhibited by dry DGs supplemented cattle. This value of 39%

suggests that supplemental RUP accounts for approximately one-third of the increase in ADG for cattle supplemented dry DGS. Corn oil supplementation, however, did not elicit increased ADG ($P = 0.25$) and tended to decrease gains compared to CGM supplemented cattle ($P = 0.09$). Looking to digestive kinetics with fat supplementation in forage-based diets, Gilbrey et al., (2006) fed increasing concentrations of CDS (0, 5, 15, or 20% on a DM basis) to cattle consuming a switchgrass diet (*Panicum virgatum L.*). Ruminal OM and NDF digestibility increased linearly ($P < 0.01$), however OM and NDF total tract digestibility were unaffected ($P > 0.05$). No treatment differences in average ruminal pH were observed for this trial ($P > 0.05$). This was not the same effect reported when corn oil was supplemented to fescue grass diets by Pavan et al., (2007). The authors observed linear decreases in DM, OM, and NDF total tract digestibility as corn oil supplementation increased. Corrigan et al., (2009b) attributed the differences observed between these two studies to the CP content of each supplemental source of fat and thus conducted three separate trials to illustrate this. In the first trial, the authors supplemented increasing concentrations of dry DGS (0.25, 0.50, 0.75, or 1.0% of BW) with increasing concentration of CDS added back to them (0.0, 5.4, 14.5, 19.1, or 22.1% of dry DGS DM) to a basal diet of 58.8% alfalfa hay, 39.2% sorghum silage, and 2% of a formulated supplemented fed ad-libitum. The fat content of DDG with CDS inclusion of 0.0, 5.4, 14.5, 19.1, and 22.1% was 6.9, 8.9, 10.4, 12.7, and 13.3%, respectively. A DDG supplementation level by CDS level interaction was observed for ADG and G:F ($P < 0.01$). As DDG supplementation increased, a cubic response in ADG was observed when 0.0 ($P = 0.04$), 14.5 ($P < 0.10$), and 19.1% ($P = 0.09$) CDS was added to the DDG. As DDG supplementation increased, a cubic response in G:F was also observed when 0.0 (P

= 0.07) and 14.5% ($P < 0.10$) was added to the DDG. No significant interactions were reported for total DMI or final BW however a linear decrease in DMI of the forage was the result of increased dry DGS supplementation and subsequent increase of fat content of the diet ($P < 0.01$). This decrease in forage intake the authors attributed to the increased energy supplied to the diet by increasing concentrations of DDG supplementation. A quadratic increase in final BW as DDG supplementation increased was also observed ($P = 0.06$). No significant trends were observed with increasing concentrations of CDS in the DDGS ($P \geq 0.18$). In the second trial conducted by Corrigan et al.,(2009) DDG was supplemented to steers fed a 58.8% alfalfa hay, 39.2% brome hay, and 2% supplement diet. The DDG was supplemented at 1.0% of BW and had either 0.0 or 22.1% CDS added back to it in order to evaluate the effects of protein and fat content on DM, OM, and NDF digestibility. No treatment differences were observed for DM, OM, or NDF total tract digestibility ($P \geq 0.14$). Ether extract digestibility was greater for cattle fed the 22.1% CDG diets. The final experiment by Corrigan et al., (2009b) utilized two duodenally and ruminally cannulated Holstein steers to estimate DM and CP digestion of the DDG treatments and basal diet fed in the first experiment. A linear increase in ruminal DM digestibility ($P < 0.01$) and a quadratic increase in lower tract and total tract digestibility ($P \leq 0.03$) was observed as the concentration of CDS in the DDG increased. The authors concluded that though the cubic interaction for ADG and G:F observed with increasing inclusions of CDS in DDG is unclear it appears that the level of CDS in the diet is critically responsible for performance responses in ADG and G:F for forage-based diets.

In order to determine the effects of increasing concentrations of CDS added to finishing diets, Pesta et al., (2012) fed 0.0, 9.0, 18.0, 27.0, or 36.0% CDS replacing a blend of DRC and HMC. A linear decrease in DMI ($P < 0.01$) was observed as CDS concentration increased while a quadratic increase in ADG and G:F ($P \leq 0.02$) was observed. Vander Pol et al. (2009) conducted two separate experiments to determine the effects of WDGS inclusion on steer performance and digestibility in finishing diets. In Trial 1, was a 2×3 factorial where WDGS was fed at 0, 20, or 40% concentration in the diet and corn oil was fed at 0, 2.5% or 5% in the diet. The 20% WDGS and 2.5% corn oil diets had the same fat concentration and the 40% WDGS and 5% corn treatment diets had the same fat content. An interaction between corn byproduct type and concentration was observed for ADG and G:F. As increasing concentrations of corn oil were included in the diet, ADG linearly decreased ($P = 0.04$) whereas no significant effect was observed in ADG when increasing concentrations of WDGS were included in the diet ($P > 0.50$). Feed efficiency also decreased linearly as corn oil diet concentration increased ($P = 0.10$), but was unaffected by increasing concentrations of WDGS added to the diet ($P > 0.20$). Cattle fed 20 or 40% WDGS diets were more efficient than their control ($P < 0.01$). In the digestion study by the same authors, ruminally and duodenally cannulated steers were fed 40% WDGS, 2 composites diets (one containing corn bran plus corn oil and the other corn containing corn gluten meal plus corn oil), or DRC-based diet with or without corn oil supplementation. The authors found cattle fed 40% WDGS had greater molar concentrations of propionate and reduced acetate:propionate ratios compared to steers in other treatments ($P < 0.01$). Total tract fat digestibility and a greater concentration of unsaturated fatty acids in duodenal fluid were also found in steers fed

40% WDGS ($P < 0.01$) compared to steers in other treatments. The authors thus concluded that the greater energy value and subsequent feeding value of WDGS over corn could be due to greater propionate production, greater fat digestibility, and more unsaturated fatty acids reaching the lower tract for digestion. Scott et al., (1998) reported that as corn steep is increasingly added to finishing diets, acetate:propionate decrease. Corn steep is quite similar to CDS found in WDGS, minus the fat content, thus this appears to support observations reported by Vander Pol et al., (2009).

When 40% WDGS is added to the diet, there is an increase in the concentration of unsaturated fatty acids flowing to the lower tract is important. Plascencia et al., (2003) reported that saturated fatty acids are less digestible in the duodenum compared to unsaturated fatty acids. Atkinson et al., (2006) further supports the results of Vander Pol et al., (2009) as they reported that high concentrate diets promote reductions in biohydrogenation in the rumen, resulting in increased flow of unsaturated fatty acids to the lower tract. Lock et al., (2005) further supported this as they observed that digestibility of fatty acids decreases with increasing chain length, however fatty acid digestibility actually increases with the prevalence of double bonds. The authors reported that for 16:0, 18:0, 18:1, 18:2, and 18:3 fatty acids, intestinal digestibility was 75, 72, 80, 78, and 77% for each, respectively.

Methods of Fat Extraction in Dry Milling Process.

Ethanol production has increased from 60 million gallons in the 1970's to 15 billion gallons in 2014. Out of nearly 200 ethanol plants in production across the United States, approximately 75% are removing oil and selling this oil to non-ruminant food industries or to the biofuel industry (RFA, Pocketbook Guide to Ethanol, 2014). Two

primary methods are utilized to remove this oil; pre-fermentation fractionation and centrifugation of the thin stillage following fermentation.

Pre-Fermentation Fractionation.

Pre-fermentation fractionation is a technology utilized by the ethanol industry to increase production efficiency and remove oil with added market value (Buckner et al., 2011). Pre-fermentation fractionation is the process of separating the corn kernel into its endosperm, germ, and bran (pericarp and tip cap) fractions (Lin et al., 2011). The endosperm fraction comprises approximately 83% of the corn kernel (RFA, 2014), is high in starch, and is the corn component fermented to produce ethanol and distillers byproducts (Kleinhans et al., 2005). Bran, which is composed primarily of carbohydrates is a component used in ruminant diets primarily. The germ, which comprises approximately 12% of the kernel, is the oil-rich corn constituent (RFA, 2014). Two methods of pre-fractionation are currently employed; wet fractionation and dry fractionation (Lin et al., 2011). Wet fractionation requires that the corn kernel be soaked in water, incubated with glutathione reductase (GSH) and protease enzymes, and then sent to the grinder for degermination. Pericarp fiber, or bran, will be highly associated with the germ portion of the kernel at this time, but these two components will be separated out from the endosperm. The pericarp and germ blended portion are then dried and aspirated, separating the bran and germ from one another (Rausch and Belyea, 2006). Dry fractionation is similar to wet fractionation; however the corn is tempered with steam and hot water before being sent to the degerminator. At the degerminator the endosperm is readily separated off from the other kernel components. The pericarp and germ are

separated into their individual constituents after going through the rollermill and subsequently being sifted in their dry forms (Rausch and Belyea, 2006).

When comparing the nutrient composition of pre-fractionated distillers grains to distillers grains without oil removal there are some marked differences in crude protein (CP) and fat concentrations of each byproduct (RFA, 2014). Distillers grains produced in plants implementing pre-fractionation technologies are more concentrated in protein, and have a fat content equal to or less than the corn kernel from which they were derived (RFA, 2014). Pre-fractionated distillers grain can have a protein content as high as 37.0% and a fat content as low as 2.0%, both of which are dependent upon the pre-fractionation technology used as well as the efficiency of that technology (RFA, 2014).

Feeding Pre-Fractionated Distillers Grains.

Research conducted on pre-fractionated corn byproducts is limited. Dejenbusch et al. (2008), however, conducted a study where partially pre-fractionated DDGS (FRAC) was fed at 13% concentration in the diet and compared to a diet containing 13% normally processed DDGS (TRAD) and a 0% DDGS control. The authors found that DMI, ADG, and G:F were not significantly different between the control, TRAD, or FRAC treatments ($P \geq 0.46$). When performance comparisons were made between TRAD and FRAC, it was observed that cattle consuming the TRAD diet had greater DMI than those consuming FRAC diets ($P \leq 0.01$), but ADG and G:F were not significantly different between treatments ($P \geq 0.07$). No statistical differences in carcass measurements were observed in this study. The authors concluded that feeding low levels of partially pre-

fractionated DDGS to cattle did not significantly affect performance when compared to the performance observed in traditionally produced DDGS.

Conversely, Gigax et al. (2012) compared feeding a 35% (DM-basis) pre-fractionated, low oil WDGS (LFAT) diet to 35% full fat WDGS (NFAT) diet and a 0% WDGS control diet. Wet distillers grains plus solubles replaced a 1:1 blend of DRC and HMC. The fat content of LFAT was 6.7%, whereas the fat content of NFAT was 12.9%. The authors found that final BW and thus HCW were greater in cattle fed NFAT diets ($P = 0.04$). Dry matter intake was similar between all treatments ($P = 0.99$), but ADG was greatest in cattle consuming NFAT diets ($P = 0.02$), with gains being similar in the LFAT and control diets. A tendency for cattle fed NFAT to be more efficient at the bunk existed ($P = 0.12$), but as was seen in the study by Godsey et al., (2010) carcass characteristics did not differ across treatments ($P \geq 0.25$).

Buckner et al. (2011) fed Dakota Bran, a pre-fermentation fractionated corn byproduct, with CP and fat contents of 14% and 11%, respectively. The corn byproduct Dakota Bran was fed at 15 or 30% of diet (DM-basis) and compared to equal concentrations of traditionally produced DDGS. A 70:30 blend of ground brome grass hay and alfalfa haylage comprised the remainder of all diets. The crude protein and fat contents of DDGS was 30% and 11%, respectively. No concentration by corn byproduct type interactions existed in this study. As the concentration of either byproduct increased in the diet, so did ending BW, DMI, ADG, and G:F ($P < 0.01$). NE_m and NE_g values for the diet also increased as corn byproduct inclusion increased ($P < 0.01$). The main effect of corn byproduct type showed that feeding DDGS resulted in a tendency of heavier ending BW (370 vs. 366 kg, $P = 0.06$) and a tendency for a greater NE_g value (0.97 vs.

0.93, $P = 0.08$) for the diet. Daily gains improved when DDGS was fed by 0.07 kg ($P = 0.05$) and feed efficiency improved by 5.5% over cattle consuming Dakota Bran diets. Another study by the same authors (Buckner et al., 2011) was conducted where feedlot cattle were fed 0, 15, 30, or 45% Dakota Bran or 30% DDGS. As Dakota Bran was increased in the diet, final BW, ADG, G:F, and HCW improved linearly ($P < 0.01$). Calculated energy values tended to increase linearly also as Dakota Bran concentration in the diet increased ($P = 0.14$). When comparing 30% Dakota Bran vs. 30% DDGS performance, finishing cattle responded similarly to both diets.

Finally, E-corn, which is a pre-fractionated, low fat corn byproduct which is comprised of the remaining material after the starch is distilled off as ethanol and the corn oil is removed, was fed to finishing beef cattle by Godsey et al. (2010). E-corn was fed at 0, 20, 40, or 60% concentration in the diet on a DM basis along with 30% DDGS or 30% wet corn gluten feed (WCGF) in a 2×4 factorial arrangement of treatments. No corn byproduct type by E-corn inclusion interactions existed in this study ($P > 0.10$). The main effect of E-corn concentration in the diet resulted in no significant differences in final BW ($P = 0.49$), but DMI responded quadratically with increasing concentrations of E-corn in the diet ($P = 0.04$). Dry matter intake was similar in cattle fed diets containing 0 to 40% E-corn, but 60% E-corn replacing DRC in the diet, reduced DMI. No difference in ADG ($P > 0.10$) were noted when E-corn was increased to the diet, but G:F responded cubically ($P = 0.02$). Feed efficiency was highest when E-corn was included at 20 or 60%, but poorest when E-corn replaced corn at 0 or 40% inclusions in the diet. The authors stated that replacing DRC with E-corn at 60% on a DM basis would result in similar live animal performance while decreasing DMI. Looking to carcass

characteristics, HCW was not different between treatments ($P = 0.49$), but marbling, fat thickness, and calculated yield grade linearly decreased with increasing inclusions of E-corn. The main effect of corn byproduct type resulted in no significant differences in final BW ($P = 0.75$), however, DMI was lower in cattle consuming WDGS diets ($P \leq 0.01$) and ADG was similar between treatments ($P > 0.10$), thus WDGS fed steers were 6% more efficient than steers consuming WCGF diets ($P = 0.02$). No significant differences were observed for any carcass measurement when comparing the two corn byproducts. The authors reported that the feeding value of E-corn replacing DRC in the diet was 118% at 20% concentrations in the diet, but reduced to 101% when E-corn was included at 60%. This could be due the decreasing fat content of the diet with increasing concentrations of E-corn included.

As the literature suggests, cattle performance is variable when feeding pre-fractionated corn byproducts in comparison to DGS byproducts with no oil removal. These variances in cattle performance could be due to the pre-fractionation method used or the remaining nutrients comprising the diet. Further research is needed on effects to cattle performance if this methodology of oil removal becomes more prevalent.

Post-Fractionation.

Removal of fat following fermentation is referred to as post-fractionation. This process is conducted by centrifuging oil from the thin stillage prior to evaporation of the thin stillage to produce CDS (RFA, 2014). Traditionally processed distillers grains (no oil removal) have a fat content of approximately 12-13%, whereas after centrifugation, fat content of distillers grains is between 7 and 9%.

Feeding Post-Fractionated Distillers Grains.

As over half of Nebraska's ethanol plants are removing oil from distillers grains via centrifugation of the thin stillage, it is not surprising that cattle feeders were concerned. Reducing fat and thus the potential energy value of distillers grains could impact cattle performance. To address this concern, Jolly et al. (2013) looked at the effects of feeding de-oiled CDS in growing cattle fed forage-based diets. De-oiled (6.3% fat) and full fat (20.1% fat) CDS, produced at the same plant were fed at 20 or 40% of the diet (DM-basis). A control diet containing no CDS was also fed for comparison. The remainder of all diets consisted of 80:20 blend of brome hay and sorghum silage. Fat content of the control diet was 1.47%. Fat content was 2.39 and 3.23% for the de-oiled and full fat 20% CDS diets, respectively, and 5.15 and 8.83% for the de-oiled and full fat 40% CDS diets. The full fat, 40% CDS diet contains a greater fat content than what is typically fed to growing cattle consuming a forage-based diet. The authors observed no statistical CDS fat content by CDS concentration interaction ($P \geq 0.14$). Steer consuming full fat CDS diets tended to be more efficient ($P = 0.07$) than those fed de-oiled CDS diets. Cattle consuming full fat CDS at 20% inclusion in the diet were 13.4% more efficient than cattle consuming 20% de-oiled CDS diets. At the 40% inclusion level, no substantial differences in G:F were present which could be attributed to the high fat concentration in the diet hindering fiber digestion (Loy et al., 2008). Concentration of CDS in the diet caused linear improvements, in both de-oiled and full fat CDS diets, for ending BW, DMI, ADG, and G:F as the concentration of CDS in the diet increased from 20 to 40% ($P < 0.01$).

Another component of this same trial by Jolly et al., (2013) was that 40% de-oiled or full fat CDS was fed with either wheat straw or grass hay. The authors reported a tendency for an interaction between fat content and forage type for DMI ($P = 0.06$). No significant difference in intake were observed for cattle fed the grass diet, but cattle fed the full fat wheat straw diet ate 5.2 kg/d compared to 6.1 kg/d consumed by cattle fed de-oiled CDS. No other interactions were reported for this study, and when looking to the main effect of fat content of CDS, no treatment differences were reported ($P \geq 0.40$). However, ending BW, DMI, ADG, and G:F were significantly greater for cattle fed grass hay over wheat straw ($P < 0.01$).

Jolly et al., (2013) conducted a finishing trial to compare the effects of feeding 27% de-oiled or full fat CDS to 40% de-oiled or full fat MDGS when replacing a DRC:HMC blend. Inclusion of CDS at 27% and MDGS at 40% was conducted as Pesta et al. (2012) and Bremer et al., (2011), respectively found that G:F was maximized when CDS and MDGS were fed at these concentrations in finishing feedlot diets. A 0% corn byproduct diet was also fed for comparison. The remainder of all diets consisted of 12% corn silage and 5% supplement and decreasing concentrations of a HMC:DRC blend with increasing corn byproduct inclusion. The authors reported that the fat content of de-oiled and full fat CDS was 6.0 and 21.1%, respectively, and 9.2 and 11.8% for de-oiled and full fat MDGS, respectively. The fat content of the diets was then 4.43% for the HMC:DRC control, 4.72% for the de-oiled CDS diet, 8.80 for the full fat CDS diet, 6.12% for the de-oiled MDGS, and 7.19% for the full fat MDGS diet. The authors reported no interactions between fat content and corn byproduct type. All diets containing corn byproducts resulted in greater G:F than did the HMC:DRC control ($P < 0.01$). When comparing G:F

values for de-oiled and full fat CDS or MDGS no significant differences were observed for performance or carcass characteristics ($P \geq 0.44$). Though not statistically significant ($P = 0.29$), a small numerical difference in G:F existed between de-oiled and full fat CDS treatments. Cattle fed de-oiled CDS were 2.75% more efficient than cattle fed full fat CDS. Only a 0.57% difference existed between de-oiled and full fat MDGS treatments for G:F. When comparing the effect of corn byproduct type, no significant differences were observed for DMI, ADG, or G:F between treatments ($P \geq 0.58$). No significant differences in carcass characteristics were observed between steers fed either of the corn byproduct types ($P \geq 0.29$). Another finishing trial conducted by the same authors evaluated the effects of feeding 35, 50, or 65% de-oiled or full fat WDGS. Wet distillers grains plus solubles replaced the HMC and DRC. A control diet containing no WDGS was also fed for comparison. Corn silage at 12% (DM basis) and 5% supplement comprised the remainder of all diets. Both de-oiled and full fat WDGS were produced from the same plant for this trial. No linear or quadratic interactions existed for final BW, ADG, or G:F ($P \geq 0.31$), however, DMI decreased linearly as concentration of WDGS increased in the diet for both de-oiled and full fat WDGS diets ($P < 0.01$). The decrease in DMI was not equal between diets containing de-oiled or full fat WDGS. Oil content as a main effect showed that ADG was greater in cattle consuming de-oiled WDGS diets ($P < 0.01$), but final BW, DMI, G:F, and all carcass measurements were not statistically different between treatments ($P \geq 0.52$). A quadratic response to DMI with increasing concentration of WDGS in the diet ($P < 0.01$) did occur with cattle fed 35% WDGS diets consuming the most per day. A linear improvement in G:F was observed with increasing concentration of WDGS in the diet ($P < 0.01$), with a tendency for a

linear increase in calculated yield grade also being observed ($P = 0.08$). No linear or quadratic significance was reported for final BW, ADG, HCW, LM area, fat depth, or marbling ($P \geq 0.13$) as WDGS concentrations increased in the diet. The authors concluded that removing a portion of the oil from distillers grains via centrifugation did not significantly affect finishing performance when fed with a HMC and DRC blend.

Finally to determine how de-oiled or full fat CDS (27% DM-basis) or MDGS (40% DM-basis) affected total tract digestibility, Jolly et al., (2013) also conducted a digestion study. Fat content of corn byproducts was 8.7 and 15.4% for de-oiled and full fat CDS, respectively, and 9.2 and 12.3% for de-oiled and full fat MDGS, respectively. DM and OM intakes and digestibility did not differ between de-oiled or full fat CDS or MDGS ($P \geq 0.17$). NDF intake, however, was greater in full fat CDS diets ($P = 0.02$) compared to de-oiled CDS diets and tended to be greater in full fat MDGS diets ($P = 0.08$) over de-oiled MDGS diets. Total tract digestibility of NDF was greater in full fat CDS diets over de-oiled CDS diets ($P = 0.02$), but did not differ between MDGS varieties ($P = 0.90$).

Objectives.

It appears that when oil is removed from distillers grains via centrifugation of the thin stillage portion, and then these CDS are added back to the wet grains, there are minimal effects on cattle performance in growing and finishing diets. Though the experiments conducted by Jolly et al, (2013) have alleviated some concerns for cattle feeders, more questions still need to be answered. Therefore the objectives of this research were to 1) determine the effects of de-oiled MDGS in growing cattle performance and rumen digestion compared to full fat MDGS 2) to determine the optimal

concentration of de-oiled MDGS in a finishing cattle diet and 3) to determine the effects of corn processing with de-oiled WDGS compared to full fat WDGS.

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Chapter II

DE-OILED DISTILLERS GRAINS IN GROWING CATTLE DIETS

Energy Value and Digestibility of De-oiled Modified Distillers Grains Plus Solubles (MDGS) in Growing Cattle Diets

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Abstract

Two experiments determined the energy value of de-oiled modified distillers grains plus solubles (MDGS) and its effects on DM, OM, and NDF digestibility in forage-based growing diets (2.54 cm ground corn residue). In Exp. 1, 60 crossbred yearling steers (initial BW = 299 ± 25 kg) were assigned to treatments organized in a $2 \times 2 + 1$ factorial with factors of MDGS concentration (20 or 40%) and MDGS oil content (7.2%, for de-oiled vs. 12.0% for full fat). A control diet of 40% dry rolled corn (DRC) was also included for comparison. Exp. 2 utilized 6 yearling steers (Initial BW = 495 ± 56 kg) and 6 steer calves (Initial BW = 228 ± 49 kg) in two identical 2×2 factorial arrangements of treatments with factors of oil content of MDGS (de-oiled, 7.2% fat vs. full fat 12.0% fat) and MDGS concentration (20 vs. 40% DM basis). Periods were 21 d long with a 7 d adaptation period, a 7 d pre-collection dosing period (TiO₂ via rumen bolus), and finally 7 d for collection with continued dosing. Wireless pH probes collected measurements continually during the collection period for the yearling steers. In Exp. 1 no MDGS concentration by fat content interactions between de-oiled and full fat MDGS ($P \geq 0.58$) were observed. Feeding 40% MDGS resulted in greater ending BW, DMI, ADG, and G:F ($P < 0.01$) compared to 20% MDGS. Steers fed de-oiled

MDGS had a greater DMI than those fed full fat MDGS ($P = 0.05$). Ending BW, ADG, and G:F were not different between de-oiled and full fat MDGS ($P \geq 0.26$). Steers fed 40% DRC performed intermediately to the 20 and 40% MDGS cattle, respectively. The energy value of MDGS relative to corn was calculated to be 124% for these growing calves. In Exp. 2 no MDGS concentration by oil content interactions were observed ($P \geq 0.68$). Additionally, the main effect of MDGS oil content was not significant ($P \geq 0.08$), however DMD, OMD, and NDFD were all greater at 40% concentration of MDGS in the diet ($P \leq 0.03$) than at 20% inclusion. Rumen pH was not different between treatments ($P \geq 0.51$). Removing oil via centrifugation did not impact steer performance in these studies. Both de-oiled and full fat MDGS are more digestible in a forage-based diet if included at 40% concentrations compared to 20% diet concentrations.

Key words: corn residue, distillers grains, oil removal

Introduction

Adding distillers grains plus solubles to high forage growing diets provides a source of protein and energy that improves animal performance (Bremer, 2010). Increasing concentrations of distillers grains in high forage diets decreases forage intake while increasing average daily gain (Morris et al., 2005; Corrigan et al., 2009). Fat within distillers grains provides an excellent source of energy. Historically, distillers grains have contained 12-13% fat (Buckner et al., 2011). Corrigan et al., (2009), found that feeding high levels of fat, a concern when distillers grains are added at high concentrations in the diet, hinders rumen fiber digestion. Optimal fat concentration to maximize ADG and feed efficiency in high quality forage-based diet was between 3.6-4.5% (Corrigan et al., 2009). Today Nebraska's ethanol plants remove oil from the thin stillage stream (condensed distillers solubles, CDS) via centrifugation and add it back to distillers grains to produce a de-oiled product. Jolly-Breithaupt et al., reported that when de-oiled and full fat CDS were fed in forage-based diets to growing calves that a numerical difference in G:F existed though no statistical difference was observed ($P = 0.14$). Cattle fed 20% full fat CDS were 13.4% more efficient than steers fed de-oiled CDS diets. No difference existed between de-oiled or full fat G:F values at 40% concentrations of CDS in the diet. Lack of numerical differences at 40% concentrations could be due to high fat content of both diets resulting in similar efficiencies if fiber digestion was hindered. The impact of de-oiled distillers grains on forage digestion in growing cattle is poorly understood however. Thus, the objective of this research was to determine the energy value of de-oiled MDGS at 20 or 40% concentrations in a forage-based growing diet and to determine if feeding de-oiled MDGS impacts nutrient (i.e. fiber) digestion similar to feeding de-oiled CDS.

Materials and Methods

Exp. 1

An 84-d growing study utilized 60 crossbred steer calves (BW = 229 ± 25 kg) that were individually fed using the Calan gate system (American Calan Inc., Northwood, NH) at the University of Nebraska-Lincoln Agricultural Research and Development Center (ARDC), near Ithaca, NE. Upon arrival at the feedlot, steers were vaccinated with a modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health, Madison, NJ), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health, Madison, NJ), and received Permethrin Pour-On (Bayer Health Care LLC, Pittsburgh, PA). Approximately 16 d after initial processing, steers were revaccinated with a modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health, Madison, NJ), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health, Madison, NJ), and a pinkeye vaccine (Piliguard Pinkeye +7, Merck Animal Health, Summit, NJ). Prior to the start of the trial, steers were limit fed a diet consisting of 25% alfalfa, 25% grass hay, and 50% Sweet Bran at 2.0% BW for 5 d to minimize variations in gut fill (Watson et al, 2013; Stock et al., 1983). Steers were then weighed on three consecutive d with weights averaged to determine initial BW. Steers were blocked into six BW blocks based on initial BW and then assigned randomly to one of 5 treatments within block. Treatments were organized in a 2 × 2 + 1 factorial design, with 5 total treatments (Table 1) and 12 steers per treatment. Factors were concentration of distillers grains (20 vs 40% of the diet DM) and fat content of modified distillers grains plus solubles (MDGS); either de-oiled (7.2% fat) or full fat (12.0% fat). Both de-oiled and full fat MDGS were purchased prior to the start of the study from *Green Plains Renewable Energy* (Central City, NE) and stored at the feedlot until needed in silo bags. Production of both products at the same plant was

achieved by producing the de-oiled product on one day and then the following day shutting off the centrifugation of the thin stillage stream to allow the production of a full fat CDS product that was then added back to the distillers grains to produce full fat de-oiled distillers grain plus solubles. A 40% (DM basis) dry rolled corn (DRC) diet was used as the control. Corn stover (ground through a 2.54 cm screen) and 5% supplement comprised the remainder of all five diets. All diets were formulated to meet the metabolizable protein requirements using the 1996 NRC model. Cattle consuming the 40% DRC control or 20% distillers grains diets had urea supplemented at 1.65% of the diet to meet metabolizable protein requirements. Diets were also formulated to provide 200 mg / steer of monensin daily (Rumensin, Elanco Animal Health, Indianapolis, IN). All steers received a Ralgro implant (Intervet Inc., Merck Animal Health, Summit, NJ) on d 21 of the study.

Feed refusals were collected weekly, weighed, and then dried in a 60°C forced air oven for 48 hours to calculate an accurate DMI for individual steers. Feed bunks were evaluated and feed offered was adjusted daily to allow ad libitum intake. At the conclusion of the study, steers were limit fed for 5 d a diet of 25% alfalfa, 25% grass hay, and 50% Sweet Bran at 2.0% BW and then were weighed on three consecutive d and averaged to determine an accurate ending BW.

Feed ingredients were analyzed to determine DM (Association of Analytical Chemist [AOAC], 1999 method 4.1.03), CP (AOAC, 1999 method 990.03) using a combustion-type N analyzer (Leco FP 528 Nitrogen Autoanalyzer, St. Joseph, MI), sulfur (TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI), NDF (Van Soest et al., 1991) incorporating heat stable α -amylase (Ankom Technology, Macedon, NY) at 1

ml per 100 ml of NDF solution (Midland Scientific, Omaha NE) along with the addition of 0.5 g of Na_2SO_3 to the NDF solution, and ether extract. Ether extract was evaluated utilizing the biphasic lipid extraction method described by Bremer et al. (2010).

Ingredients were weighed in triplicate (0.5 g) into a 16 x 100 screw top glass culture tube and vortexed with 4 mL of a 50:50 hexane and diethyl ether solution (5 to 6 mL of solution used if determining fat content of forages). Tubes were then placed in a 50° C heating block for 9 hours. After 9 hours, tubes were removed and allowed to cool for 10 minutes before 3 mL of dilute HCl (1 drop HCl/40 mL ddH₂O) were added to them, vortexed, and then centrifuged at 1000 x g for 60 minutes at 25° C. After centrifugation, the lipid layer was pipetted and expelled into a separate tube. The procedure was then repeated as 2 mL of the 50:50 hexane and diethyl ether were again added to the culture tubes and centrifuged. The lipid layer was removed a second time and then the tube weighed to determine fat content of the feed ingredient.

Data were analyzed using the GLIMMIX procedure of SAS (SAS Inc., Cary, NC) as a 2 × 2 + 1 factorial arrangement of treatments to evaluate the interaction of MDGS concentration (20% vs. 40%) and fat content (de-oiled vs. full fat). If no interaction was detected ($P < 0.05$), main effects were evaluated. Additionally, an F-test was used to determine the response to the 40% DRC control to other treatments. Treatment means were separated using a t-test ($P < 0.05$) when the F-test was significant ($P < 0.05$).

Using the 1996 NRC, the energy value of MDGS relative to DRC was calculated by using the observed ADG (Loy et al., 2008). First, the TDN of MDGS and corn stalks was set at 108% and 43%, respectively. Then the NE adjusters were set so that the observed ADG was achieved in the model for 20% and 40% MDGS inclusion (Block et

al., 2006). This resulted in NE adjusters of 131% and 106% for 20% and 40% MDGS, respectively. The change in NE adjuster per change in ADG was calculated to determine the NE adjuster required to achieve the ADG for the 40% DRC control (116%). Finally, the TDN of DRC was adjusted to achieve the observed gain for the 40% DRC control. The resulting TDN for DRC was estimated to be 87% which is similar to a previous estimated TDN of DRC in forage based diets of 83% (Loy, 2003). The TDN of DRC was compared to the TDN of MDGS to provide a relative energy value of MDGS to DRC in a growing, forage-based diet.

Exp. 2

An 84-d digestion study utilized twelve (6 yearling (initial BW = 1093 ± 56) and 6 calf-fed (initial BW = 502 ± 49) ruminally cannulated steers in a row × column transformation experimental design. Treatments were organized in a 2 × 2 factorial arrangement (Table 3.). Concentration of MDGS (20 vs. 40%) and fat content of MDGS (de-oiled vs. full fat content) were the factors examined. Both de-oiled and full fat MDGS were purchased prior to the start of the study from *Green Plains Renewable Energy* (Central City, NE) and stored at the ARDC near Ithaca, NE until needed in silo bags. The remainder of all diets consisted of 2.54 cm grind corn residue and 4% of a formulated supplement to provide 200mg/hd/d Rumensin and 90 mg/hd/d Tylan. The 20% distillers grains diets contained 1.32% urea to meet the ruminally degradable protein (RDP) requirements. In addition metabolizable protein requirements of the animals were met with distillers grains and predicted microbial protein. Steers were housed in 2.4 × 1.5 m² individual concrete slatted floor pens in a temperature controlled room (25° C)

and with ad libitum access to food and water. Cattle were fed once daily at 0800 and refused feed was removed from bunks prior to feeding. Ingredient samples were taken during collection periods prior mixing of diets, composited by period, and frozen at -20° C. A subsample of feed refusals was dried for 48 h in a 60° C forced air oven to determine DM and allow for adjustments in DMI. After ingredients were freeze dried they were ground through a 1-mm screen utilizing a Willey Mill (Thomas Scientific, Swedesboro, NJ).

This study was comprised of four, 21-d periods. Cattle were acclimated to treatment diets through days 1-15 and dosed with titanium dioxide (TiO_2) on days 8-20. Fecal and diet samples as well as orts were collected on days 15-21. Titanium dioxide was used as a marker for digestibility measurements, and was administered via rumen bolus twice daily (at 0800 and 1200) at 7.5 g per dosage. Fecal grab samples were collected from the yearling steers at 0800, 1200, and 1600 each day on d 15-21. Fecal samples were composited by day on a wet-basis by day and then freeze dried. After fecal samples were freeze dried they were ground through a 1-mm screen utilizing a Willey Mill (Thomas Scientific, Swedesboro, NJ) and then composited dry by period for each steer. The wet ash method of TiO_2 analysis was utilized (Myers et al., 2004) in order to determine titanium concentration in feces to calculate fecal output. Fecal samples were weighed in duplicate to a mass of 0.5 g per 250 ml macro Kjeldahl digestion tube. A reaction catalyst containing 3.5 g of K_2SO_4 and 0.4 g of CuSO_4 was also added to each tube prior to the addition of 13 ml of concentrated H_2SO_4 . Tubes were then swirled to allow proper mixing of reagents and then digested at 420° C for 2 h. After digestion, tubes were removed from heat and cooled for a minimum of 30 min. After cooling, 10

ml of 30% H₂O₂ was poured into each tube, swirled for mixing, and then the tube was again allowed to cool for another 30 min. The liquid mixture within the tube was brought to a total weight of 100 g with the use of ddH₂O and then filtered through Whatman No. 541 filter paper to remove any precipitate. Absorbency was measured at 410 nm after calibration of the spectrophotometer using TiO₂ standards prepared prior to analysis.

Fecal and ingredient samples were analyzed for DM (AOAC, 1999 method 4.1.03), CP (AOAC, 1999 method 990.03) using a combustion-type N analyzer (Leco FP 528 Nitrogen Autoanalyzer, St. Joseph, MI), sulfur (TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI), OM, NDF (Van Soest et al., 1991) incorporating heat stable α -amylase (Ankom Technology, Macedon, NY) at 1 ml per 100 ml of NDF solution (Midland Scientific, Omaha NE) along with the addition of 0.5 g of Na₂SO₃ to the NDF solution, and ether extract (Bremer et al., 2010). Orts were collected daily throughout the collection period and analyzed for DM (AOAC, 1999 method 4.1.03) for accurate calculation of DMI. Utilizing DM, OM, and NDF contents of ingredients comprising the diet and the fecal matter excreted DM, OM, and NDF output and digestibility was determined.

Wireless pH probes (Dascor, Inc., Escondido, CA) were inserted into the rumen to collect pH measurements continuously the last 7 d of the period. Measurement were recorded every minute (1,440 measurements/d) and downloaded at the conclusion of each period. Measurements of pH include average, minimum, and maximum ruminal pH values.

The GLIMMIX procedure (SAS Inc., Cary, NC) was used to analyze intake, fecal output, digestibility, and pH data as a 2 × 2 factorial arrangement of treatments. Because

both yearling and calf-fed steers were used in this study, the effect of animal age and its interactions with dietary treatment was tested with significance at $P \leq 0.05$. If no significant interactions were observed, the effects of concentration of distillers grains and fat content were presented irrespective of steer age. Included in the model were the fixed effects, animal, age, distillers grains concentration, distillers grain oil content, as well as the interaction between all of the fixed effects.

Results and Discussion

Exp. 1

Nutrient content of diet ingredients is found in Table 1. Consistent with our objectives, the fat content of the MDGS was 7.2% and 12.0% for de-oiled and full fat, respectively. No MDGS concentration by fat content interactions ($P \geq 0.58$) were observed for this study (Table 3), thus the main effects of diet concentration and fat content of MDGS will be discussed separately.

Concentration of MDGS

Ending BW, DMI, ADG, and G:F were significantly greater in cattle fed 40 vs. 20% MDGS (Table 4., $P < 0.01$). Nuttelman et al., 2010 observed a tendency for greater ending BW ($P = 0.13$) and significant increases in ADG ($P < 0.01$) with increasing concentrations of WDGS in forage-based diets. Ahern et al., 2014 also observed linear increases in ending BW, ADG, and G:F with increasing levels of distillers grain supplementation ($P < 0.01$) in a 60:40 sorghum silage and alfalfa hay diet. Morris et al., (2005) and Loy et al., (2003) saw decreases in forage intake with increasing concentrations of distillers grains in the diet though total DMI (distillers grains + forage) increased with increasing concentrations of distillers grains. In these two studies, steers

were fed their forage source and distillers grains separately, whereas in the current study, diets containing corn residue and MDGS were mixed prior to feeding. Furthermore, Jolly et al., (2013) observed increased ending BW, DMI, ADG, and G:F ($P < 0.01$) for both de-oiled and full fat CDS when its concentration was increased a forage-based diet.

Increasing the concentration of de-oiled MDGS in the diet results in increased ending BW, ADG, and G:F as would be expected if full fat MDGS was supplemented in forage-based diet.

Fat Content of MDGS

Steers receiving diets with 7.2% fat MDGS included had a greater DMI when compared to steers fed 12.0% fat MDGS ($P = 0.05$, Table 3.). Dry matter intake was 5.8 and 5.4 kg, for de-oiled and full fat treatments, respectively. Contrary to our results, in the study by Corrigan et al., (2009), as the concentration of CDS, and thus fat content, of DDGS increased in the forage-based diet no differences in DMI were observed. Also in the current study, ending BW (350 vs. 346 kg, $P = 0.39$) and ADG (0.59 vs 0.54 kg/d, $P = 0.26$) were not significantly different between steers fed de-oiled or full fat MDGS diets. However steers fed diets containing 12.0% fat MDGS numerically gained less than those consuming 7.2% fat MDGS diets causing G:F to be unaffected (0.099 vs 0.099, $P = 0.85$). Jolly et al., (2013) also reported no differences in ADG between cattle fed de-oiled and full fat CDS diets, but there was tendency ($P = 0.07$) for cattle fed full fat CDS to be 13.4% more efficient than those fed de-oiled CDS at 20% concentrations. When the same authors compared de-oiled vs. full fat CDS fed at 40% concentrations with either wheat straw or grass hay, no significant differences in G:F were observed between varying oil contents of distillers grains ($P = 0.40$). The effect of fat on rumen fiber

digestion as seen in studies by Corrigan et al., (2009) and Jolly et al., (2013) is contrary to what was observed in the current trial as the fat content of CDS combined with distillers grains to produce MDGS is lower than when CDS is fed alone.

Energy Value

Steers consuming the 40% DRC control diet tended to be lighter at the conclusion of the study compared to the those steers receiving the 40% full fat MDGS diet ($P = 0.08$, Table 3.). The DMI of steers consuming DRC did not differ from steers fed 40% de-oiled or full fat MDGS ($P \geq 0.28$), and ADG and G:F were intermediate for steers fed the DRC control diet compared to steers fed 20% or 40% inclusion of either full fat or de-oiled MDGS. Loy et al., (2007) observed that DMI did not differ between steers supplemented DRC or DDGS in forage-based diets ($P \geq 0.45$). The authors also reported that steers supplemented with DDGS had greater ADG and G:F than those supplemented DRC ($P < 0.01$). Similarly, Nuttelman et al., (2010) observed that ADG and G:F were greater in steers supplemented WDGS in high forage diets compared to DRC supplemented steers when DMI was held constant by design. In the current experiment, the energy value of MDGS relative to corn was calculated to be 124%. Loy et al., (2008) observed that the energy value of DDGS was 130% for low concentrations of DDGS and 118% for greater concentrations of DDGS supplementation when compared to DRC. Nuttelman et al., (2010) found that when fed at 15%, 25%, and 35% of the diet (DM-basis), WDGS had 146, 149, and 142% the energy value, respectively, compared to DRC supplemented steers fed forage-based diets. The results of the current study suggest that removing oil from thin stillage to create MDGS fat content of 7.2% vs. 12.0% does not alter steer performance in forage-based diets. Further reduction of corn oil in MDGS

may result in decreased performance, thus supplementary research will be required if additional oil is removed from distillers grains.

Exp. 2

Nutrient composition of diet feed ingredients are presented in Table 1. Both Exp. were conducted simultaneously and the same diet ingredients were utilized for both Exp, therefore analysis of diet ingredients were conducted by period for the digestion study and then utilized for both Exp. No interactions between concentration of MDGS and MDGS fat content were detected for this study ($P \geq 0.68$), thus main effects are presented (Table 5.).

Concentration of MDGS

Similar to previous observations, (Nuttelman et al., 2010; Ahern et al., 2014), increasing the concentration of distillers grains from 20 to 40% in the diet significantly increased DM intake, OM intake ($P < 0.01$), and tended to increase NDF intake ($P = 0.10$, Table 5.). DM digestibility and OM digestibility were greater in steers consuming 40% MDGS ($P \leq 0.02$) compared to 20% MDGS, was expected given that MDGS replaced corn residue. Average ruminal pH was not different between steers consuming either 20 or 40% MDGS ($P = 0.85$, Table 6.).

Fat Content of MDGS

Steers consuming full fat MDGS diets tended to consume more DM, OM, and NDF per day than did steers consuming de-oiled MDGS diets ($P = 0.15$, $P = 0.15$, and $P = 0.08$, respectively). When comparing digestibility (Table 5.) and rumen pH values (Table 6.) between steers consuming de-oiled versus those consuming full fat MDGS, no

significance between MDGS types existed ($P \geq 0.45$). Therefore, these data suggest that oil removal from distillers grains plus solubles does not improve digestibility in forage-based diets similar to those fed in this study, which is contrary to previous work which altered fat concentration by changing solubles concentration (Jolly et al., 2013). The current Exp. suggests that growing steers tend to consume more when fed full fat MDGS diets compared to when fed de-oiled MDGS diets. This is contrary to what would be expected as typically steers consuming forage-based diets of a lower fat content have greater DMI than those being fed a forage-based diet of a higher fat content. Fat hinders fiber digestion in the rumen thus typically decreasing intake. However, the digestibility of full fat MDGS diets was not different from the digestibility exhibited by steers consuming de-oiled MDGS diets ($P \geq 0.45$). Therefore, the dietary fat concentration (5.35%) in the full fat MDGS diet did not appear to depress fiber digestion in this study. Feeding de-oiled MDGS to growing steers consuming high forages diets does not appear to hinder steer performance or fiber digestion when compared to feeding full fat MDGS.

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Table 1. Nutrient Composition of Diet Ingredients, % (DM-basis).

Ingredient	DO¹ MDGS²	Full MDGS	Corn Residue³	DRC
DM, %	45.3	47.8	90.50	91.1
NDF, %	37.5	38.4	80.8	10.5
CP, %	35.5	32.6	6.7	9.9
Fat, %	7.2	12.0	1.0	4.0
Sulfur, %	0.63	0.57	0.10	0.16

¹ DO = de-oiled, Full = full fat, DRC = dry rolled corn.

² MDGS = modified distillers grains plus solubles.

³ Ground through a 2.54 cm screen

Table 2. Diet composition of de-oiled or full fat MDGS¹ diets fed to growing steers.

<i>Ingredient, % of DM</i>	Control	De-Oiled MDGS		Full Fat MDGS	
	0	20	40	20	40
De-oiled MDGS	--	20.0	40.0	--	--
Full Fat MDGS	--	--	--	20.0	40.0
DRC	40.0	--	--	--	--
Corn Stover	55.0	75.0	55.0	75.0	55.0
Fine Ground Corn	1.68	1.68	3.41	1.68	3.41
Limestone	1.19	1.19	1.11	1.19	1.11
Salt	0.30	0.30	0.30	0.30	0.30
Tallow	0.10	0.10	0.10	0.10	0.10
Urea²	1.65	1.65	0.00	1.65	0.00
Rumensin-90³	0.01	0.01	0.01	0.01	0.01
Trace Mineral Premix⁴	0.05	0.05	0.05	0.05	0.05
Vitamin ADE Premix⁵	0.02	0.02	0.02	0.02	0.02
<i>Diet Composition (% diet DM)</i>					
NDF	48.64	68.10	68.28	59.44	59.80
CP	12.28	16.76	16.18	17.89	16.73
Fat	2.25	2.25	3.45	3.25	5.45
Sulfur	0.12	0.19	0.30	0.18	0.28

¹ MDGS = modified distillers grains plus solubles.

² Urea was added to supplements formulated for control and 20% distillers grain diets to meet metabolizable protein requirements.

³ All diets formulated to provide 200 mg/steer daily of Rumensin.

⁴ Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.

⁵ Premix contained 30,000 IU of Vitamin A, 6,000 IU of Vitamin D, 7.5 IU of Vitamin E per gram.

Table 3. Diet composition of de-oiled or full fat MDGS¹ fed at 20 or 40% to ruminally fistulated steers.

<i>Item</i>	20²		40	
	DO³	FF	DO	FF
De-oiled MDGS	20.0	--	40.0	--
Full fat MDGS	--	20.0	--	40.0
Corn Residue	75.0	75.0	55.0	55.0
Fine Ground Corn	1.68	1.68	3.41	3.41
Limestone	1.19	1.19	1.11	1.11
Salt	0.30	0.30	0.30	0.30
Tallow	0.10	0.10	0.10	0.10
Urea⁴	1.65	1.65	0.00	0.00
Rumensin-90⁵	0.01	0.01	0.01	0.01
Trace Mineral Premix⁶	0.05	0.05	0.05	0.05
Vitamin ADE Premix⁷	0.02	0.02	0.02	0.02
<i>Nutrient Composition</i>				
NDF, %	68.10	68.28	59.44	59.80
CP, %	12.13	11.55	17.89	16.73
Fat, %	2.19	3.15	3.43	5.35
Sulfur, %	0.20	0.19	0.31	0.28

¹ MDGS = modified distillers grains plus solubles

² 20 and 40 = % concentration of MDGS in the diet on DM-basis..

³ DO = de-oiled MDGS, FF = full fat MDGS.

⁴ Urea was added to supplements formulated for 20% distillers grain diets to meet metabolizable protein requirements.

⁵ All diets formulated to provide 200 mg/steer daily Rumensin.

⁶ Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.

⁷ Premix contained 30,000 IU of Vitamin A, 6,000 IU of Vitamin D, 7.5 IU of Vitamin E per gram.

Table 4. Performance of steers fed de-oiled or full fat MDGS¹ at 20 or 40% inclusion in forage-based diets.

	20 % MDGS		40% MDGS		40% DRC	SEM	F-Test	P-values ²		
	DO ³	FF	DO	FF	Control			Conc.	Type	Int
Initial BW, kg	299	300	300	300	299	2	0.98	0.83	0.90	0.58
Ending BW, kg	332 ^a	330 ^a	367 ^c	362 ^{b,c}	350 ^b	5	<0.01	<0.01	0.39	0.64
DMI, kg/d	5.3 ^a	4.9 ^a	6.2 ^b	5.9 ^b	5.9 ^b	0.2	<0.01	<0.01	0.05	0.95
ADG, kg	0.39 ^a	0.35 ^a	0.78 ^c	0.73 ^c	0.60 ^b	0.05	<0.01	<0.01	0.26	0.85
G:F	0.072 ^a	0.071 ^a	0.126 ^c	0.127 ^c	0.102 ^b	0.01	<0.01	<0.01	0.85	0.98

¹ MDGS = modified distillers grains plus solubles; DRC = dry rolled corn.

² Conc. = Main effect of MDGS concentration in the diet; Type = Main effect of de-oiled vs. full fat MDGS; Int = Interaction of MDGS concentration and MDGS type.

³ DO = de-oiled MDGS; FF = full fat MDGS.

^{abc} Within a row, means without a common superscript differ ($P \leq 0.05$).

Table 5. Effects of de-oiled or full fat MDGS¹ fed at 20 or 40% on intake, fecal output, and total tract digestibility of DM, organic matter, and NDF.

<i>Distillers Level</i>	20²		40		SEM	P-values		
<i>Distillers Type</i>	DO³	FF	DO	FF		Conc.	Type⁴	Int
DM								
Intake, kg	6.02	6.64	7.77	7.72	0.51	<0.01	0.27	0.40
Fecal Output, kg	2.82	2.85	3.14	2.94	0.29	0.56	0.73	0.66
Digestibility, %	52.38	56.63	59.99	60.79	2.68	0.08	0.44	0.49
OM								
Intake, kg	5.40	5.95	7.06	6.98	0.46	<0.01	0.20	0.39
Fecal Output, kg	2.23	2.25	2.56	2.37	0.24	0.42	0.69	0.63
Digestibility, %	58.03	61.47	64.04	64.87	2.44	0.13	0.51	0.51
NDF								
Intake, kg	3.92	4.36	4.64	4.62	0.31	0.04	0.16	0.28
Fecal Output, kg	1.78	1.70	1.97	1.87	0.18	0.40	0.61	0.91.
Digestibility, %	53.94	59.35	58.27	57.41	3.00	0.87	0.62	0.25

¹ MDGS = modified distillers grains plus solubles.

² 20 and 40 = % concentration of MDGS in the diet.

² DO = de-oiled, FF = full fat.

³ Conc. = Main effect of MDGS concentration in the diet; Type = Main effect of de-oiled vs. full fat MDGS; Int = Interaction of MDGS concentration and MDGS type.

Table 6. Average, minimum, and maximum ruminal pH value of steers fed de-oiled or full fat MDGS¹.

	Concentration			Type			SEM
	20 ²	40	<i>P</i> -value	De-oiled ³	Full Fat	<i>P</i> -value	
Average pH	6.92	6.75	0.40	6.90	6.78	0.55	0.16
Minimum pH	6.44	6.27	0.32	6.40	6.31	0.58	0.15
Maximum pH	7.43	7.17	0.56	7.49	7.11	0.41	0.37

¹ MDGS = modified distillers grains plus solubles.

² 20 and 40 = % concentration of MDGS in the diet.

³ De-oiled and full fat MDGS.

Chapter III

DE-OILED DISTILLERS GRAINS IN FINISHING CATTLE DIETS

Energy Value of De-oiled Modified Distillers Grains Plus Solubles (MDGS) in Finishing Cattle Diets

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Abstract

Two finishing experiments were conducted to evaluate the effects of feeding de-oiled distillers grains on cattle performance. Exp. 1 utilized 378 calf-fed steers (initial BW = 363 ± 17 kg) fed for 153 d. De-oiled MDGS (7.2% fat) was fed at 0, 15, 30, 45 or 60% (DM-basis). Two additional diets containing full fat (12.0% fat) MDGS from the same plant were fed at 15 or 30% (DM-basis) and analyzed as a separate 2×2 factorial. All treatments had 6 replications. Exp. 2 utilized 320 yearling steers (initial BW = 397 ± 38 kg) fed 128 d. Data were analyzed as 2 separate factorials. The first factorial was a 2×3 factorial with 3 concentrations of de-oiled WDGS in the diet (0, 17.5, or 35%; DM basis) fed with either dry rolled (DRC) or steam flaked (SFC) corn. The other was a 2×2 factorial with two additional diets containing 35% full fat WDGS fed with either DRC or SFC to compare to 35% de-oiled WDGS diets. All treatments had 5 replications. Full fat and de-oiled WDGS were produced at separate plants. In Exp. 1 final BW and ADG increased linearly as de-oiled MDGS was increased in the diet ($P = 0.02$). A linear increase was observed in G:F ($P < 0.01$) as concentration of de-oiled MDGS increased, whereas twelfth-rib fat thickness and marbling increased quadratically ($P \leq 0.01$). In the embedded 2×2 factorial, an interaction existed for G:F at 30% inclusion of MDGS, decreasing the fat content from 12.0% to 7.2% decreased G:F in steers by 3.3% ($P =$

0.07). In Exp. 2 no WDGS concentration by corn processing method interaction existed when evaluating the 2×3 factorial ($P \geq 0.15$). Steers fed DRC had greater DMI compared to steers fed SFC ($P = 0.02$) and similar ADG ($P = 0.23$); however, G:F was improved for steers fed SFC ($P = 0.01$). Increasing the concentration of WDGS in the diet linearly increased final BW, ADG, G:F, HCW and fat depth ($P < 0.01$), whereas marbling scores increased quadratically ($P = 0.01$). No corn processing by WDGS type interactions were observed in the embedded 2 × 2 factorial ($P \geq 0.29$). Fat content of WDGS did not significantly impact G:F ($P = 0.14$); however steers fed full fat WDGS were numerically 3.8% more efficient. Steers fed SFC had greater G:F ($P = 0.05$) than steers fed DRC as expected. Overall, slight decreases in G:F were observed (3.3-3.8%) when removing a portion of oil from distillers grains.

Key words: corn processing, distillers grains, feedlot cattle, fractionation, oil.

Introduction

Traditionally, increasing the concentration of distillers grains plus solubles in finishing feedlot diets causes a linear improvement in G:F (Watson et al., 2014; Bremer et al., 2011). However with ethanol plants currently centrifuging oil from the thin stillage constituent and utilizing this oil in non-ruminant feed sectors or the biodiesel industry, cattle performance may be impacted. Jolly et al., (2014) compared feeding de-oiled (7.2% fat) wet distillers grains plus solubles (WDGS) to full fat (12.4% fat) WDGS at 35, 50, or 60% (DM-basis) concentrations in the diet. Dry matter intake was greater in cattle fed de-oiled WDGS compared with full fat, leading to a 2.6% numerical improvement in G:F. Determining the optimal inclusion of de-oiled distillers grains in finishing diets is yet to be researched.

Corn is processed to improve rumen starch digestibility and thus steer performance (Cooper et al., 2002a, Huntington et al., 1997). As the intensity of corn processing increases, the concentration of full fat distillers grains needed to optimize steer performance (i.e. G:F) decreases (Vander Pol et al., 2008; Corrigan et al., 2009). Whether corn processing interacts with de-oiled distillers grains has not been researched. Thus the objectives of these two studies were: 1) to evaluate the effects of feeding de-oiled MDGS at increasing concentrations in the diet, 2) to determine the optimal concentration of de-oiled WDGS fed with DRC or SFC diets and 3) to determine the feeding value of de-oiled MDGS or WDGS relative to full fat distillers grains plus solubles in beef finishing diets.

Materials and Methods

Exp 1.

Three hundred and seventy-eight cross bred steer calves (initial BW = 363 ± 17 kg) were utilized in a 154-d finishing trial conducted at the University of Nebraska-Lincoln Agricultural Research and Development Center (ARDC) near Mead, NE. All animal use procedures were reviewed and approved by the University of Nebraska Institutional Animal Care and Use Committee. Upon arrival at the feedlot, steers were vaccinated with a modified live viral vaccine (Vista Once SQ, Merck Animal Health, Summit, NJ), injectable endectocide (Cydectin, Zoetis Animal Health, Madison, NJ), and received pour-on dewormer (SafeGuard Pour-On, Merck Animal Health).

Approximately 16 d after initial processing, steers were revaccinated with a modified live viral vaccine (Vista 5, Merck Animal Health) and a pinkeye vaccine (Piliguard Pinkeye +7, Merck Animal Health). At this time steers were also treated with an antibiotic (tilmicosin injection; Micotil, Elanco Animal Health, Greenfield, IN). Steers were managed on corn residue for approximately 90-d while being supplemented with 2.27 kg/d (DM-basis) of Sweet Bran until initiation of the trial on January 18, 2013. Five days prior to the start of the trial, steers were limit fed at 2.0% BW a 50% alfalfa hay and 50% Sweet Bran (DM-basis) diet (Watson et al., 2013). Steers were then weighed on two consecutive days to obtain an accurate initial BW (Stock et al., 1983). Using d 0 BW, steers were stratified by BW, blocked into three weight blocks (heavy, medium, or light) and assigned randomly to pens within block. Forty-two pens were assigned randomly to one of 7 treatments with 9 steers per pen. There were 6 replications per treatment with 2 replications per block. Treatments (Table 1) consisted of de-oiled MDGS replacing corn at 0, 15, 30, 45, or 60% of the diet (DM basis). Two additional diets were evaluated where full fat MDGS was fed at 15 or 30% of diet DM to allow for an embedded 2×2

factorial analysis with 15 or 30% de-oiled MDGS. In all diets as distillers grains was added to the ration, the 1:1 blend of HMC and DRC was substituted. Twelve percent corn silage and 5% of a formulated supplement comprised the remainder of all diets (DM basis). Diets containing 0 or 15% distillers grains were supplemented with urea to meet or exceed the ruminally degradable protein (RDP), and thus the MP requirements of the steers (NRC, 1996). Monensin (Rumensin, Elanco Animal Health) and tylosin (Tylan,, Elanco Animal Health) were fed via a supplement at 360 mg/steer and 90 mg/steers daily, respectively.

Steers were implanted with Revalor®-XS (Merck Animal Health) on d 0. On d 154 steers were weighed by pen live and shipped to the commercial abattoir (Greater Omaha Packing Co. Inc., Omaha, NE) where they were harvested the following morning. On the day of harvest, slaughter order, liver, and HCW measurements were recorded. After a 48-chill, camera measurements were collected for LM area, fat depth, and marbling scores. Yield grade was calculated using the USDA YG equation of Boggs and Merckel (1993): $[YG = 2.5 (0.98425 * 12^{\text{th}} \text{ rib fat thickness, cm}) + (0.2 * \% \text{ KPH}) + (0.00837 * \text{HCW, kg}) - (0.0496 * \text{LM area, cm}^2)]$. A standard 2% KPH was used in the yield grade calculation. Final BW, ADG, and G:F were calculated using HCW adjusted to a common dressing percentage of 63%.

Data were analyzed using a GLIMMIX procedure of SAS as a randomized block design with pen as the experimental unit. Linear and quadratic contrasts were conducted on performance and carcass data of steers fed increasing levels of de-oiled MDGS. The model statement included the effect of MDGS concentration on each response variable. This analysis was performed to determine the optimal concentration of de-oiled MDGS to

include in feedlot diets similar to those fed in Exp. 1. The embedded 2×2 factorial was analyzed for oil content (de-oiled vs. full fat) by MDGS concentrations (15% vs. 30%) interactions. The model statement included the effect of MDGS concentration and oil content for each response variable. Pair-wise comparisons were made for distillers grain oil content within 15% and 30% inclusions if the interaction was significant. This analysis was conducted to determine performance and carcass characteristic differences between steers fed de-oiled and full fat MDGS at low diet concentrations (15%) and at concentrations commonly utilized in feedlot currently (30%). The prevalence of liver abscesses due to treatment were first totaled on a per pen basis, and then averaged across treatments prior to being analyzed in similar method as was conducted on the other performance and carcass data measurements.

The feeding value of de-oiled MDGS relative to full fat MDGS was calculated as the difference between the G:F observed for de-oiled MDGS and full fat MDGS divided by the G:F value of the full fat MDGS diet. This value was then divided by the proportion of MDGS in the corresponding diet. This value plus one, and multiplied by 100, gives feeding value relative to the DRC and HMC blend replaced (Bremer et al., 2011 and Klopfenstein et al., 2008). The feeding value of increasing concentrations of de-oiled MDGS was also calculated. This calculation was performed by taking the G:F value of the respective diet containing de-oiled MDGS, subtracting the G:F of the 0% MDGS diet (control), dividing this number by the G:F of the respective MDGS diets, and then finally dividing that number by the concentration of MDGS in the diet. This value plus one and multiplied by 100 gives the feeding value of the diet relative to the control. Treatment NEm and NEg values were also calculated, using equations found in the 1996

NRC, on a per pen basis. Inputs for these calculations included: initial shrunk BW, final shrunk BW, target shrunk final weight, DMI, and ADG. These calculated energy values were also analyzed using the GLIMMIX procedure of SAS by pen to determine treatment averages. The model statement calculated treatment averages for type by level interactions within block.

Exp 2.

Three hundred and twenty yearling steers (initial BW = 398 ± 39 kg) were utilized in a 128-d finishing study conducted at the Panhandle Research and Extension Center (PREC) research feedlot near Mitchell, NE. All animal use procedures were reviewed and approved by the University of Nebraska Institutional Animal Care and Use Committee. Upon arrival, steers were vaccinated with a modified-live vaccine (Express 5-way, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MI), Clostridium Chauvoei-Septicum-Novyi-Sordellii-Perfringens Types C&D-Haemophilus Somnus Bacterin-Toxoid injectable (Vision 7 with somnus, Merck Animal Health, Baton Rouge, LA), a pour-on parasitic (Ivomec Pour-on, Merial LTC, Duluth, GA), tagged, and branded. Prior to the start of the trial, cattle were limit fed at 2.0% of BW a diet consisting of 15% wheat straw, 35% corn silage and 50% WDGS for 5-d to minimize the effect of gut fill (Watson et al., 2013). Steers were weighed on d 0 and d 1 after the limit feeding period and these weights were averaged for an accurate initial BW (Stock et al., 1983). Using d 0 BW, steers were blocked into three weight blocks (heavy, medium, or light) and then assigned randomly to pen within block. There were 40 total pens with 8 head assigned to each pen. Pens within block were assigned randomly to one of eight treatments (Table 2) allowing for 5 replications per treatment.

Treatments were organized in a $2 \times 3 + 2$ factorial arrangement (Table 2) with factors being corn processing method of DRC or SFC [flake density targeted at 0.360 kg/L (28 lb/bu)] and concentration of de-oiled WDGS in the diet of 0, 17.5, or 35% on a DM-basis. Steam flaked corn was processed at and purchased from a commercial yard near the research feedlot and received 3 times a week when steers were on their finishing rations. Two additional diets containing more fat were fed at 35% of the diet (DM-basis). These additional diets allowed for the analysis of an embedded 2×2 factorial with factors of corn processing method (DRC vs. SFC) and (full fat vs. de-oiled) WDGS fed at 35% of the diet (DM-basis). The remainder of all diets consisted of 15% corn silage, and 6% supplement with increasing concentrations of WDGS replacing corn, urea, and soybean meal. Urea and soybean meal were added to diets containing 0 or 17.5% WDGS to meet or exceed the MP requirements of the steers (NRC, 1996). Monensin (Rumensin, Elanco Animal Health) and tylosin (Tylan, Elanco Animal Health) were fed with a micromachine at 360 mg/steer and 90 mg/steer daily, respectively. Full fat WDGS was received from *Renova Energy* in Torrington, Wyoming and de-oiled WDGS was received from *Bridgeport Ethanol* in Bridgeport, NE every 10-14 d during the experiment.

Steers were implanted on d 1 with Revalor-XS (Merck Animal Health). On d 109, the heavy BW block was shipped to a commercial abattoir (Cargill Meat Solutions, Fort Morgan, CO) for harvest. The medium and light blocks were shipped to the same plant on d 128. Hot carcass weights and liver scores were collected on the day of harvest and after a 48-h chill the LM area, fat thickness, and marbling score data. Yield grade was calculated similar to Exp. 1 except that KPH was called by Diamond T carcass data collection services (Yuma, CO).

Data were analyzed using the GLIMMIX procedure of SAS with pen as the experimental unit. The model statement for the 2×3 factorial included corn processing type by de-oiled distillers grains concentration interactions for each response variable. No interaction between corn processing method and concentration of de-oiled WDGS was detected ($P \geq 0.15$), thus linear and quadratic contrasts were used to evaluate the effect of concentration of de-oiled WDGS in the diet on performance and carcass characteristics. A model statement including the interaction between WDGS oil content (de-oiled vs. full fat) of distillers grains and corn processing method was utilized for the analysis of the embedded 2×2 factorial with significance declared at ($P \leq 0.05$). The prevalence of liver abscesses per treatment was determined using the GLIMMIX procedure of SAS for all treatments analyzed in this experiment. Prevalence of liver abscesses was determined on a per pen basis and then averaged across treatments with the interactions analyzed in both the 2×3 factorial and the 2×2 factorial model statements. In the 2×3 factorial, the prevalence of an interaction between WDGS diet concentration and corn processing method was not significant in the number of liver abscesses was not present, thus a binomial analysis for liver abscesses based on increasing concentrations of de-oiled WDGS was also conducted.

The feeding value of increasing concentrations of de-oiled WDGS in comparison to both DRC and SFC controls was calculated (Bremer et al., 2011; Klopfenstein et al., 2008) using similar calculations as those described in Exp. 1. Treatment NEm and NEg values were also calculated, using equations similar to those utilized in Exp. 1, on a per pen basis. These energy values were also analyzed using the GLIMMIX procedure of SAS by pen to determine treatment averages.

Results and Discussion

Exp1.

De-oiled MDGS were 45.3% DM, 7.2% fat, 35.5% CP, 37.5% NDF, and 0.63% S. Full fat MDGS was 47.8% DM, 12.0% fat, 32.6% CP, 38.4% NDF, and 0.57% S. Buckner et al., (2011) found that average CP for 6 Nebraska ethanol plants ranged from 31.0-32.2%. The authors reported that S ranged from 0.71-0.84% across the 6 ethanol plants that were sampled. In a 5 year study by Belyea et al., (2004), nutrient values of distillers grains were 31.3% CP and 11.9% fat. When Benton et al. (2010) reviewed numerous published articles to summarize the nutrient composition of distillers, the authors found that the average nutrient composition for distillers grains was 31.5% CP, 10.5% fat, 43.2% NDF, and 0.57% S. Both full fat and de-oiled MDGS in Exp. 1 had similar nutrient values in respect to DM, CP, NDF, and S contents as has been reported in previous research. Agreeing with our hypothesis the de-oiled product had a lower fat content in comparison to the full fat MDGS variety, thus we were able to determine a performance difference did exist when de-oiled MDGS was fed at 15 and 30% diet concentrations in comparison to full fat MDGS in feedlot diets similar to those fed in Exp. 1. Also, with de-oiled MDGS being fed at increasing diet concentrations, cattle performance from Exp.1 could be compared to what had been previously reported by Bremer et al., (2011) and Watson et al., (2014). With a de-oiled MDGS product, the potential to feed higher concentrations without detrimentally affecting steer feedlot performance is a viable hypothesis.

In Exp. 1 as de-oiled MDGS concentration increased, final BW and ADG increased linearly ($P = 0.02$; Table 3). Dry matter intake was unaffected by increasing MDGS diet concentrations, however due to the linear increase in ADG, G:F increased linearly also as MDGS diet concentration increased ($P < 0.01$). Watson et al., (2014) and Bremer et al., (2011) reported that DMI and ADG increased quadratically ($P < 0.01$) with increasing concentrations of distillers in grains in finishing beef cattle diets. Dry matter intake and ADG were maximized at roughly 30% concentrations of distillers grains (DM-basis) for both performance measurements in these two studies. In both of these studies, G:F also increased linearly as distillers grains diet concentrations increased ($P \leq 0.01$). Increases in G:F continued even at maximal inclusion of distillers grains (Watson et al., (2014) fed MDGS up to 40% of the diet (DM-basis) and Bremer et al., (2011) fed WDGS up to 50% of the diet (DM-basis)). In the current study, both NE_m and NE_g improved linearly with increasing concentrations of de-oiled MDGS ($P = 0.01$). At 15% concentrations of de-oiled MDGS, NE_m for the diet was 1.85 Mcal/kg and this value increased to 1.90 Mcal/kg when de-oiled MDGS diet concentration increased to 60%. Diet NE_g values also increased as de-oiled MDGS diet concentrations increased from 15 to 60% (1.21 and 1.26 Mcal/kg, respectively). The feeding value of MDGS compared to the HMC:DRC control diet decreased with increasing concentrations of MDGS in the diet. At 15% MDGS diet concentrations, the feeding value of distillers grains was 132% that of corn, which decreased to 111% the value of corn as diet concentrations of MDGS increased to 60%. Watson et al., (2014) also reported that as MDGS diet concentrations increased the feeding value of distillers grains decreased from 128% when diet concentrations were 10% (DM-basis) to 117% at 40% MDGS diet

concentrations (DM-basis). Bremer et al., (2011) also reported decreases in feeding value with increasing concentrations of WDGS. The authors reported that WDGS feeding value decreased from 151% to 113% the value of corn when diet concentration increased from 10 to 50% (DM-basis). In this study, it appears that de-oiled MDGS can be fed up to 60% of the diet (DM-basis) and without hindering steer performance, though the feeding value above the control continues to decrease with increasing de-oiled MDGS concentrations.

Hot carcass weight increased as de-oiled MDGS was added to the diet ($P = 0.02$). Longissimus muscle area was not statistically different between treatments ($P \geq 0.17$), however linear increases in 12th-rib fat depth ($P < 0.01$) and marbling scores ($P = 0.05$) were observed as de-oiled MDGS concentration in the diet increased. Linear improvements in 12th-rib fat thickness and marbling scores are likely related to the linear improvements observed for ADG. Watson et al., (2014) observed a tendency for a linear improvement in marbling ($P = 0.10$) and a quadratic increase in fat depth ($P = 0.12$), with calculated yield grade also increasing quadratically ($P = 0.04$) with increasing concentrations of MDGS. In the meta-analysis conducted by Bremer et al., (2011), marbling increased quadratically ($P = 0.05$) and fat depth increased linearly ($P < 0.01$) with increasing MDGS diet concentrations. In Exp. 1 the prevalence of liver abscesses was not different among treatments ($P \geq 0.63$). Yield grade however, did increase linearly with increasing concentrations of de-oiled MDGS in the diet ($P = 0.03$). Steers fed 30% de-oiled MDGS had the highest carcass yield (3.22).

Analysis of the embedded 2×2 factorial showed that no significant differences in final BW, DMI, or ADG were observed in cattle fed either de-oiled or full fat MDGS at

15 or 30% concentrations in the diet ($P \geq 0.26$) A tendency for an interaction between oil content and concentration of MDGS in the diet on G:F (Table 3; $P = 0.07$) was observed. Cattle consuming full fat MDGS diets at 30% inclusion were 3.4% ($P = 0.07$) more efficient than their de-oiled MDGS counterparts. No differences in G:F were observed when comparing de-oiled to full fat MDGS at 15 or 30% concentrations. However, numerically, cattle fed full fat MDGS at 30% (DM-basis) were 3.3% more efficient than steers fed 30% de-oiled MDGS. This numerical difference was not observed at 15% concentrations of de-oiled or full fat MDGS. Jolly et al., (2013) reported that DMI decreased linearly with increasing concentrations of both de-oiled and full fat WDGS ($P < 0.01$), otherwise no other interactions between WDGS fat content and WDGS concentration existed. For the main effect of WDGS oil content, Jolly et al, (2013) reported that ADG was greater for cattle fed de-oiled WDGS diets ($P < 0.01$) compared to cattle fed full fat WDGS. In the current study, the NE_m and NE_g values calculated for the treatment diets had a tendency to be greater for the full fat MDGS diets ($P = 0.12$, and $P = 0.10$, respectively) compared to the de-oiled MDGS diet. At 30% concentration of MDGS in the diet, NE_m of the diet tended to be greater in the full fat diet compared to the de-oiled diet ($P = 0.06$), and NE_g values were greater in the full fat diet compared to the de-oiled diet. No differences in NE_m and NE_g were observed between full fat and de-oiled diets fed at 15% concentrations of MDGS in the diet ($P \geq 0.73$). At 15% MDGS concentrations, de-oiled MDGS had 109% the feeding value of full fat MDGS, but when MDGS concentration increased to 30%, the feeding value of de-oiled MDGS decreased to 89% the value of full fat MDGS.

When comparing the carcass characteristics of cattle fed either 15 or 30% de-oiled vs. full fat MDGS, HCW, LM area, fat depth, marbling score, yield grade, and liver abscess prevalence did not differ ($P > 0.26$) in Exp. 1. No difference in carcass characteristics in Exp. 1 is similar to what Jolly et al., (2013) observed when comparing de-oiled MDGS to full fat MDGS when included at 40% (DM-basis) of the diet ($P > 0.44$).

The results of this study suggest increasing the inclusion of de-oiled MDGS in a beef feedlot diet improves G:F similar to previous work with full fat MDGS (Watson et al., 2014). Impacts of oil removal appear to be dependent upon dietary inclusion. In this study no significant differences were observed when de-oiled or full fat MDGS was fed at 15% of the diet, which may be difficult to detect due to low inclusions. When the concentration of MDGS increased to 30% in the diet, cattle consuming full fat MDGS diets were 3.4% more efficient.

Exp 2.

No WDGS concentration by corn processing method interaction was observed when evaluating the 2×3 factorial (Table 5, $P \geq 0.15$). Lack of an interaction between corn processing method (DRC vs. SFC) and WDGS diet concentration agrees with studies conducted by Buttrey et al., (2012) and Luebbe et al., (2011). Buttrey et al., (2012) looked at the interaction of corn processing when WDGS was included in the diet at 0 or 22% (DM-basis); whereas Luebbe et al., (2011) looked at low concentrations (15%) and also greater diet concentrations (30, 45, and 60%, DM-basis) when studying its interactions with either DRC or SFC. The lack of an interaction in Exp. 2 differs from what Corrigan et al., (2009) reported, however. These authors reported that final BW,

and ADG increased linearly in DRC diets ($P < 0.01$), and quadratically in SFC diets ($P < 0.05$) with increasing WDGS inclusion. The authors also reported that G:F improved linearly in DRC diets ($P < 0.01$) with increasing concentrations of WDGS in the diet, but no such improvements in G:F were reported for SFC fed cattle. Nichols et al., (2012) fed 0 or 35% WDGS (DM-basis) with increasing concentrations of a SFC:DRC blend (0:100, 25:75, 50:50, 75:25, and 100:0) and reported a significant interaction for G:F ($P = 0.03$). When 0% WDGS were included cattle fed 100% SFC diets were 11.2% more efficient than cattle fed 0% WDGS and 100% DRC diets. When WDGS diet concentration increased to 35% (DM-basis) the improvement in efficiency seen in SFC cattle decreased to 2.1% compared to cattle fed 35% WDGS and 100% DRC. Though in Exp. 2 no statistical interaction for G:F can be reported, biologically there appears to an interaction. More replications in this trial may have yielded the interaction that biology is pointing to.

In Exp. 2 the main effect of corn processing method illustrated that steers fed DRC had greater DMI ($P = 0.02$) and similar ADG ($P = 0.23$) compared to steers consuming SFC diets. Luebke et al., (2012) reported that when 0% WDGS were fed with SFC and DRC, DMI tended to be greater in DRC fed cattle compared to those fed SFC ($P = 0.06$). In Exp. 2, G:F was improved in steers fed SFC ($P = 0.01$) over DRC diets whether WDGS was fed or not. When comparing the control diets of each corn processing method (0% WDGS diets with either DRC or SFC), a 10.2% improvement in G:F was observed in cattle fed SFC over DRC. This improvement in G:F agrees with previous research, (Nichols et al., 2012) where the difference in G:F between corn processing methods was 10.0%. Luebke et al., (2012) reported an 11.1% improvement in G:F in SFC fed cattle compared to DRC fed cattle ($P < 0.01$). Observations in Exp. 2 due

to corn processing are similar to what Owens et al., (1997) found in their meta-analysis. The authors reported that when intensity of corn processing increased, DMI decreased, gains were similar between DRC and SFC fed cattle, and cattle consuming SFC were more efficient than those fed DRC. Zinn et al., (2002) reported an even steeper increase in the feeding value of SFC over DRC of 118%. In Exp. 2, steers fed SFC had greater marbling scores than those fed DRC diets ($P = 0.03$) and there was a tendency for cattle in SFC treatments to have a higher prevalence of liver abscesses (Table 5).

Increasing the concentration of WDGS in either the SFC or DRC diets resulted in a linear improvement in final BW and ADG ($P < 0.01$). Again these observations are similar to what has been reported in other numerous research trials (Bremer et al., 2011, Watson et al., 2014, and Benson et al., 2011). In Exp. 2, no differences in DMI were observed with increasing concentrations of WDGS in the diet ($P = 0.68$). No difference in DMI, along with greater ADG with increasing concentrations of WDGS resulted in a linear increase in G:F with increasing WDGS diet concentrations ($P < 0.01$). Luebke et al., (2012) reported that in SFC diets, DMI responded quadratically with increasing WDGS concentrations ($P < 0.01$) and steers fed 15 and 30% WDGS had the greatest DMI. Luebke et al., (2012) also reported that final BW and ADG linearly decreased ($P \leq 0.05$) with increasing WDGS diet concentrations in SFC diets, thus G:F linearly decreased with increasing WDGS concentrations ($P < 0.01$). In Exp. 2, diet NE_m and NE_g diet values linearly increased as WDGS diet concentration increased ($P < 0.01$). Luebke et al., (2012) reported that diets containing SFC had significantly greater NE_m and NE_g values compared to DRC diets ($P < 0.01$) in their study. In the current study, HCW, fat depth, and yield grade linearly increased with increasing concentrations of

WDGS ($P < 0.01$). Luebke et al., (2012) reported no differences in marbling ($P \geq 0.48$), but observed higher NE_m and NE_g values in SFC over DRC diets. Final BW, HCW, LM area, and fat depth ($P \geq 0.21$) did not differ between steers fed DRC or SFC diets in Exp. 2 whereas Luebke et al., (2012) observed significant increases in final BW, HCW, and fat depth in SFC fed cattle over those consuming DRC diets.

In Exp. 2, for the main effect of concentration of WDGS in the diet, a linear increase in final BW, ADG, HCW and fat depth ($P < 0.01$) was observed as WDGS concentration in the diet increased (Table 5). Similar observations were reported by Watson et al., (2014) and Bremer et al., (2011) however, they observed a quadratic increase in ADG rather than a linear one. Furthermore, a linear improvement in G:F was detected as the concentration of WDGS in the diet increased ($P < 0.01$) similar to what Bremer et al., (2011) and Watson et al., (2014) reported for feed efficiency. In Exp. 2, increasing the concentration of WDGS from 0 to 17.5% caused a 5.2% improvement in G:F and increasing the concentration of WDGS from 17.5 to 35% caused a 3.5% improvement in G:F. In the current study when WDGS was added to DRC diets, the feeding value was 154% that of the DRC control diet when WDGS were included at 17.5% and decreased to 140% that of the control as WDGS diet concentration increased to 35%. When WDGS was added to SFC diets, the feeding value was 116% that of the SFC control diet when WDGS was included at 17.5% and decreased slightly to 114% the feeding value of the control when WDGS diet concentration increased to 35%. Bremer et al., (2011) and Watson et al., (2014) also reported that the feeding value of WDGS in comparison to corn decreased as distillers grain concentrations increased. Bremer et al., (2011) reported that the feeding value decreased from 150 to 113% the value of corn as

WDGS diet concentration increased from 10 to 50% (DM-basis) and Watson et al., (2014) reported that feeding value decreased from 132 to 111% as MDGS diet concentration increased from 10 to 40% of the diet (DM-basis). In the current experiment, a linear increase in NE_m and NE_g for both DRC and SFC diets was observed as de-oiled WDGS was added to the diet ($P < 0.01$). Marbling scores increased quadratically ($P = 0.01$) with increasing concentrations of WDGS. Cattle fed 17.5% de-oiled WDGS had the greatest marbling scores. Again, Watson et al., (2014) observed a tendency for a linear improvement in marbling ($P = 0.10$) and a quadratic increase in fat depth ($P = 0.12$), with calculated yield grade also increasing quadratically ($P = 0.04$) with increasing concentrations of MDGS. In the meta-analysis conducted by Bremer et al., (2011), marbling increased quadratically ($P = 0.05$) and fat depth increased linearly ($P < 0.01$) with increasing MDGS diet concentrations.

In the embedded 2×2 factorial (Table 6), which compared de-oiled WDGS (7.9% fat content) to full fat WDGS (11.3% fat) fed at 35%, there were no corn processing method by WDGS fat content interactions ($P \geq 0.15$). For the main effect of WDGS fat content, steers tended to have greater final BW ($P = 0.12$) if they were fed full fat WDGS over de-oiled WDGS. Dry matter intake also tended ($P = 0.12$) to be greater in de-oiled WDGS diets. Fat content of WDGS did not significantly impact G:F ($P = 0.14$), which is similar to what Jolly et al., (2013) observed, however cattle fed full fat WDGS in Exp. 2 were 2.7% more efficient than their de-oiled WDGS counterparts in DRC diets and numerically 5.2% more efficient in SFC-based diets. There was a tendency for cattle consuming full fat WDGS diets to have greater final BW, HCW, DMI ($P = 0.12$), and marbling scores ($P = 0.11$) compared to cattle consuming de-oiled

WDGS diets. Average daily gain, LM area, and fat depth ($P \geq 0.18$) did not significantly differ between WDGS types, whereas Jolly et al., (2013) reported that ADG was greater in cattle fed de-oiled WDGS diets compared to those fed full fat WDGS. In Exp. 2, there was a tendency for the full fat WDGS diet to have a greater NE_m value compared to the de-oiled WDGS diet ($P = 0.06$), conversely the calculated NE_g value for the full fat WDGS diet was significantly greater than for de-oiled WDGS diet ($P = 0.03$).

Just as Owens et al., (1997) reported, the main effect of corn processing method (for the 2×2 in Exp. 2) showed that steers fed SFC had improved G:F ($P = 0.05$) compared to those fed DRC. No differences in final BW, ADG, HCW, LM area, fat depth, or marbling scores ($P \geq 0.26$) were observed when comparing SFC and DRC diets, however DMI did differ as steers fed DRC consumed more feed than did SFC fed cattle ($P < 0.05$). In DRC diets, the feeding value of de-oiled WDGS was 92% the value of full fat WDGS; whereas in SFC diets, the feeding value of de-oiled WDGS decreased to 85% the value of full fat WDGS.

This study suggests that increasing the concentration of de-oiled WDGS in the diet while feeding either SFC or DRC improves G:F. As concentration of WDGS in both the DRC and SFC diets increased, so did G:F. Traditionally, as intensity of corn processing increases, the concentration of distillers grains in the diet should decrease due to the negative associative affect that is apparent between corn processing intensity and increasing concentrations of WDGS (Corrigan et al., 2009 and Nichols et al., (2012). As the concentration of WDGS was capped at 35% on DM basis, the effects of high fat or sulfur content that could be inhibiting performance in SFC fed cattle was not observed (Luebbe et al., 2012). Removing a portion of the oil, via centrifugation of the thin

stillage, did not significantly impact G:F in this study. Feeding full fat WDGS, however, numerically improved G:F by 4.0% suggesting oil removal may have a small effect on the energy value of WDGS and subsequently on the effects of feed efficiency in finishing cattle.

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Table 1. Dietary treatments evaluating the effect of de-oiled MDGS¹ being increasingly added to the diet in Exp. 1.

MDGS Concentration	De-oiled MDGS (%, DM Basis)					Full Fat MDGS (%, DM Basis)	
	0 ³	15	30	45	60	15	30
Ingredient							
De-oiled MDGS	0.00	15.0	30.0	45.0	60.0	--	--
Full Fat MDGS	--	--	--	--	--	15.0	30.0
Corn Silage	12.00	12.0	12.0	12.0	12.0	12.0	12.0
High Moisture Corn	41.50	34.0	26.5	19.0	11.5	34.0	26.5
Dry Rolled Corn	41.50	34.0	26.5	19.0	11.5	34.0	26.5
Supplement²							
Fine Ground Corn	0.70	2.18	2.60	2.60	2.60	2.18	2.60
Limestone	1.74	1.72	1.89	1.89	1.89	1.72	1.89
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Urea	1.68	0.38	--	--	--	0.38	--
Tallow	0.01	0.13	0.13	0.13	0.13	0.13	0.13
Rumensin-90	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Tylan-40	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Potassium Chloride	0.48	0.20	--	--	--	0.20	--
Trace Mineral	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin A,D,E	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Dietary Composition, %							
NDF	12.50	19.97	21.43	25.89	30.35	17.18	21.70
CP	13.18	13.55	16.51	20.53	24.56	12.05	15.63
Fat	3.24	3.78	4.32	4.86	5.40	4.50	5.76
S	0.15	0.21	0.29	0.36	0.43	0.20	0.29

¹ MDGS = modified distillers plus solubles for both de-oiled and full fat varieties.

² Formulated to provide 360 mg/hd/d or Rumensin® and 90 mg/hd/d Tylan® in supplement.

³ Urea was included in diets containing 0 and 15% MDGS diets to meet the MP requirements of the steers.

Table 2. Dietary treatments evaluating the effect of de-oiled WDGS¹ being increasingly added to SFC² or DRC diets in Exp. 2.

De-oiled WDGS	SFC				DRC			
	0	17.5	35	35 ³	0	17.5	35	35 ³
<i>Inclusion</i>								
SFC	74.44	60.75	44.0	44.0	--	--	--	--
DRC	--	--	--	--	74.44	60.75	44.0	44.0
De-oiled WDGS	0.00	17.50	35.00	--	0.00	17.50	35.00	--
Full fat WDGS	--	--	--	35.00	--	--	--	35.00
Corn Silage	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Soybean Meal ⁴	3.56	0.10	--	--	3.56	0.10	--	--
Urea	1.00	0.65	--	--	1.00	0.65	--	--
<i>Supplement^{5,6,7}</i>								
Potassium Chloride	0.30	--	--	--	0.30	--	--	--
Limestone	1.69	1.66	1.68	1.68	1.69	1.66	1.68	1.68
<i>Dietary Composition</i>								
CP, %	12.39	14.07	16.36	15.45	12.39	14.07	16.36	15.45
Fat, %	2.67	3.57	4.43	5.62	2.67	3.57	4.43	5.62
Ca, %	0.63	0.62	0.63	0.63	0.63	0.62	0.63	0.63
P, %	0.24	0.34	0.46	0.46	0.24	0.34	0.46	0.46
Mg, %	0.12	0.16	0.20	0.20	0.12	0.16	0.20	0.20
K, %	0.63	0.54	0.68	0.70	0.63	0.54	0.68	0.70
S, %	0.10	0.18	0.26	0.20	0.10	0.18	0.26	0.20
Na, %	0.0014	0.0349	0.0697	0.0949	0.0014	0.0349	0.0697	0.0949
Zn, mg/kg	17.45	23.23	36.79	36.79	17.45	23.23	36.79	36.79
Fe, mg/kg	55.26	59.85	68.48	93.30	55.26	59.85	68.48	93.30
Mn, mg/kg	13.58	14.45	16.55	17.25	13.58	14.45	16.55	17.25
Cu, mg/kg	2.89	2.54	3.22	3.23	2.89	2.54	3.22	3.23

¹ WDGS = wet distillers grains plus solubles.

² SFC= steam flaked corn, DRC = dry rolled corn.

³ Full fat WDGS included in diet.

⁴ Soybean meal and urea was added to diets containing 0 or 17.5% WDGS via liquid supplement to meet the MP requirements for steers.

⁵ Supplement added to diet via micromaching to provide 360 mg/steer Rumensin® and 90 mg/steer Tylan®.

⁶ Supplemented formulated to contain, 30 mg/kg Zn, 50 mg/kg Fe, 10 mg/kg Cu, 20 mg/kg Mn, 0.1 mg/kg Co, 0.5 mg/kg I, and 0.1 mg/kg Se.

⁷ Supplement formulated to contain, 10670 IU/kg Vitamin A, 1342 IU/kg Vitamin D, and 77 IU/kg Vitamin E.

Table 3. Performance and carcass data for steers fed increasing inclusions of de-oiled MDGS¹ in Exp. 1.

Item	De-oiled MDGS, % Diet DM					SEM	P-value ²	
	0	15	30	45	60		Lin	Quad
Performance								
Initial BW, kg	360	360	359	359	360	0.5	0.40	0.86
Final BW, kg ³	586	605	604	601	601	6.4	0.02	0.57
DMI, kg/d	10.5	10.9	10.9	10.5	10.5	0.2	0.59	0.32
ADG, kg	1.47	1.60	1.60	1.56	1.58	0.04	0.02	0.57
G:F	0.140	0.147	0.147	0.149	0.150	0.002	<0.01	0.86
Feeding Value,⁴	--	132 %	116 %	113%	111%			
Energy Values⁵								
NE _m , Mcal/kg	1.83	1.85	1.85	1.90	1.90	0.01	<0.01	0.41
NE _g , Mcal/kg	1.19	1.21	1.21	1.26	1.26	0.01	<0.01	0.38
Carcass Characteristics								
HCW, kg	369	381	381	379	379	3.7	0.02	0.57
LM area, cm ²	82.58	83.55	80.84	82.06	82.26	1.35	0.17	0.85
12 th -rib fat, cm	1.24	1.37	1.57	1.47	1.45	0.08	<0.01	0.69
Marbling Score ⁶	490	527	535	523	506	12	0.05	0.17
Yield Grade	2.73 ^a	2.92 ^{ab}	3.22 ^b	2.95 ^{ac}	2.63 ^{ac}	0.17	0.03	0.96
Liver Abscesses, %	12	12	8.9	9.6	13.0	0.27	0.24	0.71

¹ MDGS = modified distillers grains plus solubles.

² Lin = *P*-value for the linear response to de-oiled MDGS inclusion; Quad = *P*-value for the quadratic response to de-oiled MDGS inclusion.

³ Final BW was calculated from HCW using a common dressing percentage of 63%.

⁴ Feeding value of MDGS relative to the HMC:DRC control diet.

⁵ Values calculated by pen, using 1996 NRC equations.

⁶ Marbling Score: 400 = small°, 500 = modest°.

Table 4. Performance, carcass data, and feeding value of comparisons between cattle fed de-oiled and full fat MDGS¹ in Exp. 1.

Item	15% MDGS ¹		30% MDGS ¹		SEM	Int. ³	P-value ²	
	De-oiled	Full Fat	De-oiled	Full Fat			15	30
Performance								
Initial BW, kg	360	359	359	360	0.4	0.37	0.37	0.72
Final BW, kg ⁴	605	596	604	609	6.0	0.26	0.31	0.57
DMI, kg/d	10.9	10.7	10.9	10.7	0.2	0.85	0.37	0.59
ADG, kg	1.60	1.55	1.60	1.63	0.04	0.28	0.32	0.59
G:F	0.147 ^{ab}	0.145 ^a	0.147 ^{ab}	0.152 ^b	0.0009	0.07	0.48	0.07
Net Energy Values⁵								
NE Maintenance, Mcal/kg	1.85	1.85	1.85	1.89	0.003	0.12	0.75	0.06
NE Gain, Mcal/kg	1.21	1.21	1.21	1.26	0.003	0.10	0.73	0.05
Feeding Value⁶	109%	--	89%	--				
Carcass Characteristics								
HCW, kg	381	376	381	383	3.8	0.26	0.30	0.57
LM area, cm ²	83.54	81.81	80.85	80.98	0.10	0.49	0.36	0.95
12 th -rib fat, cm	1.37	1.37	1.32	1.52	0.01	0.92	0.82	0.71
Marbling Score ⁷	527	516	535	525	5	0.97	0.53	0.56
Yield Grade	2.92	2.88	3.22	3.20	0.11	0.63	0.84	0.92
Liver Abscesses, %	12.0	7.4	8.9	7.7	0.03	0.60	0.34	0.83

¹ MDGS = modified distillers grains plus solubles.

² 15 = P-value for pair-wise contrast between de-oiled and full fat MDGS at 15% concentration; 30 = P-value for pair-wise contrast between de-oiled and full fat MDGS at 30% concentration.

³ Int. = P-value for interactions between concentration of MDGS and oil content of MDGS.

⁴ Final BW was calculated from HCW using a common dressing percentage of 63%

⁵ Values calculated by pen, using 1996 NRC equations.

⁶ Feeding Value Calculation = divide treatment G:F value by the full fat MDGS G:F value within each diet concentration, take that value and subtract 1, and then divide by the concentration of de-oiled MDGS in the diet.

⁷ Marbling Score : 400 = small°, 500 = modest °.

Table 5. Effect of corn processing method with increasing concentrations of de-oiled WDGS¹ in the finishing diet.

Item	DRC ²			SFC			SEM	Int.	P-values ³		
	0	17.5	35	0	17.5	35			CPM	Linear	Quadratic
Performance											
Initial BW, kg	389	390	390	388	388	389	1.4	0.80	0.06	0.39	0.94
Final BW, kg ⁴	582	596	605	591	597	606	6.4	0.57	0.37	<0.01	0.84
DMI, kg/d	12.5	12.3	12.3	12.0	12.0	12.2	0.2	0.25	0.02	0.68	0.42
ADG, kg	1.59	1.71	1.78	1.67	1.72	1.79	0.05	0.53	0.23	<0.01	0.84
G:F	0.127	0.139	0.145	0.140	0.144	0.147	0.004	0.15	0.01	<0.01	0.50
Net Energy Values⁵											
NE maintenance, Mcal/kg	1.68	1.76	1.81	1.79	1.81	1.83	0.01	0.25	<0.01	<0.01	0.35
NE gain, Mcal/kg	1.06	1.15	1.17	1.15	1.19	1.19	0.007	0.22	<0.01	<0.01	0.38
Calculated Feeding Value⁶	--	154%	140%	--	116%	114%					
Carcass Characteristics											
HCW, kg	367	376	381	372	376	381	4.1	0.60	0.37	<0.01	0.82
LM area, cm ²	72.9	72.9	72.9	72.9	72.9	73.7	1.3	0.99	0.74	0.77	0.82
Fat depth, cm	1.12	1.19	1.32	1.19	1.27	1.29	0.05	0.53	0.21	<0.01	0.91
Marbling Score ⁷	416	451	425	440	468	446	15	0.94	0.03	0.47	<0.01
Yield grade	3.46	3.62	3.76	3.52	3.68	3.72	0.13	0.86	0.54	<0.01	0.56
Liver abscesses, %	7	16	10	14	18	22	5	0.97	0.10	0.28	0.26

¹ WDGS = wet distillers grains plus solubles.

² DRC = dry rolled corn, SFC = steam flaked corn.

³ CPM = main effect of corn processing method of DRC or SFC, Conc. = main effect of concentration of WDGS in the diet, Linear and Quadratic P-values for the main effect of concentration of WDGS in the diet, Int. = interaction between corn processing method and concentration of WDGS in the diet.

⁴ Calculated from hot carcass weight, adjusted to a common dressing percentage of 63%.

⁵ Values calculated by pen using 1996 NRC equations.

⁶ Feeding Value Calculation = divide treatment G:F value by the 0% WDGS control G:F value within each corn processing method, take that value and subtract 1, and then divide by the concentration of de-oiled WDGS in the diet.

⁷ Marbling Score: 400 = small°, 500 = modest°.

Table 6. Comparing De-oiled and Full Fat WDGS¹ at 35% Concentration in DRC² and SFC diets

Item	DRC		SFC		SEM	Int.	<i>P</i> -values ³	
	De-oiled WDGS	Full Fat WDGS	De-oiled WDGS	Full Fat WDGS			CPM	Type
<i>Performance</i>								
Initial BW, kg	390	390	389	390	0.9	0.86	0.53	0.46
Final BW, kg ⁵	605	610	606	615	5.9	0.69	0.59	0.12
DMI, kg/d	12.3	12.2	12.2	12.0	0.2	0.54	0.26	0.12
ADG kg	1.78	1.81	1.78	1.82	0.05	0.62	0.46	0.18
G:F	0.144	0.148	0.147	0.155	0.006	0.43	0.05	0.14
<i>Net Energy Value⁶</i>								
NE maintenance, Mcal/kg	1.85	1.83	1.83	1.92	0.02	0.15	0.18	0.06
NE gain, Mcal/kg	1.17	1.19	1.19	1.28	0.01	0.18	0.07	0.03
<i>Calculated Feeding Value⁷</i>								
	92%	---	85%	--				
<i>Carcass Characteristics</i>								
HCW, kg.	381	385	381	387	3.6	0.69	0.58	0.12
LM area, cm ²	73.10	73.56	73.36	74.40	1.47	0.80	0.61	0.52
Fat depth, cm	1.32	1.32	1.30	1.37	0.08	0.37	0.52	0.37
Marbling score ⁸	427	462	488	455	18	0.29	0.58	0.11
Yield grade	3.8	3.8	3.7	3.8	0.2	0.58	1.0	0.58
Liver abscesses, %	10.0	22.0	6.0	10.0	4	0.61	0.14	0.06

¹ WDGS = wet distillers grains plus solubles.

² DRC = dry rolled corn, SFC = steam flaked corn.

⁴ CPM = main effect of corn processing method (DRC or SFC), Type = main effect of type of WDGS (de-oiled or full fat fat).

Int. = interaction between corn processing method and WDGS type.

⁵ Calculated from hot carcass weight, adjust to a common dressing percentage of 63%.

⁶ Values calculated by pen using 1996 NRC equations.

⁷ Feeding Value Calculation = divide treatment G:F value by the 0% WDGS control G:F value within each corn processing method, take that value and subtract 1, and then divide by the concentration of de-oiled WDGS in the diet.

⁸ Marbling score: 400 = small°, 500 = modest°.