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EVALUATION OF PROTEIN AND FIBER FROM DISTILLERS GRAINS PLUS SOLUBLES IN FINISHING BEEF CATTLE DIETS

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by

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Four studies were conducted to evaluate the components of distillers grains plus solubles in finishing beef cattle diets. Experiment 1 evaluated the effects of five composites of feedstuffs formulated to be similar in nutrient composition to DDGS on finishing performance of cattle. Experiment 2 evaluated isolating the protein from distillers grains using a feedstuff from the wet milling ethanol industry to determine the impacts of protein on the feeding value of WDGS in finishing performance of cattle. Experiments 3 and 4 evaluated the effects of protein from distillers grains with the diets used in Exp. 2 on site of digestion, ruminal VFA concentration and pH. In Exp. 1, replicating distillers grains plus solubles with proportions of high-protein distiller grains, corn bran, and condensed distillers solubles did not result in similar performance as cattle fed distillers grains plus solubles. Cattle consuming the CaO treated corn stover and byproducts were less efficient than cattle fed the composite with corn bran. Replacing high-protein distillers grains from the composite diet with condensed distillers solubles and corn bran resulted in greater DMI and tended to improve feed efficiency. In Exp. 2, protein made up a large portion of the calculated feeding value of the distillers grains plus solubles. In Exp. 3 and 4, DM and NDF total tract digestibility were greater for protein of distillers grains than for distillers grains plus solubles. Excess protein, from distillers

grains plus solubles, above the animals requirement does serve as an energy source to beef cattle on finishing diets.

Key Words: distillers grains plus solubles, finishing, protein, treated corn stover

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Introduction

In the last decade, ethanol production has increased significantly, which directly correlates to greater distillers grains plus solubles (DGS) production. For every liter of ethanol produced from the dry-grind process, 0.84 kg of DGS is produced (Kim et al., 2010). Increased ethanol production has led to increased demand for corn and utlimately higher corn prices (Watson, 2015). Corn is the primary ingredient in finishing diets, supplying the majority of the energy for ruminant animals (Galyean and Gleghorn, 2001; Vasconcelos and Galyean, 2007). As a result of high corn prices, replacing corn with ethanol byproducts can be economically favorable while still providing energy. Distillers grains included at or below 20% of diet DM are utilized to meet the protein requirements, with greater inclusion levels serving as an energy source. Excess protein used as energy is deaminated in the liver, producing ketone bodies to be used as energy, and urea is excreted (Klopfenstein et al., 2008).

Ethanol plants are always striving to improve efficiency and profitability, which has led to the development of new technologies, especially within the dry-grind processing industry. These technologies improve efficiency have focused on producing more from the same kernel of corn. In the dry-grind process, corn is ground and corn starch is hydrolyzed to sugar and sugar fermented to produce ethanol. The unfermented components included mostly fiber, protein, fat, minerals (Kim et al., 2010). Currently, the germ component of DGS can be further processed to seperate corn oil (Depenbusch et al., 2008). The fiber component may be subjected to cellulosic fermentation yielding additional ethanol and a DGS lower in NDF. The remaining NDF has been reported to be

less digestible and lower in energy relative to fiber from traditional DGS (Lundy et al., 2015). Following cellulosic fermentation, protein can be separated and removed from DGS. Distillers grains plus solubles contains approximately 31% CP (DM basis) and serves as an excellent source of protein (Buckner et al., 2011; Klopfenstein et al., 2008). Depending on the amount of protein removed, the role of DGS as a protein source could change. The combinations of further processing of germ, fiber, and protein may have a significant impact on the use of DGS in ruminant diets in the future.

Ethanol Production

Ethanol can be produced by dry-grind processing, wet milling, or dry milling. Each process yields unique byproducts, therefore it is important to understand each processes' techniques in order to better understand the characteristics of the byproducts.

Dry-Grind Processing

The traditional dry-grind process starts with grinding whole corn and transferring the fine ground corn into a slurry tank to be mixed with process water and thermostable α – amylases to produce a solution called slurry. The thermostable α – amylases gelatinize the corn slurry in a jet cooker, a process called liquefaction. The result is mash which is diluted with thin stillage, acquired by previous batches, prior to fermentation. The corn mash enters the saccharification tank, which hydrolyzes dextrin into glucose by glucoamylase enzyme. The liquid, rich in glucose, is transferred to a fermentation column to be fermented into ethanol by yeast, then distilled and dehydrated into fuel grade ethanol. The remaining product after fermentation is called heavy stillage. This is centrifuged to separate the solids from the liquids. During centrifugation, a large portion of oil is emulsified and ash, for the most part, is soluble so more ends up in the liquid

fraction also known as thin stillage. The solids are distillers wet grains, which contains the highest portion of protein (Liu, 2011). The liquid is evaporated to produce condensed distillers solubles (CDS) and later is combined with distillers wet grains to form wet distillers grains plus solubles (WDGS) which can be dried to produce modified distillers grains plus solubles (MDGS) or dried distillers grains plus solubles (DDGS; Kim et al., 2008b). Nutrient composition of DGS can change based on the amount of thin stillage added to the mash. Protein, oil, and ash contents are much greater in whole stillage than corn, as a result of starch removal, these components can be 3-fold that of corn (Liu, 2011).

Wet Milling

The main purpose of the wet milling industry is to isolate and recover starch to produce high fructose corn syrup, glucose, and ethanol (Rausch and Belyea, 2006). Only #1 and #2 grade corn can be used because most products produced are for human food consumption (Stock et al., 2000). First, corn grain is sifted through screens to remove broken kernels, chaff, pieces of cobs, and any foreign material (U.S. Grain Council, 2012). Then corn is steeped in weak sulfurous dioxide solution for 40-48 h to soften the kernels and cause leaching of solubles from the germ, a process known as degerming. The corn and weak sulfurous acid solution are combined to form steepwater (4-8% solids), which is concentrated by evaporation into heavy steepwater (35-40% solids; Rausch and Belyea, 2006). The corn kernels are ground through a system of hydrocyclones, pressed, and dried to remove the germ fraction from the slurry. The germ is dried and oil is extracted from the germ to produce corn oil. Fiber, which contains pericarp and cell-wall fiber components, is separated by pumping the slurry through a

screen, leaving starch and protein within the slurry. The slurry is centrifuged, removing the protein fraction because it is weighs less than starch. The protein fraction is called gluten, which is then concentrated using gluten thickener, centrifuged and dewatered by vacuum belt filtration and then dried to form corn gluten meal (Rausch and Belyea, 2006; U.S. Grain Council, 2012). The remaining slurry is primarily composed of starch, which is purified to remove residual protein and utilized to produce ethanol with a similar procedure as dry-grind processing ethanol plants (Rausch and Belyea, 2006). The starch may be dried and marketed as-is or used to make corn syrups and sweetners. Some milling plants convert starch to dextrose, which is then fermented to produce ethanol and a byproduct feed called distillers solubles (Stock et al., 2000).

The byproducts from wet milling include steep liquor, corn germ meal, corn gluten feed, corn gluten meal, and distillers solubles. Steep liquor (40-50% DM) can be fed to animals as a liquid protein feed containing 25% CP or added to other byproducts, such as corn gluten feed. Corn germ meal (90% DM) is what remains after oil extraction of the corn germ. It contains 26% CP, 2% fat, and 4% NDF (Rausch and Belyea, 2006). Corn gluten feed is the bran and fibrous portions of the corn kernel that is sold wet or dry. It contains approximately 14-24% CP, 3.5% fat, and 35-48% NDF; however the composition of CGF is variable based on the amount of steep liquor added to the bran (Rausch and Belyea, 2006; Stock, 2000). Thus, CGF does not have a consistent nutrient profile and differs among wet milling plants (Stock, 2000). Corn gluten meal contains 65% CP, 2.5% fat, and 11% NDF and is high in escape protein. The primary use of CGM is in pet food and poultry industries, with very little being added to CGF (Stock, 2000). Distillers solubles from wet milling corn processing comes from the fermentation of

starch, like the dry-grind process, and contains 22% CP, 12% fat, and very little fiber (Rausch and Belyea, 2006; U.S. Grain Council, 2012). However, unlike CDS from dry grind facilities, wet milling distillers solubles contains less fat (Stock et al., 2000).

Many feedlots utilize CGF from the wet milling industry in finishing diets. Stock et al. (2000) summarized several studies performed at the University of Nebraska evaluating CGF in finishing beef cattle diets. Two different wet CGF were evaluated; one containing wet bran and steep (combination of steep liquor and distillers solubles) (WCGF-A) and was 40-42% DM with 15-18% CP (DM basis). The second WCGF contained dry bran, steep (combination of steep liquor and distillers solubles) and germ meal (WCGF-B) and was 60% DM with 20-25% CP (DM basis). When WCGF-A was fed at levels from 20 to 60% (DM basis), the net energy value was estimated to be 1% more than that of corn. When WCGF-B was included at the same inclusion levels, the net energy value was estimated to be 15% more than that of corn. The greater energy value for WCGF-B is attributed to greater DM and CP values and lower NDF values due to more steep and less bran added to WCGF-B. Therefore, it is critical for producers to understand the nutrient content of CGF and understand that they are not all nutritionally equal.

Dry Milling

Dry milling corn processing accounts for only a small fraction of total ethanol produced in the U.S. The process utilizes physical separation of the germ, endosperm, and bran. First, corn is screened to remove foreign material, crop residue, fines, and broken kernels and washed with water to achieve a moisture content of 20-22%, which causes differential swelling and increased resiliency of the germ (Stock et al., 2000).

Germ and bran are separated from the endosperm by an abrading system similar to the degermination in wet milling. However, total separation of corn components from the endosperm is incomplete, leaving residual germ and bran attached to endosperm. These components are removed through aspiration, screening, and other milling techniques. Bran is removed from the germ via aspiration, isolating the germ for oil extraction (Stock et al., 2000). Germ from dry milling contains less oil (26%, DM basis) compared to germ from wet milling (35-40%, DM basis; Rausch and Belyea, 2006). The endosperm is sorted by size to yield large, medium, and fine grits, meals, or flours for breakfast cereals. Livestock feed byproducts include bran, broken corn kernels, deoiled germ, and inseparable components of germ, bran, and endosperm. These materials are combined, dried, and marketed as hominy feed. It contains approximately 57% starch, 11% CP, 25% NDF, and 5% fat (DM basis; Larson et al., 1993; Stock et al., 2000).

Larson et al. (1993) conducted three feeding trials to establish the nutritive value of hominy feed in finishing diets. As hominy feed replaced dry-rolled corn (DRC; 0, 15, 30, 45, 100%, respectively), DM digestibility decreased. However, starch digestibility and NDF digestibility increased as hominy feed inclusion increased. Heifers fed hominy feed with or without fat added at 0, 13.3 (0.67% added fat), 26.7 (1.33% added fat), and 40% (2.0% added fat) of diet DM. There was no interaction with hominy feed inclusion and fat addition. Heifers fed 13.3 or 26.7% hominy feed or hominy feed plus fat consumed more than heifers consuming 0 or 40% diets. Average daily gain and feed efficiency were not different. When hominy feed replaced DRC at 0, 13.3, 26.7, and 40% (DM basis) and fed to steers, DMI was greatest for steers consuming 40% hominy feed. Even though hominy feed contains 20% less starch than corn, it was calculated to be 87%

the energy of corn. Hominy feed can replace corn up to 40% in finishing diets and provide adequate performance.

Partial Fractionation

Partial fractionation is the process of physically separating the 3 main components of a corn kernel; endosperm, germ, and bran before the cooking process. This allows the germ (12% of the kernel), which is not fermentable, to avoid fermentation and be further processed to yield corn oil. Partial fractionation creates a bran stream containing high levels of cellulose, hemicellulose, and lignin which can be combusted for energy use, fermented into cellulosic ethanol, or marketed as a feedstuff **(**Cereal Process Technologies, 2012). In traditional dry milling ethanol production, the entire corn kernel was subjected to fermentation. Distillers grains plus solubles derived from partial fractionation contains less fat and phosphorous but has increased concentration of protein. Front-end fractionation separates the components before fermentation with the goal of increasing ethanol yields, lowering production of by-products that require drying, reducing frequency of cleaning the system to remove oil, and using less energy (U.S. Grains Council, 2012). However, front-end fractionation could not become profitable and has ceased to exist in most current production facilities.

Few studies have reported feeding byproducts from front-end fractionation. Godsey et al. (2010) fed a corn byproduct from the front-end fractionation of endosperm and germ called E-corn, which contains low levels of fat (5.3%) and heat-treated starch. The hypothesis was E-corn will perform similar to dry-rolled corn (DRC) in a finishing diet because previous work showed similar feeding values between E-corn and DRC. Increasing E-corn up to 60% of the diet (DM basis) had greater DMI but no effect on

average daily gain (ADG). Feed efficiency improved for 20 and 60% E-corn inclusion. Marbling, 12th rib fat, and calculated yield grade decreased with inclusion of E-corn, suggesting that E-corn had a lower energy value than DRC. Overall, E-corn can replace conventional dry-rolled corn at 20% of diet (DM basis) and provide similar performance with a slight reduction in carcass quality.

Depenbusch et al. (2008) compared traditional DGS to front-end fractionated DGS utilizing 610 yearling heifers on steam-flaked corn based finishing diets. Traditional DGS (26% CP, 12% crude fat, 26% NDF) was included in the diet at 12.9% DM and partial fractionated DGS (43% CP, 4% crude fat, 23% NDF) was included at 13.5% DM. Performance data showed no difference between traditional DGS and partial fractionated DGS on final BW, ADG, or G:F. Dry matter intake was lower for heifers consuming partial fractionated DGS compared to traditional DGS. Kelzer et al., (2011) individually fed 48 steers DRC control, 35% conventional DDGS or 35% high-protein distillers grains (HPDG; 5.1% fat and 39% CP) finishing diets. Kelzer et al. (2011), similar to Depenbusch et al. (2008), found reduced intakes for steers consuming HPDG compared to corn but no difference with DDGS. These data suggest that feeding partial fractionated DGS will result in similar performance to traditional DGS. Partial fractionated DGS contained 46% less phosphorus than traditional DGS, which could decrease phosphorus excreted. Producers could feed partial fractionated DGS to help waste removal challenges by allowing manure application to occur more frequently allowing more nitrogen application on the same section of land without the over application of phosphorus.

Back-end Fractionation

The main process for removing corn oil is back-end fractionation. Corn oil is extracted from thin stillage via centrifugation following fermentation and distillation before drying occurs (CEPA, 2011). Thin stillage contains approximately 30% of the oil available in the corn, of which most can be recovered by centrifugation (U.S. Grains Council, 2012). An additional washing technique removes another 30% of the corn oil from wet cake. The two techniques combined extract 60 to 70 percent of the corn oil available (CEPA, 2011).

Jolly et at. (2013) compared back-end fractionated DGS in finishing cattle diets. Treatments were : 1) low-fat CCDS (6.0%) at 27% inclusion, 2) normal-fat CCDS (21.1%) at 27% inclusion, 3) low-fat (9.2%) modified distillers grains plus solubles (MDGS) at 40% inclusion, 4) normal-fat (11.8%) MDGS at 40% inclusion in a 1:1 blend of DRC and high-moisture corn (HMC) diets. There were no differences in performance or carcass characteristics between low-fat and normal-fat CCDS and MDGS. This suggests cattle fed low-fat CCDS or MDGS will perform similar to normal-fat CCDS or MDGS. Jolly et al. (2014) also compared low-fat (7.9%) and normal-fat (12.4%) WDGS in finishing cattle diets. Treatments consisted of low-fat and normal-fat WDGS at inclusions of 35, 50, and 65% in a 1:1 blend of DRC and HMC diets. There was no difference in final BW, DMI, ADG, and G:F between low-fat and normal-fat. Likewise, carcass characteristics were not different for oil-extracted compared to normal-fat WDGS.

Bremer et al. (2015) analyzed low-fat (7.2%) MDGS and normal-fat (12%) MDGS at 15 and 30% inclusion in a 1:1 blend of DRC and HMC finishing diets. No

differences were observed between low-fat and normal-fat MDGS for final BW, DMI, ADG, and carcass characteristics. However, normal-fat MDGS at 30% inclusion had a 3.4% improvement in G:F compared to low-fat MDGS.

Advancements in Technology for Dry-Grind Process

In 2004, 7.3 million metric tons of DGS were produced while in 2014, 39 million metric tons were produced (RFA, 2016). The influx in supply led to decreased prices for byproducts and corn (Dale, 2008). In efforts to increase profitability of corn byproducts, the dry-grind industry developed several different pretreatment processes that recycle DGS by utilizing the unfermented sugars remaining after starch fermentation, primarily from fiber. Several different pretreatments options exist including ammonia fiber expansion (AFEX) and liquid hot water (LHW), coupled with the enzymatic hydrolysis which converts polymeric sugars into monomeric (hexose and pentose) sugars utilized by specific microbes (Kim et al., 2008b). Both pretreatment techniques increased the hydrolysis rate of DDGS over non-pretreated material with a result of 90% cellulose to glucose conversion within 24 hours of hydrolysis (Kim et al., 2008b). Virtually all bacteria utilize hexose (i.e. glucose) first and when glucose is limiting the pentose sugars are broken down (Ezeji and Blaschek, 2008). After pretreatment, hydrolysis, and fermentation, the product is called “enhanced DDGS or eDDGS” (Kim et al., 2008b). The nutrient composition of eDDGS varies relative to DDGS with 41.2% and 28.3% crude protein, respectively, 2.88% and 6.52% NDF/ADF, respectively (Perkis et al., 2008). The final result produces more ethanol and leaves behind a byproduct rich in protein (Dale, 2008).

Separating amino acids via protease treatment from DGS will also add value back to the ethanol market for existing ethanol plants. The amino acids derived can be separated and isolated for chemical precursors (Brehmer et al., 2008). Another profit center for ethanol plants is developing advancements in the conventional dry-grind process to obtain higher-valued byproducts. The lack of diversity of marketable byproducts, relative to the wet milling process, makes the dry-grind process more vulnerable to marketing issues (Rausch and Belyea, 2006). This dilemma motivated dry-grinding facilities to develop methods of separating the germ and fiber from corn before fermentation. As a result, quick germ, quick germ quick fiber, and enzymatic dry-grind were developed. These techniques incorporate wet milling technologies to separate and recover the germ, pericarp fiber, and endosperm fiber. Recovery of germ allows extraction of corn oil, for higher-value uses. Recovery of pericarp increases fermentor capacity and provides an enhanced DGS product for nonruminant livestock. Similar to separation of amino acids, enzymatic dry-grinding uses protease and amylase during the incubation step allowing endosperm fiber to be separated (Rausch and Belyea, 2006).

AFEX

Ammonia fiber expansion is a pretreatment technology process that facilitates enzymatic hydrolysis before fermentation. There are many pretreatment processes that exist for enzymatic hydrolysis. Ammonia fiber expansion (or explosion) is not a novel development. For many years AFEX has been used to improve digestibility of crop residues (Dale, 1983). The AFEX process can utilize wet distillers grains or corn stover to produce ethanol in what is called a 2nd generation technology. Corn stover is the residual plant material left after corn grain harvest and a common source of

lignocellulose (Brehmer et al., 2008). As stated previously, current ethanol production occurs with fermentation of only the starch portion of corn. Pretreatment of cellulosic components gives the ethanol industry another option. Without pretreatment, the densely-packed crystalline cellulose is resistant to enzymatic hydrolysis and overall fermentation of cellulose (Brehmer et al., 2008). The processes begins by supplying ammonia under pressure (0.65 – 3.5 MPa) and moderate temperatures (70-150^{o}C) for a short residence time (5-15 min), which allows the ammonia sufficient time to react with the components of WDG. The pressure is rapidly released causing the biomass structure to break apart causing lignin solubilization, hemicellulose hydrolysis, cellulose decrystallization, and increased surface area for an almost complete enzymatic conversion of cellulose and hemicellulose to fermentable sugars (Teymouri et al., 2005). Utilizing WDG instead of DDGS has major effects on hydrolysis, causing reduced yields of sugars and overall ethanol production (Kim et al., 2008b). The reduction in sugar yields can be caused by various factors including inefficient mixing of the slurry due to high viscosity, buildup of glucose and cellobiose that inhibit cellulase activity. During hydrolysis and fermentation, AFEX pretreated WDG hydrolyzes at least 70 – 80% of glucans to glucose. Glucan content of DGS is approximately 18 – 20% which is divided between cellulose (2/3) and residual starch (1/3). The overall results comparing DDGS and WDG shows that ethanol yields per bushel of corn may be increased by 7 – 10% with WDG (Kim et al., 2010). The livestock feed product eDDGS, generated from WDG pretreated by AFEX, contained 50.8% crude protein (CP), 7.2% crude fat, 0.5% NDF/ADF, and 6.0 ash (DM basis; Kim et al., 2008b). This varies dramatically from traditional DDGS according to

Spiehs et al. (2002) which has 30.2% CP, 10.9% crude fat, 8.8% CF, and 5.8% ash. Overall, AFEX can increase ethanol production by 12% (Brehmer et al., 2008).

Controlled pH Liquid Hot-Water

Similar to AFEX, LHW pretreats hemicellulose allowing easier hydrolysis and dissolution of hemicellulose providing more rapid saccharification of insoluble cellulose by cellulase enzymes and improved subsequent enzymatic hydrolysis efficiency (Mosier et al., 2005). The process starts with corn fiber (40% DM) from a Vetter press (VetterTec®) mixing with stillage creating slurry. The protein and lactic acid in stillage buffer the slurry to pH 4.0. Maintaining a pH above 4.0 limits hydrolysis of polysaccharides. Limiting hydrolysis of polysaccharides to monosaccharides is critical because monosaccharide degradation produces furfural and 5-hydroxymethylfurfural, which inhibit the ability of bacteria or yeast to ferment sugars to ethanol (Mosier, 2005). The slurry is heated to 160^{o}C for an average retention time of 20 minutes and then cooled to 100^{o}C. The pretreated slurry is then centrifuged leaving a solid cake (26% DM) and a clear liquid. The result is nearly all the residual starch is solubilized along with 50% of corn fiber dissolved into fermentable sugars (Mosier et al., 2005). Previous research from Kim et al. (2008b) reported the composition of eDDGS from LHW pretreatment of WDG were 94.4% DM, 41.2% CP, 14.7% crude fat, 2.9% NDF/ADF, and 5.3% ash (DM basis). The DDGS used in that study contained 89.6% DM, 28.3% CP, 14.5% crude fat, 6.5% NDF/ADF, and 4.8% ash. Differences in composition of feed corn, processing methods, fermentation efficiency, and extents of process liquid recycle cause the variability in the composition of DDGS (Kim et al., 2008b).

Protein Separation

The removal of protein/amino acids from DGS may impact feedlots use of the corn byproduct. Therefore, it is important to understand the process of amino acid removal and the effects it has on the overall finished product. Polypeptides are broken-down to a few bonds and even to free amino acids by removal and separation via protease enzymes breaking peptide bonds, a mechanism called peptide cleavage or protease digestion (Brehmer, 2008). This process works in conjunction with AFEX and utilizes the solid stream after pretreatment. As a result, the protein content of DDGS still remains high (52.9%) because the fiber portion was reduced which increased the concentration of the remaining components (Brehmer et al., 2008). It is not clear how much protein can be separated. The end product, free amino acids, would be used as precursors for chemical compounds.

If some protein is removed from DGS, its role in ruminant diets, depending on the amount removed, may change. One protein component not often discussed is protein contributions from residual yeast. Han and Liu (2010) sampled DDGS from 3 different plants and reported that yeast contributed 20% of the total protein, with the remaining 80% from corn. Liu (2011) found in the literature at least four methods for estimating yeast contribution towards DGS. However, little research is available on yeast cells from DGS and their contributions to the overall protein quality of DGS. Protein quality and amino acid composition of a feedstuff are important for ruminant and nonruminant animals alike. Both animals require specific amino acids for maintenance and growth. Nonruminant animals depend completely on feed to provide the protein they require. Ruminant animals are unique because they have a microbial population within the rumen.

The microbes utilize some of the amino acids from feed to aid in their own maintenance, growth, and other cellular functions. Some of those microbial cells pass into the abomasum and small intestine, where ruminants can digest and absorb the microbial cells. Therefore, ruminants have 2 sources of protein, feed and microbial cells.

Protein as an Energy Source

When DGS is included and provides MP greater than requirements of the animal, protein in DGS can be utilized as an energy source. The primary protein in DDGS is zein protein (Klopfenstein et al., 2008). Approximately 63% of the protein from DGS is rumen undegradable protein, which contributes to metabolizable protein (MP) and supplies energy, when supplied in excess, to the ruminant animal (Castillo-Lopez et al., 2013). Firkins et al. (1985) performed one of the first finishing trials with WDG as an energy source, feeding 0, 25, and 50% of diet DM. When WDG was included, ADG improved. Cattle consuming 50% WDG gained 1.20 kg/d while corn-control cattle gained 1.08 kg/d. There was no difference in DMI for treatments; however, feed conversion tended to improve with inclusion of WDG in the diet. The authors attributed increased efficiency of WDG as a result of lower likelihood of subacute acidosis and increased fiber digestibility of byproduct diets. Trenkle (1997) also observed a tendency for increased ADG, no difference in DMI, and improved feed efficiency when replacing 20% of corn with WDG. Replacing 40% of the diet DM with WDG decreased feed intake by 10% without affecting ADG, resulting in improved feed efficiency.

Larson et al. (1993) examined WDG in combination with thin stillage, as a source of protein and energy, in efforts to reduce the use of fossil fuels and drying cost associated with DDGS. Concerns of transporting moisture and occurrence of spoilage

limited the amount of WDGS use at the time. The two byproducts were fed in the same ratio (1.68:1 ratio of WDG:thin stillage) as produced by the alcohol plants. In two finishing studies, calf-fed and yearling, cattle fed 5.2, 12.6, or 40% wet distillers byproduct had reduced DMI and improved ADG compared to the corn control. Calf-feds were 2, 6, and 14% more efficient and yearlings were 5, 10, and 20% more efficient, respectively, compared to cattle fed DRC based diets. These data are supported by findings from Ham et al. (1994) that reported improved ADG, not significant but a numerical reduction in DMI, and improved feed efficiency for cattle consuming 40% WDG byproduct compared to corn. Protein content from wet distillers byproducts was lower than estimated (21.9% CP for WDG byproducts), so lower DMI and protein content yielded less metabolizable protein (MP) for the intermediate byproduct (5.2 and 12.6%) diets than the corn-control but still above NRC (1985) requirements. The improvement in ADG was not as a result of CP or MP but from increased energy utilization of the WDG byproducts. The authors attributed this effect to several factors: byproducts contained 3 times more corn oil, addition of residual ethanol to the diet, and increased fiber consumption paired with lower starch availability, similar to Firkins et al. (1985).

More recently, Watson et al. (2014) included WDGS at 0, 10, 20, 30, 40, and 50% inclusion in a 50:50 blend of HMC:DRC-based finishing diets. They reported a quadratic increase in carcass-adjusted final BW as WDGS increased in the diet. A quadratic response was reported for DMI. As inclusion of WDGS increased from 0 to 20%, DMI increased, and as inclusion went from 30 to 50% of the diet, DMI decreased. A similar quadratic response was observed for ADG, as WDGS increased from 0 to 40% gain

increased from 1.66 kg/d to 1.96 kg/d, respectively, and at 50% inclusion of WDGS, ADG decreased. Watson et al. (2014) data agree with Trenkle (1997) and Larson et al. (1993) as discussed previously. Feed efficiency decreased as inclusion of WDGS increased with 40% WDGS having the greatest G:F.

Trenkle (2008) replaced 0, 20, 40, and 60% of DRC with WDGS in finishing diets. Unlike previous studies (Firkins et al., 1985; Larson et al., 1993; Ham et al., 1994; Vander Pol et al., 2006; and Watson et al., 2014), they observed no difference between 0, 20, and 40% inclusion of WDGS for final BW, ADG, DMI, and G:F when fed to steers and heifers. Vander Pol et al. (2009) observed the same response with no difference in final BW, DMI, ADG, and G:F when heifers were fed 0, 20, and 40% WDGS. Few studies have evaluated WDGS at inclusions above 50%; Farlin et al. (1981) had one of the first studies on feeding WDGS as a protein and energy source. They replaced 21.25, 42.50, and 63.75% (DM basis) of corn with WDGS. At 63.75% inclusion of WDGS, cattle had an 11.2% reduction in DMI, similar ADG, and a 10% improvement in G:F relative to the corn-control. Trenkle (2008) reported decreased final BW, DMI, ADG, and poorer G:F when cattle consumed 60% WDGS compared to 0, 20, and 40% WDGS.

Feeding values based on performance results, calculated using the feed efficiency of DGS diet relative to the control diet, and divided by WDGS inclusion, provides an energy estimate of DGS. Larson et al. (1993) suggested that the increased corn oil in DGS accounted for part of the increase in energy relative to corn. Klopfenstein et al. (2008) suggested that RUP and corn oil can only account for 20% increase above corn. Watson et al. (2014) reported feeding values highest at (178%) 10% inclusion of WDGS and declined as inclusion of WDGS increased to 50% WDGS (121%). Conroy et al.

(2016) evaluated the individual components of DGS on growing cattle performance. All diets included 50% hay and with 40% DRC as the control diet. When 40% MDGS replaced 40% DRC, cattle had greater ADG and G:F. The calculated feeding value of MDGS was approximately 118% the value of corn. The isolated protein from MDGS (20% CGM, DM basis) had a calculated feeding value of 134% the value of corn. Oglesbee et al. (2016) observed a similar response when individual components of DGS were fed in finishing diets. Similar to previously discussed studies, the authors reported an improvement in ADG and G:F when 20 or 40% WDGS replaced DRC. The calculated feeding value of WDGS at 40% was 130% the value of corn. When 17.5% CGM was added with 14% corn bran and 3% solvent extracted meal to replicate the protein and fiber of DGS, the feeding value was 121% the value of corn. These data suggest that protein within DGS is a significant portion of the feeding value of the DGS overall.

The effect of corn processing, specifically DRC, HMC, or SFC, can alter cattle performance when feeding DGS. Vander Pol et al. (2008) compared processing methods of corn (whole corn, finely-ground corn, DRC, 1:1 blend of DRC:HMC, HMC, or SFC) in finishing diets containing 30% WDGS (DM basis). The authors reported lower ADG for fine-ground corn and SFC relative to the other processing methods. Average daily gain tended to be greater for cattle fed DRC compared to HMC. All processing methods, except whole corn, had reduced DMI. Cattle consuming HMC were more efficient than cattle fed fine-ground corn, SFC, and whole corn. However, at 30% inclusion of WDGS, cattle fed DRC, DRC:HMC, and HMC had no difference in G:F. There was a tendency for cattle fed DRC to have poorer G:F relative to cattle fed HMC. When WDGS replaced 0, 15, 27.5, and 40% (DM basis) of DRC, HMC, or SFC-based finishing diets, an

interaction of processing by WDGS level was observed for ADG and G:F (Corrigan et al., 2009). Steers fed WDGS in DRC rations had improved final BW and ADG. In HMC and SFC diets, as WDGS inclusion increased, final BW and ADG improved. Cattle fed DRC and HMC improved G:F as WDGS inclusion increased. There were no differences in animal performance as WDGS inclusion increased in SFC diets. In agreement with Vander Pol et al. (2008), DMI decreased for all corn processing methods. Watson et al. (2014) also reported a quadratic decrease in DMI as WDGS concentration increased when feeding a 1:1 blend of DRC:HMC.

Condensed Corn Distillers Solubles

Condensed distillers solubles (CDS), sometimes referenced as syrup, is a liquid product from dry-grind ethanol production. In dry-grind processing, after the alcohol has been distillated and removed, what remains is known as whole stillage. In order to reduce energy costs from drying, whole stillage is centrifuged producing wet grains and thin stillage. Wet grains become the primary component in distiller grains. Thin stillage (5% DM) is condensed through evaporation to form CDS (30% DM; Lardy, 2007; NASEM, 2016). The two fractions are combined to produce dry, modified, or wet distillers grains plus solubles. Wet grains is greater in CP and fiber components, but CDS is greater in fat and minerals (Rausch and Belyea, 2006). Condensed distillers solubles contain approximately 25% CP, the RUP is estimated to be approximately 25 to 30% (% CP), 20% fat, 1.57% P, 0.92% S, and 2.3% NDF (NASEM, 2016). When more of the CDS fraction is added back to the wet grains fraction, then fat, phosphorus, potassium, and sulfur concentrations are increased compared to DG without CDS. In plants producing WDGS, 20% (DM basis) is the average inclusion of CDS added to the wet grains

(Corrigan et al., 2007). Cao et al. (2009) evaluated ratios of DG:CDS at 100:0, 87:13, 73:27, and 60:40 on nutrient digestibility in TMR diets fed to Holstein cows. Distillers byproduct was included in the TMR at 8% DM. Keeping in mind that the experimental diets were formulated for dairy cows, reporting differences between 8% of the diet may be difficult to interpret. However, the authors reported ruminally degradable DM increased as the ratio of CDS increased. A greater CDS:DG ratio can provide more protein available for rumen degradation without inhibiting animal performance. Cao et al. (2009) reported the immediately soluble DM and CP fractions increased as CDS inclusion increased. Rate of DM and CP degradation were not different among CDS treatments. Increasing the CDS fraction increased rumen degradability as the result of a greater soluble DM and CP fractions. Corrigan et al. (2009) observed a similar response with greater ruminal, postruminal, and total tract DM digestibilities when CDS, as a proportion of DDG, increased. Godsey et al. (2009) reported no differences in cattle performance feeding ratios of WDG:CDS at 100:0, 85:15, and 70:30 at 20 and 40% WDGS DM inclusions in finishing diets. In finishing diets, a greater CDS:DG ratio will increase the rumen degradation of the diet with little impact on animal performance.

Trenkle (2003) observed a decrease in DMI as CDS (as an ingredient) inclusion increased from 0 to 8% (DM basis) in DRC-based finishing diets. There were no differences in ADG, G:F, or carcass characteristics among treatments. Trenkle and Pingel (2004) replaced corn grain and supplemental urea with CDS at 0, 4, 8, 12% (DM basis) in DRC-based finishing diets. They reported no differences in performance or carcass characteristics with inclusion of CDS. Pesta et al. (2015) observed reduced DMI as CDS inclusion increased from 0 to 36% in a blend of DRC/HMC-based finishing rations.

Average daily gain increased and G:F improved when CDS supplementation increased. Calculated dietary inclusion of CDS for maximal ADG was 20.8 and greatest G:F at 32.5% (DM basis). Hot carcass weight improved with inclusion of CDS with the greatest HCW observed at 18% inclusion (DM basis). Oglesbee et al. (2016) conducted a finishing trial evaluating the different components of WDGS. When 8% CDS was added to several diets containing different components of DGS, the authors observed greater DMI, ADG, and final BW with CDS addition. These data suggest feeding up to 8% CDS may effectively reduce dietary inclusion of corn and improve performance. The authors suggested that greater levels of CDS inclusion may be acceptable. As Harris et al. (2014) replaced SFC with CDS in finishing diets and observed a decrease in DMI. Average daily gain increased and G:F improved and was greatest for both traits at 27% CDS inclusion. Pesta et al. (2015) evaluated feeding CDS at 0, 7, 14, 21% of diet with 20% MDGS or 20% Synergy (a combination of wet corn gluten feed and MDGS) in finishing diets. A tendency for diet x CDS inclusion interaction was observed for ADG. Cattle fed MDGS had improved ADG with the greatest gain for 14% CDS inclusion (DM basis). There were no differences in ADG were observed when feeding Synergy. Feed efficiency improved with increasing CDS inclusion, regardless of byproduct type. In MDGS diets, HCW increased but Synergy had no effect on HCW. Dry matter intake, regardless of diet, was greatest at 14% CDS and lowest at 21% CDS (DM basis). The authors hypothesized that the depression in DMI and ADG for 21% CDS (DM basis) may be due to high dietary fat (8.8% DM basis) within those diets. The dietary fat supplied from CDS used in this experiment was 18.5% (DM basis). Lardy (2007) suggests that CDS fat content ranges from 9 to 15%. The variability of nutrients in CDS depends upon the ethanol

plants' methods for extraction of fat. Segers et al. (2015) evaluated the effect of fat concentration from CDS in growing diets. Condensed distillers solubles was fed at 0, 10, 19, and 27% with dry-corn gluten feed to provide 45% byproduct from each diet. Compared to DRC-based growing diet, cattle consuming 10% CDS had lower ADG. Increasing CDS had no effect on ADG, DMI, or G:F. Results from a digestion trial using the same diets reported improved DM digestibility as CDS inclusion increased. Fat digestibility increased as inclusion of CDS increased with the greatest digestibility at 19% CDS (DM basis). Corrigan et al. (2009) reported greater ether extract intake and digestibility with DDG containing 22.1% CDS (DM basis). Increased ether extract intake did not affect total tract DM, OM, and NDF digestibility. Greater inclusion of dietary fat, mainly from CDS, did not impact fiber digestibility (Segers et al., 2015). Previous work has reported dietary fat reduced ruminal fiber digestion and limit intake (Kowalczyk et al., 1977; Zinn, 1989; Zinn, 1994; Zinn et al., 2000). Henderson (1973) reported long-chain fatty acids may inhibit some rumen microbes, especially cellulolytic bacteria. Inhibiting primary fiber digesting bacteria could cause more fiber to escape the rumen without degradation. Gilbery et al. (2006) reported increased ruminal OM, NDF, ADF, microbial CP synthesis, and true ruminal CP digestibility with increased CDS supplementation in low-quality forage diets. Therefore, it is possible that fat from DGS may behave differently in the rumen relative to other unsaturated fat supplements and not inhibit fiber digestion in the rumen with inclusions up to 15% (DM basis). Results from Segers et al. (2015) and Gilbery et al. (2006) suggest that CDS supplementation in growing or high forage diets does not negatively affect fiber digestion. CDS supplementation did not perform as well as corn in growing diets (Segers et al., 2015).

When priced competitively to corn, CDS can replace corn and be utilized as an energy source.

Sulfur

During the saccharification process of dry-grind ethanol production, sulfuric acid is used to lower the pH of the slurry to 4.5 to provide the proper environment for conversion of starch to glucose (Kwiatkowski et al., 2006). Additionally, sulfuric acid may be used during cleaning between batches (Vannes et al., 2009). These processes add S to the already 3-fold concentrated DGS relative to corn. The recommended level of dietary S is less than 0.3%, with an upper limit of 0.4% (NRC, 1996). Other than DGS, several other sources of S or sulfate with potential toxicological effects include molasses, elemental S, drinking water, and gypsum or ammonium sulfate. The potential hazard associated with feeding S above the tolerated level is inducing polioencephalomalacia (PEM), a neurologic disorder that causes necrosis of the cerebral cortex (Gould, 1998). Rumen available S is converted to H_2S by rumen microbes. Nichols et al. (2011) observed cattle consuming a wet corn gluten feed (87.5% DM basis) based finishing diet containing 0.46% S had significantly lower H_2S production compared to diets containing similar amounts of S but less wet corn gluten feed (0.0, 37.5, or 44.0%; DM basis). Not all dietary S is available to rumen microbes, particularly S-containing amino acids contained in the rumen undegradable protein (RUP) portion of DGS (NASEM, 2016). According to Church (1988), eructated gases enter the trachea at pressures approximating those occurring in the esophagus during the expulsive phase of eructation and penetrate deeply into the lungs. Inhalation of eructated H_2S causes systemic sulfide absorption causing softening of the gray matter in the brain. Clinical signs of S-induced PEM

include blindness, incoordination, and recumbency with seizures. There are other causes associated with PEM, such as thiamine deficiency, acute lead poisoning, and water deprivation-sodium ion toxicosis (Gould, 1998).

Vanness et al. (2009) compiled data from 4,143 cattle on finishing diets including byproducts and found cattle consuming diets with 0.46% S or below, provided adequate levels of roughage (approximately 6 – 7.5%), had 0.14% risk of S-induced PEM. When diets exceeded 0.56% the occurrence increased considerably to 6%. Other than S-induced PEM, feedlots may notice performance issues when feeding high dietary S. Sarturi et al. (2013) observed reduced DMI in feedlot cattle fed 0.30% of total dietary S compared to 0.20% DM. Uwituze et al. (2011 and 2011b) reported an 11% and 8.9% decrease in DMI from DRC and SFC, respectively, finishing diets containing 30% dry DGS high in S (0.65%) compared to matching diets at a lower S (0.42%) level. Spears et al. (2011) fed varying levels of dietary S (0, 0.15, or 0.30% of DM) by supplementing NH4SO4 in ground corn-based (85% of DM) finishing diets and observed a decrease in DMI for cattle consuming a finishing ration with 0.31 or 0.46% compared to 0% supplemental S. However, in growing diets containing 86% corn silage, Spears et al. (2011) fed concentrations of supplemental S at 0.12, 0.30, and 0.46% and found no difference in DMI. Unfortunately, there were no ruminal parameters measured by Spears et al. (2011) to indicate if H_2S gas production was altered by growing diets and was the reason for similar performance between treatments. Increasing forage in finishing diets may be able mitigate negative effects of greater concentrations of S without impacting performance. Inorganic sources of S (i.e. NH_4SO_4) may not be appropriate to compare against a blend of organic and inorganic S from DGS. Uwituze et al. (2011, 2011b), Spears et al. (2011),

and Sarturi et al. (2013) reported decreased ADG, by approximately 0.20 kg, for diets with greater dietary S (0.30, 0.65, and 0.46% of DM, respectively) with limited effect on feed efficiency. Cattle fed diets greater in dietary S had lesser HCW (Uwituze et al., 2011; Spears et al., 2011; Sarturi et al., 2013) and lesser 12^{th} rib fat (Spears et al., 2011; Sarturi et al., 2013).

A deeper look into the rumen environment by Sarturi et al. (2013) showed a tendency for steers fed finishing diet with 0.55% S to have greater concentration of H_2S in ruminal gas cap compared to steers consuming 0.40% S. Likewise, steers consuming wet DGS had 72% greater H_2S concentration in ruminal gas cap than steers fed dry DGS, which denotes a negative correlation between ADG and H_2S production as S concentration increases in the diet. Ruminal pH increased in steers fed 0.65% S finishing diets, which may be attributed to decreased VFA concentration and greater ruminal ammonia concentrations (Uwituze et al., 2011). Sarturi et al. (2013) reported decreased propionate production for cattle fed 0.30% dietary S, compared to 0.20%, and only slight changes in ruminal pH. Overall, when feeding DGS, it is important to know the S concentration and understand that wet DGS appears to be more easily converted into H_2S and have significant impacts on performance of feedlot cattle.

High levels of S in distillers grains can cause PEM and other metabolic issues. Not all S in distillers grains is treated equally when it comes to hydrogen sulfide production. Sarturi et al. (2013b) studied the effects of organic and inorganic sources of S. Corn gluten meal served as an organic source and ammonium sulfite was fed as inorganic source of S. Wet distillers grains plus solubles was considered a combination of organic and inorganic source of S. In this metabolism trial, S content tended to reduce

intake only when inorganic S was fed. Rumen available S was measured via IVDMD analytical procedure to measure ruminal reduction to sulfide. Both inorganic S and WDGS resulted in greater levels of rumen available S compared to organic sources. Organic S is less available in the rumen because the majority of S is from S containing amino acids, which either escape degradation or are incorporated into rumen microorganisms. Ruminal H_2S gas was collected from the ruminal gas cap, inorganic and WDGS had greater ruminal H_2S gas production compared to organic sources even though an organic S source and WDGS were fed at similar dietary levels of S. The regression equation between ruminal hydrogen sulfide gas concentration and total S intake only explained 29% of the ruminal H_2S variation. While adjusted ruminal protein S and rumen available S accounted for 58 and 65%, respectively, of ruminal H_2S production, these results demonstrate that source of S is more useful than total S in determining H_2S production.

Fiber in High Concentrate Diets

Digestion is defined as the process of physically and chemically breaking down nutrients into substances that can be absorbed. Ruminant animals are able to digest fiber by utilizing a symbiotic relationship with microorganisms. Fiber digestion occurs almost exclusively in the rumen because mammals lack the digestive enzymes to break fiber polymers. Therefore, maximizing ruminal fiber digestion is most energetically efficient because the rumen is the site of fiber digestion (Moore et al., 1990). Optimal concentration and type of roughage in concentrate diets are related to many factors such as availability, price, and interaction with other ingredients in the diet (Hales et al., 2014). In recent years, there has been an increase in the use of alternative roughage sources due

to reduced hay availability and abundance of crop residues. Changing roughage sources can affect various factors in fiber digestion such as extent of digestion, rate of passage, and rate of digestibility. It is important to examine these characteristics of different roughage types before substituting them in concentrate diets.

Roughage plays an important role in high-concentrate diets to help maintain rumen function and prevent ruminal acidosis. Roughage is typically the most expensive ingredient when priced on an energy basis. Forages are difficult ingredient to handle when mixing rations due to its bulky nature. All these factors are important considerations when selecting roughage source and level. According to a survey from Galyean and Gleghorn (2001), consulting nutritionists reported that finishing diets contained 4.5 to 13.5% (DM basis) roughage, with the main sources being alfalfa hay and corn silage. In finishing diets, cattle consume feed to a chemostatic intake. Gut fill rarely limits intake of finishing diets, so when greater levels of roughage are included, the animal typically consumes more feed to maintain similar energy intake. Compensation from increased DMI occurs only until the level of roughage is high enough to impose limitations via gut fill (Galyean and Defoor, 2003).

Using Neutral Detergent Fiber to Evaluate Forage Quality

Neutral detergent fiber is a measurement of cellulose, hemicellulose, and lignin that can be used to evaluate forage quality (Jung and Allen, 1995). Past studies (Theurer et al. 1999; Shain et al. 1999; Defoor et al. 2002) summarized by Galyean and Defoor (2003) have evaluated the effects of substituting roughage type based on NDF concentration and concluded that the substitution of low-quality for high-quality roughage is possible without negatively affecting DMI, ADG, or G:F. The effects of

exchanging roughage on NDF concentration for digestibility characteristics needs further examination. A meta-analysis by Galyean and Defoor (2003) compiled 11 trials to evaluate roughage source and level on DMI by feedlot cattle. The authors reported that DMI, as a % of BW, increased as level of roughage increased. However, the correlation was relatively low ($r^2 = 0.699$) between DMI and roughage level. Using the values provided within the trial or values from the NRC (1996) NDF, eNDF, and NEg were calculated and used for the regression of DMI. Dietary NEg supplied by roughage resulted in small differences in DMI and can be explained by small changes in NEg provided among the data points in the database. High correlations for NDF and eNDF ($r^2 = 0.92$ and $r^2 = 0.931$, respectively) demonstrate that the effects of roughage level on DMI are associated with NDF supplied by roughage in feedlot diets. The greater variation by eNDF were slightly higher than that of NDF suggesting eNDF is a better tool for evaluating roughage source and level. The authors explain that NDF is a more practical choice for feedlots to use when considering different roughage sources. The relationship between NDF from roughage and DMI in finishing diets can be partially explained by lower risk of acidosis. Greater NDF intake per unit of grain might increase or stabilize ruminal pH by lower proportions of fermentable substrate in each bite, as well as stimulate more chewing and saliva secretion. It is unlikely that the inherent buffering capacity of roughages, included at low levels, in finishing diets has much effect on ruminal pH. Another contribution towards more stable ruminal pH might be increased passage rate of the feed. If increasing NDF from roughage increased the passage rate of grains, less fermentation of those grains would occur within the rumen, resulting in a lower acid load and increased DMI (Galyean and Defoor, 2003).

Defoor et al. (2002) determined the effects of dietary NDF supply from roughages on NE_g intake by comparing alfalfa hay, sudan hay, cottonseed hulls, and wheat straw (40, 66, 86, and 80% NDF) in three 4 × 4 Latin squares at 5%, 10%, and 15% of dietary DM. Net energy for gain intake tended to be greater for cottonseed hulls (45.55/kg of $BW^{0.75}$) compared to alfalfa and sudan hay (35.74 and 40.66/kg of $BW^{0.75}$) with no difference between cottonseed hulls and wheat straw. Therefore, roughages with greater NDF concentrations provide more energy at similar DM inclusions. Defoor et al. (2002) also examined three different methods of dietary roughage exchange in a 90% concentrate steam-flaked corn based diet. Cottonseed hulls and sudan silage were compared to alfalfa at 12.5% of dietary DM, equal NDF level, and equal NDF level with particles less than 2.36 mm considered to supply minimal NDF to the diet. NE_g intakes were greater for cottonseed hulls and sudan silage at equal dietary DM inclusion in comparison to alfalfa. This indicates that cottonseed hulls and sudan silage, which are higher in NDF, are required at lesser concentrations in the diet for similar responses to alfalfa. No difference was observed for NE_g intake between cottonseed hulls and alfalfa at equal NDF levels, so the exchange of alfalfa for cottonseed hulls can be made at equal NDF inclusion. Feeding sudan silage showed no difference in NE_g intake compared to alfalfa at equal NDF inclusion excluding particles 2.36 mm or smaller, which indicates that sudan silage is needed at a lower level of NDF for substitution.

A similar study by Quinn et al. (2011) found no difference with in vitro digestibility between alfalfa and coastal bermudagrass at equivalent NDF concentrations, suggesting that at equal NDF concentrations, different roughage sources will not affect digestibility between roughage types. Poore et al. (1991) reported the opposite effect

when including chopped wheat straw and chopped alfalfa hay at equal NDF concentrations of the diet on lactating Holstein cows. Organic matter digestibility was greater for alfalfa than wheat straw (67.2 vs. 63.5%) and NDF digestibility followed a similar pattern (43.5 vs 31.2%). The difference between the experiments is that Poore et al. (1991) matched the NDF concentration of the diet and not of the individual forages. This suggests that NDF composition is different between the overall diet and roughage type in terms of digestibility. Hales et al. (2014) found similar results, reporting that dry matter and organic matter digestibility was reduced for alfalfa hay as inclusion increased within the diet demonstrating that increasing the NDF concentration of the diet will negatively impact digestibility.

Using Dry Matter Inclusion to Evaluate Forage Quality

Another method of exchanging different roughage types is DM concentration. Galyean and Defoor (2003) also compiled previous work (Kreikemeier et al. 1990 and Bartle et al. 1994) evaluating roughage inclusion based on DM concentration. Animal performance was significantly different for high-quality compared to low-quality roughages. However, fiber digestibility was not accounted for in these studies.

Moore et al. (1990) compared the effects of partial exchange of alfalfa hay, cottonseed hulls, and wheat straw (DM basis) on digestibility in a 65% concentrate steam-flaked milo diet. The control diet included alfalfa hay at 35% DM, and cottonseed hulls or wheat straw replaced half of alfalfa hay in the remaining two diets. Dry matter intake was greater for cottonseed hulls compared to alfalfa hay (6.9 and 5.9 kg/d, respectively), and cottonseed hulls had significantly lower DM (74.9%) and NDF (43.9%) digestibility compared to alfalfa hay (80.3 and 56.4% for DM and NDF

digestibility, respectively) and wheat straw (79.4 and 51.6% for DM and NDF digestibility, respectively). Cell solubles digestibility was similar between all three roughage types. In the second experiment by Moore et al. (1990), in situ digestibility of DM and NDF were evaluated on the same diets. Digestibility of cottonseed hulls and wheat straw (41.3 and 53.8%, respectively) tended to be lower than alfalfa hay (80.1%). Likewise, cottonseed hulls and wheat straw had tendencies for reduced NDF digestibility (22.4 and 40.4%) compared to alfalfa hay (61.7%). Despite reduced digestibility, the combination of wheat straw and alfalfa increased DM and NDF digestibility for alfalfa. Increased digestibility for alfalfa is explained as an effect from longer rumen retention time. Total tract digestion of DM and NDF decreased for cottonseed hulls, which agrees with previous work of Moore et al. (1990). The complete or partial substitution, on a DM basis, of alfalfa for cottonseed hulls reduces DM and NDF digestibility.

Moore et al. (1990) reported rumination of wheat straw was greater (14 min/h) compared to the alfalfa hay and cottonseed hulls (10 and 11 min/h). This agrees with Mertens et al. (1997), who summarized several studies that found similar results for oat straw, which required more time for rumination compared to alfalfa (Sudweeks et al., 1979 and Freer et al., 1962). Shain et al. (1999) further analyzed rumination and compared particle size (small or large) of alfalfa hay to wheat straw and corncobs. Rumination time was longer for large particle size wheat straw compared to both alfalfa hay diets. Also, steers spent more time ruminating small particle size wheat straw compared to small particle size alfalfa hay and corncobs. Since all diets were formulated for equal NDF, these results suggest that lower quality roughages increase rumination. According to Cole et al. (1976) altering rumination time causes differences in particle

size and ultimately changes rate of passage. In contrast to this statement, Moore et al. (1990) reported no difference in liquid turnover between wheat straw, alfalfa hay, or cottonseed hulls with different rumination times. Increased rumination did not impact rate of passage. Ruminal pH did not differ between alfalfa hay, cottonseed hulls, and wheat straw (6.0, 6.4, and 6.4, respectively) which supports Weiss and Shockey (1991) who found no difference in ruminal pH between orchardgrass and alfalfa silage.

Ruminal pH was not affected by low-quality roughages at low inclusion levels and should not be a concern when determining roughage source for concentrate diets. Wheat straw and oat straw had noticeable increases in rumination. Theoretically, increasing rumination would trigger a cascade of events including: increased saliva production, reduced particle size, and increased supply of bicarbonate to the rumen and as a result would increase pH, but this was not the case with Moore et al. (1990).

In agreement with the results by Moore et al. (1990), Poore et al. (1991) reported no difference in ruminal passage rate when feeding chopped alfalfa hay or chopped wheat straw, at a particle size of 5 cm, as a proportion of roughage NDF. Liquid passage rate of alfalfa hay was similar to wheat straw. These results agree with Shain et al. (1999), who reported no difference in ruminal passage rate between an all-concentrate diet, alfalfa or wheat straw with small (2.54 cm) particle size, alfalfa or wheat straw with large (12.4 cm) particle size, and corncobs. Alternatively, Hoffman et al. (1998) determined alfalfa silage had a faster rate of passage (4.86%/h) than perennial ryegrass silage (4.05%/h), and dry matter intake was reduced for perennial ryegrass silage. The authors suggested that in high forage diets the rate of passage and feed intake have a direct relationship in which slower passage rates restrict feed intake. Mertens et al. (1980) reported shorter lag time

for alfalfa (0.86 h) compared to coastal bermudagrass (3.05 h). Therefore, alfalfa spent less time in the rumen thereby allowing less time for cellulolytic and other classes of bacteria to break down the β- 1,4 or β- 1,6 bonds of the fiber constituents. It can be concluded when a roughage has increased rate of passage and decreased retention time, digestibility will decrease.

One area of research that most authors agreed upon was the effect of starch on the passage rate of roughages. Most of the papers suggest that starch has limited or no effect on passage rate of the roughage. Eng et al. (1964) agree with this reasoning and state the average rate of passage for roughages is dependent on the amount consumed and remains independent of grain passage rate.

Moore et al. (1990) found rate of digestion, at 96 h of fermentation, was not significantly different between wheat straw, alfalfa hay, and cottonseed hulls, but the combination of alfalfa with wheat straw displayed tendencies to have a faster rate of digestibility. In contrast to these findings, Mertens et al. (1980) found decreased rate of digestion for alfalfa and fescue (6.70 and 6.58%/h, respectively) compared to orchardgrass. Kinser et al. (1988) reported rate of digestion was significantly reduced when rice hulls replaced corncobs in pelleted diets fed to rams. Rice hulls had more grams per day of DM, OM, and NDF flow through the duodenum. Providing evidence that rice hulls are less digestible and are of lower forage value in comparison to corncobs. Ruminal pH was similar for cattle fed both rice hulls and corncobs (5.60 and 5.61) agreeing with Moore et al. (1990) and Weiss and Shockey (1991). Total VFA production was slightly greater for rice hulls (107.3 m*M*) compared to corncobs (101.5 m*M*) but not statistically significant. Poore et al. (1991) also reported VFA production with acetate,

propionate, butyrate, and valerate concentrations greater for alfalfa, but the acetate:propionate ratio was reduced for wheat straw. Shain et al (1999) also reported decreased VFA production for wheat straw. However, acetate:propionate ratio increased numerically for wheat straw diets. This may be due to increased rumination causing more salivation, which creates a dilution affect and increases the pH of the rumen. This increase in pH provides a more favorable environment for the production of acetate over propionate (Sudweeks, 1977; Latham, 1974).

Corn Residue

The increased demand for fuel ethanol led to rising corn price in the past ten years. The response to high corn prices caused more land to be converted from forage production to corn production. It is estimated that from 2006 to 2011, 0.526 million ha of range and pastureland were converted to corn and soybean production from Minnesota, Iowa, North Dakota, South Dakota, and Nebraska (Wright and Wimberly, 2013). With less traditional forage available, alternative forages, such as corn stover, were more easily available and became more common as a forage source with higher corn prices. Corn stover consists of stalk, leaf, cob, and husk components of the corn plant after grain harvest. For every kilogram of corn grain produced, approximately 0.8 kg of aboveground residue can be harvested (Watson et al., 2015). According to USDA-NASS (2016), corn grain production in 2015 was estimated to be 3.45 trillion kg yielding 2.76 trillion kg of corn stover available. Other factors that influence corn stover availability include uses in the ethanol industry for cellulosic fermentation, livestock grazing, and proximity to feedlots (Watson et al., 2015).

Chemical Treatment

Corn stover is usually considered low-quality forage because the plant has reached physiological maturity resulting in low protein content and digestibility (Klopfenstein et al., 1987). At maturity, the corn plant has developed cross-linkages of lignin within the cell wall (Jung and Allen, 1995). Enzymes that breakdown cell wall carbohydrates have limited access to hemicellulose and cellulose due to the lignin cross linkages (Jung and Deetz, 1993). Chemical treatment of corn stover using alkali compounds, sodium, calcium, or ammonium hydroxide, breaks cross linkages between hemicellulose, lignin, and cellulose, as well as disruption of H bonding between cellulose molecules (Klopfenstein et al., 1972; Fahey et al., 1993). These reactions make hemicellulose and cellulose more available for rumen microbial degradation (Klopfenstein, 1978). The improvement in degradation of hemicellulose and cellulose by rumen microorganism improves rate and extent of digestion (Klopfenstein et al., 1987). Several chemicals have been screened in laboratory experiments to treat corn stover. Four primary chemicals used include: sodium hydroxide, ammonium hydroxide, calcium hydroxide, and potassium hydroxide (Klopfenstein, 1978). The practical application of these treatments is impeded by technical, economical, and environmental concerns (Shi et al., 2016).

There have been many studies evaluating the effects of treating forages with alkali compounds. The treatment of forages with NaOH has been practiced for many decades and has reported to improve the feeding value of forages (Sundstøl et al., 1988). Klopfenstein et al. (1972) examined treating corn stover with NaOH at 0, 3, or 5%, and adding water to bring moisture to 50%, then ensiling the residue. Treatments were fed to

lambs in a metabolism trial. Treatment of corn stover at 3 and 5% NaOH increased true organic matter digestibility compared to untreated corn stovers with no difference between 3 and 5% NaOH. *In Vitro* DMD was increased for 3% NaOH treated corn stover compared to untreated corn stover. Five percent NaOH treatment caused a further increase in DMD over 3% NaOH treatment. There were no differences for VFA profiles, rumen ammonia concentrations, and rumen pH between treatments. It should be noted that the authors shared concerns about the level of Na added to the diet by chemical treatment and should be considered when formulating rations. Fahey et al. (1993) summarized 24 studies with NaOH treatment on crop residues. An average improvement of 22% was calculated for DMI and a 30% increase in DM digestibility with NaOH-treated crop residues. Lately, the use of NaOH has decreased due to environmental concerns of Na leaching into the soil and excessive Na intake of the animal (Shi, 2016). Therefore, more attention has been on using weaker bases, such as ammonia and $Ca(OH)_2$, to treated forages.

The mode of action for ammoniation is similar to that of NaOH. However, improvement in the digestibility of roughages treated with ammoniation tends to be lesser compared to NaOH (Fahey et al., 1993). Males (1987) observed an average improvement in IVDMD of 16% with NaOH treatment compared to NH_3-treated straw. Two advantages to NH_3-treated forages, over NaOH treatment, is added N and reduced Na added to the forage (Males, 1987). There is two methods to applying NH_3 to forages. The most common method is dry application and the other method being wet application (Males, 1987). Saenger et al. (1982) performed a feeding and metabolism trial utilizing corn stover treated with anhydrous ammonia (NH_3) at 3% and 2% DM, respectively.

Corn stover bales were treated with NH_3 by covering all bales with plastic and applying NH_3 into the sealed enclosure. Bales remained covered for three weeks and were uncovered one week prior to initiation of trial. Ammoniation increased the crude protein content of corn stover by approximately 7.2 %, which is due to N retention by the corn stover. Cattle consuming treated corn stover had greater DMI than cattle fed non-treated corn stover in both trials. Morris and Mowat (1980) also observed greater intakes of corn stover with ammoniation compared to non-treated corn stover. Fahey et al. (1993) summarized 21 studies using NH_3-treated crop residues and reported an average increase in DMI of 22%. Saenger et al. (1982) observed a 10% increase in DM digestibility for treated corn stover compared to non-treated corn stover. Likewise, Fahey et al. (1993) summarized 32 studies and reported an average increase of 15% in DM digestibility of NH_3-treated crop residues. Oji et al. (1977) found similar results when corn stover was treated with 3 or 5% NH_3 fed to lambs in a metabolism trial. Ammoniated corn stover was reconstituted with 30% moisture and ensiled for at least 30 days. Lambs fed either 3 or 5% NH_3 treated corn stover improved DMI compared to non-treated corn stover with no difference between NH_3 concentration. Likewise, DM digestibility was improved with treatment of corn stover with no difference between 3 or 5% NH_3.

Previously, $Ca(OH)_2$ was believed to be ineffective at improving digestibility (Fahey et al., 1993). However, recent studies have reported the effectiveness of CaO treatment on the digestibility of corn stover (Chapple et al., 2014; Duckworth et al., 2014; Shreck et al., 2015; Shi et al., 2016). Compared with NaOH and ammonia, $Ca(OH)_2$ may be less expensive and safer to handle (Shi, 2016). Duckworth et al. (2014) evaluated the effects of CaO-treated corn stover fed with 40% MDGS (DM basis) on growth

performance, carcass characteristics, and ruminal metabolism in finishing diets. Treating corn stover with 5% CaO (DM basis) and hydrating to 50% DM, included at 20% (DM basis) of the diet, improved DM digestibility but decreased DMI and ADG compared to untreated corn stover. Chapple et al. (2015) fed the same amount of MDGS and corn stover, except that their control contained 5% untreated corn stover. Since control diets were different between the two studies, direct comparison is difficult. Chapple et al. (2015) reported increased apparent NDF and ADF digestibility for treated corn stover. Cattle consuming CaO treated corn stover had decreased DMI and similar ADG compared to untreated corn stover. In addition, Chapple et al. (2015) hydrated all treated corn stover to 50% DM and treated with 5% CaO, 4% CaO plus 1% NaOH, and 3% CaO plus 2% NaOH. There were no differences in digestibility of corn stover between the combinations of CaO and NaOH. Shreck et al. (2015) evaluated CaO treated corn stover in diets containing 40% WDGS on finishing performance and carcass characteristics. Corn stover was treated at 5% (DM basis) with CaO, hydrated to 50% DM, and included in the diet at 20% (DM basis). Cattle consuming treated corn stover had greater ADG, G:F, and final BW compared to untreated corn stover. Shreck et al. (2015) performed a metabolism study with similar diets only corn stover was include at 25% (DM basis) of the diet. Greater DM, OM, and NDF digestibilities were observed for treated corn stover compared to untreated corn stover. Shi et al. (2015) examined various levels of CaO treatment (3, 5, and 7% of dry-corn stover) and various moisture levels (40, 50, and 60%) on digestibility parameters. Treated corn stover improved digestibility compared to untreated corn stover. Corn stover treated with 7% CaO at 60% moisture had the greatest DM, OM, and NDF digestibilities. However, there was no difference between 7% and

5% CaO at 60% moisture. Using 5% CaO treatment, or a combination of CaO and NaOH, will sufficiently improve digestibility. Overall, improved NDF digestibility suggests that CaO treatment of corn stover is effective at solubilizing some carbohydrates.

Pelleting

Another modification to improve the utilization of corn stover is pelleting. The primary advantage of pelleting is that a product is produced which can be easily stored and transported. Typically, corn stover will be treated (i.e. alkali treatment) before the pelleting process. The major disadvantage for pelleting is the cost of collection and transportation of bulky residues prior to treatment and pelleting (Klopfenstein, 1978). Several companies have created pelleted feeds by combining corn stover with DGS or other corn byproducts. Incorporation of these byproducts improves the nutritional composition of the corn stover pellet. Several studies have examined the contributions of these pelleted products in beef cattle diets. Clark et al. (2013) evaluated a pelleted corn stover product, included at 15% (DM basis), as a roughage in finishing diets. The pellet contained 33% corn stover, 33% DDG, and 33% undescribed commodities. It was not reported whether the corn stover was chemically treated. Compared to the corn control, cattle consuming the corn stover pellet had lower ADG, DMI, HCW, 12^{th} rib back fat, and yield grade. Digestive disturbances, such as acidosis and bloat, became an occurring issue and was believed to be caused by lower amounts of effective fiber from the pellet. It is possible that the poor performance observed in this study was partially due to reoccurring digestive disturbances. Sewell et al. (2009) analyzed several forages, including corn stover, wheat straw, switchgrass, and corn fiber:wheat chaff combinations,

treated with 5% (DM basis) CaO and 35% water and pelleted with DDGS. The pelleted product was 75% residue and 25% DDGS (DM basis) and replaced corn in the diet. Like previously discussed, DM, NDF, and ADF digestibility were improved when wheat straw and corn stover were chemically treated and pelleted compared to unprocessed forages. When treated wheat straw pellets were included at 50% (DM basis) of the diet, cattle had improved ADG and G:F compared to conventional wheat straw. When treated wheat straw pellets replaced corn, cattle had similar ADG but greater DMI. Therefore, chemically treating and pelleting crop residues improves diet digestibilities compared to conventional crop residues. Pelleting corn stover makes storage and transportation of low quality forages easier and more economical. Data suggest pelleted crop residues may serve as a partial corn replacement for finishing diets.

Conclusion

Based on the literature cited in this review it is clear that ethanol byproducts (i.e. distillers grains) are widely utilized protein source for beef cattle feeding operations. As demand for ethanol continues, ethanol plants will continue to develop methods of fractionating the components of corn. More components will be removed resulting in an altered distillers grains. Knowing the techniques and methods of ethanol production from dry-grind, wet milling, and dry milling facilities will provide better insight into the potential byproducts produced. At times of high corn price, utilizing distiller grains or condensed distillers solubles to provide protein and energy can prove to be economical without compromising performance. When feeding ethanol byproducts understanding the concentration of rumen available S (i.e. inorganic sources) will prove helpful in avoiding S toxicity issues. Processing corn stover by alkali treatment and pelleting has proven to

improve the digestibility and utilization of low quality forages in finishing diets. Therefore, the objectives for this thesis include: 1) determine the effect of replacing corn bran, from the dry milling industry, which contains more protein, from a DGS composite diet with CaO treated corn stover on feedlot performance and carcass traits; 2) evaluate the effect of exchanging protein from a DGS composite with corn bran and CDS on feedlot performance and carcass traits; 3) evaluate protein from DGS on feedlot performance, carcass traits, nutrient digestibility, ruminal VFA concentration, and ruminal pH.

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CHAPTER II. MODIFYING DIFFERENT COMPONENTS OF DISTILLERS GRAINS AND THE IMPACT ON FEEDLOT PERFORMANCE

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ABSTRACT

Crossbred yearling steers (n = 448; initial BW 368 kg; SD=13) were utilized in a generalized randomized block design to determine the effect of altering distillers grains plus solubles (DGS) composition on performance and carcass characteristics. Treatments were: 1) negative control (CON) with 50% dry-rolled corn; 2) positive control (DDGS) dried DGS replaced corn at 50% of diet; 3) pelleted corn stover (PEL-STV) treated with calcium oxide, containing 18.75% solubles (CDS), 12.5% treated corn stover, and 18.75% high-protein dried distillers grains plus solubles (HPDG), pelleted; 4) non-pelleted corn stover (STV), treated with calcium oxide, containing treated corn stover, CDS, and HPDG at same DM inclusion as PEL-STV; 5) component DGS(COMP) including 18.75% CDS, 12.5% corn bran, isolated from the dry-milling ethanol process, and 18.75% HPDG; 6) component medium protein (COMP-MED) contained 24.4% CDS, 16.2% corn bran, and 9.4% HPDG; and 7) component low protein (COMP-LOW) had 30% CDS and 20% corn bran (DM basis). Performance and carcass characteristics were analyzed using the MIXED procedures of SAS with pen as the experimental unit. Block was a fixed effect and contrasts were developed to determine effects of exchanging components in DGS. Dry matter intake and ADG were greater for DDGS compared to CON ($P < 0.01$). Combining corn bran, CDS, and HPDG together in similar proportions to DDGS reduced G:F by 9.0% ($P < 0.01$) compared to DDGS. There was a quadratic increase in DMI as protein was removed between COMP, COMP-MED, and COMP-LOW ($P < 0.04$). Steers fed DDGS had heavier HCW ($P < 0.01$) and increased 12th rib fat thickness ($P < 0.02$) compared to COMP. As protein decreased between COMP, COMP-MED, and COMP-LOW fat thickness decreased linearly ($P = 0.02$). Replacing

corn bran with a treated corn stover mixture further reduced feed efficiency ($P < 0.04$). Pelleted corn stover decreased DMI ($P < 0.02$) with no affect on ADG or G:F ($P \geq 0.37$). When the treated corn stover mixture replaced corn bran, 12th rib fat thickness decreased ($P < 0.02$). Replacing the fiber from DDGS with the treated corn stover mixture supplied less energy. As the portion of CDS and corn bran in the composite DGS increased, performance remained similar. Combining individual ingredients of corn bran, HPDG, and CDS did not mimic the fiber, protein, and fat fractions of DDGS.

Key Words: beef cattle, corn stover, distillers grains plus solubles

INTRODUCTION

The composition of distillers grains plus solubles (DGS) changes as nutrient components are removed during ethanol production. The removal of oil from DGS has been reported to lower the energy value of DGS by 3.5% when DGS was included in the diet at 30% (DM basis; Bremer et al., 2015). Fermentation of corn bran via secondary fermentation systems will lower the concentration of fiber in DGS. Separation of protein may reduce the protein concentration of DGS and alter use in feedlot diets. Partially fractionated DGS containing less fiber and more protein compared to traditional DGS has been reported to perform similarly to traditional DGS in finishing diets (Depenbusch et al., 2008; Kelzer et al., 2011). Lundy et al. (2015) reported poorer feed efficiency for WDGS from secondary cellulosic ethanol fermentation compared to traditional wet distillers grains plus solubles (WDGS). Bremer et al. (2008) described methods of protein separation available to ethanol plants to enhance their value-added products. Ethanol plants ability to isolate components of DGS will continue to increase, which means understanding protein, fiber, fat, and the interactions of those components from DGS in beef cattle diets will allow for prediction of performance as nutrients change in the future.

Corn stover has become more available with higher corn prices (Watson, 2015). New techniques to commercially process corn stover, in combination with DGS, are available. Pelleted DGS and CaO treated corn stover when included in finishing diets cattle performed similarly to corn at 20% inclusion (DM basis; Gramkow et al., 2016). Little research has examined replacing fiber from DGS removed by secondary fermentation with treated corn stover or utilizing condensed distillers solubles (CDS) and corn bran for the protein component of DGS. The objectives of this study were to

determine the effect of replacing corn bran from the dry-milling industry, which contains more protein than bran from the wet-milling industry, in DDGS with CaO treated corn stover and to evaluate the effect of exchanging protein in DDGS with corn bran and CDS on feedlot performance and carcass traits.

MATERIALS AND METHODS

All animal care and management procedures were approved by the University of Nebraska – Lincoln Institutional Animal Care and Use Committee.

Crossbred yearling steers (n = 448; initial BW 368 kg; SD=13) were utilized in a generalized randomized block design at the University of Nebraska-Lincoln Eastern Nebraska Research and Extension Center feedlot (Mead, NE). Initial receiving and processing of the calves into the feedlot included vaccination for protection against bovine rhinotracheitis virus and bovine viral diarrhea types 1 and 2 viruses (Bovi-Shield Gold One Shot; Zoetis, Florham Park, NJ); control against gastrointestinal roundworms, lungworms, eye worms, grubs, sucking lice, and mange mites (Dectomax injectable; Zoetis); and prevention of *Haemophilus somnus* (Somubac; Zoetis). Cattle were given a booster vaccination 14 d after initial vaccination for protection against bovine rhinotracheitis virus and bovine viral diarrhea types 1 and 2 viruses (Bovi-Shield Gold 5; Zoetis) and prevention of *Haemophilus somnus* (Ultrabac-7; Zoetis). Steers grazed corn stalks After backgrounding, steers were limit-fed (2% of BW) a diet consisting of 50% Sweet Bran® (Cargill Wet Milling, Blair, NE), and 50% alfalfa hay (DM basis) for 5 d before weighing to equalize gut fill (Watson et al., 2013). Steers were weighed 2 consecutive days (d 0 and 1) using a hydraulic squeeze chute with load cells mounted on the chute (Silencer, Moly Manufacturing Inc., Lorraine, KS: scale readability ± 0.90 kg)

to establish initial BW. Steers were implanted with 36 mg of zeranol (Ralgro, Merck Animal Health, De Soto, KS) during the initial weighing (d 1) process. Steers were blocked by BW into three blocks on d 0, stratified by BW within block, and assigned randomly to 56 pens.

Pens were assigned randomly to one of seven dietary treatments (Table 2.1) with eight replications per treatment and eight steers per pen. The light and heavy BW blocks contained 2 replications each and the middle block contained 4 replications. Steers were re-implanted with 200 mg of trenbolone acetate and 20 mg of estradiol (Revalor-200, Merck Animal Health) with the middle block (4 replications) on d 36 and light and heavy blocks (4 replications) on d 38.

Cattle were fed *ad libitum* with feed bunks evaluated daily at approximately 0630 h for refusals and managed so that trace amounts of feed were left in the bunk at time of feeding. Feed was delivered with a truck mounted mixer and delivery unit (Roto-Mix model 274, Roto-Mix, Dodge City, KS; scale readability ±0.91 kg) each morning at 0800 h. Steers were adapted to finishing diets over a 19-d period through a series of 4 diets containing 40, 30, 20, and 10% alfalfa hay (DM basis) for 4, 5, 5, and 5 d, respectively, with HMC, DRC or byproducts replacing alfalfa hay, respectively. In step-up diets 2, 3, 4, and finisher high-moisture corn (HMC) and dry-rolled corn (DRC) replaced 4, 4, 4, 1.5% and 6, 6, 6, 3% of alfalfa hay in the CON diet, respectively. In step-up diets 2, 3, 4, and finisher HMC and DDGS replaced 4, 4, 4, 1.5% and 6, 6, 6, 3% of alfalfa hay in the DDGS diet, respectively. In step-up diets 2, 3, 4, and finisher HMC and a combination of CDS, and CaO treated corn stover with CDS and HPDG (pelleted and non-pelleted) replaced 4, 4, 4, 1.5% and 6, 6, 6, 3% of alfalfa hay in the STV and PEL-STV diets,

respectively. In step-up diets 2, 3, 4, and finisher HMC and a combination of CDS, corn bran, and HPDG replaced 4, 4, 4, 1.5% and 6, 6, 6, 3% of alfalfa hay in the COMP diet, respectively. In step-up diets 2, 3, 4, and finisher HMC and a combination of CDS, and corn bran replaced a portion of alfalfa hay in COMP-MED and COMP-LOW, respectively. The composite DGS diet (COMP) was formulated to replicate the protein, fiber, and fat from DGS utilizing isolated components of corn from the dry-milling ethanol industry (Table 2.1). Corn bran (ICM Biofuels; St. Joseph, MO; 65.3% DM, 24.1% CP, 56.3% NDF, and 5.5% fat; DM basis) was utilized as the fiber portion. High-protein dried distillers grains plus solubles (ICM Biofuels; 92.3% DM, 37.7% CP, 40.3% NDF, and 8.4% fat; DM basis) was utilized as a protein source. A portion of the protein and fat was replicated with the inclusion of CDS (ICM Biofuels; 35.5% DM, 34.8% CP, 7.4% NDF, and 6.7% EE; DM basis).

Diets were formulated to meet or exceed MP requirements using the NRC (1996). Nutrient composition for all experimental diets are listed in Table 2.2. All finishing diets contained 31.5% high-moisture corn, 5.5% alfalfa hay, 4.0% corn silage, 5.0% liquid molasses, 4.0% dry meal supplement formulated with 30 g / ton of monensin (Rumensin, Elanco Animal Health, Greenfield, IN) and 90 mg / steer of tylosin (Tylan, Elanco Animal Health) daily. Supplements were formulated and mixed at the on-site feed mill. The supplement for CON contained urea at 1.36% (DM basis) to meet the RDP requirement and 1.43% limestone (DM basis) to meet and / or exceed the Ca requirement (NRC, 1996). The supplement for DDGS, COMP, COMP-MED, and COMP-LOW contained 1.98% limestone (DM basis) to meet and/or exceed the Ca requirement (NASEM, 2016). The supplement for STV and PEL-STV contained 0.49% limestone

(DM basis) since those treatments contained CaO (71% Ca based on molecular weight) treated corn stover. Supplements were mixed weekly in a stationary ribbon mixer (model S-5 Mixer; H.C. Davis Sons Manufacturing Co., Inc., Bonner Springs, KS).

Both corn stover ingredients, pelleted and non-pelleted, were harvested from the same field and processed by Pellet Technology, USA (Gretna, NE). The corn stover was reduced to a small particle size (297-1,680 μm). Then CDS was added to hydrate the corn stover to 50% DM. As CDS was added, CaO was also simultaneously added (5% of forage DM). After CaO treatment, the mixture was sent through an extruder (66-121°C) to increase the rate of the chemical reaction. Following the extrusion process, HPDG was added. At this point the non-pelleted corn stover mixture was completed and the pelleted corn stover was pelleted (Zeeck, 2013). The final product was composed of approximately 31% treated corn stover, 19% CDS, 48% HPDG, and 1.6% CaO. The pelleted corn stover in the current experiment is similar to the product used in previous studies evaluating the alkaline treatment and pelleting of corn stover with CDS and dried DGS (Welchons et al, 2016; Gramkow et al, 2016). Gramkow et al. (2016b) examined an alternative alkaline treatment process on corn stover. The alternative method utilized CDS instead of water to hydrate the corn stover before CaO treatment. When compared to traditional alkaline treatment hydrated with water, hydrating corn stover with CDS resulted in improved total-tract DM and OM digestibilities when included in growing diets fed to steers. As described above, the same alternative CaO treatment of corn stover hydrated with CDS examined with Gramkow et al. (2016) was used for in the current study. High-moisture corn, DRC, alfalfa hay, and corn silage were harvested from fields

at the Eastern Nebraska Research and Extension Center (Mead, NE) and processed at the research feedlot.

Orts were removed from the bunk when refusals were present, and dried in a 60°C forced-air oven (model LBB2-21-1, Despatch, Minneapolis, MN) for 48 h to determine DM content (AAOC, 1965; method 935.29). Individual feed ingredients were dried in 60°C forced air ovens (model LBB2-21-1, Despatch, Minneapolis, MN) for 48 h (AAOC, 1965; method 935.29) weekly to ensure accurate DM's were used when mixing dietary treatments. Individual feed ingredients were sampled weekly, composited by month, freeze dried, and ground through a 1-mm screen using a Wiley mill (number 4; Thomas Scientific, Swedesboro, NJ). Feed samples were analyzed for OM, CP, NDF, ADF, and lignin to calculate nutrient composition of dietary treatments (Table 2.3). Ash was evaluated by placing samples in a muffle furnace for 6 h at 600°C (AOAC, 1999; method 4.1.10). Crude protein and S were determined using a combustion type N and S analyzer (TruSpec N Determinator and TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI; AOAC, 1999; method 990.03). Neutral detergent fiber content was determined using the procedure described by Van Soest et al. (1991) with modifications described by Buckner et al. (2010). The modification applied to DDGS, HPDG, CDS, pelleted and non-pelleted corn stover, and corn bran was a biphasic lipid extraction (Bremer et al., 2010) prior to NDF analysis (Buckner et al., 2013). Acid detergent fiber and lignin content were determined using the procedure described by Van Soest et al. (1963). Ether extract was determined by a biphasic lipid extraction procedure described by Bremer (2010). Samples were heated in a 1:1 mixture of hexane and diethyl ether for 9 h, dilute HCl was added, and samples were centrifuged to separate the lipid layer from

other liquid. The lipid layer was pipetted off, heated to drive off remaining solvent, and weighed.

Cattle were shipped according to projections made utilizing pen weights on d 113 and predicted ADG to reach a final BW of 658 kg, at which all cattle were assumed to have 1.27 cm or more of fat thickness at the 12th rib. On day 149, steers in the heavy block (2 replications) were fed 50% of the previous days feed call and shipped approximately 10 h after feeding. On day 156, steers in the light and middle blocks (6 replications) were fed 50% of the previous days feed call and shipped approximately 10 h after feeding. Steers were harvested at Greater Omaha Packing Co. (Omaha, NE). Upon day of harvest, HCW was collected. After a 48-h chill, LM area, 12th rib fat, and USDA marbling scores were collected. Final BW was calculated by dividing HCW by a common dressing percentage (63%). Feeding values were calculated using the following equation: [((compared treatments G:F – CON G:F) / CON G:F) / compared treatments inclusion rate*100 + 100].

Performance data (BW, DMI, ADG, G:F) and carcass data (HCW, 12th rib back fat, marbling, quality grade, yield grade) were analyzed using the MIXED procedures of SAS (SAS Institute, Inc., Cary, N.C.) with dead or chronic steers removed from analysis. One steer from COMP, one steer from COMP-MED, and three steers from COMP-LOW diets were removed from the experiment due to diagnosis of sulfur induced polioencephalomalacia (S-PEM) by the Nebraska Veterinary Diagnostic laboratory. Pen was the experimental unit and block was treated as a fixed effect. Linear and quadratic contrasts were developed for steers fed COMP, COMP-MED, COMP-LOW to determine the impacts of replacing protein from DGS with CDS and corn bran. Additionally,

pairwise comparisons were pre-planned to determine the following effects: 1) replacing corn with commodity DGS as an internal validation (CON vs DDGS); 2) replacing DDGS with a composite DGS (DDGS vs. COMP) to test if combining 18.75% HPDG, 12.50% corn bran from the dry-milling process, and 18.75% CDS could replicate the components of DDGS; 3) replacing corn bran from the composite DGS with a treated corn stover byproduct mixture (COMP vs. STV) to test if the CaO treated corn stover can replace the fiber removed from DDGS by secondary fermentation processes; 4) pelleting the treated corn stover byproduct mixture (PEL-STV vs. STV) to test the effect of pelleting CaO treated corn stover that replaced the fiber portion of DDGS. Treatment differences were considered significant when $P \leq 0.05$ with tendencies between $P > 0.05$ and $P \leq 0.10$.

Dietary treatments were modified on d 35 due to S-PEM. The cause of S-PEM was due to high sulfur content of CDS. The maximum tolerable concentration of dietary sulfur in diets containing more than 85% concentrate is 0.30% (NASEM, 2016). Before d 35, all diets except CON exceeded 0.30% dietary sulfur with BRN-LOW having the greatest dietary sulfur with 0.72%. Condensed distillers solubles and DDGS were reduced by 11.25% and replaced with DRC. Increasing the NDF content, primarily from forages, of the diet reduces the risk of S-PEM and decreases the amount of ruminal H_2S produced (Nichols et al., 2013; Morine et al., 2014a, b). We replaced 5% (DM basis) of HMC with grass hay. The high sulfur CDS was replaced and reintroduced throughout a 6 day step-up period, and experimental treatments resumed on d 41. The cause of high sulfur in the CDS and DDGS was a result of high sulfur in the water used in the dry grind process at the ethanol plant that supplied both CDS and DDGS. Sulfur from DGS is a

combination of organic (origin from corn) and inorganic (origin from chemicals during the dry grinding process). Sarturi et al. (2013) studied the effects of organic and inorganic sulfur sources on rumen availability. The authors reported that organic S sources were 100% ruminally available and S from WDGS had greater degradation in the rumen resulting in greater ruminal H_2S gas production compared to organic sources. Therefore, the source of high S concentration causing S-induced PEM was CDS and DDGS.

RESULTS AND DISCUSSION

CON vs. DDGS

Performance and carcass data are provided in Table 2.4. Steers fed DDGS instead of CON (i.e. replacing 50% dry-rolled corn with DDGS) had increased carcass adjusted final BW (655 vs. 631 kg for DDGS and CON, respectively; $P < 0.01$), increased DMI (12.9 vs. 11.9 kg/d, respectively; $P < 0.01$) and increased ADG (1.89 vs. 1.74 kg/d, respectively; $P < 0.01$) and no difference ($P = 0.80$) for G:F. Previous research has reported that replacing up to 40% (DM basis) of DDGS in the diet resulted in greater DMI, ADG, and improved G:F (Buckner et al., 2007; Klopfenstein et al., 2008). The feeding value of DDGS has been documented to be approximately 112% the value of corn (Bremer et al., 2011). The 12% improvement in feeding value of DGS has been attributed to the fat and RUP of DGS (Larson et al., 1993). Improvements in cattle performance have been attributed to the greater feeding value of DDGS (Buckner et al., 2007; Bremer et al., 2011). In the current trial, the feeding value of DDGS was 101% the value of corn. Feed efficiency was not different for CON and DDGS (0.145 vs. 0.144, respectively; $P = 0.80$). While feeding DGS has been reported to improve G:F, studies in which DGS was included at 50% or greater in the diet, have reported poorer G:F response

compared to lower inclusions of DGS (Vander Pol et al. 2006; Depenbusch et al., 2009; Nuttelman et al., 2011). Klopfenstein et al. (2008) summarized five trials comparing 10, 20, 30, and 40% DDGS inclusion (DM basis) to a corn control. There was a cubic response observed for G:F with the optimal inclusion of DDGS being 10%. Feed efficiency continued to decline from 20 to 40% DDGS with 40% DDGS having a similar G:F as the corn control. Depenbusch et al., (2009) evaluated DDGS at 15, 30, 45, 60, or 75% (DM basis) fed to heifers in finishing diets. Dry matter intake, ADG, and final BW responded quadratically to increasing levels of DDGS and were optimized at 15% DGS. Feed efficiency linearly decreased as inclusion of DDGS increased. In the current study, no difference in G:F for CON and DDGS may be due to the high inclusion of DDGS. The inclusion of 50% DDGS (DM basis) in the diet was selected so that individual feed ingredients (i.e. corn bran, CDS, and HPDG) could be included at large enough inclusion rates so that treatment differences could be detected when comparing smaller components of DDGS. Hot carcass weight was 15 kg more for steers fed DDGS ($P < 0.01$) compared to CON. Increased HCW with DDGS inclusion has been reported in previous publications (Benson et al., 2005; Buckner et al., 2007). However, several publications reporting poor growth performance at 50% or greater DDGS inclusion reported lower HCW (Gunn et al., 2009; Depenbusch et al., 2009). There were no differences ($P = 0.34$) for LM area between CON and DDGS. Steers fed DDGS had increased 12th rib fat (1.61 vs. 1.43 cm^2, respectively; $P < 0.01$) compared to CON. Marbling was not different between DDGS and CON ($P = 0.25$).

DDGS vs. COMP

Performance and carcass data are provided in Table 2.4. Replacing DDGS (91.1% DM, 34.4% CP, 35.9% NDF, 8.7% fat, and 0.40% S; DM basis) with similar proportions of CDS, corn bran, and HPDG (COMP; 57.2% DM, 33.2% CP, 32.0% NDF, 7.2% fat, and 0.57% S; DM basis) decreased final BW (655 vs. 623 kg, respectively; $P < 0.01$) and decreased DMI (12.9 vs. 12.4 kg/d, respectively; $P = 0.05$). Average daily gain was greater for cattle fed DDGS (1.89 vs. 1.69 kg/d; $P < 0.01$) compared to COMP, respectively. Steers fed DDGS had improved G:F compared to COMP (0.145 vs. 0.132, respectively; $P < 0.01$). The COMP diet had a calculated feeding value of 83% relative to corn, which was lower than the feeding value of DDGS (101%). Hot carcass weights were heavier for cattle fed DDGS compared to COMP (413 vs. 393 kg, respectively; $P < 0.01$). There were no differences ($P = 0.83$) in LM area between DDGS and COMP. There was increased 12th rib fat (1.61 vs. 1.53 cm^2; $P = 0.02$) for DDGS compared to COMP, respectively. There were no differences ($P = 0.82$) in marbling between DDGS and COMP. Previous research examined an ethanol byproduct, Dakota Bran (Poet Nutrition, Sioux Falls, SD), which is a blend of corn bran and CDS (53% DM, 14.7% CP, 32.0% NDF, 10.9% fat, and 0.82% S; DM basis; Buckner et al. 2011b). Authors replaced equal parts of DRC and HMC in the finishing diet with 15, 30, or 45% Dakota Bran. As inclusion of Dakota Bran increased, ADG and G:F improved linearly ($P < 0.01$). Steers consuming 30% Dakota Bran or DDGS had similar growth performance and carcass characteristics. These results show that Dakota Bran, a product low in protein and high in fiber, can provide similar energy as DDGS. In the current study, combining 37.5% CDS, 25% corn bran, and 37.5% HPDG, as proportions of DDGS, did not result in similar performance to DDGS. One explanation for poorer performance of cattle fed COMP

could be that one or more of the individual ingredients (i.e. HPDG, CDS, and/or corn bran) did not contain a similar nutrient composition as the component (i.e. protein, fat, and/or fiber) in DDGS. The individual ingredients in COMP may not have been included in the correct proportions to replicate the components in DDGS.

COMP vs. STV

Performance and carcass data are provided in Table 2.4. The composition of the byproducts in COMP (57.2% DM, 33.2% CP, 32.0% NDF, and 7.1% fat; DM basis) and STV (68.0% DM, 25.4% CP, 44.3% NDF, and 5.4% fat; DM basis; Table 2.3) indicate that replacing corn bran with treated corn stover reduced CP and fat concentration while providing more NDF. There were no differences ($P = 0.88$) in final BW between COMP and STV. Exchanging corn bran for non-pelleted treated corn stover increased DMI (12.4 vs. 13.3 kg/d, respectively; $P < 0.01$) with no difference in ADG (1.69 vs. 1.70 kg/d, respectively; $P = 0.91$), resulting in steers fed STV being 4.5% less efficient in comparison to steers fed COMP (0.126 vs. 0.132, respectively; $P = 0.04$). When corn bran was replaced by treated corn stover the feeding value decreased 9%. In the current study, there was no difference ($P \geq 0.79$) in HCW and LM area between COMP and STV. When treated corn stover replaced corn bran, 12th rib fat decreased (1.37 vs. 1.53 cm^2, respectively; $P < 0.02$). Marbling was not different ($P = 0.82$) for COMP and STV. These data suggest that replacing corn bran with CaO treated corn stover and byproduct mixture provides less energy to the diet as a result of lower fat and CP concentrations but similar growth performance as a result of increased intake and poorer G:F.

PEL-STV vs. STV

Performance and carcass data are provided in Table 2.4. The composition of the byproducts in STV was 68.0% DM, 25.4% CP, 44.3% NDF, and 5.4% fat (DM basis; Table 2.3). The composition of the byproducts in PEL-STV was 73.9% DM, 24.8% CP, 42.5% NDF, and 5.0% fat (DM basis). There were no differences ($P = 0.35$) for final BW between PEL-STV and STV. Pelleting the treated corn stover, CDS, and HPDG decreased DMI, with steers fed PEL-STV consuming 12.8 kg/d in comparison to 13.3 kg/d for steers fed STV ($P = 0.03$). Previous authors reported greater DMI for cattle consuming pelleted feeds compared to non-pelleted feeds (Peterson et al., 2015). Greater DMI has been attributed to faster passage rate as a result of lower total tract digestibility (Coleman et al., 1978; Le Liboux et al., 1999) and smaller particle size of pelleted feeds (Blaxter et al., 1956; Weir et al. 1959; Moore et al., 1964). Gramkow et al. (2016) evaluated a similar CaO treated corn stover pelleted with DGS as the current experiment. Digestibility of the pelleted corn stover was not different compared to MDGS. However, DMI increased as inclusion of pelleted stover increased in the diet. Cattle in the current trial had lower DMI when 38.75% (DM basis) of the diet was pelleted feed. Both STV and PEL-STV would have similar particle sizes prior to pelleting. Pelleted corn stover in the PEL-STV treatment was exposed to higher heat and pressure from pelleting compared to STV. Heat and pressure generated during pellet production further breaks down the treated corn stover (Zeeck, 2013). There were no differences between PEL-STV and STV for ADG (1.65 vs. 1.70 kg/d, respectively; $P = 0.37$) and G:F (0.127 vs. 0.126, respectively; $P = 0.63$). The pelleted treated corn stover may have provided more energy than the non-pelleted treated corn stover, which allowed the animal to consume less DM and perform similar to the non-pelleted treated corn stover. There were no differences (*P*

≥ 0.35) in HCW, LM area, and 12th rib fat between PEL-STV and STV. Marbling had a tendency to decrease for steers fed PEL-STV compared to STV (482 vs. 511, respectively;; P = 0.07). Pelleting decreased animal intake without affecting growth performance or carcass characteristics.

Linear and Quadratic Responses for Protein

In order to diversify marketable products and add value to DGS, ethanol plants have developed technologies to further fractionate corn. The fiber component is subjected to cellulosic fermentation yielding additional ethanol and a DGS lower in NDF content. The remaining NDF has been reported to be less digestible and lower in energy relative to fiber from traditional DGS (Lundy et al., 2015). Following cellulosic fermentation, protein can be separated via protease enzymes and sold in alternative markets (Brehmer et al., 2008). Both COMP-MED and COMP-LOW were formulated to replace the protein from DGS by removing HPDG and increasing the concentrations of CDS and corn bran. The proportion of CDS to corn bran remained the same as in COMP but their concentrations were greater as HPDG was removed. These two diets may have nutrient compositions similar to future ethanol corn byproducts. There were no differences (P = 0.19) for final BW between COMP (57.2% DM, 33.2% CP, 32.0% NDF, 7.2% fat, and 0.57% S; DM basis), COMP-MED (46.7% DM, 31.9% CP, 29.4% NDF, and 6.7% fat; DM basis), and COMP-LOW (36.1% DM, 30.5% CP, 26.9% NDF, and 6.2% fat; DM basis; Table 2.5). As HPDG was replaced with CDS and corn bran between COMP, COMP-MED, and COMP-LOW, DMI quadratically increased (P = 0.04) with COMP-MED increasing and COMP-LOW decreasing, compared to COMP. Pesta et al. (2015) observed a linear decrease in DMI as CDS concentration increased from 0 to 36%. One

reason for decreased DMI with greater concentrations of CDS is high S (Sarturi et al., 2013b), and dietary S of 0.44% S in COMP-LOW in this study may have been enough to cause decreased DMI. One steer from COMP-MED and three steers from COMP-LOW were diagnosed with PEM, suggesting that the byproducts did contain high levels of S. Limiting DMI due to S concentration does not explain why DMI increased from COMP to COMP-MED. There were no significant differences ($P = 0.16$) in ADG due to changing portion of protein. Replacing proportions of protein tended ($P = 0.10$) to improve G:F linearly. Pesta et al. (2015) reported as CDS inclusion increased from 0 to 36%, G:F improved quadratically. The authors calculated that the maximum G:F response occurred at 32.5% CDS resulting in cattle being 12% more efficient than those fed 0%. The authors note that G:F plateaus at the greatest inclusion of CDS, which means that even greater inclusions than tested may be feasible. Limiting factors of inclusions greater than 36% CDS include handling properties of the diet (decreasing DM content and winter storage capabilities) and addition of dietary fat and/or S. Replacing HPDG with proportions of CDS and corn bran resulted in greater feeding values (83 vs. 89 and 90% relative to corn for COMP vs. COM-MED and COMP-LOW, respectively). There were no differences ($P = 0.19$) for HCW between COMP, COMP-MED, and COMP-LOW. Removing protein tended to increase LM area quadratically ($P = 0.08$) and linearly decrease 12th rib fat ($P = 0.02$). There were no differences ($P = 0.28$) for marbling. Displacing half the protein with CDS and corn bran (at equal proportions to COMP) caused increased DMI and tended to increase LM area. When protein was completely displaced by a combination of CDS and corn bran, DMI, ADG, and G:F were similar to COMP.

IMPLICATIONS

Replacing the fiber from DDGS with a treated corn stover mixture supplied less energy. As the portion of CDS and fiber (corn bran) from the composite DGS increased, finishing performance was similar. If protein in DGS is removed, CDS and corn bran may be able to displace the protein without sacrificing animal performance. Combining individual ingredients of corn bran, HPDG, and CDS at various inclusion levels did not mimic the fiber, protein, and fat fractions of DDGS suggesting some component(s) was missing.

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Table 2.1. Dietary treatments containing modified components of distillers grains fed to steers[1].

Item	Treatment						
	CON[3]	DDGS	PEL-STV[6]	STV	COMP	COMP-MED	COMP-LOW
Ingredient, % DM[2]							
HMC	31.50	31.50	31.50	31.50	31.50	31.50	31.50
DRC	50.00	–	–	–	–	–	–
DDGS	–	50.00	–	–	–	–	–
CDS	–	–	11.25	11.25	18.75	24.40	30.00
Treated Corn Stover[4,5]	–	–	38.75	38.75	–	–	–
Corn Bran[7]	–	–	–	–	12.50	16.20	20.00
HPDG	–	–	–	–	18.75	9.40	–
Alfalfa hay	5.50	5.50	5.50	5.50	5.50	5.50	5.50
Corn Silage	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Liquid Molasses	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Supplement[8]							
Fine ground corn	0.725	1.534	3.022	3.022	1.534	1.534	1.534
Limestone	1.430	1.976	0.488	0.488	1.976	1.976	1.976
Salt	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Urea	1.355	-	-	-	-	-	-
Tallow	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Beef trace mineral[9]	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Vitamins A, D, and E[10]	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Rumensin 90[11]	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165
Tylan 40[12]	0.0087	0.0087	0.0087	0.0087	0.0087	0.0087	0.0087

[1]All values presented on a DM basis.

[2]HMC = high-moisture corn; DRC = dry-rolled corn; DDGS = dried distillers grain plus solubles; CDS = condensed distillers solubles; HPDG = high protein dried distillers grains plus solubles.

[3]Supplemented with urea at 1.36% of diet to meet the DIP requirement.

[4]Corn stover treated with CaO by Pellet Technology USA, LLC, Gretna, NE.

[5]Treated corn stover at 12.50%, 7.50% condensed distillers solubles, and 18.75% high-protein dried distillers grains plus solubles processed by Pellet Technology USA, LLC, Gretna, NE.

[6]Treated corn stover, condensed distillers solubles, and high-protein dried distillers grains pelleted by Pellet Technology USA, LLC, Grenta, NE.

[7]Corn bran is isolated from dry-milling process and is not purified bran (contains more protein).

[8]Supplement formulated to be fed at 4% dietary DM.

[9]Premix contained 10%Mg, 6% Zn as ZnO, 4.5% Fe as $FeSO_4$, 2% Mn as MnO, 0.5% Cu as $CuSO_4$, 0.3% I as $Ca(IO_3)2(H_2O)$, and 0.05% Co as $CoCO_3$.

[10]Premix contained 1,500 IU vitamin A, 3,000 IU vitamin D, and 3.7 IU vitamin E per g.

[11]Formulated to provide 375 mg·steer·d^{-1} monensin (Rumensin; Elanco Animal Health, Greenfield, IN).

[12]Forumated to provide 90 mg·steer·d^{-1} tylosin (Tylan; Elanco Animal Health).

[13]DM basis.

Table 2.2. Composition of dietary treatments containing modified components of distillers grains fed to steers[1].

Item	Treatment						
	CON[3]	DDGS	PEL-STV[6]	STV	COMP	COMP-MED	COMP-LOW
Dietary Composition[13]							
DM	81.7	82.2	73.4	70.4	65.3	60.0	54.7
OM	94.4	92.3	90.7	90.7	91.2	90.6	89.9
CP	15.5	22.7	18.2	18.5	22.1	21.5	20.8
NDF	12.2	25.8	29.1	30.0	23.8	22.5	21.3
ADF	6.7	14.8	17.3	18.0	11.2	10.4	9.6
Lignin	1.5	3.0	3.0	3.3	1.9	1.8	1.7
Fat	3.66	6.10	4.32	4.50	5.33	5.14	4.95
Ca	0.78	0.97	0.55	0.58	1.01	1.02	1.03
P	0.26	0.60	0.71	0.72	0.69	0.78	0.87
K	0.74	1.17	1.42	1.43	1.32	1.47	1.61
S	0.16	0.31	0.41	0.41	0.40	0.42	0.44

[1]All values presented on a DM basis.
[2]HMC = high-moisture corn; DRC = dry-rolled corn; DDGS = dried distillers grain plus solubles; CDS = condensed distillers solubles; HPDG = high protein dried distillers grains plus solubles.
[3]Supplemented with urea at 1.36% of diet to meet the DIP requirement.
[4]Corn stover treated with CaO by Pellet Technology USA, LLC, Gretna, NE.
[5]Treated corn stover at 12.50%, 7.50% condensed distillers solubles, and 18.75% high-protein dried distillers grains plus solubles processed by Pellet Technology USA, LLC, Gretna, NE.
[6]Treated corn stover, condensed distillers solubles, and high-protein dried distillers grains pelleted by Pellet Technology USA, LLC, Grenta, NE.
[7]Corn bran is isolated from dry-milling process and is not purified bran (contains more protein).
[8]Supplement formulated to be fed at 4% dietary DM.
[9]Premix contained 10%Mg, 6% Zn as ZnO, 4.5% Fe as $FeSO_4$, 2% Mn as MnO, 0.5% Cu as $CuSO_4$, 0.3% I as $Ca(IO_3)2(H_2O)$, and 0.05% Co as $CoCO_3$.
[10]Premix contained 1,500 IU vitamin A, 3,000 IU vitamin D, and 3.7 IU vitamin E per g.
[11]Formulated to provide 375 mg·steer·d^{-1} monensin (Rumensin; Elanco Animal Health, Greenfield, IN).
[12]Forumated to provide 90 mg·steer·d^{-1} tylosin (Tylan; Elanco Animal Health).
[13]DM basis.

Table 2.3. Nutrient analysis for ingredients containing modified components of distillers grains fed to steers.

	Ingredient							
% DM basis	HMC[1]	DRC[1]	DDGS[1]	Pelleted Treated Corn Stover[2,3,4]	Treated Corn Stover[2,3]	Corn Bran[5]	HPDG[1]	CDS[1]
DM	71.4	89.9	91.1	85.1	77.4	37.0	92.3	35.5
OM	98.2	98.4	95.0	87.1	87.1	97.6	97.2	85.3
CP	11.1	11.1	34.4	21.8	19.1	24.1	37.7	34.8
NDF	9.8	8.7	35.9	52.7	55.1	56.3	40.3	7.4
ADF	2.8	4.1	20.2	31.7	33.5	20.2	18.6	2.8
Lignin	0.8	1.2	4.3	5.4	6.0	2.8	2.8	0.8
Fat	4.3	3.9	8.7	4.5	5.0	5.5	8.4	7.0
Ca	0.04	0.03	0.04	1.36	1.61	0.09	0.05	0.09
P	0.31	0.26	0.94	0.55	0.65	0.39	0.50	2.23
K	0.42	0.38	1.19	1.03	1.36	0.35	0.50	2.94
S	0.10	0.10	0.40	0.40	0.42	0.25	0.42	0.92

[1]HMC = high-moisture corn; DRC = dry-rolled corn; DDGS = dried distillers grains plus solubles; CDS = condensed distillers solubles; HPDG = high protein dried distillers grains plus solubles.
[2]Corn stover treated with CaO by Pellet Technology USA, LLC, Gretna, NE.
[3]Treated corn stover at 12.50%, 7.50% condensed distillers solubles, and 18.75% high-protein dried distillers grains plus solubles processed by Pellet Technology USA, LLC, Gretna, NE.
[4]Treated corn stover, condensed distillers solubles, and high-protein dried distillers grains pelleted by Pellet Technology USA, LLC, Grenta, NE.
[5]Corn bran is isolated from dry-milling process and is not purified bran (contains more protein).

Table 2.4. Effects of modifying different components of distillers grains on animal performance and carcass characteristics.

Item	Treatment[1]					SEM	*P* - value			
	CON	DDGS	PEL-STV	STV	COMP		CON vs. DDGS	DDGS vs. COMP	COMP vs. STV	STV vs PEL-STV
Initial BW, kg	367	368	368	368	367	1	0.65	0.65	0.52	0.74
Final BW, kg[2]	631	655	617	625	623	6	<0.01	<0.01	0.88	0.35
DMI, kg/d	11.9	12.9	12.8	13.3	12.4	0.2	<0.01	0.05	<0.01	0.03
ADG, kg[3]	1.74	1.89	1.65	1.70	1.69	0.04	<0.01	<0.01	0.91	0.37
G:F[3]	0.144	0.145	0.127	0.126	0.132	0.002	0.80	<0.01	0.04	0.63
Feeding Value[4]	100	101	76	74	83	-	-	-	-	-
HCW, kg	398	413	389	394	393	4	<0.01	<0.01	0.88	0.35
LM area, cm[2]	85.3	83.8	84.8	83.9	83.5	1.1	0.34	0.83	0.79	0.56
12[th] rib fat, cm	1.43	1.61	1.35	1.37	1.53	0.05	0.01	0.02	0.02	0.73
Marbling[5]	529	511	482	511	514	11	0.25	0.82	0.82	0.07

[1]CON = 50% dry-rolled corn; DDGS = 50% dried distillers grains plus solubles; PEL-STV = pelleted 7.50% condensed distillers solubles, 12.5% treated corn stover, 18.75% high-protein dried distillers grains plus solubles, with an additional 11.25% condensed distillers solubles added at mixing; STV = 7.5% solubles, 12.5% treated corn stover, 18.75% high-protein dried distillers grains plus solubles, with an additional 11.25% condensed distillers solubles added at mixing; COMP = 18.75% solubles, 12.5% corn bran, and 18.75% high-protein dried distillers grains plus solubles.

[2]Calculated from HCW/common dress (63%).

[3]Calculated from carcass weight, adjusted to 63% common dressing percent.

[4]Feeding Value Calculation: [((compared treatments G:F – CON G:F) / CON G:F) / compared treatments inclusion rate*100+100]

[5]Marbling score: 400 = Small00.

0

Table 2.5. Effects of modifying different components of distillers grains on animal performance and carcass characteristics.

Item	Treatment[1]					SEM	*P* - value			
	CON	DDGS	COMP	COMP-MED	COMP-LOW		CON vs. DDGS	DDGS vs. COMP	Lin[2]	Quad[3]
Initial BW, kg	367	368	367	367	369	1	0.65	0.65	0.11	0.43
Final BW, kg[4]	631	655	623	635	629	6	<0.01	<0.01	0.48	0.19
DMI, kg/d	11.9	12.9	12.4	12.8	12.3	0.2	<0.01	0.05	0.66	0.04
ADG, kg[5]	1.74	1.89	1.69	1.77	1.72	0.04	<0.01	<0.01	0.58	0.16
G:F[5]	0.144	0.145	0.132	0.136	0.137	0.002	0.80	<0.01	0.10	0.51
Feeding Value[6]	100	101	83	89	90	-	-	-	-	-
HCW, kg	398	413	393	400	396	4	<0.01	<0.01	0.48	0.19
LM area, cm^2	85.3	83.8	83.5	87.1	86.1	1.1	0.34	0.83	0.10	0.08
12^{th} rib fat, cm	1.43	1.61	1.53	1.43	1.38	0.05	0.01	0.02	0.02	0.67
Marbling[7]	529	511	514	512	497	11	0.25	0.82	0.28	0.67

[1]CON = 50% dry-rolled corn; DDGS = 50% dried distillers grains plus solubles; COMP = 18.75% solubles, 12.5% corn bran, and 18.75% high-protein dried distillers grains plus solubles; COMP-MED = 24.4% solubles, 16.2% corn bran, and 9.4% high-protein dried distillers grains plus solubles; COMP-LOW = 30% solubles and 20% corn bran.

[2]Lin. = *P*-value for the linear response of protein with COMP, COMP-MED, COMP-LOW.

[3]Quad. = *P*-value for the quadratic response of protein with COMP, COMP-MED, COMP-LOW.

[4]Calculated from HCW/common dress (63%).

[5]Calculated from carcass weight, adjusted to 63% common dressing percent.

[6]Feeding Value Calculation: [((compared treatments G:F – CON G:F) / CON G:F) / compared treatments inclusion rate*100+100]

[7]Marbling score: 400 = Small00.

1

2

CHAPTER III. EVALUATION OF PROTEIN IN DISTILLERS GRAINS ON NUTRIENT DIGESTIBILITY, RUMEN FERMENTATION CHARACTERISTICS, GROWTH PERFORMANCE, AND CARCASS CHARACTERISTICS IN BEEF CATTLE FINISHING DIETS

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ABSTRACT

Three studies evaluated the relative contribution of excess rumen undegradable protein (RUP) from distillers grains plus solubles (DGS) on growth performance, carcass traits, nutrient digestibility, ruminal VFA concentrations and pH. In Exp. 1, crossbred steers (n = 324; initial BW = 291; SD = 24 kg) were utilized in a randomized block design to determine the relative contributions of protein on the feeding value of DGS. Protein in wet DGS (WDGS) was simulated using corn gluten meal (CGM; 8.75 and 17.5% inclusion, LOW-CGM and HIGH-CGM, respectively; DM basis) to provide similar RUP as 20 (20DGS) and 40% WDGS (40DGS; DM basis), respectively. In addition to CGM, 10% (DM basis) condensed distillers solubles (CD) was added to HIGH-CGM (CGM-CDS) to compare to 40DGS diet. All treatments were compared to a dry-rolled corn control (CON). In Exp. 2, six duodenally fistulated steers were utilized in an unbalanced 6 × 6 row-column design with six periods and four treatments (CON, 40DGS, HIGH-CGM, CGM-CDS) to evaluate site of nutrient digestion. In Exp. 3, six ruminally fistulated steers were utilized in an unbalanced 6 × 6 row-column design with six periods and four treatments (CON, 40DGS, HIGH-CGM, CGM-CDS) to evaluate bacterial purine:N, ruminal VFA concentration, and ruminal pH. Both Exp. 2 and 3 used modified DGS. In Exp. 1, a quadratic increase ($P = 0.04$) in ADG was observed as CGM increased from 0% (1.65 kg) to 17.5% (1.73 kg). A linear increase ($P < 0.01$) in G:F was observed as CGM increased from 0% (0.161) to 17.5% (0.169). Isolating the protein portion of 20% WDGS by feeding 8.75% CGM decreased ($P < 0.01$) G:F compared to 20% WDGS. Similarly, protein from 40% WDGS replaced by 17.5% CGM increased ($P < 0.01$) DMI and decreased ($P < 0.01$) G:F compared to 40% WDGS. Relative to the control diet,

20DGS, 40DGS, LOW-CGM, HIGH-CGM, and CGM-CDS had 134, 125, 110, 129, and 121% the feeding value of corn, respectively. In Exp. 2, total tract digestibilities of DM and OM were less ($P \leq 0.03$) for steers fed 40DGS compared to CON, HIGH-CGM, and CGM-CDS (OM digestibilities of 72.9, 84.7, 80.5, and 84.3%, respectively; SEM = 3.1%). Total tract NDF digestibility was not different ($P = 0.64$) among treatments. Excess protein used as an energy source from DGS accounts for the majority of the feeding value response observed when feeding DGS.

Key Words: distillers grains plus solubles, finishing, protein

INTRODUCTION

As advances in technology continue in the ethanol industry, isolating and separating components of distillers grains plus solubles (DGS) is becoming more prevalent. These changes may influence the use of DGS in feedlot diets. Currently, ethanol plants are able to separate a portion of the protein from DGS for use in alternative markets. Previous research has examined the fiber, protein, and fat of DGS. Lodge et al. (1997) evaluated composites of DGS using wet corn gluten feed, condensed distillers solubles (CDS), corn gluten meal (CGM), and tallow formulated to be similar in nutrient profiles as wet DGS (WDGS). The feeding value of the composite DGS and WDGS, both included at 40% of the diet (DM basis), were 124% and 131% relative to corn (Klopfenstein et al., 2008). The feeding value of only protein or only fat from DGS were both 118% relative to corn. Oglesbee et al. (2016) combined 17.5% CGM, 14% corn bran, and 3% solvent extracted germ meal (DM basis) to replicate the protein and fiber portions of DGS. The feeding value, calculated from performance data, for WDGS, fiber component, and protein component were 130%, 83%, and 121%, respectively, relative to corn. Conroy et al. (2016) isolated protein, fiber, and CDS from DGS. The feeding values for WDGS, protein, fiber, and CDS were 136%, 118%, 96%, and 82%, respectively, relative to corn. All authors concluded that protein and fat from DGS are the majority of the feeding value of DGS. Limited research has examined isolating only the protein portion of DGS. Further investigation on the relative contributions of the protein fraction from DGS is required to determine feeding value of protein from DGS.

The objectives of these experiments were to: isolate and evaluate the protein from DGS on animal performance and carcass characteristics in finishing diets (Exp 1);

evaluate protein from DGS on site and extent of nutrient digestibility (Exp 2); and evaluate protein from DGS effect on ruminal VFA concentration and pH (Exp 3).

MATERIALS AND METHODS

All procedures involving animal care and management were approved by the University of Nebraska's Institutional Animal Care and Use Committee.

Experiment 1

Crossbred calf-fed steers [n = 324; 291 kg (SD = 24) initial BW] were utilized in a generalized randomized block design at the University of Nebraska Panhandle Research and Extension Center feedlot (Scottsbluff, NE). Before the start of the experiment, steers were received, given an identification tag, and vaccinated with an infectious bovine rhinotracheitis, parainfluenza-3, bovine viral diarrhea virus, bovine respiratory syncytial virus modified live virus vaccine (Bovi-Shield Gold 5 Way; Pfizer Animal Health, New York City, NY), vaccinated with a *Clostridium chauvoei*, *C. septicum*, *C. novyi*, *C. sordelli*, *C. perfringens* types C and D bacterin toxoid (Vision 7 Somnus with spur; Merck Animal Health, De Soto, KS), and treated with Ivomec (Ivomec; Merial, Duluth, GA) for internal and external parasite control. Steers were limit-fed (2% of BW) a diet consisting of 15% straw, 25% alfalfa hay, 35% corn silage, and 25% WDGS (DM basis) for five d prior to weighing to equalize gut fill (Watson et al., 2013). Steers were individually weighed using a hydraulic squeeze chute with load cells mounted on the chute (Silencer, Moly Manufacturing Inc., Lorraine, KS: scale readability ± 0.45 kg) for two consecutive days (d 0 and 1) to establish initial BW (Stock et al., 1983). Steers were blocked by BW into two blocks (light and heavy) and stratified by BW within block, and assigned randomly to 36 pens.

Pens were assigned randomly to one of six dietary treatments with six replications per treatment and 9 steers per pen. Dietary treatments are provided in Table 3.1. In the experimental diets, the protein portion of WDGS was mimicked by CGM (74.2% CP, 7.0% NDF, 3.5% fat) to provide similar protein as 20 and 40% WDGS. Corn gluten meal is produced from the wet milling processing of corn grain. Corn gluten meal is high in protein, approximately 68% CP (NASEM, 2016). Previous work has estimated that the percentage of rumen undegradable protein (RUP) from CGM ranges from 46-86% (% of CP; Zinn et al., 1981; Stern et al., 1983; Titgemeyer et al., 1989). The most current RUP estimate is 69% of CP (NASEM, 2016). Therefore, the protein component of distillers grains could be examined without the addition of other components (i.e. fiber and fat). Diets were formulated to provide 360 mg/steer of Monensin (Rumensin, Elanco Animal Health) and 90 mg/steer of Tylosin (Tylan, Elanco Animal Health) daily via micro-machine.

Steers were implanted on d 1 with 16 mg of estradiol and 80 mg of trenbolone acetate (Component TE-IS, Elanco Animal Health) and re-implanted with 24 mg of estradiol and 120 mg of trenbolone acetate (Component TE-S, Elanco Animal Health) on d 90. Steers were individually weighed once at the end of the experiment, and a 4% pencil shrink was applied for calculation of final live BW. Carcass-adjusted performance was calculated using HCW adjusted to a common dressing percent of 63%.

Feed bunks were assessed at approximately 0600 h and managed for trace (≤0.2 kg/steer) amounts of feed remaining in the bunk each morning at time of feeding. Feed was delivered with a truck mounted mixer and delivery unit (Roto-Mix model 274, Roto-Mix, Dodge City, KS; scale readability ± 0.91 kg) each morning at 0800 h. Steers were adapted to finishing diets over a 21-d period with a series of 4 diets containing 20, 15, 10,

and 5% of both alfalfa hay and wheat straw for 3, 4, 7, and 7 d, respectively, with DRC replacing alfalfa hay and wheat straw. Concentration of wet distillers grains with solubles (20 and 40%; WDGS; Bridgeport Ethanol LLC, Bridgeport, NE; 31.1% CP, 29.8% NDF, 7.4% fat), corn silage (15%), and liquid supplement (6%) were included at the same concentration in the adaptation diets as the finishing diets (DM basis; Table 3.1). Corn gluten meal (ADM Corn Processing, Columbus, NE; 81.4% DM, 74.2% CP, 7.0% NDF, 3.5% fat) was included in the DRC-based diets at 8.75 or 17.50% (DM basis), respectively, replacing corn. The CGM used in Exp 1 was delivered as needed from November 2014 until May 2015 and was stockpiled in a concrete bunker silo through the remainder of the experiment. The CDS (Bridgeport Ethanol LLC, Bridgeport, NE; 19.3% CP) used in Exp 1 was stored in liquid bulk tanks. The liquid supplement for CON contained 1.34% Ca to meet the NRC (1996) requirements and 1.3% urea (DM basis) to meet or exceed rumen degradable protein requirements (NRC, 1996). The liquid supplement for 20DGS, 40DGS, LOW-CGM, HIGH-CGM, and CGM-CDS contained 1.4% limestone (71% Ca by atomic weight) to meet the NRC (1996) requirements. Ingredient and diet samples were collected weekly and dried in a 60°C forced-air oven for 48 h to determine DM of the samples (AOAC International, 1997; Method 930.15). Composited ingredient samples were sent to a commercial laboratory (Servi-Tech Laboratories, Hastings, NE) and analyzed for CP (AOAC International, 2000; Method 990.03), NDF (ANKOM, 2006), ether extract (AOAC International, 2006; Method 2003.6), Ca, P, S (Mills and Jones, 1996), and total starch (AOAC International, 2000; Method 996.11) content. Dry-rolled corn was processed at the research feedlot using a roller mill.

Cattle were shipped according to projections made utilizing interim BW and ADG to target a final BW of 635 kg. Steers were harvested at a commercial abattoir (Cargill Meat Solutions, Fort Morgan, CO) on d 182 (heavy block) and d 193 (light block). All carcass data were collected by Diamond T Livestock Services (Yuma, CO). Hot carcass weight and liver scores were recorded on day of harvest. After a 48-h chill, LM area, marbling score, and 12th-rib fat were recorded. Yield grade was calculated from the following formula: 2.50 + (6.35 x 12^{th} rib fat thickness, cm) + (0.2 x 2.5 [KPH]) + (0.0017 x HCW, kg) - (2.06 x LM area, cm^2) from USDA (1997). Final BW was carcass-adjusted using HCW and a common dressing percent (63%) to calculate ADG and G:F. Hot carcass weights were used to reduce errors associated with gut-fill differences among dietary treatments (Meyer et al., 1960; Watson et al., 2013). Feeding value was calculated from the following formula: [((compared treatments G:F – CON G:F) / CON G:F) / compared treatments inclusion rate*100 + 100]. Dietary NEm and NEg values were calculated for each treatment based on intake and performance of cattle. These data were analyzed as dietary NE for each pen, similar to performance data using equations from the NRC (1996) as described by Vasconcelos and Galyean (2008).

Performance and carcass characteristics were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.) with pen as the experimental unit. The model included block and dietary treatment as a fixed effects. Liver abscesses were analyzed as a binomial response using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, N.C.) with animal as the experimental unit. The model included block and dietary treatment. Dead or chronic steers were removed from analysis. Five steers were removed from the experiment due to injury or respiratory issues. Two steers were

removed from the experiment from CON due to chronic illness. One steer was removed from the experiment from HIGH-CGM treatment due to a broken leg. One steer was removed from CGM-CDS due to ruptured internal organs. Linear and quadratic contrasts were developed to compare DGS concentration (20 vs. 40) and protein concentration. Pairwise comparisons were pre-planned to determine the addition of CDS (HIGH-CGM vs. CGM-CDS) and feeding value of protein from DGS (20DGS vs. LOW-CGM; 40DGS vs. HIGH-CGM). Treatment differences were considered significant when $P \leq 0.05$ with tendencies between $P > 0.05$ and $P \leq 0.10$. Treatment comparisons were made using pair-wise comparisons when the *F*-test statistic was significant.

Experiment 2

Six duodenally fistulated crossbred steers (380 kg initial BW; SE = 50) were utilized in an unbalanced 6 × 6 row-column design, with six periods and four treatments, at the University of Nebraska Metabolism Lab (Lincoln, NE). Each period consisted of 21-d with 16-d adaptation followed by a 5-d collection period. Dietary treatments were similar to Exp. 1 (Table 3.2). Modified distillers grains plus solubles (MDGS; Flint Hills Resources, Fairmont, NE; 34.1% CP, 38.5% NDF, 10.8% fat) was utilized in Exp 2 and Exp 3. Diets were offered once daily at 0800 allowing for ad libitum intake. Feed refusals were collected from d 16 to 20, weighed, and subsampled to determine nutrient intake. Steers were individually housed in 2.1 x 3.7 m pens equipped with slatted floors and given ad litbitum access to water. All diets contained 5% dry meal supplement that provided 375 mg/steer daily of monensin (Rumensin; Elanco Animal Health, Greenfield, IN) and 90 mg/steer daily of tylosin (Tylan; Elanco Animal Health). Supplements were mixed weekly in a mobile ribbon mixer (model L-1000A Food Mixer; Leland Detroit

Manufacturing Co., Fort Worth, TX) and stored in 37-L barrels. The barrels were stored at room temperature (20°C). Diets were mixed weekly in a stationary ribbon mixer (model S-5 Mixer; H.C. Davis Sons Manufacturing Co., Inc., Bonner Springs, KS) and stored in 200-L barrels. The barrels were stored in a cooler held at 4°C to ensure diet quality was maintained.

Fecal output was estimated by top dressing titanium dioxide (TiO_2; 10 g/d) at time of feeding (0800) throughout the period. Fecal and duodenal samples were collected from d 17 to 21 at 0800, 1200, 1600 h. A single 250-mL fecal aliquot and two 250-mL duodenal aliquots were retained from each collection. Fecal samples were composited by day (wet weight basis) within steer, lyophilized (Virtis Freezemobile 25ES; Life Scientific, Inc., St. Louis, MO), and ground through a 1-mm screen using a Wiley mill (number 4; Thomas Scientific, Swedesboro, NJ). The lyophilized and ground daily composites were then composited on a dry weight basis by steer within collection period. Fecal samples were analyzed for TiO_2 concentration as described by Myers et al. (2004). Concentration of TiO_2 was then used to calculate fecal DM output using the following equation (Cochran and Galyean, 1994): g marker dosed per d/concentration of marker in feces.

One 250mL duodenal sample was stored at 4°C. The second 250mL duodenal sample was lypholized (Virtis Freezemobile 25ES; Life Scientific, Inc.) and ground through a 1-mm screen using a Wiley mill (number 4; Thomas Scientific). The steer x h sample was then composited on an equal dry weight basis by collection period. Duodenal samples were analyzed for TiO_2 concentration as described by Myers et al. (2004). Concentration of TiO_2 was then used to calculate OM flow using the following equation

(Cochran and Galyean, 1994): g marker dosed per d/concentration of marker in duodenal sample.

Individual feed ingredients were dried in 60°C forced-air oven (model LBB2-21-1; Despatch Industries) for 48 h (AAOC, 1965; method 935.29) weekly to ensure that accurate DM were used when mixing dietary treatments. Samples of individual ingredients were taken prior to mixing diets, composited by period, lyophilized (Virtis Freezemobile 25ES; Life Scientific, Inc.), and ground through a 1-mm screen using a Wiley mill (number 4; Thomas Scientific). Feed samples were analyzed for OM, CP, NDF, fat, and starch to calculate nutrient composition of dietary treatments (Table 3.2). Duodenal and fecal samples were analyzed for DM, OM, NDF, and starch. Laboratory DM was determined after drying in a 100°C forced-air oven for 24 h (AOAC, 1990; methods 930.15). Ash and OM were determined by placing samples in a muffle furnace for 6 h at 600°C (AOAC, 1999; method 4.1.10). Crude protein was determined by using a combustion chamber (TruSpec N Determinator; Leco Corporation, St. Joseph, MI; AOAC, 1999; method 990.03). Neutral detergent fiber analysis was conducted using the procedure described by Van Soest et al. (1991) with modifications to the analysis of corn and byproducts described by Buckner et al. (2013). The modifications applied to corn prior to NDF analysis consisted of grinding corn through a 0.5-mm screen fitted on a Tecator Cyclotec Mill (ThermoFisher Scientific, Eden Prairie, MN). Additionally, 2 doses (0.5 mL/dose) of α-amylase (catalog number FAA; ANKOM Technology, Macedon, NY) were added during the hour boil in NDF solution. The modification applied to the byproducts was a biphasic lipid extraction (Bremer et al., 2010) prior to NDF analysis (Buckner et al., 2013). Ether extract was determined by a biphasic lipid

extraction procedure described by Bremer (2010). Briefly, samples were heated in a 1:1 mixture of hexane and diethyl ether for 9 h, dilute HCl was added, and samples were centrifuged to separate the lipid layer from other liquid. Lipid layer was pipetted off, heated to drive off remaining solvent, and weighed. Starch content was determined using spectrophotometry (Spectra Max 250 Spectrometer, Molecular Devices, Sunnyvale, CA) after converting starch to glucose using an enzyme kit (Megazyme International Ireland Ltd., Wicklow, Ireland; method 996.11; AOAC, 2003).

Nutrient composition of dietary treatments and feces were used to calculate total tract digestibility of DM, OM, NDF, and starch. Total tract digestibility was calculated using the following equation (Cochran and Galyean, 1994): [(kg of nutrient fed − kg of nutrient refused – kg of nutrient in feces)/(kg of nutrient fed − kg of nutrient refused)] × 100. Steers from Exp. 2 were only duodenally fistulated. Experiment 3 was conducted to provide a purine:nitrogen ratio in order to account for microbial nutrient contributions. True ruminal digestibility was calculated as the difference between the amount of nutrient ingested and the amount present at the duodenal cannula after correcting for microbial nutrient contributions.

Throughout the experiment, challenges resulted from issues with either duodenal cannulae or animal health. After the fourth period, 4 animals had been removed over the course of the trial. Overall, eight experimental observations were removed from the initial 6 periods. A seventh and eighth period were added to provide additional replications/treatment. As a result of complications with animals, nutrient digestibility data were analyzed as a Row x Column design with 4 dietary treatments (CON, 40DGS, HIGH-CGM, and CGM-CDS) and 8 periods using the MIXED procedures of SAS (SAS

Inst. Inc., Cary, NC). Steer within period was the experimental unit. Steer was included in the random statement. The model included treatment and period as independent fixed effects. Treatment differences were considered significant when $P \leq 0.10$ with tendencies between $P > 0.10$ and $P \leq 0.15$.

Experiment 3

Six ruminally fistulated crossbred steers (350 kg initial BW; SD = 43) were utilized in an unbalanced 6 × 6 row-column design, with six periods and four treatments, at the University of Nebraska Metabolism Lab (Lincoln, NE). Each period consisted of 14-d with 11-d adaptation followed by collections from d 12 to 14. Exp. 3 was performed in order to measure ruminal pH, ruminal VFA concentrations, and correct for microbial cell flow into the duodenum in Exp 2. Corrections for microbial cells required isolating bacterial cells from rumen contents and analyzing purine:nitrogen. Dietary treatments were the same as Exp. 2 (Table 3.2). Experiment 3 was performed after Exp. 2. Diets were offered once daily at 0800 at ad libitum intake. Feed refusals were collected from d 11 to 13, weighed, and subsampled to determine nutrient intake. Steers were housed similar to Exp 2. Feed and supplement were mixed and stored similar to Exp 2. Supplement in Exp 3 included the same ingredients as Exp 2.

A suction strainer technique was used to collect rumen fluid samples (approximately 50 mL) at 0900, 1300, and 1700 h on d 12 and 0700 (1 h pre-feeding), 1100, 1500, and 1900 h on d 13 of each collection period. All 7 time points were combined to provide a 12 h measurement of VFA concentration. During each sampling, the suction probe was moved around the rumen to make sure a representative sample of rumen fluid was collected. Rumen fluid samples were immediately frozen after collection

and remained frozen until VFA concentration was measured. At the time of analysis, rumen fluid samples were thawed in a cooler (4°C) to ensure no additional fermentation occurred. After thawing samples were prepared according to Erwin et al. (1961) and analyzed for VFA concentration using a Trace 1300 gas chromatograph (Thermo Fisher Scientific, Inc., Omaha, NE) fitted with a Zebron capillary column (Phenomenex Inc., Torrance, CA; catalog number 7HM-G009-22). The column was 30 m in length with an inside diameter of 0.32 mm and a film thickness of 1 μm. Crotonic acid (catalog number 107- 93-7; Sigma-Aldrich, St. Louis, MO) was used as an internal standard for all samples. Each sample collected was analyzed twice for VFA concentration to ensure an accurate value was obtained. Total run time on the gas chromatograph was 9.75 min. During analysis, the inlet and flame ionization detector temperatures were held at 280°C. Oven temperature started at 160°C and increased 8°C per minute until it reached 200°C. Helium (catalog number SGSPPULW800P; Matheson Tri-Gas, Lincoln, NE) was used as the carrier gas. Column carrier flow was set at 2.4 mL/min. Flow rates of compressed air (catalog number SGSPPULW700; Matheson Tri-Gas) and hydrogen (catalog number SGSPPULW500P; Matheson Tri-Gas) were set at 350 and 30 mL/min, respectively.

Wireless pH loggers (Dascor, Inc., Escondido, CA) were placed in the rumen on d 7, prior to feeding, and recorded pH measurements every minute until d 14 of each collection period. Only pH measurements from d 10 to 13 were used to estimate rumen pH. Probes were attached to a weight to ensure the electrode remained in the ventral sac of the rumen. All probes were calibrated prior to being placed in the rumen each collection period by submersing them in pH 4 and 7 standard solutions. Ruminal pH

measurements from each period were adjusted using the beginning and ending calibration values. All pH data were exported onto a computer where data were sorted.

Samples of whole rumen (2 kg) contents were taken from the ventral portion of the rumen on d 14, blended (model NJ600WM 30 NINJA; Intertek, London, UK) into a homogenous mixture, strained through 4 layers of cheesecloth, and centrifuged to isolate bacterial cells (Leupp et al., 2009). Whole rumen contents were flash frozen using liquid nitrogen for isolation of bacterial cells. Samples were blended on high speed for 1 min and strained through 4 layers of cheesecloth. Liquid was then placed in 250-mL centrifuge bottles and centrifuged at 500 × *g* for 20 min at 4°C to remove feed particles and protozoa. Supernatant was removed and centrifuged again at 500 ×*g* for 20 min at 4°C. Bacteria were separated from free supernatant by centrifuging at 30,000 × *g* for 20 min at 4°C and were subsequently frozen at −4°C and lyophilized. Duodenal contents from Exp. 2 and ruminal bacterial isolates from Exp. 3 were analyzed for purine concentration to determine microbial flow using a modified Zinn and Owens (1986) procedure with a more dilute HClO4 to hydrolyze material containing purines (as described by Crawford et al., 2008). Purine concentration was determined on a spectrophotometer (Spectra Max 250 Spectrometer, Molecular Devices) at 260 nm.

Throughout the experiment, challenges resulted from issues with animal health. After the first period, one animal was removed. After the fifth period, one animal was removed. As a result, one observation from CON and 40DGS and two observations from CGM-CDS were not analyzed. Data for VFA concentration and average ruminal pH were analyzed as a repeated measure using the MIXED procedure of SAS. Time within day was the repeated measure. The model included day, time, treatment, and all resultant

interactions, in addition to period as an independent fixed effect. Data for all other ruminal pH traits were analyzed using the MIXED procedure of SAS. The model included treatment and period as an independent fixed effect. Six covariance structures were tested (unstructured, variance components, Cholesky, autoregressive, Toeplitz, and compound symmetry), and the structure that resulted in the lowest Bayesian information criterion (compound symmetry) was determined the best fit (Littell et al., 1998). Treatment differences were considered significant when $P \leq 0.10$ with tendencies between $P > 0.10$ and $P \leq 0.15$.

RESULTS AND DISCUSSION

Experiment 1

Linear and Quadratic Responses for CON, 20DGS, and 40DGS

There was a tendency for a linear increase for final BW (600 vs. 613 kg for CON vs. 40DGS, respectively; $P = 0.06$) due to WDGS inclusion (Table 3.3). As WDGS inclusion increased from 0 to 40%, DMI decreased linearly (10.3 vs. 9.7 kg for CON vs. 40DGS, respectively; $P < 0.01$) with a tendency for a linear increase in ADG (1.65 vs. 1.71 kg for CON vs. 40DGS, respectively; $P = 0.06$). Increasing WDGS inclusion linearly improved G:F (0.161 vs. 0.176 for CON vs. 40DGS, respectively; $P < 0.01$). These results support previous data with varying levels of WDGS (Firkins et al., 1985; Ham et al., 1994; Watson et al., 2014; Oglesbee et al., 2016). Cattle fed 20DGS and 40DGS had a feeding value of 134% and 125% relative to corn, respectively. This is comparable to the meta-analysis by Klopfenstein et at. (2008), which reported feeding value of 40% WDGS was 131% compared to corn. As WDGS inclusion increased, HCW tended ($P = 0.06$) to increase. All other carcass traits were not impacted ($P \geq 0.21$) by

WDGS inclusion. There was no difference ($P > 0.19$) in liver abscess scores among CON, 20DGS, and 40DGS.

Linear and Quadratic Responses for Protein

The protein portion of WDGS was mimicked by CGM at concentrations equal to the protein contained in 20 and 40% WDGS. Increasing protein concentrations quadratically increased ($P = 0.04$) final BW (Table 3.4). Cattle fed HIGH-CGM were 16 kg heavier compared to CON. There were no differences ($P \geq 0.13$) in DMI between CON, LOW-CGM and HIGH-CGM. Gain increased quadratically ($P = 0.04$) as CGM increased. Cattle fed 17.5% CGM (protein concentration equal to 40% WDGS) gained 1.73 kg/d compared to CON which gained 1.65 kg/d. As protein increased in the diet, G:F increased linearly (0.161 vs. 0.169 for CON vs. HIGH-CGM, respectively; $P < 0.01$). There was a quadratic increase ($P = 0.04$) for HCW with steers fed HIGH-CGM having the greatest HCW at 388 kg compared to CON and LOW-CGM. There were no differences ($P = 0.12$) in dressing percent as protein increased. There tended to be a quadratic increase ($P < 0.10$) in LM area with HIGH-CGM having the largest LM area, CON intermediate, and LOW-CGM with the smallest. There were no differences ($P \geq 0.22$) in calculated yield grade and 12^{th} rib fat among CON, LOW-CGM, and HIGH-CGM. Marbling tended to increase linearly ($P = 0.10$) as protein concentration increased. There were no differences ($P = 0.19$) for liver abscesses between CON, LOW-CGM, and HIGH-CGM.

Several studies have fed cattle concentrations of DGS to exceed the cattle's' MP requirement and reported greater energy per kg of DM for distillers grains or DGS than corn it replaced (Farlin et al., 1981; Firkens et al., 1985; Larson et al., 1993; Ham et al.,

1994; Trenkle et al., 1997). In the current experiment, all diets were formulated to meet or exceed metabolizable protein requirements (NRC, 1996). Based on animal performance and nutrient analysis, MP balance was calculated using equations from NRC (1996). Cattle consuming CON, 20DGS, and LOW-CGM had an MP balance of -9, 118, and 208 g/kg $SBW^{0.75}$, respectively. Likewise, cattle consuming 40DGS, HIGH-CGM, and CGM-CDS had 301, 477, and 443 g/kg $SBW^{0.75}$, respectively. Therefore, improvements in animal performance over corn is a result from excess protein, primarily RUP, being utilized more efficiently than the corn it replaced. These results indicate an energy response for CGM, not a protein response.

HIGH-CGM vs. CGM-CDS

The addition of 10% CDS (CGM-CDS) decreased final BW (602 vs. 616 kg, respectively; $P = 0.04$) compared to HIGH-CGM (Table 3.4). Conroy et al. (2016) observed a similar response when 10% CDS was added with 14% CGM in a corn-based diet. In that study, compared to 10% CDS only, the addition of 14% CGM increased DMI but ADG and G:F were not different. In this experiment, DMI tended to be lower ($P = 0.08$) for cattle fed CGM-CDS compared to HIGH-CGM. Average daily gain decreased for CGM-CDS, with steers gaining 1.66 kg/d in comparison to 1.73 kg/d for steers fed HIGH-CGM ($P = 0.08$). In a similar experiment by Oglesbee et al. (2016), the addition of 8% CDS to a distillers grains fiber composite diet resulted in improved DMI and ADG. The authors reported no difference ($P = 0.32$) in G:F between HIGH-CGM and CGM-CDS. Olgesbee et al. (2016) observed no effect of CDS on G:F. Conroy et al. (2016) observed poorer G:F when 10% of corn was replaced with CDS. Supplementing CDS decreased ADG and DMI at a similar rate, which did not change G:F. Condensed

distillers solubles has variable impacts on performance when combined with DGS composite diets. Belyea et al. (1998) examined the variability in distillers solubles from one wet milling ethanol plant. The authors found that metabolizable energy of CDS (2400 kcal/kg) was lower than corn (3400 kcal/kg). Although the CDS from their experiment was derived from the wet milling industry similar sources of variation could be observed from dry milling plants. Potential variability between ethanol plants may help explain the differences observed between the current trial and Olgesbee et al., (2016) and Conroy et al. (2016). Compared with HIGH-CGM, feeding CGM-CDS decreased HCW (379 vs. 388 kg, respectively; $P = 0.04$), Conroy et al. (2016) observed a numerical decrease of 8 kg with the inclusion of 10% CDS. The addition of 10% CDS tended to decrease dressing percent (63.0% vs. 63.5%, respectively; $P = 0.06$) compared to HIGH-CGM. There were no differences ($P \geq 0.21$) in LM area and calculated yield grade between HIGH-CGM and CGM-CDS. There was a decrease in 12th rib fat (1.16 vs. 1.29 cm, respectively; $P = 0.05$) for CGM-CDS compared to HIGH-CGM. There were no differences ($P \geq 0.19$) in marbling score and liver abscesses between both HIGH-CGM and CGM-CDS. The result of poorer ADG lead HCW, dressing percent, and 12th rib fat to decrease compared to HIGH-CGM. However, recent data with the addition of lower inclusion levels of CDS (approximately 10%) in DGS-based diets appears to have variable impact on performance and carcass characteristics (Oglesbee et al., 2016; Conroy et al., 2016). Further research may need to be performed studying the interactions of CDS with DGS composite diets.

20DGS vs. LOW-CGM

Isolating the protein portion of 20% WDGS by feeding 8.75% CGM (LOW-CGM) decreased final BW (596 vs. 608 kg, respectively; $P = 0.05$) compared to 20DGS (Table 3.5). There were no differences ($P = 0.16$) in DMI between 20DGS and LOW-CGM. Steers fed LOW-CGM tended to have decreased ADG (1.63 vs. 1.69 kg, respectively; $P = 0.09$) compared to 20DGS. This resulted in steers fed LOW-CGM being 5.8% less efficient than steers consuming 20DGS (0.162 vs. 0.172, respectively; $P < 0.01$). Lodge et al. (1997) fed 10.5% CGM to steers as part of a DGS composite treatment. When CGM was removed from the diet, the feeding value of the DGS composite without CGM decreased from 124 to 118%, respectively. This suggests that protein in the DGS composite contributed a majority of the feeding value observed for the DGS composite. In the current experiment, the feeding value for protein was less than that of WDGS (110 vs. 134% for LOW-CGM vs. 20DGS, respectively) relative to corn. Lower inclusion rates of protein (i.e. LOW-CGM) do not provide excess MP which can be used as energy. Therefore, within lower inclusion rates of DGS, protein will contribute less towards the feeding values compared to greater inclusion rates of DGS. There was a tendency for decreased HCW ($P = 0.09$) for LOW-CGM compared to 20DGS. All carcass traits and liver abscess scores were not different ($P \geq 0.17$) between 20DGS and LOW-CGM.

40DGS vs. HIGH-CGM

When comparing 40% WDGS to HIGH-CGM, there were no differences ($P = 0.65$) in final BW; however, steers fed HIGH-CGM consumed 0.5 kg/d more than 40DGS (10.2 vs. 9.7 kg, respectively; $P < 0.01$; Table 3.5). There were no differences ($P = 0.61$) for ADG between 40DGS and HIGH-CGM. This translated into steers

consuming 40DGS having improved G:F values compared to HIGH-CGM (0.176 vs. 0.169, respectively; $P < 0.01$). Lodge et al. (1997) compared a distillers composite treatment containing 12.2% CGM to 40% DDGS in finishing lamb diets. There was no difference in lamb finishing performance between a distillers composite diet with 12.2% CGM and 40% DDGS. Unlike the LOW-CGM vs. 20DGS comparison, the feeding value of protein was greater than WDGS (129 vs. 125% for HIGH-CGM vs. 40DGS, respectively). The MP requirements of the animals for both 40DGS and HIGH-CGM were met according to NRC (1996). Improved feeding values for protein were a result of excess RUP being digested. deaminated and used by the animal for energy. Therefore, similar feeding values for 40DGS and HIGH-CGM demonstrated feeding greater levels of protein meet the protein requirements of the animal and supplied additional energy. Oglesbee et al. (2016) reported the feeding value of a diet with 17.5% CGM was 121%, which was lower than WDGS at 130% the value of corn. The addition of CGM to the composite DGS diet increased the feeding value by 30%, which was the animals' response to additional energy being provided by excess RUP from CGM. In this experiment there were no differences ($P \geq 0.26$) for carcass traits or liver abscess scores between 40DGS and HIGH-CGM.

Displacing a portion of corn grain with other feed ingredients, such as CGM or CDS, was considered when designing the experimental treatments. The inclusion of 26-50.9% (DM basis) corn grain in calf-fed diets leads to improved feed efficiency compared to inclusions greater than 50.9% corn (Watson et al., 2016). In the current experiment the CGM diets replaced only 8.75 and 17.5% of corn compared to the WDGS diets which replaced 20 and 40%. This did not affect the comparison between 20DGS

and LOW-CGM (59.00 vs. 70.25% DRC, respectively). This may have affected G:F between the HIGH-CGM and 40DGS (61.50 vs. 39.00% DRC, respectively) comparison since 40DGS had considerably less corn grain in the diet. This means that part of the G:F response observed by HIGH-CGM may have come from lower inclusion of corn and not entirely from excess RUP.

Experiment 2 and 3

Nutrient intake and digestibility data are presented in Table 3.6 for Exp 2. Dry matter intake was greater ($P = 0.08$) for 40DGS compared to HIGH-CGM and CON, but not different than CGM-CDS. Greater DMI for DGS based diets compared to corn has been well documented in previous research (Klopfenstein et al., 2008). Corrigan et al. (2009), observed an increase of 1.5 kg for OM intake (OMI) when steers consumed 40% WDGS (DM basis) compared to corn. In this study, OMI was numerically greater ($P = 0.17$) for 40DGS compared to CON (7.4 vs. 6.6 kg; respectively) suggesting cattle on 40DGS had intakes that previous data support (Klopfenstein et al., 2008). Neutral detergent fiber intake was greater ($P < 0.01$) for 40DGS than all other treatments. The 40DGS diet had approximately twice the NDF content of CON, HIGH-CGM, and CGM-CDS (26.1 vs. 14.8, 13.6, and 13.2% NDF; respectively). Corrigan et al. (2009) and Vander Pol et al. (2009) both reported similar results, NDF intake for cattle consuming 40% WDGS was greater than corn diets. In the current study, starch intake was greatest ($P < 0.01$) for CON and HIGH-CGM with CGM-CDS greater than 40DGS. Previous work has reported starch intake to be lowered with increased levels of DGS (Corrigan et al., 2009, Luebbe et al., 2012, and Vander Pol et al., 2009). Replacing 10% of DRC with

CDS reduced the starch content in the diet by 12.7% and subsequently lowered starch intake by 8.6%.

Fecal DM, OM, NDF, and starch output were greater ($P < 0.08$) for 40DGS compared to other treatments. This can be explained by OMI being numerically greater for 40DGS and total tract digestibility for OM and starch being lower for steers fed 40DGS. Flow of feed OM, bacterial OM, total OM, NDF, and starch into the duodenum were not different ($P \geq 0.52$; Table 3.7) among treatments. Although cattle fed 40DGS had numerically greater feed OM, likely due to the greater DMI of cattle consuming 40DGS compared to CON, HIGH-CGM, and CGM-CDS.

There was no difference ($P = 0.16$) in total tract DM digestibility between treatments, but 40DGS was numerically lower than all other treatments. A similar relationship was observed for total tract OM digestibility, which tended to be lower ($P < 0.14$) for 40DGS compared other treatments (Table 3.6). A similar response was observed for Corrigan et al. (2009), who reported lower total tract OM digestibility for 40% WDGS compared corn-based diets. Total tract OM digestibility for DGS in the current study is similar to Corrigan et al. (2009) and Luebbe et al. (2012; 76.0% vs. 79.3 and 78.6%, respectively). Klopfenstein et al. (2008) reported that DGS improves ADG and G:F compared to corn, while having lower digestibility than corn. Hamilton et al. (2016) suggest that diets containing DGS have additional digestible energy supplied by DGS that is not accounted for when evaluating only digestible OM. The relationship of digestible OM and digestible energy from Hamilton et al. (2016) supports the results from the current studies with lower OM digestibility for cattle fed 40DGS than cattle fed CON (Exp 2) and cattle fed 40DGS had better ($P < 0.01$) G:F and tended ($P = 0.06$) to

have improved ADG compared to cattle fed CON (Exp 1). Therefore, less of the OM was digested in the DGS diet but the DGS diet supplied more energy that the animal could use for growth. There was no difference in total tract NDF digestibility ($P = 0.53$) among treatments. Steers consuming 40DGS and CGM-CDS had numerically greater total tract NDF digestibility compared to CON and HIGH-CGM (59.3 and 55.9 vs. 47.9 and 48.0%, respectively). Total tract starch digestibility was lower ($P < 0.01$) for 40DGS compared to other treatments. Distillers grains plus solubles contains less starch as a result of starch fermentation for ethanol production. The small amount of starch available in DGS may be difficult to access and have lower digestibility by the animal, as well as microbes, because the ethanol plant already exposed the starch to yeast and other microbes during ethanol production. Ham et al. (1994) observed an improvement in total tract starch digestion when wet distillers grains was paired with thin stillage. Other than DM, thin stillage and CDS should have similar nutrient profiles. In the current study, the addition of CDS (32.4% CP, 4.7% NDF, and 6.7% fat) to HIGH-CGM did not negatively affect starch digestion. Vander Pol et al. (2009) suggests that supplemental corn oil impedes starch digestibility relative to fat supplied by CDS or WDGS. In the current study, additional oil from CDS was likely separated off by centrifugation. According to Jolly et al. (2013), 50% of ethanol plants were removing additional corn oil from CDS in 2012. In this study, the concentration of fat (6.7% DM basis) from CDS may not have been enough to limit total tract starch digestion.

Ruminal and post ruminal apparent and true OM, NDF, and apparent and true starch digestibility were not different ($P > 0.18$) among treatments (Table 3.7; Exp 2). Ruminal NDF digestibility was numerically greater ($P = 0.35$) for 40DGS compared to

CON, HIGH-CGM, and CGM-CDS (65.9 vs. 44.6, 51.1, and 49.2 %; respectively). Both Vander Pol et al. (2009) and Luebbe et al. (2012) observed numerical improvements for ruminal NDF digestibility for inclusions of 40-45% WDGS compared to DRC (14.8 and 16.5 percent unit increase, respectively). Luebbe et al. (2012) suggest greater ruminal NDF digestibility may be the result of a dilution effect. As DGS replaces corn in the diet, the amount of starch decreases, which may promote an increase in ruminal NDF digestion. Corrigan et al. (2009) reported greater 22-h in situ NDF digestibility when samples (i.e. DRC, WDGS, corn bran) were incubated in steers fed 40% WDGS compared to corn-based diets. Therefore, as DGS concertation increases, the rumen environment appears to be more favorable and promotes greater NDF digestibility. Postruminal OM digestibility was numerically (P = 0.18) lower for 40DGS compared to CON, HIGH-CGM, and CGM-CDS (47.7 vs. 61.3, 64.0, and 69.4%; respectively). We measured a bacterial purine:N ratio of 0.1 from our rumen samples. We believe that this ratio is not accurate because it overestimated bacterial OM flow from the duodenum. Overestimated bacterial OM flow resulted in relatively high microbial efficiency estimates. Based on findings from Cooper et al. (2002), we decided to adjust the data using an assumed purine:N ratio of 0.3. Microbial CP flow through the duodenum was not different (P = 0.88) among treatments. Microbial efficiency was calculated using g of microbial CP divided by g of fermentable OM in the rumen. There was no difference (P = 0.72) in microbial efficiency among treatments.

Dry matter intakes for Exp 3 were similar to Exp 2 (Table 3.8) with cattle consuming 40DGS (P = 0.06) having the greatest DMI. Unlike Exp 2 where cattle fed CON had the lowest DMI, in Exp 3 cattle fed CGM-CDS tended to have the lowest DMI.

Hour within day was evaluated for average ruminal pH and a treatment × h interaction ($P < 0.01$; Figure 3.1) was observed. At time of feeding (0800) and for 2 h after, cattle consuming the CON treatment had a greater pH ($P = 0.01$) than HIGH-CGM and CGM-CDS. Cattle fed 40DGS had lower ruminal pH ($P = 0.01$) than cattle fed CON treatment from 0900 to 1100. At 1100, cattle fed CON treatment had the greatest ruminal pH ($P < 0.04$), 40DGS was greater than HIGH-CGM, and CGM-CDS was intermediate between CON and 40DGS. At 4 and 5 h post-feeding, cattle fed CON, 40DGS, and CGM-CDS treatments had no difference ($P > 0.07$) in ruminal pH, whereas cattle fed HIGH-CGM maintained a lower ruminal pH ($P < 0.05$). From 1400 to 1600, cattle consuming CON, 40DGS, and CGM-CDS were not different ($P > 0.07$); however, cattle consuming HIGH-CGM had a lower ruminal pH ($P < 0.04$). Ruminal pH was not different ($P > 0.05$) between treatments from 1700 to 0200. Cattle consuming CON, 40DGS, and HIGH-CGM had no difference ($P > 0.06$) in rumen pH from 0300 to 0700, whereas cattle on the CGM-CDS treatment maintained a lower pH ($P < 0.05$).

The addition of CGM to the diet appears to have an impact on ruminal pH. The ruminal pH response cannot be explained by DMI. Cattle consuming HIGH-CGM had similar DMI as cattle fed CON and cattle fed CGM-CDS consumed less DM than cattle fed HIGH-CGM and CON. Therefore, factor(s) other than DMI were likely the cause of lower ruminal pH for both CGM treatments. Time below pH 5.6 was not different among treatments however, area below pH 5.6 was greater for CGM diets. These results suggest all cattle were exposed to subacute acidosis for a similar amount of time but CGM fed cattle were subjected to a lower pH at time of subacute acidosis compared to CON and 40DGS fed cattle.

Acetate molar proportion was not different ($P = 0.18$) between treatments. Propionate molar proportion had a treatment × h interaction (Figure 3.2; $P = 0.09$). From 1 h to 11 h post-feeding, propionate molar proportion remained greatest ($P < 0.09$) for HIGH-CGM compared to all other treatments. Butyrate molar proportion had a treatment × h interaction (Figure 3.3; $P = 0.03$). From 1 to 11 h post-feeding, butyrate molar proportion remained lowest ($P < 0.08$) for HIGH-CGM compared to all other treatments. Acetate:Propionate ratio was lower ($P = 0.08$) for HIGH-CGM compared to the other treatments. Total VFA concentration had a treatment × h interaction (Figure 3.4; $P = 0.10$). At 1300, CON and HIGH-CGM were the greatest ($P = 0.10$) total VFA concentration with 40DGS and CGM-CDS were the lowest VFA concentrations. At 1500, CON had the greatest ($P = 0.05$) total VFA concentration, 40DGS had the lowest, and HIGH-CGM and CGM-CDS were intermediate. At 1700, HIGH-CGM had the greatest ($P = 0.03$) total VFA concentration, 40DGS and CGM-CDS had the lowest, and CON was intermediate. The time points for peak total VFA concentration for HIGH-CGM agree with the pH data. The pH for HIGH-CGM was lowest from 4 to 8 h post-feeding and the total VFA concentration was greatest for HIGH-CGM 8 h post-feeding. Effects of HIGH-CGM on ruminal pH may be correlated with total VFA concentration. Russell (1998) reported approximately 25% of the change in A:P ratios are associated with lower ruminal pH. Cattle fed CGM had lower average ruminal pH and tended to have lower minimum ruminal pH than cattle fed CON and 40DGS. As described previously, lactic acid from CGM may have promoted rumen bacteria to produce propionate however, Exp. 3 only measured VFA concentration so it is difficult to explain why HIGH-CGM had greater propionate concentrations than the other treatments. This

helps explain the lower average ruminal pH for cattle fed HIGH-CGM. Since the protein content of CGM was greater than that of DGS, less CGM was required to match the CP of DGS in the diet. As a result, there was more starch and less NDF in both HIGH-CGM and CGM-CDS compared to 40DGS. When the primary energy source that the rumen microbial population uses changes from NDF to starch, the A:P ratio generally decreases (Grant, 1997; Coe et al., 1999; Sayer, 2004). The difference in NDF and starch intake for HIGH-CGM, compared to 40DGS, helps explain the increase in propionate concentration. Ham et al. (1994) reported lower propionate concentration and a greater A:P ratio for 40% wet distillers grains with 15% thin stillage compared to 15% thin stillage only in corn-based diets. With the exception of fat content and DM, CDS can have similar nutritive properties to thin stillage. The similarities of CDS and thin stillage may help explain the lower propionate and greater A:P ratio when CDS was added to HIGH-CGM. With these combinations of factors, it is difficult to specify why ruminal pH dropped for steers fed CGM diets. The trend line for total VFA concentration for each treatment was tested for linear and quadratic relationships. The total VFA concentration trend line for HIGH-CGM was quadratic ($P = 0.03$) and linear ($P = 0.05$) for CGM-CDS.

IMPLICATIONS

These studies provide further evidence that as DGS concentration increases in the diet, cattle have greater finishing performance even though digestibility of DGS is lower compared to corn. Similarly, isolating protein from DGS by utilizing CGM resulted in similar finishing performance. Protein from DGS did not contribute towards the lower digestibility of DGS. Providing excess RUP from DGS contributes greatly to the performance of DGS. The average feeding value for CGM at inclusion rates equal to the

protein in WDGS at 20 and 40% was 122. Wet DGS had an average feeding value of 128 at 20 and 40% inclusion rates. These results reaffirm that protein accounts for the majority of the feeding value response in DGS.

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Table 3.1. Composition of dietary treatments containing protein components of distiller grains fed to steers[1] (Exp. 1).

	Treatment					
Item	CON	20DGS	40DGS	LOW-CGM	HIGH-CGM	CGM-CDS
Ingredient, % DM[2]						
DRC	75.50	59.00	39.00	70.25	61.50	51.50
WDGS	–	20.00	40.00	–	–	–
Corn Silage	15.00	15.00	15.00	15.00	15.00	15.00
CGM	–	–	–	8.75	17.50	17.50
CDS	–	–	–	–	–	10.00
SBM	3.50	–	–	–	–	–
Supplement[3,4]						
Limestone	1.340	1.400	1.400	1.400	1.400	1.400
Urea	1.300	-	-	-	-	-
Salt	0.300	0.300	0.300	0.300	0.300	0.300
KCl	0.200	-	-	-	-	-
Dietary Composition						
DM	71.5	61.1	50.8	71.1	70.8	64.3
CP	13.9	13.0	17.3	14.3	20.0	21.0
NDF	14.8	18.9	23.0	14.6	14.4	13.5
Fat	2.8	3.7	4.6	2.9	2.9	2.6
Ca	0.51	0.53	0.54	0.52	0.52	0.52
P	0.28	0.37	0.49	0.28	0.30	0.45
K	0.71	0.71	0.88	0.53	0.52	0.82
S	0.11	0.20	0.31	0.16	0.22	0.32

[1]All values presented on a DM basis.

[2]DRC = dry-rolled corn; WDGS = wet distillers grains plus solubles; CGM = corn gluten meal; CDS = condensed distillers solubles; SBM = soybean meal.

[3]Supplement formulated to be fed at 6% of dietary DM.

[4]Supplement formulated to provide a dietary DM inclusion of 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, 0.1 mg/kg Se, 1.0 IU/g vitamin A, 0.125 IU/g vitamin D, 0.0015 UI/g vitamin E, 360 mg·steer·d^{-1} monensin (Elanco Animal Health, Greenfield, IN), and 90 mg·steer·d^{-1} tylosin (Elanco Animal Health).

Table 3.2. Composition of dietary treatments containing protein components of distiller grains fed to steers[1] (Exp. 2 and 3).

	Treatment			
Item	CON	40DGS	HIGH-CGM	CGM-CDS
Ingredient, % DM[2]				
DRC	76.5	40.0	62.5	52.5
MDGS	–	40.0	–	–
Corn Silage	15.0	15.0	15.0	15.0
CGM	–	–	17.5	17.5
CDS	–	–	–	10.0
SBM	3.5	–	–	–
Supplement[3]				
Fine ground corn	1.273	2.977	2.786	2.977
Urea	1.405	-	-	-
Limestone	1.639	1.541	1.549	1.541
Salt	0.291	0.278	0.280	0.278
Tallow	0.121	0.160	0.117	0.160
KCl	0.179	-	0.180	-
Beef trace minerals[4]	0.049	0.046	0.047	0.046
Vitamin A, D, and E[5]	0.017	0.016	0.016	0.016
Rumensin 90[6]	0.016	0.015	0.015	0.015
Tylan 40[7]	0.011	0.010	0.011	0.010
Nutrient Composition, %				
DM	83.6	69.7	83.6	78.5
CP	12.5	18.5	19.6	22.1
NDF	14.8	26.1	13.6	13.2
Fat	3.6	6.5	3.5	3.8
Starch	55.6	32.6	48.8	42.6

[1]All values presented on a DM basis.
[2]DRC = dry-rolled corn; MDGS = Modified distillers grains plus solubles; CGM = corn gluten meal; CDS = condensed distillers solubles; SBM = soybean meal.
[3]Supplement formulated to be fed at 5% of dietary DM.
[4]Premix contained 10%Mg, 6% Zn as ZnO, 4.5% Fe as $FeSO_4$, 2% Mn as MnO, 0.5% Cu as $CuSO_4$, 0.3% I as $Ca(IO_3)2(H_2O)$, and 0.05% Co as $CoCO_3$.
[5]Premix contained 1,500 IU vitamin A, 3,000 IU vitamin D, and 3.7 IU vitamin E per g.
[6]Formulated to provide 375 mg·steer·d^{-1} monensin (Rumensin; Elanco Animal Health, Greenfield, IN).
[7]Forumated to provide 90 mg·steer·d^{-1} tylosin (Tylan; Elanco Animal Health).

Table 3.3. Linear and quadratic effect of distillers grains on finishing performance and carcass characteristics (Exp. 1).

Item	Treatment[1]			SEM	*P* - value	
	CON	20DGS	40DGS		DGS Lin.[2]	DGS Quad.[3]
Initial BW, kg	291	292	292	0.5	0.23	0.95
Final BW, kg[4]	600	608	613	4	0.06	0.86
DMI, kg/d	10.3	9.8	9.7	0.1	<0.01	0.21
ADG, kg[4]	1.65	1.69	1.71	0.02	0.06	0.83
G:F[4]	0.161	0.172	0.176	0.002	<0.01	0.12
Feeding Value[5]	-	134	125	-	-	-
NEm[6]	1.89	1.99	2.02	0.01	<0.01	0.06
NEg[6]	1.24	1.33	1.37	0.01	<0.01	0.07
HCW, kg	378	383	386	3	0.06	0.87
Dressing, %	63.5	63.3	63.6	0.2	0.64	0.21
LM area, cm^2	87.2	87.4	89.0	1.1	0.26	0.62
Calculated YG[7]	2.93	2.96	2.95	0.09	0.91	0.85
12th-rib fat, cm	1.21	1.21	1.24	0.04	0.58	0.81
Marbling[8]	422	428	429	9	0.60	0.85
Liver abscess, %	21.2	18.5	14.8	0.5	0.41	0.89

[1]CON = 75.5% DRC; 20DGS = 20% wet distillers grains plus solubles; 40DGS = 40% wet distillers grains plus solubles.
[2]Lin. = *P*-value for the linear response of wet distillers grains inclusion for CON, 20DGS, 40DGS.
[3]Quad. = *P*-value for the quadratic response of wet distillers grain inclusion for CON, 20DGS, 40DGS.
[4]Calculated from carcass weight, adjusted to 63% common dressing percent.
[5]Feeding Value Calculation: [((compared treatments G:F – CON G:F) / CON G:F) / compared treatments inclusion rate*100+100]
[6]Dietary NE equations from the NRC (1996) as described by Vasconcelos and Galyean (2008).
[7]Yield Grade Calculation: 2.50 + (6.35 x 12^{th} rib fat thickness, cm) + (0.2 x 2.5 [KPH]) + (0.0017 x HCW, kg) - (2.06 x LM area, cm^2) from USDA (1997)
[8]Marbling score: 400 = Small00.

Table 3.4. Linear and quadratic effect of isolated protein from distillers grains on finishing performance and carcass characteristics (Exp. 1).

Item	Treatment[1]				SEM	*P* - value		
	CON	LOW-CGM	HIGH-CGM	CGM-CDS		Protein Lin.[2]	Protein Quad.[3]	HIGH-CGM vs. CGM-CDS
Initial BW, kg	291	291	292	291	0.5	0.58	0.41	0.11
Final BW, kg[4]	600	596	616	602	4	0.02	0.04	0.04
DMI, kg/d	10.3	10.0	10.2	10.0	0.1	0.85	0.13	0.08
ADG, kg[4]	1.65	1.63	1.73	1.66	0.02	0.02	0.04	0.04
G:F[4]	0.161	0.162	0.169	0.166	0.002	<0.01	0.19	0.32
Feeding Value[5]	-	110	129	121	-	-	-	-
NEm[6]	1.89	1.91	1.95	1.94	0.01	<0.01	0.59	0.85
NEg[6]	1.24	1.26	1.30	1.30	0.01	<0.01	0.69	1.00
HCW, kg	378	376	388	379	3	0.02	0.04	0.04
Dressing, %	63.5	63.1	63.5	63.0	0.2	0.95	0.12	0.06
LM area, cm^2	87.2	85.8	89.1	87.1	1.1	0.24	0.10	0.21
Calculated YG[7]	2.93	3.04	3.00	2.85	0.09	0.61	0.50	0.24
12th-rib fat, cm	1.21	1.27	1.29	1.16	0.04	0.22	0.75	0.05
Marbling[8]	422	433	443	426	9	0.10	0.94	0.19
Liver abscess, %	21.2	9.3	11.3	11.8	0.5	0.19	0.27	0.94

[1]CON = 75.5% DRC; LOW-CGM = 8.75% corn gluten meal to mimic the protein portion of 20DGS; HIGH-CGM = 17.5% corn gluten meal to mimic the protein portion of 40DGS; CGM-CDS = 17.5% corn gluten meal and 10% solubles.
[2]Lin. = *P*-value for the linear response of corn gluten meal for CON, LOW-CGM, HIGH-CGM.
[3]Quad. = *P*-value for the quadratic response of corn gluten meal for CON, LOW-CGM, HIGH-CGM.
[4]Calculated from carcass weight, adjusted to 63% common dressing percent.
[5]Feeding Value Calculation: [((compared treatments G:F – CON G:F) / CON G:F) / compared treatments inclusion rate*100+100]
[6]Dietary NE equations from the NRC (1996) as described by Vasconcelos and Galyean (2008).
[7]Yield Grade Calculation: 2.50 + (6.35 x 12^{th} rib fat thickness, cm) + (0.2 x 2.5 [KPH]) + (0.0017 x HCW, kg) - (2.06 x LM area, cm^2) from USDA (1997)
[8]Marbling score: 400 = Small00.

Table 3.5. Effect of excess rumen ungradable protein from distillers grains on finishing performance and carcass characteristics (Exp. 1).

Item	Treatment[1]					SEM	*P* - value	
	CON	20DGS	40DGS	LOW-CGM	HIGH-CGM		20DGS vs. LOW-CGM[2]	40DGS vs. HIGH-CGM[2]
Initial BW, kg	291	292	292	291	292	0.5	0.32	0.51
Final BW, kg[3]	600	608	613	596	616	4	0.09	0.65
DMI, kg/d	10.3	9.8	9.7	10.0	10.2	0.1	0.16	<0.01
ADG, kg[3]	1.65	1.69	1.71	1.63	1.73	0.02	0.08	0.61
G:F[3]	0.161	0.172	0.176	0.162	0.169	0.002	<0.01	0.01
Feeding Value[4]	-	134	125	110	129	-	-	-
NEm[5]	1.89	1.99	2.02	1.91	1.95	0.01	<0.01	<0.01
NEg[5]	1.24	1.33	1.37	1.26	1.30	0.01	<0.01	<0.01
HCW, kg	378	383	386	376	388	3	0.09	0.66
Dressing, %	63.5	63.3	63.6	63.1	63.5	0.2	0.64	0.69
LM area, cm^2	87.2	87.4	89.0	85.8	89.1	1.1	0.32	0.95
Calculated YG[6]	2.93	2.96	2.95	3.04	3.00	0.09	0.53	0.69
12th-rib fat, cm	1.21	1.21	1.24	1.27	1.29	0.04	0.41	0.49
Marbling[7]	422	428	429	433	443	9	0.65	0.26
Liver abscess, %	21.2	18.5	14.8	9.3	11.3	0.5	0.17	0.60

[1]CON = 75.5% DRC; 20DGS = 20% wet distillers grains plus solubles; 40DGS = 40% wet distillers grains plus solubles; LOW-CGM = 8.75% corn gluten meal to mimic the protein portion of 20DGS; HIGH-CGM = 17.5% corn gluten meal to mimic the protein portion of 40DGS.

[2]Comparison of the protein portion of WDGS, mimicked by corn gluten meal, and WDGS.

[3]Calculated from carcass weight, adjusted to 63% common dressing percent.

[4]Feeding Value Calculation: [((compared treatments G:F – CON G:F) / CON G:F) / compared treatments inclusion rate*100+100]

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

[6]Yield Grade Calculation: 2.50 + (6.35 x 12^{th} rib fat thickness, cm) + (0.2 x 2.5 [KPH]) + (0.0017 x HCW, kg) - (2.06 x LM area, cm^2) from USDA (1997)

[7]Marbling score: 400 = Small00.

Table 3.6. Effects of excess rumen ungradable protein from distillers grains in finishing steers diets on intake and total tract digestibility (Exp. 2).

Item	Treatments				SEM	*P* - value
	CON[1]	40DGS[2]	HIGH-CGM[3]	CGM-CDS[4]		
Steers, n	7	8	8	7	-	-
Intake, kg/d						
DM	6.8[c]	7.8[a]	7.1[bc]	7.5[ab]	0.5	0.08
OM	6.6	7.4	6.9	7.1	0.5	0.17
NDF	1.0[b]	2.0[a]	1.0[b]	1.0[b]	0.01	<0.01
Starch	3.8[a]	2.6[c]	3.5[a]	3.2[b]	0.2	<0.01
Fecal output, kg/d						
DM	1.21[b]	2.02[a]	1.23[b]	1.24[b]	0.25	0.02
OM	1.11[b]	1.79[a]	1.10[b]	1.08[b]	0.21	0.02
NDF	0.52[b]	0.91[a]	0.46[b]	0.43[b]	0.09	0.02
Starch	0.289[b]	0.337[a]	0.159[b]	0.231[b]	0.044	0.04
Total tract digestibility, %						
DM	79.6	74.4	82.3	83.1	3.1	0.16
OM	81.0	76.0	83.4	84.5	2.8	0.14
NDF	47.9	59.3	48.0	55.9	7.3	0.53
Starch	92.1[a]	86.6[b]	94.8[a]	92.1[a]	1.3	<0.01

[a,b,c]Means within a row with different superscripts differ ($P \leq 0.10$).

[1]Control (CON) treatment containing 76.5% dry-rolled corn (DRC), 15.0% corn silage, 3.5% soybean meal, and 5.0% supplement.

[2]Modified distillers treatment containing 40.0% DRC, 40.0% modified distillers grains plus solubles, 15.0% corn silage, and 5.0% supplement.

[3]Treatment formulated to mimic protein portion of 40DGS with corn gluten meal (CGM) at 17.5%, 62.5% DRC, 15.0% corn silage, and 5.0% supplement.

[4]Treatment formulated to mimic protein portion of 40DGS with the addition of corn gluten meal at 17.5% and condensed distillers solubles at 10.0%, 52.5% DRC, 15.0% corn silage, and 5.0% supplement.

Table 3.7. Effects of excess rumen ungradable protein from distillers grains in finishing steers diets on ruminal and post-ruminal digestibility (Exp. 2).

Item	Treatment				SEM	*P* - value
	CON[1]	40DGS[2]	HIGH-CGM[3]	CGM-CDS[4]		
Steers, n	4	4	6	5	-	-
DMI, kg/d	6.8[c]	7.8[a]	7.1[bc]	7.5[ab]	0.5	0.08
Ruminal digestibility, %						
Apparent OM[5]	44.2	49.9	50.9	50.4	5.5	0.81
True OM[5,6]	54.7	59.7	58.4	58.1	4.9	0.90
NDF	44.6	65.9	51.1	49.2	7.1	0.35
Apparent Starch[5]	70.7	68.7	75.6	75.5	6.2	0.36
True Starch[5,6]	71.2	69.3	76.0	76.2	6.2	0.35
Duodenal flow, kg/d						
Bacterial OM[6]	0.68	0.64	0.68	0.65	0.14	0.98
Feed OM	2.60	2.75	2.42	2.62	0.45	0.94
Total OM	3.25	3.44	2.85	3.09	0.57	0.89
NDF	0.52	0.61	0.43	0.48	0.09	0.52
Starch	0.89	0.68	0.94	0.97	0.18	0.72
Postruminal digestibility, % entering						
OM	61.3	47.7	64.0	69.4	6.2	0.18
Starch	73.8	83.5	73.3	72.0	6.2	0.59
Microbial CP flow, kg/d	0.32	0.27	0.24	0.25	0.08	0.88
Microbial Efficiency[7]	21	16	18	17	3	0.77

[a,b,c]Means within a row with different superscripts differ ($P < 0.10$).

[1]Control (CON) treatment containing 76.5% dry-rolled corn (DRC), 15.0% corn silage, 3.5% soybean meal, and 5.0% supplement.

[2]Modified distillers treatment containing 40.0% DRC, 40.0% modified distillers grains plus solubles, 15.0% corn silage, and 5.0% supplement.

[3]Treatment formulated to mimic protein portion of 40DGS with corn gluten meal (CGM) at 17.5%, 62.5% DRC, 15.0% corn silage, and 5.0% supplement.

[4]Treatment formulated to mimic protein portion of 40DGS with the addition of corn gluten meal at 17.5% and condensed distillers solubles at 10.0%, 52.5% DRC, 15.0% corn silage, and 5.0% supplement.

[5]Calculation of apparent vs. true used data from Exp 3 to account for bacterial cells flowing into the duodenum.

[6]Caculated using assumed purine:N ratio of 0.3 from Cooper et al. (2002).

[7]Microbial Efficiency, g of Microbial CP/g of OM fermented in the rumen.

Table 3.8. Effects of excess rumen undegradable protein from distillers grains in finishing steers diets on ruminal volatile fatty acid concentration (Exp. 3).

Item	Treatment				SEM	*P*-value[5]	
	CON[1]	40DGS[2]	HIGH-CGM[3]	CGM-CDS[4]		F-Test	Int.
Steers, n	8	7	8	7			
DMI, kg/d	10.1[ab]	11.5[a]	9.8[ab]	9.0[b]	0.6	0.06	-
Ruminal VFA							
Acetate, mol/100 mol	50.5	48.7	45.3	48.6	1.7	0.18	0.41
Propionate, mol/100 mol	33.2[b]	35.6[b]	42.6[a]	34.5[b]	2.3	0.03	0.09
Butyrate, mol/100 mol	12.4	11.6	7.8	11.4	1.7	0.22	0.03
Acetate:propionate	1.7[a]	1.4[a]	1.1[b]	1.5[a]	0.2	0.08	0.21
Total, m*M*	107.1	89.9	105.0	96.3	5.9	0.16	0.10

[a,b]Means within a row with different superscripts differ ($P < 0.10$).
[c,d]Means within a row with different superscripts tened to differ ($P > 0.10$ and $P \leq 0.15$).
[1]Control (CON) treatment containing 76.5% dry-rolled corn (DRC), 15.0% corn silage, 3.5% soybean meal, and 5.0% supplement.
[2]Modified distillers treatment containing 40.0% DRC, 40.0% modified distillers grains plus solubles, 15.0% corn silage, and 5.0% supplement.
[3]Treatment formulated to mimic protein portion of 40DGS with corn gluten meal (CGM) at 17.5%, 62.5% DRC, 15.0% corn silage, and 5.0% supplement.
[4]Treatment formulated to mimic protein portion of 40DGS with the addition of corn gluten meal at 17.5% and condensed distillers solubles at 10.0%, 52.5% DRC, 15.0% corn silage, and 5.0% supplement.
[5]*F*-test = overall *F*-test representing variation due to treatment, Int. = interaction of treatment × hour

2

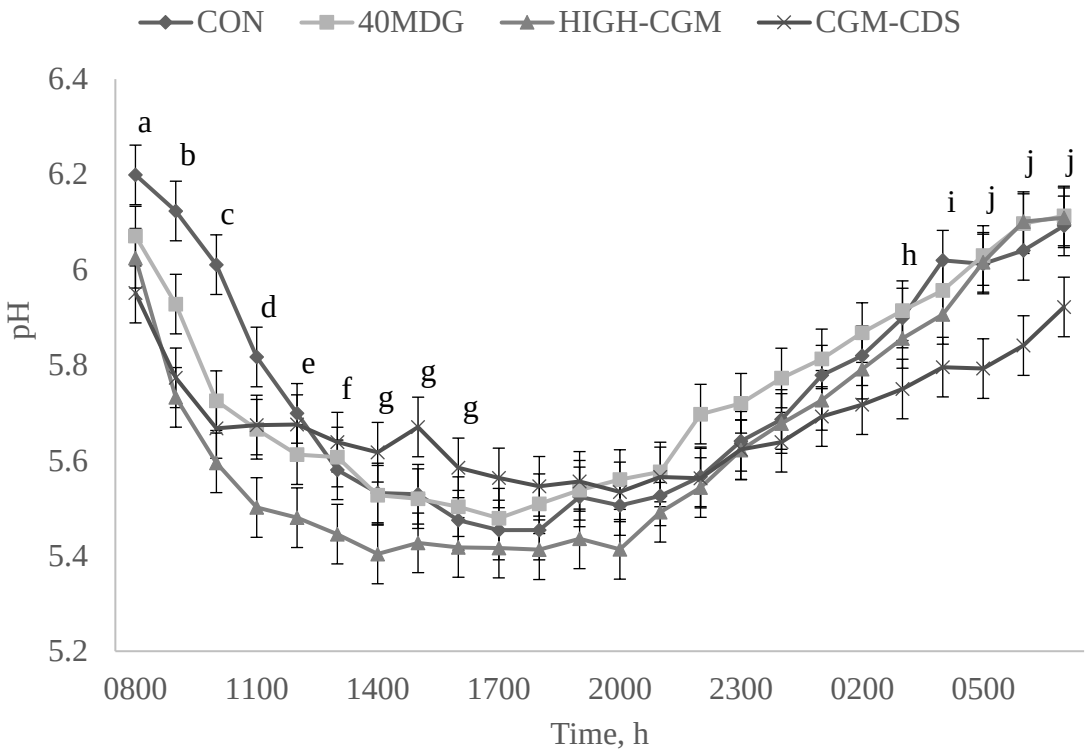

Figure 3.1. Ruminal pH of cattle fed 4 different dietary treatments was monitored over 6 periods. The control (CON) treatment contained 76.50% dry-rolled corn (DRC), 15.00% corn silage, 3.50% soybean meal, 3.55% supplement, and 1.45% urea. The 40DGS treatment contained 40.00% DRC, 40.00% modified distillers grains plus solubles, 15.00% corn silage, and 5.00% supplement. The HIGH-CGM treatment contained 62.50% DRC, 17.50% corn gluten meal (CGM), 15.00% corn silage, and 5.00% supplement. The CGM-CDS treatment replaced 10% of DRC from the HIGH-CGM diet with condensed distillers solubles. There was an hour × treatment interaction ($P < 0.01$). Treatment differences ($P < 0.05$) within time points are marked with a letter (a, b, c, d, e, f, g, h, i, and j) to signify statistical differences between treatments within that time point. Time points marked with an "a" indicate that the CON treatment had the greatest pH and HIGH-CGM and CGM-CDS had the lowest. The 40DGS treatment was intermediate. Time points marked with a "b" indicate that the CON treatment had the greatest pH and HIGH-CGM and CGM-CDS treatments were the lowest. The 40DGS treatment had a greater pH than the HIGH-CGM and CGM-CDS treatments. Time points marked with a "c" indicate that the CON treatment had the greatest pH and the remaining 3 treatments are the same. Time points marked with a "d" indicate that the CON had the greatest pH and the HIGH-CGM treatment had the lowest. The 40DGS treatment had a greater pH than the HIGH-CGM, and the CGM-CDS treatment was intermediate between CON and 40DGS. Time points marked with an "e" indicate that the CON and CGM-CDS treatments had the greatest pH and the HIGH-CGM treatment had the lowest. The 40DGS treatment was intermediate. Time points marked with an "f" indicate that 40DGS and CGM-CDS treatments had the greatest pH and the HIGH-CGM treatment had the lowest. The CON treatment was intermediate. Time points marked with a "g" indicate that the HIGH-CGM treatment had the greatest pH and the CGM-CDS treatment had the lowest. The CON and 40DGS treatments were intermediate. Time points marked with an "h" indicate that the 40DGS treatment had the greatest pH and the CGM-CDS treatment had the lowest. Time points marked with an "i" indicate that the CON treatment had the greatest pH and that the CGM-CDS treatment had the lowest. Time points marked with a "j" indicate that CON, 40DGS, and HIGH-CGM treatment had a greater pH than the CGM-CDS treatment.

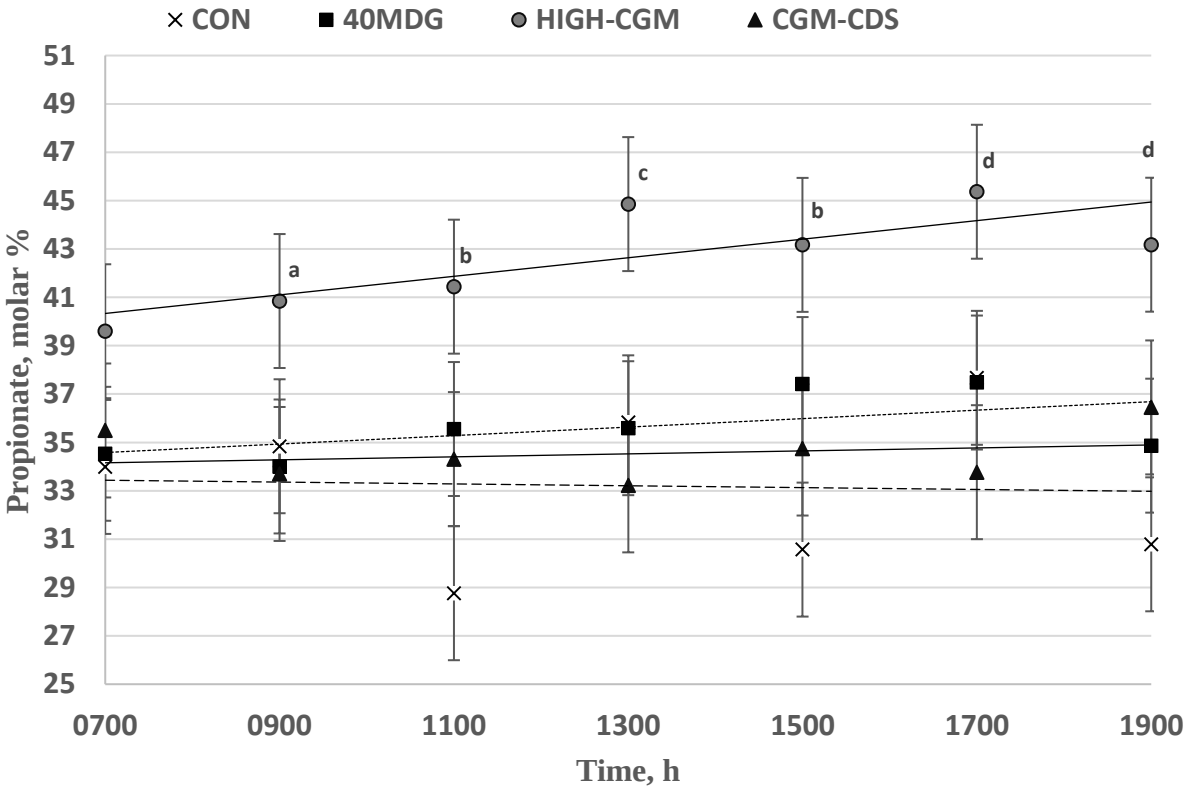

Figure 3.2. Ruminal propionate of cattle fed 4 different dietary treatments was monitored over 6 periods. The control (CON) treatment contained 76.50% dry-rolled corn (DRC), 15.00% corn silage, 3.50% soybean meal, 3.55% supplement, and 1.45% urea. The 40DGS treatment contained 40.00% DRC, 40.00% modified distillers grains plus solubles, 15.00% corn silage, and 5.00% supplement. The HIGH-CGM treatment contained 62.50% DRC, 17.50% corn gluten meal (CGM), 15.00% corn silage, and 5.00% supplement. The CGM-CDS treatment replaced 10% of DRC from the HIGH-CGM diet with condensed distillers solubles. There was an hour × treatment interaction ($P < 0.10$). Treatment differences ($P < 0.10$) within time points are marked with a letter (a, b, and c) to signify statistical differences between treatments within that time point. Time points marked with an "a" indicate that the HIGH-CGM treatment had the greatest propionate concentration and 40DGS and CGM-CDS had the lowest. The CON treatment was intermediate. Time points marked with a "b" indicate that the HIGH-CGM treatment had the greatest propionate concentration and CON had the lowest. The 40DGS and CGM-CDS treatments were intermediate. Time points marked with a "c" indicate that the HIGH-CGM treatment had the greatest propionate concentration and the remaining three treatments were lower in propionate concentration. Each treatments' trend line by time was tested for linear and quadratic relationships and none were found.

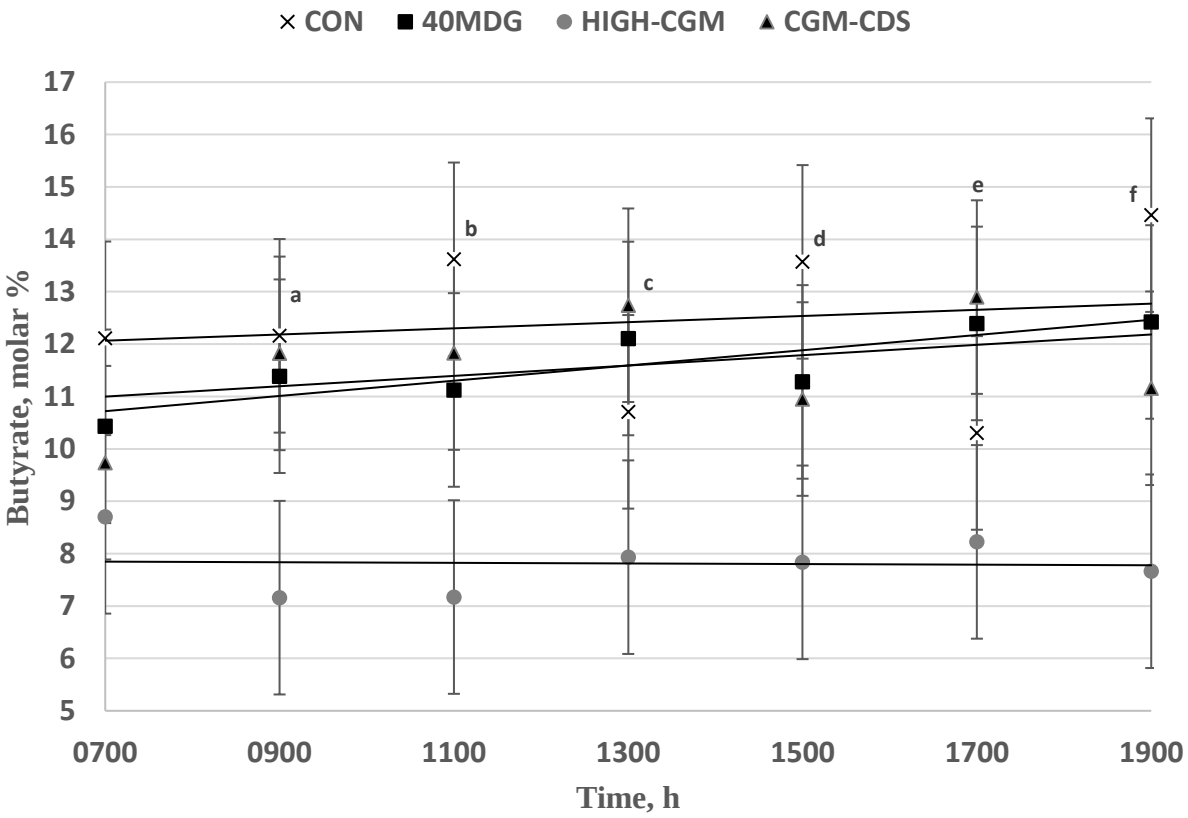

Figure 3.3. Ruminal butyrate of cattle fed 4 different dietary treatments was monitored over 6 periods. The control (CON) treatment contained 76.50% dry-rolled corn (DRC), 15.00% corn silage, 3.50% soybean meal, 3.55% supplement, and 1.45% urea. The 40DGS treatment contained 40.00% DRC, 40.00% modified distillers grains plus solubles, 15.00% corn silage, and 5.00% supplement. The HIGH-CGM treatment contained 62.50% DRC, 17.50% corn gluten meal (CGM), 15.00% corn silage, and 5.00% supplement. The CGM-CDS treatment replaced 10% of DRC from the HIGH-CGM diet with condensed distillers solubles. There was an hour × treatment interaction ($P < 0.10$). Treatment differences ($P < 0.10$) within time points are marked with a letter (a, b, c, and d) to signify statistical differences between treatments within that time point. Time points marked with an "a" indicate that the CON and CGM-CDS treatments had the greatest butyrate concentration and HIGH-CGM had the lowest. The 40DGS treatment was intermediate. Time points marked with a "b" indicate that the CON treatment had the greatest butyrate concentration and HIGH-CGM had the lowest. The 40DGS and CGM-CDS treatments were intermediate. Time points marked with a "c" indicate that the CGM-CDS treatment had the greatest butyrate concentration and HIGH-CGM had the lowest. The CON and 40DGS treatments were intermediate. Time points marked with a "d" indicate that the CON and 40DGS treatments had the greatest butyrate concentration and HIGH-CGM had the lowest. The CGM-CDS treatment was intermediate. Each treatments' trend line by time was tested for linear and quadratic relationships and none were found.

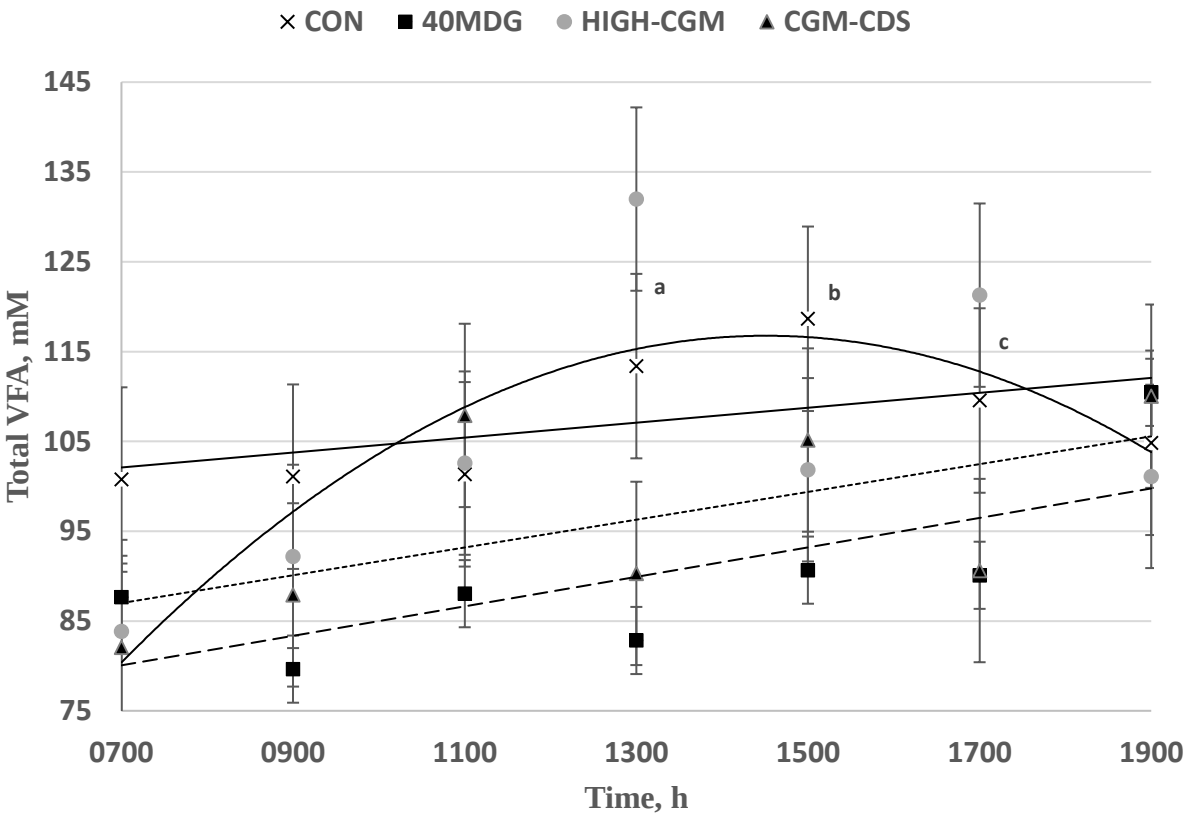

Figure 3.4. Ruminal total VFA of cattle fed 4 different dietary treatments was monitored over 6 periods. The control (CON) treatment contained 76.50% dry-rolled corn (DRC), 15.00% corn silage, 3.50% soybean meal, 3.55% supplement, and 1.45% urea. The 40DGS treatment contained 40.00% DRC, 40.00% modified distillers grains plus solubles, 15.00% corn silage, and 5.00% supplement. The HIGH-CGM treatment contained 62.50% DRC, 17.50% corn gluten meal (CGM), 15.00% corn silage, and 5.00% supplement. The CGM-CDS treatment replaced 10% of DRC from the HIGH-CGM diet with condensed distillers solubles. There was an hour × treatment interaction ($P < 0.10$). Treatment differences ($P < 0.10$) within time points are marked with a letter (a, b, and c) to signify statistical differences between treatments within that time point. Time points marked with an "a" indicate that the HIGH-CGM and CON treatments had the greatest total VFA concentration and 40DGS and CGM-CDS had the lowest. Time points marked with a "b" indicate that the CON treatment had the greatest total VFA concentration and 40DGS had the lowest. The HIGH-CGM and CGM-CDS treatments were intermediate. Time points marked with a "c" indicate that the HIGH-CGM treatment had the greatest total VFA concentration and the 40DGS and CGM-CDS treatments had the lowest. The CON treatment was intermediate. Each treatments' trend line by time was tested for linear and quadratic relationships. The CGM-CDS treatment's trend line is linear ($P = 0.05$). The HIGH-CGM treatment's trend line is quadratic ($P = 0.03$).