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Impact of ethanol process changes on distillers grains for beef cattle

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IMPACT OF ETHANOL PROCESS CHANGES ON DISTILLERS GRAINS FOR BEEF CATTLE

by

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Distillers grains plus solubles (DGS) have been widely utilized in beef cattle diets. Fractionation of the corn kernel pre- and post-fermentation has changed the composition of DGS and allowed for the production of other feed byproducts over time. The use of fractionated DGS and other feed byproducts from the ethanol industry has not been heavily researched in beef cattle diets. Three experiments were conducted to evaluate the effect of feeding high protein distillers grains (HiPro DDG) and corn bran plus solubles (Bran + Solubles) in beef cattle diets. Experiment 1 evaluated the effect of byproduct type on finishing performance and carcass characteristics. Experiment 2 evaluated the effect of byproduct type on nutrient digestibility, ruminal pH, ruminal VFA production, and in vitro gas production. Byproducts replaced corn at 40% of diet DM in Exp. 1. Experiment 3 compared feeding Bran + Solubles to wet DGS at 20 and 40% of diet DM compared to a corn control. In Exp. 2, Feeding HiPro DDG or Bran + Solubles resulted in decreased digestibility compared to corn or traditional wet and dry DGS, but increased energy intake. Traditional wet and dry DGS also resulted in decreased digestibility while energy intake was increased. Volatile fatty acid profiles and pH parameters were not different across treatments. Feeding HiPro DDG and Bran + Solubles improved gains and feed efficiency compared to traditional dry or wet DGS and

corn. Compared to wet DGS, Bran + Solubles resulted in similar performance and carcass characteristics. Increased inclusion of both byproducts resulted in a linear increase in carcass weight. Overall, nutrient digestibility for HiPro DDG or Bran + Solubles is similar to traditional wet or dry DGS while performance was increased.

Key Words: bran, distillers grains, finishing, fractionation, high protein, solubles

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CORN MILLING PROCESSES

Ethanol Production

Just over 102.2 million liters of ethanol were produced globally in 2017. Of that, 60.0 million liters, roughly 58%, was produced in the United States alone (RFA, 2018). The primary source for ethanol production in the United States is corn starch. According to the U.S. Environmental Protection Agency (2018), 89.0% of ethanol production came from plants utilizing corn starch alone, 3.0% from plants using a blend of corn starch and other cereal grains, 1.0% from plants utilizing cellulosic biomass from corn residue, and 7% from other feedstocks. For every liter of ethanol produced in a dry-grind process, 0.84 kg (DM) of distillers grains plus solubles (DGS) is produced (Kim et al., 2010). Ethanol can be produced from a variety of pathways, but the two primary pathways are dry and wet milling. The primary objective of the dry milling process is the isolation of starch for ethanol production, while ethanol production is one of many pathways possible with wet milling. Wet milling involves the separation of individual components for processing. Traditionally, dry milling utilized the entire corn kernel for grinding and processing. Recent technological advancements have allowed dry milling plants to separate components of the kernel during processing to differentiate products, thus hoping to increase economic value.

DRY MILLING

Process

The traditional dry milling process can utilize a variety of cereal grains including corn, sorghum, barley, and wheat alone or in a blend of any of the grains (Stock et al., 2000). In Nebraska, the primary grain used is No. 2 yellow dent corn. The process begins with the grinding of a whole kernel of dry corn at approximately 85% dry matter (DM). The grinding process breaks down the outer portion of the kernel called the pericarp and makes the starch in the kernel more readily available for conversion to sugar and fermentation to ethanol. The ground product is then transferred to a slurry tank where it is mixed with water and alpha-amylase to produce a slurry. The slurry is allowed to cook for several hours until a "mash" is produced.

Glucoamylase is then added to the mash in the saccharification step to break the starch down into simple sugars such as glucose. Once the starch has been broken down to glucose, the mixture is transferred to fermentation tanks where yeast is added to the mash to produce ethanol, carbon dioxide, and solids from the fermented grains. The ethanol mix is sent to distillation columns where the solids and liquids are separated by boiling point. The ethanol is then distilled and dehydrated to fuel grade ethanol (OSHA, 2018). The remaining solids are referred to as whole stillage and are approximately 5 to 10 percent DM.

Whole stillage is sent through a series of centrifuges to separate thin stillage from the courser solids, referred to as wet distillers grains (WDG). Thin stillage is evaporated to produce a 20 to 35 percent DM product called condensed distillers solubles (CDS). The CDS can be added to WDG to produce wet distillers grains plus solubles (WDGS) or it can be dried with distillers grains to produce modified distillers grain plus solubles (MDGS) or dry distillers grains plus solubles (DDGS; Stock et al., 2000).

Nutrient Composition

Approximately two-thirds of the original corn kernel consists of starch (NASEM, 2016). Following fermentation, only about one-third of the original DM is present in the whole stillage. With starch alone being removed during fermentation and other components being virtually unaffected, the other nutrients present become concentrated in the distillers grains product (Stock et al., 2000). Traditional distillers grains consist of approximately 31.0% crude protein (CP) whereas corn is approximately 9.0% CP (Buckner et al., 2011b; NASEM, 2016). This suggests that the nutrient concentration is approximately three-fold in distillers grains versus the original corn kernel. Traditional distillers grains also contain approximately 10.5% fat, 30.0% neutral detergent fiber (NDF), 15.0% acid detergent fiber (ADF), 0.86% phosphorus, and 0.67% sulfur (NASEM, 2016). It is important to note that there is significant variation in nutrient composition among ethanol plants (Belyea et al., 2004, Buckner et al., 2011b, Cromwell et al., 1993, Liu et al., 2011, Spiehs et al., 2002). Nuttelman et al. (2011) reported that the nutrient composition of distillers grains did not change significantly when dried to either MDGS or DDGS.

The feeding value of WDGS is variable and dependent upon a number of factors including the feed it is replacing in the diet, the processing method of grain in the diet, and inclusion level. When fed in dry-rolled corn (DRC) based finishing diets, distillers grains from corn fermentation (CDG) resulted in a 10% greater feeding value than distillers grains from sorghum fermentation (SDG; Al-Suwaiegh et al., 2002). Feeding value was calculated using the following equation $\{((G{:}F_{TRT} - G{:}F_{CON})/G{:}F_{CON}) / \text{byproduct inclusion, \%}) + 1\} * 100$. Other experiments have concluded that CDG had numerically

greater feed efficiencies resulting in greater feeding values than SDG when fed in steam-flaked corn (SFC) based diets (Depenbusch et al., 2005; Galyean and Vasconcelos, 2007).

Feed efficiency was improved when WDGS was fed at increasing inclusion in both DRC and high-moisture corn (HMC)-based diets (Bremer et al., 2015). Efficiencies in SFC-based diets remained constant as WDGS level was increased (Corrigan et al., 2009). The difference in feed efficiency in the SFC-based diets may be due to a negative associative effect related to the increase in starch availability of the SFC. Corn fiber is highly digestible (DeHaan, 1983) so adding corn fiber from WDGS to the already highly-fermentable SFC may have resulted in acidosis. Additionally, replacing a feed that already has improved digestibility relative to DRC may not result in any performance improvements.

Dietary inclusion level also impacts the feeding value of distillers grains, especially when fed as WDGS or MDGS. Watson et al. (2014) summarized 17 studies where WDGS was fed at differing inclusions. Low inclusions were considered anything less than or equal to 20%, mid-inclusions were considered between 25 and 40%, and high inclusions were considered greater than or equal to 40% diet (DM). Feeding values of WDGS at low, mid, and high levels were 140%, 122%, and 125%, respectively. Furthermore, Bremer et al. (2011) performed a meta-analysis of 20 studies summarizing the feeding values of WDGS, MDGS, and DDGS at differing levels of inclusion. The feeding value of both WDGS and MDGS were maximized at 10% of diet DM at 150% and 128%, respectively. Dry distillers grains plus solubles did not follow the same trend and remained constant at 112% regardless of inclusion level. This suggests that drying

the distillers grains affects the animal's ability to utilize it, despite the lack of difference in nutrient composition. An explanation may be provided by Nuttleman et al. (2013) who reported a numeric decrease in fiber digestibility as DGS are dried to MDGS and DDGS. Though variable, drying WDGS to DDGS reduced fiber digestibility by 15.6% and 3.5% in two different experiments. Given the high concentration of fiber in DGS, even a slight reduction in fiber digestibility caused by drying may be responsible for the reduced feeding values of MDGS and DDGS.

WET MILLING

Process

The wet milling process is more complex and results in more products than the dry-milling process. The primary purpose of wet milling is to isolate highly purified starch and protein (Rausch and Belyea, 2006). Corn is the only cereal grain that can be utilized for wet milling, but a variety of types of corn can be used, including yellow dent, high amylose, and waxy corn (Jansen et al., 2007). Following screening to remove unwanted particles and broken kernels, the process begins with adding corn to a steep tank containing water and sulfur dioxide to soften the corn kernel. Steeping typically takes 30 to 48 hours (CRA, 2009; Stock et al., 2000). The liquid product from the steeping process is referred to as steep liquor. The softened corn kernel then goes through a series of grinds where the germ can be separated to produce corn oil. The germ can then be dried to make germ meal.

The remainder of the kernel continues through another, more aggressive grind step where the starch and protein in the endosperm are separated from the fiber

component. Fiber can then be combined with steep liquor and other components to produce a form of corn gluten feed (CGF) while the remaining solid fraction is separated into both protein and starch using centrifuges. The protein is then dried to corn gluten meal (CGM), which is a high protein, low fiber feed used primarily in non-ruminant, aquaculture and companion animal diets (Rausch and Belyea, 2006). The starch component can then be washed to go into the ethanol fermentation stream, dried for the food industry, or used to produce dextrose. If the starch is fermented to ethanol, distillers solubles, a byproduct with low levels of fat compared to dry-milling CDS, is formed (Stock et al., 2000).

Nutrient Composition

Due to the complex separation process required for wet milling, a greater number of byproducts are produced from this process than from dry-milling. The byproducts of wet-milling include steep liquor, germ meal, corn gluten feed, corn gluten meal, and distillers solubles. Steep liquor (46% DM) is the liquid portion from the steeping process. The high protein content (32% CP) makes steep liquor a suitable protein supplement for both ruminants and non-ruminants. Steep liquor can also be added to other byproducts like CGF. Corn germ meal (90% DM) is the fibrous portion of the germ that remains following hexane oil extraction. The moderate protein (22% CP) and fat (7.7% fat) content make it a highly desirable ingredient in non-ruminant animal diets (NASEM, 2016; Rausch and Belyea, 2006).

Corn gluten feed contains a high rumen degradable protein (RDP) proportion (69% RDP) and a moderate protein concentration (25% CP). It is also high in neutral detergent fiber (45% NDF), which limits its use to mostly ruminant diets, but because of

the small particle size it has a limited effect on acidosis control (Rausch and Belyea, 2006). It is important for producers to understand that the proportion of fiber and steep liquor is not constant across plants so the composition of CGF is variable (Stock et al., 2000). Corn gluten meal (90% DM) is high in protein (67% CP), especially rumen undegradable protein (RUP), and low in fiber. Distillers solubles from wet milling have a lower fat content than distillers solubles from dry-milling due to the removal of oil from the germ.

Two types of CGF can be utilized in beef finishing diets. The first is a product containing wet bran and steep liquor. This CGF product is approximately 40% DM and contains 15-18% CP (Stock et al., 2000). Across seven studies where this type of CGF was fed in finishing diets, the average efficiency and net energy for gain was similar to corn grain. The net energy value was determined to be 1% more than corn grain itself (Stock et al., 2000). The other type of CGF is composed of dry bran, steep liquor, distillers solubles, and germ meal. This product is 60% DM and contains 20-25% CP. Stock et al. (2000) summarized five studies where this CGF was fed in finishing diets and determined the net energy to be 15% greater than corn grain. The major difference observed in net energy value are likely due to the increased energy value of both steep liquor and germ meal over bran. Replacing bran with both byproducts resulted in improved feed efficiency. The 60% DM feed (Sweet Bran, Cargill Corn Milling, Blair, NE) has since been used in a variety of beef diets, especially for newly received cattle (Huls et al., 2016).

PARTIAL FRACTIONATION

Front-end Fractionation

Increased demand for efficiency within ethanol plants has resulted in the implementation of new technologies to extract more out of each corn kernel. One of those technologies is kernel fractionation; most commonly partial fractionation. In this process, the kernel undergoes physical separation prior to the cooking process (Depenbusch et al., 2008). The goal of partial fractionation is to separate the kernel into the germ, endosperm, and bran. The germ, which represents about 12% of the kernel, is then available for oil extraction to be sold as food-grade corn oil while the bran can be used for cattle feed (U.S. Grains Council, 2012). Once the endosperm is fermented, high protein distillers grains (HPDG) are produced (Buckner et al., 2011). Due to removal of the germ, HPDG contain less fat, but a higher concentration of protein and NDF than traditional distillers grains (Depenbusch et al., 2008).

The increased protein as well as an increase in readily fermentable fiber potentially provides a good source of energy for ruminant animals. In addition, the lower fat content may be beneficial for digestibility in forage-based diets. The protein content of front-end fractionated distillers grains can be as high as 45% CP while the fat content can be as low as 2% depending on which pre-fermentation fractionation process the plant uses (US Grains Council, 2012).

Many of the opportunities associated with front-end fractionation were never realized so most are no longer being used. As a result, only a small number of studies have been conducted to determine the effect of feeding fractionated distillers grains. Depenbusch et al. (2008) summarized feeding partially fractionated DGS (FRAC; 43% CP, 4% crude fat, 23% NDF, 0.81 P) compared to traditional distillers grains (TRAD; 26% CP, 12% crude fat, 26% NDF, 0.44 P) and a control treatment (CONT). Byproducts

were included at 13% of diet DM and replaced steam-flaked corn. Heifers fed FRAC consumed less than those fed TRAD, but average daily gain (ADG) and feed efficiency (G:F) were not different ($P \geq 0.07$) for the two byproduct types. In this study, fractionated DGS appear to produce performance results similar to traditional DGS. It is important to consider that byproducts were included at relatively low inclusions so differences may be difficult to accurately detect. Additionally, DGS do not produce the same response when included in SFC-based diets as when included in DRC or HMC-based diets (May et al., 2007; Vander Pol et al., 2006).

E-corn is a front-end fractionated product created from the remaining meal from starch fermentation and the germ following oil removal. Godsey et al. (2010) fed E-corn at 0, 20, 40, and 60% in both WCGF and WDGS diets and determined the optimum inclusion level to be 20% of diet DM. Buckner et al. (2011) also fed a front-end fractionated product termed Dakota Bran (POET Nutrition, Sioux Falls, SD), which was made by combining corn bran with distillers solubles. Dakota Bran was included at 0, 15, 30, or 45% diet (DM) and compared to traditional DDGS at 30% diet (DM). Protein and fat content of Dakota Bran were 14.7% and 10.9%, respectively. Average daily gain, G:F, and HCW linearly increased with greater inclusion of Dakota Bran. Cattle performed similarly ($P \geq 0.19$) when fed either Dakota Bran or DDGS at 30% of diet DM. It can be concluded that Dakota Bran does not significantly affect performance when compared to traditional DDGS.

Back-end Fractionation

Back-end fractionation is a more popular method for corn oil extraction than front-end fraction. In fact, 90% of dry grind ethanol plants in the U.S. are extracting corn

oil this way (Iowa Renewable Fuels Association, 2014). In this process, oil is extracted from the thin stillage following centrifugation that removes thin from whole stillage. The thin stillage, which contains approximately 30% of the oil available in corn, is then heated and the corn oil is removed by a second centrifuge (CEPA, 2011). Traditional DGS contain approximately 12% fat, and when oil is removed post-fermentation the fat content is reduced to approximately 8% (Jolly et al., 2014).

Thin stillage is evaporated to corn condensed distillers solubles (CCDS). One might assume that oil removal from thin stillage would change the feeding value of CCDS. Jolly et al. (2013) compared CCDS with (6.0% fat) and without (21.1% fat) oil removal at 27% of diet DM as well as MDGS with (9.2% fat) and without (11.8% fat) oil removal at 40% of diet DM in growing diets. There were no statistical differences in performance or carcass characteristics between normal fat CDS or MDGS and de-oiled CDS or MDGS. However, steers fed de-oiled CDS had numerically greater ADG, and subsequent G:F than those fed normal fat CDS. The feeding value of de-oiled and normal fat CDS were 159% and 147% that of corn, respectively. While the data showed no significant differences between de-oiled and normal fat CDS in growing diets, producers may be interested in a 12% numeric increase in feeding value for de-oiled CDS. Jolly et al. (2014) then studied the effect of oil removal on the value of DGS. De-oiled WDGS (7.9% fat) or full-fat WDGS (12.4% fat) were fed at 35, 50, and 65% diet (DM) and compared to a dry-rolled corn, high-moisture corn based control finishing diet. Oil removal did not affect ADG, G:F, or any carcass characteristics so it was concluded that oil removal via centrifugation had no impact on finishing cattle performance.

Bremer et al. (2015) compared de-oiled WDGS (7.2% fat) to full-fat WDGS (12% fat) at 15 and 30% diet (DM) in diets similar to Jolly et al. (2014). A tendency ($P = 0.07$) for a 3.4% improvement in feed efficiency was observed for cattle fed full-fat MDGS at 30% diet (DM) compared to de-oiled MDGS while no statistical differences were observed for the 15% inclusion.

Despite research supporting little detriment to feeding de-oiled DGS, producer perception is still that de-oiled DGS will have a negative impact on cattle performance relative to traditional DGS. Burhoop et al. (2018) studied the impact of adding 2% corn oil with 38% de-oiled MDGS and compared that to 40% full-fat MDGS (11.6% fat) and 40% de-oiled MDGS (8.9% fat) in a DRC:HMC diet. Corn oil was added to the de-oiled MDGS diet to equalize fat content with full-fat MDGS at approximately 7.5% dietary fat. The corn oil added treatment resulted in significantly greater ADG and F:G compared to other treatments. De-oiled MDGS produced greater intakes and numerically greater gains than full-fat MDGS, but F:G was similar. The authors concluded that, despite the improvement in feed efficiency with adding corn oil to the diet, the benefits are too small to offset the input cost.

New technological advances have allowed the ethanol industry to move beyond oil extraction and toward cellulosic ethanol production. Cellerate Process Technology® (Syngenta, Wilmington, DE) uses the corn kernel instead of biomass feedstocks to produce ethanol in a secondary fermentation process. This process results in a novel, cellulosic wet distillers grains (C-WDG). Lundy et al. (2016) evaluated the effect of feeding C-WDG (39.1% CP, 32.7% NDF, 7.3% EE, 1.6% starch) compared to traditional WDG (T-WDG; 34.1% CP, 32.2% NDF, 7.7% EE, 5.1% starch) in DRC-based diets.

Distillers grains were fed at 30 and 45% (DM) in a metabolism study and 30% (DM) in a finishing study. Digestibility and energy of C-WDG was lower than T-WDG. This resulted in an 8% decrease in efficiency for C-WDG compared to T-WDG. Cellulosic WDG performed similar to the control diet.

PROTEIN

Protein for the Ruminant Animal

To understand protein digestion and metabolism in the ruminant animal, one must first understand the terms RDP (rumen degradable protein) and RUP (rumen undegradable protein). Rumen undegradable protein may also be referred to as bypass protein or undegradable intake protein (UIP). Rumen degradable protein is the portion of the total protein intake that is broken down and utilized by the microbes within the rumen (NASEM, 2016). Microbes require both energy, which is supplied by fermentable substrates (i.e. fiber and starch) and nitrogen for survival within the rumen. Microbes are able to transform proteins and non-protein nitrogen (i.e. urea) into new amino acids the animal can utilize to form microbial crude protein (MCP). Microbial crude protein in combination with digestible RUP, the portion of protein intake that bypasses rumen fermentation and is available to the animal post-rumen, make up metabolizable protein (MP) that is available for the ruminant animal (Burroughs et al., 1975; NASEM, 2016). Because some feedstuffs provide protein that is highly degradable in the rumen and others provide protein that is not degradable in the rumen, MP is more meaningful than CP in ruminant diets.

Protein Quantification in DGS

As previously established, processing corn grain into distillers grains removes the starch component and concentrates all other kernel components, including protein. The CP content of corn grain (dry-rolled) is approximately 9% while the CP content of distillers grains is approximately 30% of DM (NASEM, 2016). The primary protein in distillers grains is zein protein (Klopfenstein et al., 2008). Of the protein in distillers grains, approximately 63% is undegradable in the rumen (Castillo-Lopez et al., 2013). While the need for RUP is secondary to rumen microbial nitrogen needs, in growing calves, grazing yearling, and lactating cows, RUP is essential for maximum production (Hollingsworth-Jenkins, 1994).

Metabolizable protein, that which is can be absorbed and utilized by the ruminant animal, includes both microbial crude protein (MCP) and RUP. Metabolizable protein is then utilized for both ruminal recycling to supply needed RDP for microbial synthesis and host animal requirements. Lapierre and Lobley (2001) reported that 27 to 60% of recycled urea re-enters the rumen. In such cases, even when RDP is insufficient, the animal is able to survive. In situations involving byproducts such as DGS where RUP is fed in greater concentrations, excess MP can be recycled for energy production. Metabolizable protein is more reduced than carbohydrate and has bypassed ruminal fermentation giving it an energy value 43% greater than carbohydrate (Kleiber, 1961; NASEM, 2016). It is important to understand the mechanics of protein recycling and utilization by the ruminant animal when considering the performance responses observed with DGS.

Carlson et al. (2016) performed a study to determine the relative contribution of protein to the improved performance observed when feeding distillers grains. Corn gluten

meal (CGM) was utilized to mimic the protein portion of WDGS to provide similar protein as 20 and 40% of diet DM as WDGS. At 20% inclusion, steers fed 20PRO tended ($P = 0.09$) to have decreased ADG while maintaining similar DMI ($P = 0.16$) resulting in a 5.8% decrease in feed efficiency for 20PRO steers compared to 20WDG steers. At 40%, however, steers fed 40% CGM (40PRO) ate more, but had similar ADG ($P = 0.61$) to steers fed 40% WDGS (40WDGS). This resulted in a feeding value of 129% for 40PRO while 40WDGS had a feeding value of 125%. The average feeding value for CGM at inclusion levels equal to the protein in 20 and 40% WDGS was 122. Wet distillers grains plus solubles had an average feeding value of 128. This suggests that protein accounts for a good portion of the feeding value response observed when feeding distillers grains.

Conroy et al. (2016) evaluated the effect of feeding WDGS or isolating each component of distillers grains in finishing diets. Corn gluten meal was again used to formulate a diet with comparable protein to 40% WDGS (PROT). Additional component diets included a fat diet (FAT) using full-oil germ meal, and a fiber diet (FIB) using dry bran and solvent extracted meal (SEM). All diets contained 10% CDS to accurately mimic the nutrient composition of WDGS. Steers fed PROT and FAT had greater intakes ($P = 0.04$) than all treatments other than FIB. The wet distillers treatment resulted in greater ADG than all other treatments. The resulting feeding values were 96%, 65%, and 118% for PROT, FAT, and FIB, respectively. No single component accounted for the 136% feeding value of WDGS. However, FIB had performance most similar to WDGS and PROT had a feeding value very similar to corn.

Oglesbee et al. (2016) evaluated each distillers grains component alone, but also compared a blend of all isolated components to WDGS using the same ingredients as Conroy et al. (2016). The author concluded that fiber alone was not responsible for the increased performance of WDGS. The addition of protein, fat, and CDS increased performance. The combined inclusions of fiber, protein, fat, and CDS resulted in the same performance as WDGS fed at 40% of the diet (DM). The addition of CGM to the basal fiber diet significantly increased final BW, HCW, DMI, ADG, 12th rib fat, and calculated yield grade. Increased weight gain resulted in improved G:F ($P < 0.01$) as well. The improvement in efficiency increased the feeding value of the diet from 17 to 47%. This dramatic increase from a single component would support the idea that protein supplies a major portion of the increase in performance observed with distillers grains.

FIBER

Fiber in Finishing Diets

Neutral detergent fiber is a representation of the fibrous carbohydrates present in a particular feedstuff. In general, NDF contents cannot be digested by mammalian enzymes, therefore NDF can be used as a proxy for digestibility. The ruminant microbiome has the unique capability of digesting fiber particles. Complex feedstuffs are broken down into monomers that can be utilized by other microorganisms to produce VFA, vitamins and cofactors needed within the community (Krause et al., 2013). Cellulolytic bacteria, predominantly *F. succinogenes*, can attach directly to fiber particles in a highly ordered fashion to begin the process of digestion (McAllister et al., 1994;

Miron et al., 2001). Fiber digestion primarily occurs in the reticulorumen and is highly dependent on rate of microbial digestion (kd) and rate of passage (kp) through the rumen (Huhtanen et al., 2006).

Neutral detergent fiber is comprised of both the primary and secondary plant cell wall. The primary cell wall is on the outermost part of the plant and is readily digested by rumen microbes. The secondary cell wall forms inside the primary cell wall and may become lignified with maturation. Lignification decreases the digestibility of the secondary cell wall. Neutral detergent fiber is the fraction of cell wall that remains following reflux in a heated neutral detergent solution and filtering. It is composed of hemicellulose, cellulose, and lignin and provides the major source of digestible energy (DE) in most beef cattle diets except finishing diets which contain a high amount of concentrate. In addition to supplying DE to cattle, NDF also provides a source of physically effective fiber (peNDF) that helps stimulate rumination, insalivation, and reticuloruminal motility. These actions help to elevate ruminal pH and limit the incidence of acidosis. Physically effective fiber also helps to form a rumen mat that acts as a filtering mechanism to prevent feed from passing through the rumen undigested (NASEM, 2016). Many forages, plant residues, and byproduct feeds are high in neutral detergent fiber (NDF) content, and range from 30 to 75% of DM. Wet distillers grains plus solubles (WDGS) is a high-fiber byproduct (30% NDF) common in finishing diets today (Hales et al., 2013; Klopfenstein et al., 2008; NASEM, 2016).

With the exception of feedlot finished cattle, grazed and harvested forages account for 90 to 100% of the diets fed to beef cattle in the United States (NASEM, 2016). According to a survey conducted by Samuelson et al (2016), consulting

nutritionists reported that most finishing diets contain 8 to 10% roughage on a DM basis. Different from data presented by Vasconcelos and Galyean (2007) where alfalfa hay was a primary roughage source, corn silage and corn stalks were the two most widely used roughage sources in finishing diets. This change may suggest that supply of corn stalks has increased, and has therefore made them more cost effective. Regardless of roughage type, 86.1% of nutritionists reported that they used some type of processing method for mechanically altering the roughage before adding it to the diet. Also reported, the most common method of fiber analysis used when considering roughage source was NDF.

Fiber Concentration Considerations

Hales et al. (2013) evaluated the effect of roughage concentration in dry-rolled corn-based diets to determine the optimum level of dietary fiber in finishing diets. Ground alfalfa hay replaced DRC at 2% (AH-2), 6% (AH-6), 10% (AH-10), and 14% (AH-14) of DM in diets containing 25% WDGS. Dry matter intake increased linearly ($P = 0.02$) with increased inclusion of AH. Final BW, ADG, and G:F increased from 2 to 6% AH, but then decreased from 6 to 14% AH. Given the performance analysis, a producer considering feed efficiency to be the most important measure should consider 3% alfalfa hay, or equivalent roughage on NDF basis, as optimum in finishing diets. When considering ADG to be most important, 7% alfalfa hay appears to be the optimum concentration when 25% WDGS is included in the diet.

Given the highly digestible nature of steam-flaked corn, considerations must be made regarding acidosis when SFC is included at high concentrations, i.e. finishing diets. Chewing time and NDF content have been shown to be positively correlated. Furthermore, the percentage of dietary NDF and peNDF have been reported to account

for 92.0 and 93.1% of the variation in DMI, respectively (Galyean and Defoor, 2003). Theoretically, adding roughage should increase chewing and salivation. Buffers present in saliva provide protection from pH changes within the rumen so increased salivation should provide protection from acidotic instances (Armentano and Pereira, 1997). May et al. (2011) evaluated the effect of DDGS inclusion as well as roughage inclusion in SFC-based diets fed to beef steers. Distillers grains were included at 15 or 30% while alfalfa hay was included at 7.5, 10, or 12.5%. The authors observed no interaction between WDGS and alfalfa hay inclusion. Increasing dietary alfalfa hay inclusion, however, tended ($P < 0.8$) to linearly increase intakes while linearly decreasing ($P < 0.05$) G:F. Therefore, 7.5% alfalfa hay was determined to be the optimum inclusion level for SFC-based diets that include distillers grains.

Quinn et al. (2011) compared the effect of substituting forages based on the 7.5% inclusion level established by May et al. (2011) by feeding 7.5% alfalfa hay (AH) in combination with either 15 or 30% WDGS or comparing that to other available forage sources. Bermudagrass hay (BG) or sorghum silage (SS) replaced AH at inclusion levels to equalize the NDF content to 7.5% AH. All diets were compared to a SFC-based control diet that contained 10% AH, but no distillers grains. Steers fed AH with distillers grains had lower final shrunk BW and ADG ($P < 0.02$) than those fed BG or SS. Additionally, feeding SS decreased G:F compared to BG. The authors concluded that feeding BG with distillers grains resulted in the greatest performance relative to other combinations, and that exchanging roughages on an equal NDF-basis in SFC-based diets may not be ideal. These results differ from those reported by Benton et al. (2015) who compared alfalfa hay at 4 (low) and 8% (standard) of diet DM to corn silage (CSIL) and

corn stalks (CSTK) in DRC and HMC-based finishing diets containing 30% WDGS. As in the study conducted by Quinn et al. (2011), the CSIL and CSTK inclusion levels were formulated to provide equal dietary NDF to the standard and low alfalfa diets. The resulting diets included 6.13 and 12.26% CSIL or 3.04 and 6.08% CSTK on a DM basis. All diets were compared to a control diet that contained no roughage. Cattle that were fed no roughage had lower DMI ($P < 0.01$) and tended ($P \leq 0.10$) to have the lowest final BW and ADG of all treatments. Standard inclusion of roughage had greater ($P \leq 0.04$) DMI and ADG compared to the low inclusion diets, regardless of roughage type. Feed efficiency, however, was not affected by either roughage source ($P = 0.23$) or inclusion ($P = 0.49$). Therefore, the authors concluded that roughage sources can be substituted on an equal NDF-basis in diets containing 30% WDGS and performance would not be negatively impacted, but removing roughage from the diet was not beneficial.

CONDENSED DISTILLERS SOLUBLES

CDS in Finishing Diets

Condensed distillers solubles (CDS) have been used in beef diets for some time. In 1990, Rust et al. evaluated the use of CDS (7.56% DM) as an energy source in finishing diets. Individually fed steers consuming a 90% concentrate diet were assigned to one of the four following treatments: free choice water, free choice water plus 7.27 kg CDS/day, free choice water plus 7.27 kg CDS/day mixed into the grain, or free choice CDS with no water. Steers allowed free choice CDS had greater G:F ($P < 0.05$) than those allowed the free choice water control diet. The metabolizable energy (ME) of CDS when used as the only source of liquid was calculated to be 4.68 Mcal/kg. The authors concluded that, if used as a replacement for water, CDS may be included at levels up to

20% DM without negatively impacting performance. When fed at limited levels, though, CDS had similar efficiencies and therefore similar calculated ME values to one another. Trenkle (2002) fed CDS at 0%, 4%, and 8% DM in diets containing cracked corn, corn silage, and ground hay. Feed efficiency was improved by 5% at 4% inclusion and 1.5% at 8% inclusion while ADG was maximized at 4% of diet DM. These data suggested that there may be a maximum inclusion level for CDS much lower than the 20% suggested by Rust et al. (1990) when CDS was fed in a traditional manner. Pesta et al. (2012) fed CDS at 0, 9, 18, 27, and 36% of DM in HMC:DRC finishing diets. While ADG was maximized at 20.8%, DMI decreased in a linear fashion ($P < 0.01$). Feed efficiency was maximized at 32.5% where steers were 12% more efficient than those fed 0% CDS suggesting that CDS could be fed at greater inclusions than previously reported. Feeding values, however, were 210, 166, 142, and 139% for 9, 8, 27, and 36% CDS, respectively.

Early research on CDS was conducted by feeding in diets containing no byproducts. The evolution of the cattle feeding industry has involved a great deal of byproduct feeding the past 10 years. Consequently, it is extremely important to understand how feed ingredients interact with byproducts when the two are fed in combination. Pesta et al. (2012) evaluated feeding CDS at 0, 7, 14, and 21% in combination with 20% MDGS or 20% Synergy (ADM, Columbus, NE). Addition of CDS impacted DMI, ADG, F:G, final BW, and HCW ($P < 0.05$) regardless of byproduct type. Though ADG was maximized at 14% inclusion in the MDGS diets, G:F continued to improve up to 21% inclusion in both byproduct diets suggesting that approximately 20% CDS may be optimal. Bremer et al. (2009) evaluated feeding CDS in combination with 35% WCGF in HMC-based finishing diets. Performance was not affected by

replacing HMC with CDS. Therefore, the authors concluded that CDS can effectively be utilized as a method of reducing dietary corn, up to 20% of diet DM.

Corn processing method interactions also need to be considered when including a new diet ingredient. Titlow et al. (2013) fed CDS in both SFC and DRC-based finishing diets. As CDS replaced either type of corn, DMI increased quadratically. Average daily gain was maximized at 15% CDS in DRC-based diets while 30% CDS was optimum in SFC diets. Feed efficiency was maximized at 30% CDS in both corn diets. A greater performance response was observed when CDS was fed replacing a greater portion of SFC. Regardless of corn processing method, it appears that up to 30% CDS can be fed in finishing diets where no other byproducts were fed (Pesta et al., 2012). These results are in agreement with those from Harris et al. (2014) who found 27% to be the optimum inclusion level for CDS in SFC-based diets. These authors included CDS at 0, 9, 18, 27, or 36% replacing SFC in finishing diets containing no other byproducts. Performance appeared to drop off fairly dramatically at 36% CDS suggesting there is a maximum level of CDS inclusion in diets containing no other byproducts.

More recently, Hansen et al. (2018) fed 0, 8, 16, or 20% de-oiled CDS as well as 16% de-oiled CDS with 20% WDGS in high-moisture and dry-rolled corn-based finishing diets. As CDS inclusion was increased, ADG and G:F linearly increased. The relative feeding value of 20% CDS in this experiment was 147% that of corn. When CDS was fed in combination with 20% WDGS, ADG was not affected while DMI was decreased. This resulted in improved feed efficiency and a relative feeding value of 161% that of corn. These data suggest that feeding CDS in diets containing WDGS is superior to feeding CDS in diets without byproducts, and that 20% is an acceptable inclusion.

CDS in Growing and Forage-based Diets

Some feed ingredients have differing performance reactions in finishing and growing diets. Therefore, it is important for the producer to understand how these ingredients interact depending on what type of diet they are feeding. Condensed distillers solubles have been shown to be effective at improving performance in finishing diets, but an understanding of their impact in growing diets must also be established. Sharp and Birkelo (1996) replaced soybean meal, molasses, and DRC with CDS up to 20% in hay-based growing diets. Gains were not affected, but DMI was lower with increased levels of CDS, resulting in a tendency ($P = 0.14$) for improved feed efficiency. Corrigan et al. (2009) evaluated the effect of CDS inclusion level within DDGS when supplementing growing steers. Gains linearly increased up to 14.5% CDS, but then a quadratic response was observed at 19.1% and 22.1% inclusion of CDS in DDGS. The authors attributed an increase in ether extract concentration with increased CDS to the decrease in performance observed due to a hindrance on fiber digestibility.

More recently, the implementation of partial fractionation has changed the nutritional makeup of CDS due to the removal of fat. Jolly et al. (2013) evaluated the effect of oil removal on the feeding value of CDS in growing cattle. Condensed distillers solubles replaced a blend of brome hay and sorghum silage at 20% and 40% DM. Fat content did not affect final BW, DMI, or ADG, but cattle fed traditional CDS had 13.6% greater G:F than de-oiled CDS cattle at 20% inclusion. That margin was only 1% at 40% inclusion. The authors concluded that the greater fat content of traditional CDS likely affected fiber digestion at 40% inclusion. Hansen et al. (2018) followed up their finishing study by evaluating the effect of CDS in brome hay-based growing diets. Inclusion of

CDS increased from 0% to 40% diet DM replacing DRC. Increased levels of CDS resulted in a quadratic increase in DMI, and subsequently decreased G:F. The relative feeding value of CDS was less than that of corn in growing diets, and a TDN value of 73.7% was calculated for CDS at 40% inclusion. Similarly, Conroy et al. (2016) calculated a feeding value of 93% that of corn in forage-based growing diets containing DRC. These studies suggest that CDS do not have the same positive effect on performance observed in finishing diets when used in growing diets.

The liquid nature of CDS allows it to be used in a variety of situations. Wilken et al. (2009) ensiled either CDS or WDGS with corn stalks in a 50:50 blend. The blend was fed so that 15, 20, 25, or 30% (DM) byproduct was supplied to each animal. Steers fed WDGS and corn stalks were more efficient than those fed CDS and corn stalks. Despite the differences observed at the same level of inclusion, when higher levels of CDS corn stalks were compared to lower levels of WDGS corn stalks, performance was statistically similar. The authors stated that, if CDS can be purchased at a lower price than WDGS, CDS may be a suitable alternative when ensiled with corn stalks.

CONCLUSIONS

It has been clearly established that the ethanol industry along with other corn refining industries have revolutionized the world of cattle feeding in the last 30 years. In the United States, the proximity of cattle feeding to the starch substrates for ethanol fermentation have allowed producers to take advantage of opportunities available with grain byproducts. As previously stated, corn is the primary source of starch for the major types of grain processing, but other cereal grains like wheat, barley, and sorghum can be utilized as well. Both wet and dry milling produce feed products that can be fed to

ruminant animals. Distillers grains plus solubles are the primary feed product from the dry milling industry while corn gluten feed is the primary feed product produced by the wet milling industry. Both byproducts have been shown to improve finishing cattle performance in a number of situations. In many cases, corn gluten feed can also be used as a valuable ingredient in growing rations due to its peNDF content. Additionally, recent technological advances in the dry milling industry have allowed ethanol companies to fractionate the corn kernel. This process results in distillers grains that have decreased fat content with elevated protein and NDF content. Early fractionation did not appear to affect the feeding value of distillers grains as most of the fractionation was being done post-fermentation. Technologies like Cellerate® (Syngenta, Wilmington, DE) allow for pre-fermentation fractionation and the ability to remove more of the fat from the corn kernel. This specific technology produces a high protein distillers grains that slightly reduces efficiency in finishing cattle. This type of technology is new, however, so further research needs to be conducted to establish a conclusion on its effectiveness.

The primary components of the corn kernel and, consequently, distillers grains are starch, protein, fiber, and fat. When analyzed as individual components, protein and fiber appear to be the major contributing factors to the positive performance results observed when feeding distillers grains. The only byproduct that appears to be significantly altered by fractionation is condensed distillers solubles (CDS). During back-end fractionation, fat is centrifuged off of the CDS stream, therefore removing a portion of the fat. Condensed distillers solubles, however, tend to only increase performance when fed in finishing diets where concentrate levels are high. Nonetheless, byproducts from the corn milling

industry have been proven to be excellent feed ingredients for beef cattle and will likely continue to be utilized for many years.

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CHAPTER II. Effect of feeding distillers grains that have undergone a fiber separation process on performance, carcass characteristics, and metabolism of finishing beef steers.

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ABSTRACT

Two experiments were conducted to evaluate high-protein distillers grains (HIPRO) and corn bran plus solubles (BRAN+SOL) in finishing diets on performance, carcass characteristics and nutrient digestibility. In Exp. 1, 300 crossbred calf-fed steers (initial BW = 282 kg; SD = 10 kg) were used in a generalized randomized block design with treatments being a corn-based control (CON), traditional dry distillers grains plus solubles (DDGS), traditional wet distillers grains plus solubles (WDGS), HIPRO, and BRAN+SOL. Byproducts were included at 40% of diet (DM) and replaced a 50:50 blend of high-moisture and dry-rolled corn. All diets contained 15% corn silage and supplement. In Exp 2, six ruminally fistulated steers were utilized in a 6 × 6 Latin square design with six periods and six treatments. Diets were similar to those in Exp. 1 with the addition of a 20% HIPRO treatment (HIPRO20). Treatments included a corn control, high protein distillers grains plus solubles included at 40% of diet DM (HIPRO40), BRAN+SOL, WDGS, DDGS. In Exp. 1, feeding HIPRO and BRAN+SOL increased ADG and G:F ($P < 0.05$) compared to CON and WDGS while steers fed DDGS were intermediate. Feeding BRAN+SOL and HIPRO increased G:F by 10.3% and 8.6%, respectively. Final BW and HCW followed the same trend as ADG and G:F. In Exp. 2, feeding HIPRO40 or BRAN+SOL decreased DM and OM digestibility compared to CON ($P \leq 0.08$), but were similar to WDGS and DDGS ($P \geq 0.16$). Neutral detergent fiber digestibility and acid ADF digestibility were greatest for BRAN+SOL, but were not statistically different ($P > 0.14$) from all other treatments except DDGS ($P < 0.01$), which

had the least NDF and ADF digestibilities. Gross energy intake was greater ($P < 0.01$) for the treatments with 40% byproduct. No treatment effects were observed for average pH, maximum pH, or magnitude of pH change ($P \geq 0.73$). Additionally, treatment did not affect total VFA concentration ($P = 0.75$), proportion of any VFA measured ($P \geq 0.46$) or acetate:propionate ratio ($P = 0.96$). Replacing corn with high protein distillers grains plus solubles or Bran + Solubles at 40% of diet DM resulted in improved ADG, G:F, and DE despite having decreased OM digestibility compared to corn.

Key Words: beef cattle, bran, fractionation, high protein distillers grains, solubles

INTRODUCTION

Distillers grains plus solubles (DGS) have proven to be a high-quality feed for ruminant animals (Klopfenstein et al., 2008). The composition of DGS, however, has been changing in recent years. Pre- and post-fermentation fractionation of the corn kernel allows for separation of nutrients and has been shown to produce a product with reduced fat content (Bremer et al., 2015; Jolly et al., 2013). Industry perception has been that decreased fat results in decreased animal performance. However, results of several studies have shown minimal impact when oil is removed post-fermentation (Bremer et al., 2015; Burhoop et al., 2018; Jolly et al. 2013).

Recent advancements have allowed ethanol plants to utilize the separated fiber fraction of the corn kernel for cellulosic ethanol production. Lundy et al. (2015) reported reduced feed efficiency for cellulosic wet DGS resulting from a secondary fermentation process compared to traditional wet DGS. Crude protein (CP) of cellulosic wet DGS was reported to be 39.1% while traditional wet DGS had 34.0% CP. These results differ from those reported by Depenbusch et al. (2008) who found no difference in feed efficiency when fractionated DGS were fed to heifers. Additionally, the fraction with more concentrated fiber can be combined with condensed distillers solubles (CDS) to create another feed product. Fiber has been reported to be a large contributor to the increase in performance observed when DGS are included in ruminant diets (Conroy et al., 2016). In addition, CDS have a NE_m and NE_g of 2.08 and 1.28 Mcal/kg, respectively, when fed in finishing diets (Hansen et al., 2018; Pesta et al., 2012).

Buckner et al. (2011) fed a combination of corn bran and CDS (Dakota Bran, POET Nutrition, Sioux Falls, SD) to finishing steers and observed a linear increase in feed efficiency with inclusion of Dakota Bran. Results for the impact of high protein DGS from fractionation are inconclusive and limited data are available regarding the impact of corn bran plus solubles. Therefore, the objective of Exp. 1 was to evaluate the effect of feeding both HiPro DDG and Bran + Solubles on performance and carcass characteristics, and to establish a feeding value for HiPro DDG and Bran + Solubles. The objective of Exp. 2 was to evaluate the effect of feeding HiPro DDG and Bran + Solubles on nutrient digestibility, digestible energy, ruminal environment, and in vitro gas production. The new byproducts used in these studies were a result of a pre-fermentation fractionation process using Fiber Separation Technology™ (ICM Inc., Colwich, KS).

MATERIALS AND METHODS

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

Exp. 1 – Cattle Finishing Experiment

Crossbred calf-fed steers (n = 300; initial BW 282 kg; SD = 10 kg) were used in a generalized randomized block design at the University of Nebraska—Lincoln Eastern Nebraska Research and Extension Center near Mead, NE. Prior to the initiation of the trial, all animals were processed upon arrival into the feedlot with a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza 3, bovine respiratory syncytial virus, *Manheimia haemolytica* (Bovi-Shield Gold 5, Zoetis, Inc., Kalamazoo, MI), *Histophilus somnus* (Ultrabac 7, Zoetis, Inc.),

Dectomax (Zoetis, Inc.) and an oral anthelmintic (Safeguard, Merck Animal Health, De Soto, KS). Steers were re-vaccinated 14 d following initial vaccination for *Manheimia haemolytica* (Bovi-Shield Gold One Shot, Zoetis, Inc.) and *Histophilus somnus* protection (Somubac, Zoetics, Inc.). Additionally, prior to initiation of the trial, steers were limit fed (Watson et al., 2013) a diet containing 50% wet corn gluten feed (Sweet Bran, Cargill Corn Milling, Blair, NE) and 50% alfalfa hay (DM basis) at 2.0% of BW for 5 d to equalize gut fill. Steers were weighed on d 0 and d 1 to establish initial BW (Stock et al., 1983), and were implanted (200 mg TBA, 40 mg E; Revalor XS, Merck Animal Health, De Soto, KS) on d 1. Animals were blocked into one of 3 blocks by initial BW, stratified by BW within block, and assigned randomly to one of 30 pens.

Pens were assigned randomly to one of 5 dietary treatments (Table 2.1) with 6 replications per treatment and 10 steers per pen. The light and heavy blocks contained 1 replication each and the middle block contained 4 replications. Treatments included high protein distillers grains (HIPRO), corn bran plus solubles (BRAN+SOL), traditional dry distillers grains (DDGS), traditional wet distillers grains (WDGS), and a corn-based control (CON). High protein DGS and Bran + solubles were produced from the same process and were sourced from the same ethanol plant (Corn Plus, Winnebago, MN). Traditional dry and wet DGS were sourced from E Energy (Adams, NE) and Green Plains Ethanol (York, NE), respectively. A schematic of HIPRO and BRAN+SOL production compared to traditional DGS production is provided in Figure 2.1. The nutrient composition of each byproduct is provided in Table 2.2. Byproducts replaced a 50:50 blend of high-moisture and dry-rolled corn at 40% diet (DM basis). All diets contained 15% corn silage and 5% supplement. Supplements were formulated to provide

33.0 mg/kg monensin (Rumensin, Elanco Animal Health, Greenfield, IN) and 9.7 mg/kg tylosin (Tylan, Elanco). All diets were formulated to meet or exceed metabolizable protein (MP) requirements using the NRC (1996). Soypass (LignoTech USA, Inc., Rothschild, WI) was phase fed in the CON diet to exceed MP requirements (Table 2.1).

Cattle were fed *ad libitum* and feed bunks were evaluated daily at approximately 0530 h for refusals so that trace amounts of feed were left in the bunk at the time of feeding. Feed was delivered with a truck mounted mixer and delivery unit (Roto-Mix, Dodge City, KS) daily at 0800 h. All feed refusals were subsampled and dried for 48-h in a 60ºC forced-air oven for DM analysis and calculation of refusal DM weight (AOAC, 1999 method 4.1.03). Dietary ingredients were sampled weekly for DM determination. Dietary as-fed ingredient inclusions were adjusted on a weekly basis. Steers were fed for 190 d and were harvested at a commercial abattoir (Greater Omaha, Omaha, NE). Hot carcass weight and liver scores were collected on the d of harvest. Hot carcass weight was used to adjust inal BW, ADG, and G:F using a 63% dressing percentage. Marbling score, 12^{th} rib fat thickness, and LM area were collected after a 48 h chill.

All data were analyzed using the MIXED procedure of SAS (SAS Inst. In., Cary, NC) as a randomized block design. Pen (n = 6 per treatment) was used as experimental unit while block (n = 3) was analyzed as a fixed effect. Dead steers were removed from analysis. Two animals were removed due to death from respiratory infection. One animal was removed from the BRAN+SOL treatment while the other was removed from the CON treatment. Treatment differences were considered significant when $P \leq 0.05$ and tendencies were considered when $P \leq 0.10$. Feeding values of byproducts were calculated using the following equation: {((($G:F_{TRT} - G:F_{CON}$)/$G:F_{CON}$) / byproduct inclusion, %) +

1} × 100. Feed efficiency of treatment is denoted as $G:F_{TRT}$, and $G:F_{CON}$ represents the feed efficiency of the control treatment. Dietary NEm and NEg values were calculated for each treatment based on intake and performance of steers. The data were analyzed as dietary NE for each pen, similar to performance data using equations from the NRC (1996) as described by Vasconcelos and Galyean (2007).

Exp. 2 – Digestion Experiment

A 126-d metabolism study was conducted utilizing six ruminally fistulated crossbred yearling steers (initial BW = 529 kg; SD = 31 kg). The experiment was arranged in a 6 × 6 Latin square with six steers and six periods. Steers were assigned randomly to one of six treatments with each steer assigned to each treatment once throughout the study. Treatments included a corn-based control, 20% high protein DGS (HIPRO 20), 40% high protein DGS (HIPRO 40), 40% corn bran plus solubles (BRAN+SOL), traditional wet DGS (WDGS), and 40% traditional dry DGS (DDGS). All diets contained 15% corn silage and supplement. Byproducts replaced a 50:50 blend of high-moisture and dry-rolled corn. All diets were formulated to meet or exceed MP requirements using the NRC (1996). The supplement was formulated to provide 90 mg/steer daily of tylosin (Tylan-40, Elanco Animal Health, Greenfield, IN) and 33.0 mg/kg of monensin (Rumensin-90®, Elanco; Table 2.3).

Steers were housed in individual concrete slatted pens (2.1 × 3.7 m) and allowed *ad libitum* access to feed and water. They were fed once daily at 0800 h and feed refusals were removed and weighed prior to feeding. Ingredient samples were taken on days 17 and 19 of each period. Feed samples were composited by period, lyophilized (Freezemobile 25ES, VirTis, Gardiner, NY), ground through a 1-mm screen on a Willey

Mill, and analyzed for dry matter (DM), organic matter (OM; AOAC, 1999, Method 4.1.10), neutral detergent fiber (NDF), fat, crude protein (CP), and gross energy. Ash was evaluated by placing samples in a muffle furnace for 6 h at 600ºC. Crude protein and S were determined using a combustion-type N and S analyzer (FlashSmart N/Protein Analyzer, CE Elantech, Inc., Lakewood, NJ). Neutral detergent fiber was determined using the procedure described by Van Soest et al. (1991) with modifications described by Buckner et al. (2010) for byproducts. Acid detergent fiber content was determined using the procedure described by Van Soest (1963). Lipid content was determined by a biphasic lipid extraction process described by Bremer (2010). Nutrient composition of each dietary treatment is provided in Table 2.3.

Each period consisted of 21 days including a 16 day adaptation phase with 5 days of collection. Titanium dioxide, an indigestible marker, was dosed intraruminally twice daily at 800 and 1600 h each day of the experiment to provide a total of 10 g/d for use as an estimate of total fecal output. Fecal grab samples were collected four times daily at 700, 1100, 1500, and 1900 h on days 17-20. Samples were composited by day, lyophilized and ground through a 1-mm screen on a Wiley Mill (Thomas Scientific). Dried and ground samples were then composited by period for each steer and analyzed for titanium dioxide. Titanium dioxide concentration was determined as described by Myers et al. (2004). Concentration of TiO_2 was then used to calculate fecal DM output using the equation described by Cochran and Galyean (1994). Feed and fecal samples were analyzed for DM, OM, NDF, and gross energy. A Parr 6400 Bomb Calorimeter (Parr Instrument Company, Molin, IL) was used to analyze feed and fecal samples for gross energy. The instrument used 99.5% pure oxygen set to 450 psi on the outlet gauge.

Nitrogen gas was set to 80 psi on the outlet gauge. Precut fuses (part # 845DD2) were used to ignite samples. Benzoic acid samples were used to standardize the machine each day prior to analyzing other samples. After calibration, samples ranging between 0.400-0.404 g were weighed into combustion capsules. If pellets could not be formed from samples of HMC, DRC, or corn silage , 0.2000-0.2999 g of mineral oil was added. Capsules were allowed to rest overnight to allow full dispersion of mineral oil throughout the sample. Each sample was then burned in the machine. The recorded temperature rise was then used to calculate heat of combustion (Hc): $\frac{\mathrm{WT-e1-e2-e3-(Hcs)(Ms)}}{\mathrm{m}}$; where (*W*) is the energy equivalent of the calorimeter, (*T*) is the observed temperature rise, (*e*1) is the heat produced by burning nitrogen in the air, (*e*2) is the heat produced by formation of sulfuric acid, (*e*3) is the heat produced by the heating wire and cotton thread, (*m*) is the mass of the sample, (*Hcs*) is the heat of combustion for the spiked material, and (*Ms*) is the mass of the spiking material (Hamilton, 2016).

Submersible wireless pH loggers (Dascor, Inc., Escondido, CA) were inserted in the rumen on d 14, and recorded pH measurements every minute through d 21. Ruminal pH data were analyzed from d 17-20 to allow for adaptation and to ensure that pH reported was representative of samples taken during collection time points. Loggers were attached to a weight to ensure the electrode remained in the ventral sac of the rumen. All loggers were calibrated prior to being inserted in the rumen each period by submersing them in pH 4 and 7 standards 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. Ruminal pH was averaged by day and

day was analyzed as a repeated measure. Measurements included average pH, minimum and maximum pH, and magnitude of pH change.

Rumen in situ bags (Dacron 5 x 10 cm; Ankom Technology, Macedon, NY) were used to estimate NDF digestibility at 16 and 24 hours of incubation using 1.25 g (as-is, not ground) of dry corn bran produced from a wet corn milling process. The bran used in the in situ bags has a larger particle size than bran present in the Bran + Solubles product as Bran + Solubles is produced through a dry corn milling process where the corn kernel is ground. Bags were placed in a mesh bag and inserted into the ventral sac of the rumen at different start times so they could be removed at the same time. Bags were incubated for 16 and 24 h incubation periods starting on d 20 with 2 bag / steer per time period. All bags were removed at 1400 h on d 21. Following removal, samples were machine washed 5 times with 3 min per cycle (1 min agitation and 2 min spin; Whittet et al. 2003) and immediately frozen. Bags were analyzed for NDF using the ANKOM system. After going through the NDF procedure, bags were dried in a 60ºC forced-air oven for 24 h. Weights from the dried bags were used to calculate NDF digestibility.

Samples of rumen fluid were collected using a vacuum pump on day 20 at 0700, 1100 and 1400 h and immediately frozen. At time of analysis, rumen fluid samples were thawed in a cooler (4ºC) to ensure no additional fermentation occurred. Following thawing, samples were prepared according to Erwin et al. (1961) and analyzed for VFA concentration using a Trace 1300 gas chromatograph (Thermo Fischer Scientific, Inc., Omaha, NE) fitted with a capillary column (Phenomenex Inc., Torrance, CA). The column was 30 m in length with an inside diameter of 0.32 mm and a film thickness of 1µ. An internal standard of crotonic acid was used for all samples. Total run time was

9.75 min. During analysis, the inlet and flame ionization detector temperatures were held at 280ºC. Oven temperature started at 160ºC and increased 8ºC per minute until it reached 200ºC. Helium was used as a carrier gas. Column carrier flow was set at 2.4 mL/min. Flow rates of compressed air and hydrogen were set at 350 and 30 mL/min, respectively. Peak areas were determined with auto-integration and manual review of chromatograms. The VFA concentrations were calculated using a ratio relative to known amounts of the internal standard (Crotonic acid) and an external standard mix of acetate, propionate, isobutyrate, butyrate, isovalerate, and valerate.

Additionally, samples of rumen fluid were collected and utilized to determine gas production by treatment. Two 250 mL bottles were collected from each animal at 1400 h on d 21 of each period. These samples were collected 6 h post-feeding. The DM of whole rumen contents was determined using 100 mL of this sample which was frozen immediately after collection. The remaining sample was incubated using ANKOM gas bottles for 6 h. Following incubation, the 6 h sample was flash frozen. Each sample was also analyzed for VFA concentration using the method described above. Rate of VFA production was calculated using the following equation: [(6 h VFA concentration – 0 h VFA concentration)/ 6 h incubation].

Digestibility, intake data, and gas production data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc. Cary, NC). Treatment and period were treated as fixed effects while steer within period was a random effect. Ruminal pH data were summarized by hour and analyzed with day as repeated measures using the GLIMMIX procedure of SAS (SAS Institute, Inc. Cary, NC). Due to malfunctioning probes, only three were included in the analysis of pH data. Data for VFA concentration

were analyzed as a repeated measure by hour using the MIXED procedure of SAS (SAS Institute). The model included time, treatment, and time by treatment interactions. Steer was considered a random effect. *P*-values ≤ 0.10 were considered significant. If significant, treatments were separated and compared using a t-test.

RESULTS AND DISCUSSION

Exp. 1 – Cattle Finishing Experiment

Performance and carcass results are provided in Table 2.4. Dry matter intake was not affected by treatment ($P = 0.62$). Average daily gain (ADG) was impacted by dietary treatment ($P = 0.02$) with steers fed HIPRO or BRAN+SOL having the greatest ADG. Steers fed CON or WDGS had similar ($P = 0.96$) gains to one another, but were lowest among all treatments. Steers fed DDGS were intermediate in ADG, but not different ($P > 0.14$) from any other treatments. Similar intakes and improved ADG resulted in the HIPRO and BRAN+SOL treatments having improved ($P < 0.05$) G:F compared to CON and WDGS. The DDGS treatment was intermediate and not different ($P > 0.20$) than CON or WDGS. Feeding HIPRO tended ($P = 0.09$) to improve G:F over DDGS. Hot carcass weight and final BW followed a similar trend to ADG. The HIPRO and BRAN+SOL cattle had the greatest HCW, but were not different ($P > 0.41$) from each other. Steers fed CON or WDGS had the lightest carcass weights, while DDGS was intermediate. No other performance or carcass characteristics were affected by dietary treatment ($P \geq 0.62$).

Previous research suggests that feeding traditional DDGS at 40% of diet DM results in greater DMI, ADG, and G:F compared to corn based diets (Buckner et al.,

2007; Klopfenstein et al., 2008). The performance improvements observed when feeding DGS have been largely attributed to the protein and fiber components (Larson et al., 1993; Conroy et al., 2015; Carlson et al., 2016). In the current study, the increased protein content of the HIPRO DDGS (36.0% CP v. 31.3% CP in traditional DDGS) appears to be consistent in creating the performance response observed in previous research with traditional DDGS. Biologically, digestible RUP has approximately 143% the energy value of starch in ruminant diets (Kleiber, 1961). Although RUP content of HIPRO DDGS was not measured in the current study, if an RUP value of 63% of CP similar to that of traditional DGS (Castillo-Lopez et al., 2013) is assigned to HIPRO DDGS, 22.7% of DM is RUP. Therefore, 9.1% of diet DM is supplied in the form of RUP. This is 1% greater than the traditional DDGS diets (8.1%) when included at 40% DM.

Feeding HIPRO resulted in an 8.6% improvement in feed efficiency over CON. Based on feed efficiency, the feeding value of HIPRO DDGS was 121% of corn. A meta-analysis by Bremer et al. (2011) established a feeding value of 112% for traditional DDGS regardless of inclusion in DRC:HMC diets. From these results we can conclude that a one percentage point increase in RUP from HIPRO DDGS in the diet resulted in a nine percentage point improvement in feeding value over traditional DDGS. These results are not consistent with results by Kelzer et al. (2011) who observed no difference ($P >$ 0.40) in performance or carcass characteristics when a low-fat, high-protein DGS was fed at 35% of diet DM compared to traditional DGS. The composition of DGS used in Kelzer's study was very similar to HiPro DDG used in the current study (39.0% CP; 23.6% NDF; 5.1% fat). Additionally, Lundy et al. (2015) reported a 27% decrease in

feeding value for the cellulosic WDG product (39.1% CP) despite having greater CP than WDGS used for comparison in their study. Furthermore, the cellulosic WDG in their study resulted from a post-fermentation fractionation process, whereas HIPRO DDGS resulted from a pre-fermentation fractionation process in our study. Whether the different effects observed result from how fractionation occurs or differences in inclusion level is not clear at this point.

As previously mentioned, fiber has been shown to account for an appreciable portion of the positive performance response observed when feeding DGS (Carlson et al., 2016; Conroy et al., 2016; Oglesbee et al., 2016). In the current study, feeding Bran + Solubles resulted in a 10.3% improvement in G:F while providing a feeding value of 126% compared to corn. These results are slightly better than those observed by Buckner et al. (2011) who reported a feeding value of 114% that of corn for Dakota Bran fed at 45% of diet DM. The bran:solubles ratio is unknown for Dakota Bran, but Bran + Solubles are produced with approximately a 50:50 blend of corn bran and CDS. Therefore, when fed at 40% of diet DM, 20% of diet DM is CDS. Hansen et al. (2018) and Pesta et al. (2012) reported that feeding 18% and 20% CDS resulted in feeding values of 166% and 147%, respectively when fed in diets containing no other byproducts. This suggests that the high relative amount of CDS present in Bran + Solubles is responsible for a great deal of the positive performance response observed in the current study.

Exp. 2 – Digestion Experiment

Nutrient intake and digestibility are presented in Table 2.5. No treatment differences were observed for dry matter intake ($P = 0.55$). However, total tract dry

matter digestibility (TTDMD) was decreased ($P < 0.10$) with 40% inclusion of byproduct, regardless of type. These results are consistent with previous research feeding traditional DGS (Corrigan et al., 2009; Vander Pol et al., 2009; Carlson et al., 2016) as well as with fractionated DGS. Lundy et al. (2016) reported that lambs fed 45% cellulosic WDG had lower TTDMD than those fed CORN or traditional WDGS. When high protein distillers grains were included at 20% of the diet (DM) TTDMD was intermediate, but not different ($P > 0.16$) from CON and all other byproduct treatments except for HIPRO40. Results for total tract organic matter digestibility (TTOMD) followed the same trend as TTDMD.

Treatment affected NDF intake ($P < 0.01$) with steers fed BRAN+SOL having the greatest intake and CON having the least ($P < 0.01$). Steers fed DDGS, WDGS, and HIPRO40 were intermediate, but not different from ($P > 0.13$) BRAN+SOL or HIPRO20. Total tract NDF digestibility (TTNDFD) was numerically greatest for BRAN+SOL at 61.6%, but was not statistically different ($P > 0.14$) from all other treatments except, DDGS, which was lower ($P < 0.01$). The lowest numerical TTNDFD was observed for the DDGS treatment at 45.5%.

In situ NDF disappearance of corn bran was not affected by treatment ($P = 0.64$) and averaged 15.3%. In situ digestibilities are consistent with results from Sayer et al. (2013) who observed limited in situ NDF disappearance for corn bran from wet milling at 16 and 24 h time points. Disappearance increases with greater ruminal retention time. Discrepancies in total tract NDF digestibility and in situ NDF disappearance can be explained by the differences in bran present in the two products. Bran from wet milling

has a larger particle size than bran in Bran + Solubles as this bran is ground to a size similar to DGS (approximately 0.66 mm diameter; Liu et al., 2008).

Acid detergent fiber intake and digestibility were also impacted by treatment ($P < 0.01$). Intake was greatest for HIPRO40, BRAN+SOL and WDGS. The control treatment resulted in the lowest ADF intake ($P < 0.01$), and HIPRO20 and DDGS were intermediate to all treatments, but not different ($P = 0.32$) from one another. Total tract ADF digestibility (TTADFD) was numerically greatest for the BRAN+SOL treatment; however, inclusion of all byproduct treatments except DDGS ($P = 0.69$) resulted in greater TTADFD than CON ($P < 0.03$).

Gross energy intake when expressed as Mcal/d was not significantly different ($P = 0.56$) across treatments; however, when gross energy intake is expressed as Mcal/kg, HIPRO40 and BRAN+SOL had the greatest ($P < 0.01$) energy intake. No other energy calculations were significantly different across treatments; however, digestible energy (DE) intake expressed as Mcal/kg was numerically greater for byproduct treatments compared to CON. This is primarily due to the numerical differences observed in DMI for the different treatments. Treatments with lower DMI had lower energy intake. Feeding Bran + Solubles and HiPro DDG numerically increased DE intake (Mcal/kg) as well. The general increase in both GE and DE may explain the improved ADG and G:F observed in Exp. 1. Research has shown that the additional protein and fat in distillers grains provides additional DE to the animal while organic matter digestibility is decreased (Hamilton, 2016.) This relationship can be observed in Figure 2.2. Olsen et al. (2008) reported that OMD was highly correlated ($r^2 = 0.93$) to DE; however, when DGS were included in the diet, discrepancies occurred suggesting that energy is being

consumed but not realized in the feces. Fecal energy is the largest and most variable loss of intake energy (Brown, 1966), which may explain why GE intake is significantly different for byproduct treatments but not for DE.

No treatment effects were observed for average pH, maximum pH, or magnitude of pH change ($P \geq 0.73$; Table 2.6). Minimum ruminal pH was numerically lowest for the HIPRO20 treatment at 4.85, although this was not significantly different ($P > 0.18$) from CON, BRAN+SOL, DDGS or WDGS. Feeding HIPRO40 resulted in a minimum pH of 5.15; numerically greatest of all treatments. These results are consistent with previous research regarding traditional distillers grains. Distillers grains do not tend to affect ruminal pH parameters (Bremer et al., 2010; Corrigan et al., 2009; Vander Pol et al., 2009). However, Sayer (2004) reported an increase in average ruminal pH when 30 and 45% corn bran from wet milling was fed in combination with distillers solubles. Again, it is important to consider the difference in particle size of the bran in Bran + Solubles compared to bran produced during wet milling. Bran produced from wet milling has an NDF content of approximately 75% (DeHaan, 1983; Sayer et al., 2013; Scott et al., 1998) while Bran + Solubles has only 32%. The nutrient composition of Bran + Solubles is much like that of DGS; therefore, the potential for acidosis control observed when feeding corn bran alone may not be realized when feeding BRAN+SOL.

There was a time by treatment interaction ($P < 0.01$) for butyrate molar concentration primarily due to the difference in concentration at 0700 h (Fig. 2.3). There appears to be a time by treatment interaction for propionate concentration; however, limited observations and error do not allow for the interaction to be picked up significantly (Fig. 2.4; $P = 0.47$). Propionate appears to spike at 1100 h for both HIPRO

treatments with HIPRO 20 at 55.6% propionate. Both treatments then decline in propionate concentration by 1400 h. The spike in propionate and relative steady state of acetate subsequently decreased the A:P ratio at 1100 h (Fig. 2.5). Treatment did not affect total VFA concentration ($P = 0.75$; Table 2.6), molar concentration of any of the measured VFAs ($P \geq 0.46$), or A:P ratio ($P = 0.96$) when averaged over three time points. However, time was significant for propionate, butyrate, and A:P ($P < 0.01$) when molar concentrations were evaluated at 0700, 1100, and 1400 h individually (Figures 2.3-2.5). Relative proportions of all VFA appear to be consistent with previous research on corn-based finishing diets including byproducts (Burhoop et al., 2018; DiCostanzo and Crawford, 2013; Sayer et al., 2013).

Gas production was not significantly ($P \geq 0.15$) different across treatments for total mL produced, rate of gas production, and VFA production rate over 6 hours (Table 2.7). Total gas production is an indicator of extent of digestion within the rumen while rate of production is an indicator of how digestible a feedstuff may be. Total gas production is lower than results from Hansen (2017) who reported total gas production ranging from 13.5-18.9 mL/g DM. Additionally, Hansen (2017) and Hilscher (2018) reported gas production rates much lower than what was observed in the current study (18-30 %/h). Gas production measures for the two previously mentioned studies were conducted over a 24-h period whereas gas production data were only collected for 6 h in the current study. Given the curvilinear pattern of gas production over time (Getachew et al., 2004), it is logical that the rates observed in the current study would be greater than those observed in previous research. In addition, corn-based finishing diets are more digestible than growing diets like those fed by Hansen (2017) and corn-silage-based

finishing diets like those fed by Hilscher (2018). Limited gas production data are available for further comparison. High protein DGS fed at 40% of diet DM consistently had numerically reduced total gas production, rate of gas production, and rate of VFA production. Distillers grains are high in RUP (63%; NASEM); therefore it is logical that a greater portion of the protein is bypassing rumen fermentation than BRAN+SOL despite having similar dietary CP values. Because nearly 20% of diet DM is protein, a large portion of the HIPRO40 diet is likely not fermented in the rumen, explaining the reduced production values.

In summary, feeding high protein distillers grains or corn bran plus solubles resulted in decreased digestibility compared to corn, but increased energy intake. Traditional wet and dry distillers grains also resulted in decreased digestibilities while energy intake was increased. Volatile fatty acid profiles and pH parameters were not different across treatments. Overall, nutrient digestibility for high protein distillers grains and corn bran plus solubles is similar to traditional wet or dry distillers grains. The increased energy intake and greater protein concentration from fractionation appear to be contributing to greater performance observed in Exp. 1 for HIPRO and BRAN+SOL. Overall, relative feeding values of 121% and 126% were established for HiPro DDG and Bran + Solubles, respectively.

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Table 2.1. Dietary composition (DM basis) of treatments fed to calf-fed steers (Exp. 1)

	Treatment[1]				
	CON	HIPRO	BRAN+SOL	DDGS	WDGS
Ingredients[2]					
HMC	39.25	20.50	20.50	20.50	20.50
DRC	39.25	20.50	20.50	20.50	20.50
Corn Silage	15.00	15.00	15.00	15.00	15.00
HiPro DDG	-	40.00	-	-	-
DDGS		-	-	40.00	-
WDGS	-	-	-	-	40.00
Bran + Solubles	-	-	40.00	-	-
Supplement					
FGC	-	1.8875	1.8875	1.8875	1.8875
Limestone	1.6600	1.6200	1.6200	1.6200	1.6200
Tallow	0.1625	0.1000	0.1000	0.1000	0.1000
Urea	1.2900	-	-	-	-
SoyPass[3]	3.0000	-	-	-	-
Salt	0.3000	0.3000	0.3000	0.3000	0.3000
Beef Trace Min.[4]	0.0500	0.0500	0.0500	0.0500	0.0500
Vit. ADE[5]	0.0150	0.0150	0.0150	0.0150	0.0150
Rumensin-90	0.0165	0.0165	0.0165	0.0165	0.0165
Tylan-40	0.0110	0.0110	0.0110	0.0110	0.0110

[1] Treatments included CON-control; HIPRO20-20% high protein distillers grains; HIPRO40-40% high protein distillers grains; BRAN+SOL-40% corn bran plus solubles; DDGS-40% traditional dry distillers grains; WDGS-40% traditional wet distillers grains

[2]DRC = dry-rolled corn, HMC = high-moisture corn, HiPro DDG = high-protein dry distillers grains, DDGS = dry distllers grains plus solubles, WDGS = wet distillers grains plus solubles, FGC = fine-ground corn

[3]Soypass (Lignotech USA, Rothschild, WI) was phase fed in the CON diet to meet MP requirements beginning with 3.0% DM on d 1. Animals were stepped down to 1.5% DM on d 43, and 0% on d 65

[4]Premix contained 10% Mg, 6% Zn, 4.5% Mn, 0.5% Cu, 0.3% I, and 0.05% Co

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

Table 2.2. Nutrient composition of byproducts fed to steers (Exp. 1 and 2)

Nutrient[1]	HiPro DDG	Bran + Solubles	WDGS[2]	DDGS[3]
DM, %	91.8	40.7	32.8	91.4
CP, %	36.0	33.5	30.1	32.5
NDF, %	32.0	32.3	30.2	31.6
Fat, %	9.4	9.8	11.6	6.2
Sulfur, %	0.68	0.70	0.65	0.70

[1]Nutrients expressed on a dry-matter basis
[2]Wet distillers grains plus solubles
[3]Dry distillers grains plus solubles

Table 2.3. Dietary composition (DM basis) of treatments fed to ruminally cannulated steers (Exp. 2)

	Treatment[1]					
	CON	HIPRO20	HIPRO40	BRAN+SOL	DDGS	WDGS
Ingredient[2]						
DRC	39.3	30.5	20.5	20.5	20.5	20.5
HMC	39.3	30.5	20.5	20.5	20.5	20.5
Corn Silage	15.0	15.0	15.0	15.0	15.0	15.0
HiPro DDG	-	20.0	40.0	-	-	-
Bran + Solubles	-	-	-	40.0	-	-
DDGS	-	-	-	-	40.0	-
WDGS	-	-	-	-	-	40.0
Supplement						
FGC	-	1.8875	1.8875	1.8875	1.8875	1.8875
Limestone	1.66	1.62	1.62	1.62	1.62	1.62
Tallow	0.1625	0.10	0.10	0.10	0.10	0.10
Urea	1.29	-	-	-	-	-
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Beef Trace Min.[3]	0.05	0.05	0.05	0.05	0.05	0.05
Vit. ADE[4]	0.015	0.015	0.015	0.015	0.015	0.015
Rumensin-90	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165
Tylan-40	0.011	0.011	0.011	0.011	0.011	0.011
Nutrient Composition, % DM						
DM	63.7	66.0	68.8	50.0	68.7	44.7
NDF	13.9	18.4	22.9	23.0	22.7	22.2
CP	13.4	14.2	19.6	18.6	17.3	18.2
Fat	3.9	5.0	6.1	6.2	4.8	7.0

[1]Treatments included CON-control; HIPRO20-20% high protein distillers grains; HIPRO40-40% high protein distillers grains; BRAN+SOL-40% corn bran plus solubles; DDGS-40% traditional dry distillers grains; WDGS-40% traditional wet distillers grains

[2]DRC = dry-rolled corn, HMC = high-moisture corn, HiPro DDG = high-protein dry distillers grains, DDGS = dry distillers grains plus solubles, WDGS = wet distillers grains plus solubles, FGC = fine-ground corn

[3]Premix contained 10% Mg, 6% Zn, 4.5% Mn, 0.5% Cu, 0.3% I, and 0.05% Co

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

Table 2.4. Effect of feeding HiPro DDG or Bran+Solubles on performance and carcass characteristics of finishing steers (Exp. 1)

	Treatment						
	CON	HIPRO	BRAN+SOL	DDGS	WDGS	SEM	*P*-Value
Performance							
Initial BW, kg	274	273	275	274	274	1.8	0.70
Final BW, kg	597[b]	620[a]	629[a]	612[ab]	597[b]	17.3	0.03
DMI, kg/d	9.8	9.6	9.7	9.7	9.5	0.28	0.62
ADG, kg	1.71[b]	1.83[a]	1.87[a]	1.78[ab]	1.70[b]	0.089	0.02
G:F	0.175[c]	0.190[ab]	0.193[a]	0.183[bc]	0.179[c]	-	0.02
Energy Value							
NE_m, Mcal/kg[1]	1.96	2.05	2.05	1.94	1.97	0.037	0.13
NE_g, Mcal/kg[2]	1.31	1.39	1.39	1.31	1.31	0.032	0.12
Feeding Value, %[3]	-	121	126	111	106	-	-
Carcass Characteristics							
HCW, kg	376[b]	390[a]	396[a]	385[ab]	376[b]	10.9	0.03
LM Area, cm^2	85.1	85.8	87.7	87.1	85.8	0.26	0.84
Marbling[4]	463	461	454	480	453	14.5	0.69
Fat Depth, cm	1.27	1.27	1.27	1.30	1.22	0.022	0.92
Calc YG[5]	3.2	3.3	3.2	3.2	3.1	0.11	0.86

[abc] Values within rows with unique superscripts are different ($P < 0.10$)

[1] Predicted NE_m values for diets calculated using NRC (1996) equations, assumed TDN value of corn (88%)

[2] Predicted NE_g values for diets calculated using NRC (1996) equations, assumed TDN value of corn (88%)

[3] Feeding value expressed as a relative percentage to the energy value of corn

[4] 400 = Small^0, 500 = Modest^0

[5] Calculated as 2.5 + (0.9843 × 12th rib fat, cm) + (0.2 × 2.5(KPH, %)) – (0.0496 × LM Area, cm^2) + (0.0084 × HCW, kg)

Table 2.5. Effect of feeding high protein distillers grains or corn bran plus solubles on dry matter, organic matter, NDF and ADF digestibility, energy intake, and in situ NDF digestibility (Exp. 2)

	Treatment[1]							
	CON	HIPRO20	HIPRO40	BRAN+SOL	DDGS	WDGS	SEM	*P*-Value
DM								
Intake, kg/d	11.8	12.1	11.0	11.7	10.9	11.4	0.65	0.55
Fecal output, kg/d	2.5	2.9	3.1	2.9	2.9	2.9	0.24	0.45
Digestibility,%	79.1^{a}	76.1^{ab}	72.0^{c}	74.5^{bc}	73.1^{bc}	74.0^{bc}	1.55	0.04
OM								
Intake, kg/d	11.4	11.6	10.5	11.1	10.4	10.8	0.62	0.42
Fecal output, kg/d	2.2	2.6	2.7	2.5	2.5	2.5	0.24	0.56
Digestibility,%	81.0^{a}	78.0^{ab}	74.6^{b}	77.4^{b}	76.0^{b}	76.8^{b}	1.49	0.06
NDF								
Intake, kg/d	1.64^{c}	2.23^{b}	2.52^{ab}	2.69^{a}	2.48^{ab}	2.53^{ab}	0.143	<0.01
Fecal output, kg/d	0.70^{c}	1.04^{b}	1.19^{ab}	1.03^{b}	1.35^{a}	1.00^{b}	0.107	<0.01
Digestibility,%	57.6^{a}	54.0^{ab}	52.8^{ab}	61.6^{a}	45.5^{b}	59.0^{a}	3.58	0.07
ADF								
Intake, kg/d	0.77^{c}	1.26^{b}	1.59^{a}	1.64^{a}	1.17^{b}	1.52^{a}	0.083	<0.01
Fecal output, kg/d	0.45	0.53	0.61	0.54	0.62	0.54	0.054	0.26
Digestibility,%	42.0^{b}	58.4^{a}	62.4^{a}	66.9^{a}	44.8^{b}	63.2^{a}	6.86	<0.01
Energy								
GE Intake, Mcal/d	50.5	54.7	52.4	55.9	50.7	53.0	3.02	0.56
GE Intake, Mcal/kg	4.27^{d}	4.52^{c}	4.78^{a}	4.79^{a}	4.65^{b}	4.65^{b}	0.024	<0.01
Fecal Energy, Mcal/d	11.3	13.3	14.5	13.8	13.0	13.7	1.13	0.32
DE, Mcal/d	39.1	41.5	37.9	42.1	37.3	39.3	2.50	0.61
DE, Mcal/kg[2]	3.32	3.44	3.48	3.59	3.45	3.42	0.081	0.34
In situ NDFD, %[3]	16.0	16.1	14.6	13.9	15.7	15.5	0.01	0.64

[a-d] Values within rows with differing superscripts are different ($P < 0.10$)

[1]Treatments included CON-control; HIPRO20-20% high protein distillers grains; HIPRO40-40% high protein distillers grains; BRAN+SOL-40% corn bran plus solubles; DDGS-40% traditional dry distillers grains; WDGS-40% traditional wet distillers grains

[2]Mcal of Digestible Energy per kg of dry feed consumed
[3]In situ bags containing corn bran were incubated in rumen of steers fed each treatment and averaged by treatment for digestibility

Table 2.6. Effect of feeding high protein distillers grains or corn bran plus solubles on ruminal pH and VFA production (Exp. 2)

	Treatment[1]							
	CON	HIPRO20	HIPRO40	BRAN+SOL	DDGS	WDGS	SEM	*P*-Value
pH								
Average pH	5.40	5.36	5.75	5.47	5.53	5.45	0.501	0.73
Maximum pH	6.08	6.35	6.51	6.21	6.23	6.31	0.298	0.90
Minimum pH	4.89[b]	4.85[b]	5.15[a]	4.99[ab]	5.04[ab]	4.91[b]	0.087	0.08
pH Magnitude	1.18	1.49	1.36	1.22	1.19	1.40	0.243	0.83
VFA Proportion, %[2]								
Acetate, %[3]	51.5	48.3	53.1	51.7	49.7	54.2	3.98	0.72
Propionate, %	34.4	37.9	29.4	30.0	34.1	29.1	5.41	0.46
Butyrate, %	10.8	9.1	12.1	14.0	10.9	11.8	2.14	0.60
Total VFA, mM	120.6	112.1	106.9	112.7	109.9	101.2	8.95	0.75
A:P ratio[4]	1.91	1.97	2.22	1.88	1.82	2.04	0.328	0.96

[a-b] Values within rows with differing superscripts are different ($P < 0.10$)

[1]Treatments included CON-control; HIPRO20-20% high protein distillers grains; HIPRO40-40% high protein distillers grains; BRAN+SOL-40% corn bran plus solubles; DDGS-40% traditional dry distillers grains; WDGS-40% traditional wet distillers grains

[2]Average concentration over three time points (700 h, 1100h, 1500 h)

[3]Percent of total VFA

[4]Acetate:Propionate ratio

Table 2.7. Effect of feeding high protein distillers grains or corn bran plus solubles on gas production and rate of VFA production using ANKOM gas production modules (Exp. 2)

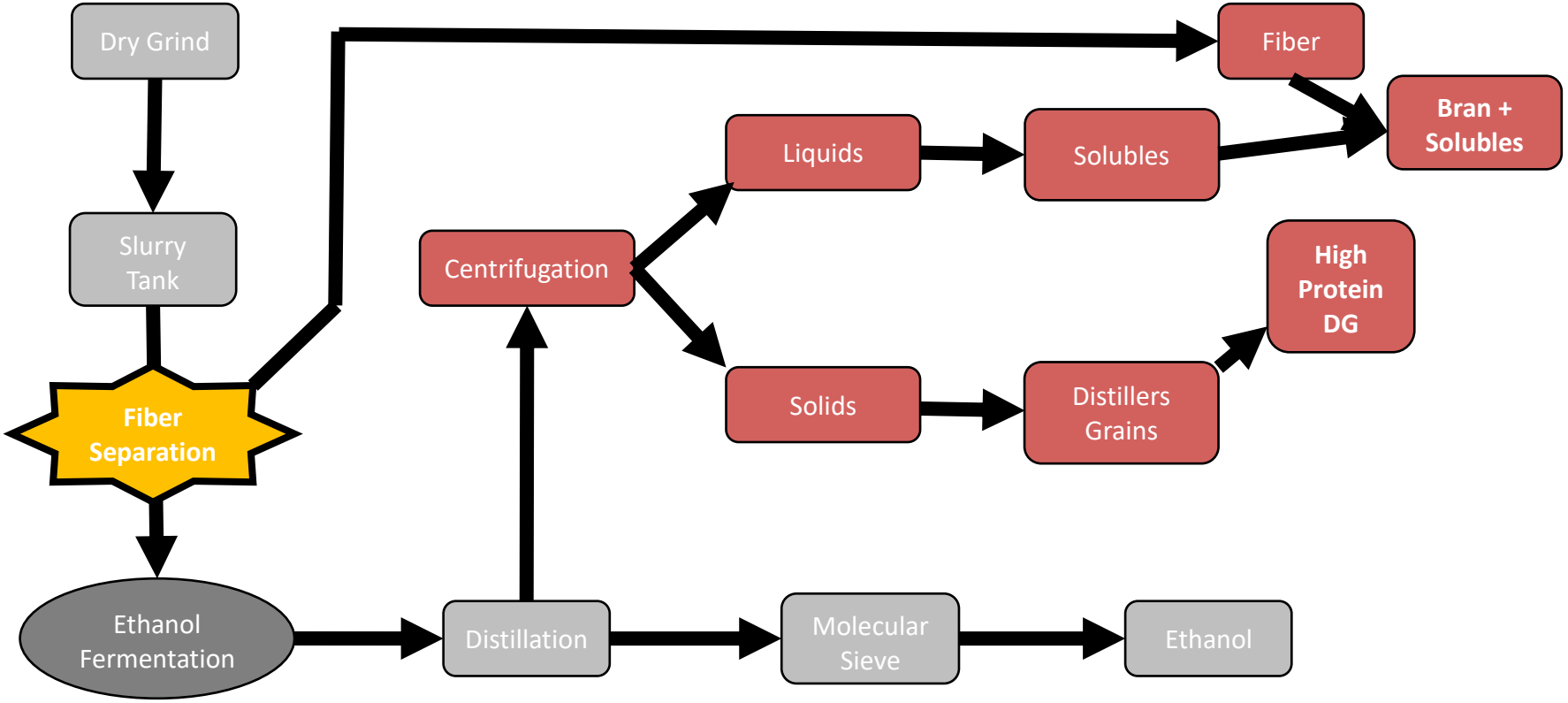
	Treatment[1]							
	CON	HIPRO20	HIPRO40	BRAN+SOL	DDGS	WDGS	SEM	*P*-value
Gas Production[2]								
Total, mL/g DM	7.43	8.45	7.59	7.55	8.63	7.64	0.831	0.79
Rate, %/h	66.8	56.9	59.0	66.1	60.5	58.5	0.04	0.18
VFA Production Rate[3]								
Acetate, mM/h	7.9	5.7	5.9	7.8	5.3	5.7	0.87	0.15
Propionate, mM/h	5.6	4.4	3.7	3.9	3.6	4.5	1.20	0.75
Butyrate, mM/h	2.6	2.5	1.8	2.4	2.4	2.2	0.47	0.58
Total, mM/h	18.9	14.3	13.5	15.7	12.3	14.2	1.95	0.23

[1]Treatments included CON-control; HIPRO20-20% high protein distillers grains; HIPRO40-40% high protein distillers grains; BRAN+SOL-40% corn bran plus solubles; DDGS-40% traditional dry distillers grains; WDGS-40% traditional wet distillers grains

[2]Whole rumen contents sampled on d 21 at 1400 h, incubated in gas bottles with ANKOM (ANKOM Technology, Macedon, NY) gas production modules for 6 h, calculated mL gas/g whole rumen content (DM) from cumulative pressure using the Ideal gas law and Avogadro's law, then analyzed mL/g DM using Gompertz model to estimate total and rate of gas production.

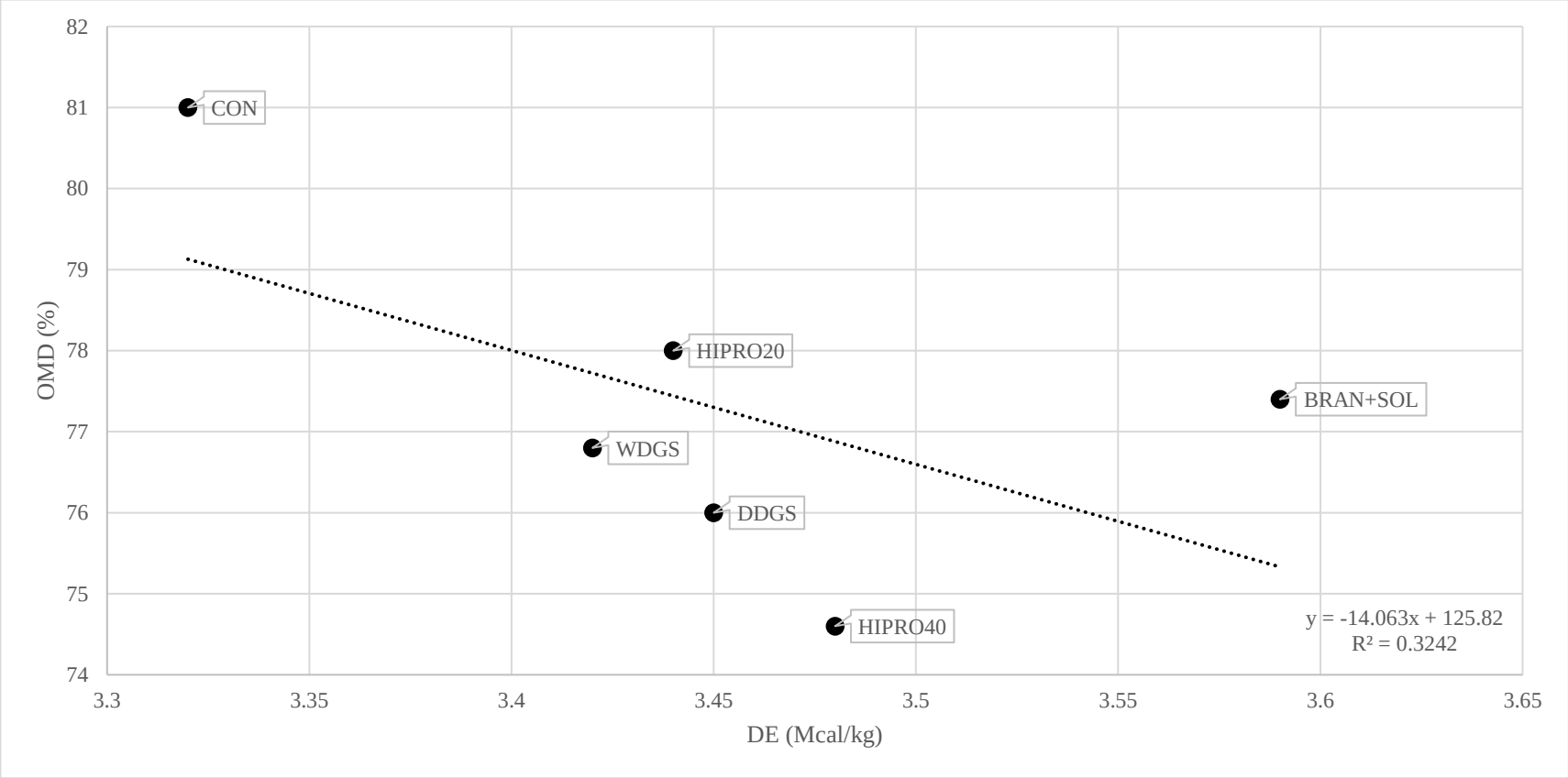
[3]Average rate of VFA production by treatment calculated by ([6 h] – [0 h])/ 6 h

Figure 2.1. Representation of fiber separation during dry-milling process.



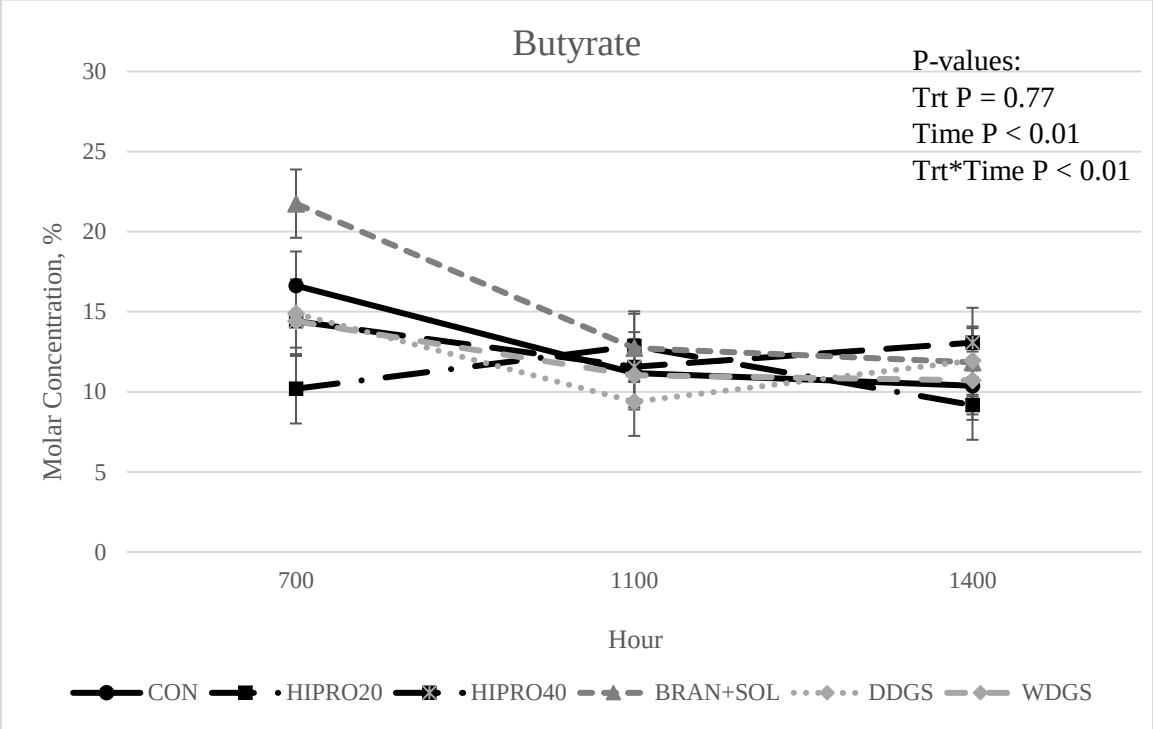
Description: During the dry-milling process fiber is removed pre-fermentation. The fiber can then be combined with solubles to create Bran + Solubles. With fiber removed, protein is further concentrated and the resulting product of this process is High-protein distillers grains.

Figure 2.2. Relationship between digestible energy and organic matter digestibility in finishing diets containing corn, HiPro DDG, Bran + Solubles, DDGS, and WDGS



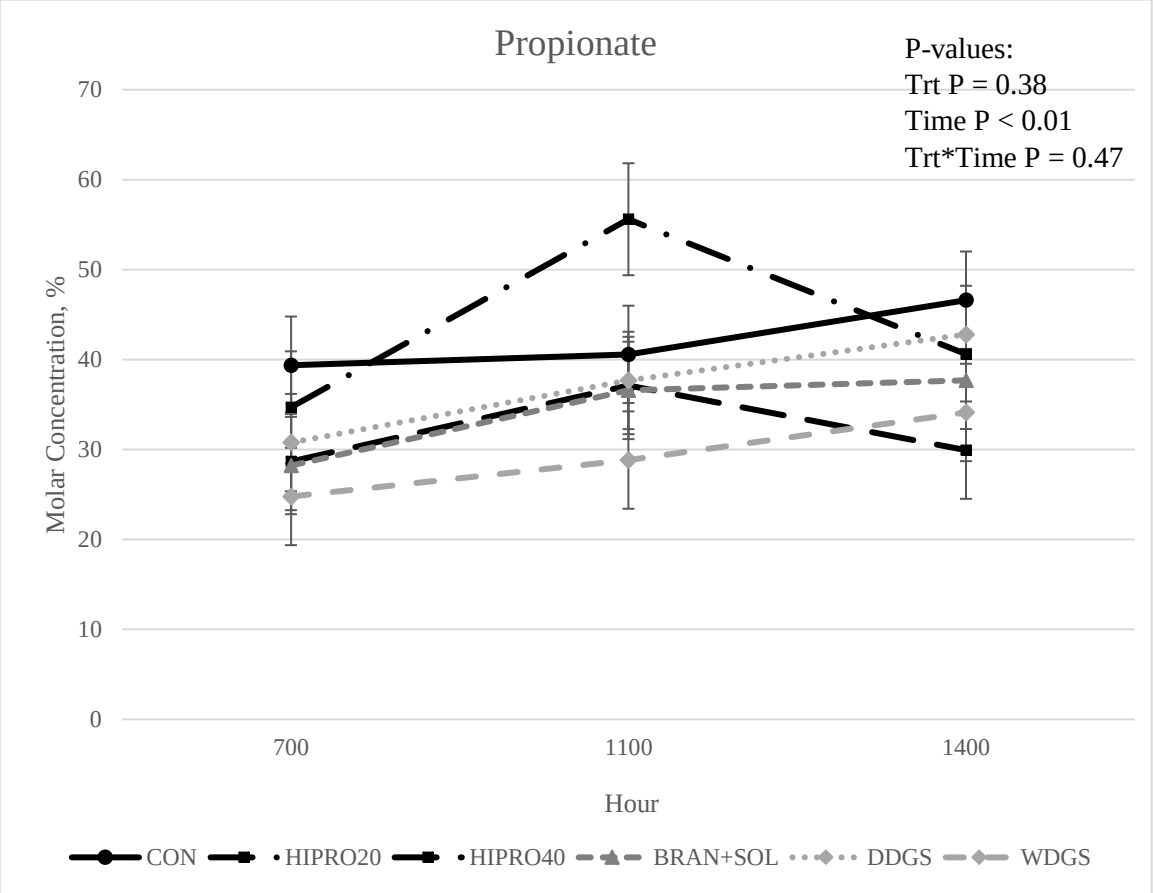
Description: Treatments included a corn control (CON), high-protein DG fed at 20% of diet DM (HIPRO20), high-protein DG fed at 40% of diet DM (HIPRO40), Bran + Solubles (BRAN+SOL), traditional dry DGS (DDGS), and traditional wet DGS (WDGS). BRAN+SOL, DDGS, and WDGS were all included at 40% of diet DM. While DE increases, OMD decreases in diets containing byproducts.

Figure 2.3. Simple effects of time and treatment on Butyrate molar concentration at 0700, 1100, and 1400 h (Exp. 2)



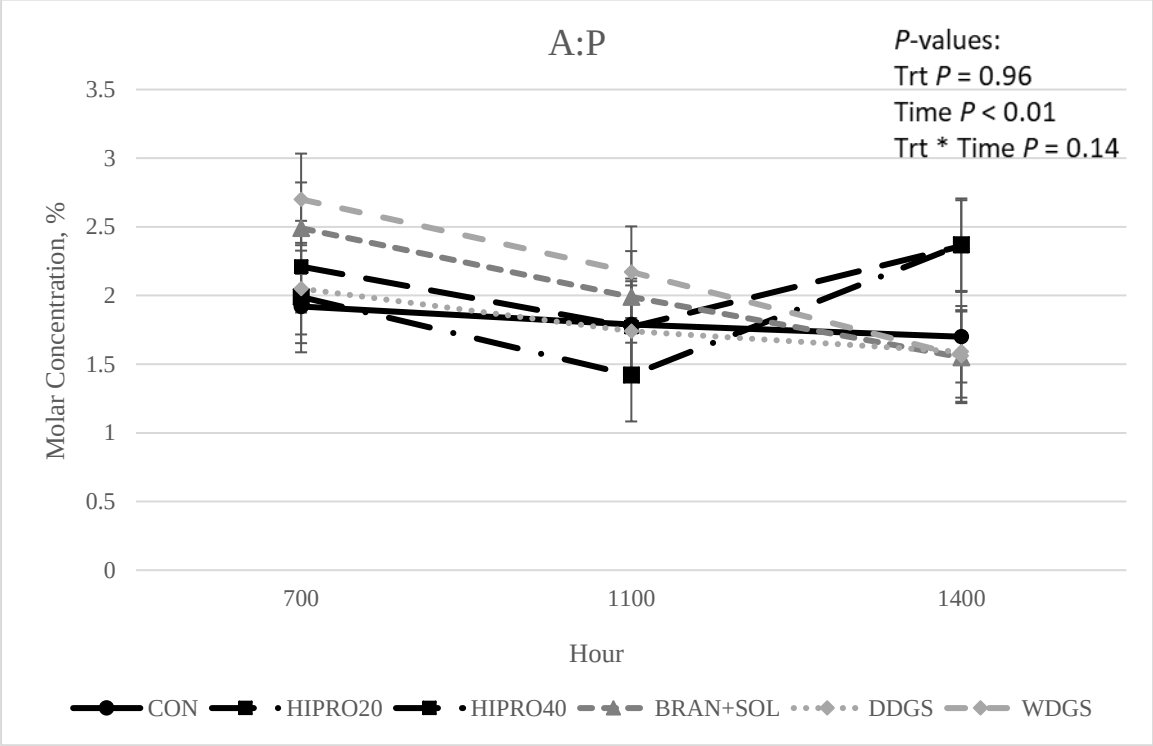
Description: Treatments included a corn control (CON), high-protein DG fed at 20% of diet DM (HIPRO20), high-protein DG fed at 40% of diet DM (HIPRO40), Bran + Solubles (BRAN+SOL), traditional dry DGS (DDGS), and traditional wet DGS (WDGS). BRAN+SOL, DDGS, and WDGS were all included at 40% of diet DM.

Figure 2.4. Simple effects of time and treatment on Propionate molar concentration at 0700, 1100, and 1400 h (Exp. 2)



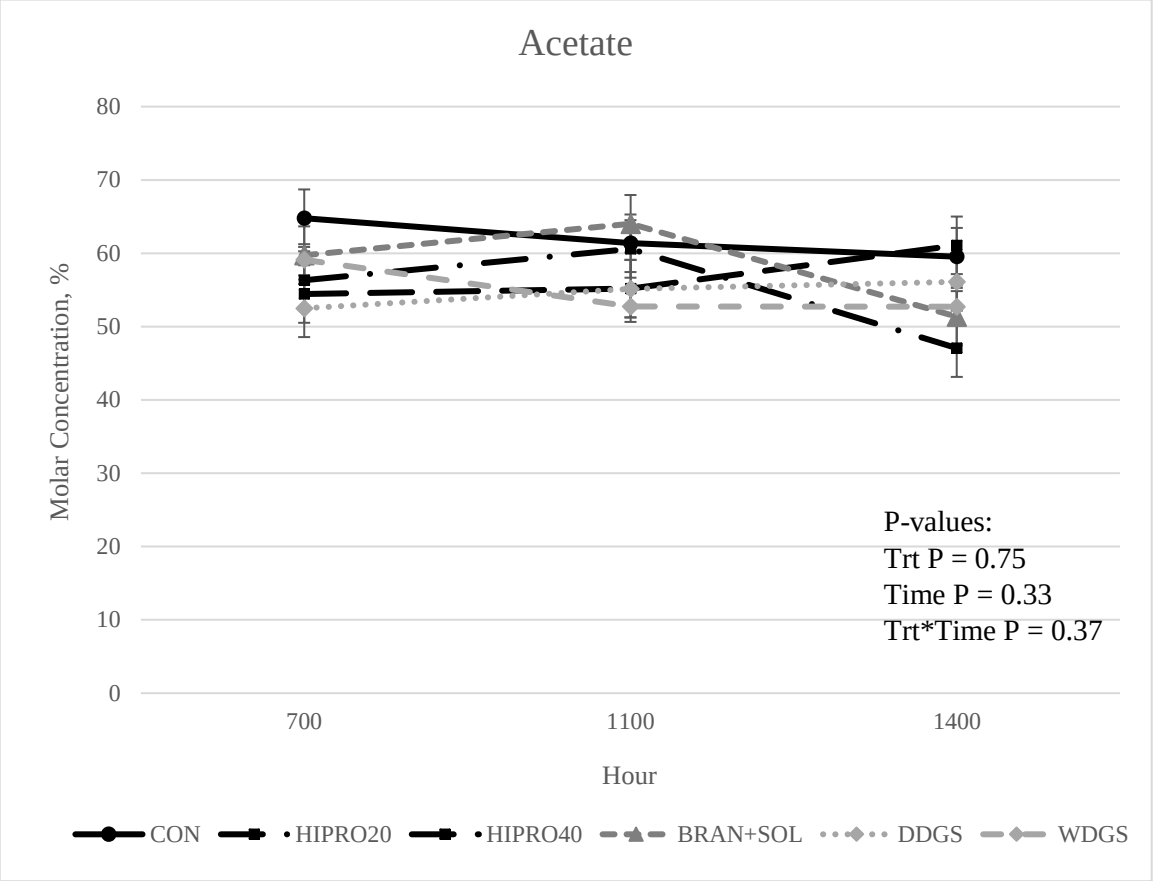
Description: Treatments included a corn control (CON), high-protein DG fed at 20% of diet DM (HIPRO20), high-protein DG fed at 40% of diet DM (HIPRO40), Bran + Solubles (BRAN+SOL), traditional dry DGS (DDGS), and traditional wet DGS (WDGS). BRAN+SOL, DDGS, and WDGS were all included at 40% of diet DM.

Figure 2.5. Simple effect of treatment on Acetate:Propionate molar concentration at 0700, 1100, and 1400 h (Exp. 2)



Description: Treatments included a corn control (CON), high-protein DG fed at 20% of diet DM (HIPRO20), high-protein DG fed at 40% of diet DM (HIPRO40), Bran + Solubles (BRAN+SOL), traditional dry DGS (DDGS), and traditional wet DGS (WDGS). BRAN+SOL, DDGS, and WDGS were all included at 40% of diet DM.

Figure 2.6. Simple effects of time and treatment on Acetate molar concentration at 0700, 1100, and 1400 h (Exp. 2)



Description: Treatments included a corn control (CON), high-protein DG fed at 20% of diet DM (HIPRO20), high-protein DG fed at 40% of diet DM (HIPRO40), Bran + Solubles (BRAN+SOL), traditional dry DGS (DDGS), and traditional wet DGS (WDGS). BRAN+SOL, DDGS, and WDGS were all included at 40% of diet DM.

CHAPTER III. Effect of feeding corn bran plus solubles or wet distillers grains on performance and carcass characteristics in finishing diets.

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ABSTRACT

Crossbred yearling steers (n = 300; initial BW = 415 kg; SD = 36 kg) were used to evaluate the effect of feeding corn bran plus solubles (BRAN+SOL), a new dry mill ethanol byproduct, on performance and carcass characteristics of finishing steers. Animals were blocked by initial BW, stratified by BW, and assigned randomly to pen (n = 30; 10 steers/pen). Treatments were arranged in a 2 × 2 + 1 factorial design with two byproducts (WDGS or BRAN+SOL) and two inclusions (20% or 40% of DM) as the factors. Effect of inclusion of each byproduct was analyzed including a corn-based control as 0% of diet DM using linear and quadratic contrasts. Byproducts replaced a 50:50 blend of high-moisture and dry-rolled corn. A quadratic increase was detected for DMI with increasing inclusion of BRAN+SOL and WDGS ($P \leq 0.08$). The slope of the quadratic comparisons were different ($P = 0.07$) due to a decrease in DMI at 40% WDGS. Cattle fed BRAN+SOL did not differ in DMI at 20% or 40%, but both were greater than CON. Gains increased quadratically with increased inclusion of both byproducts ($P \leq 0.01$). This led to a linear improvement in G:F with increased inclusion of WDGS ($P < 0.01$) and a slightly lower linear improvement in G:F for increased inclusion of BRAN+SOL ($P = 0.10$). Efficiencies were similar ($P \geq 0.13$) for BRAN+SOL and WDGS up to 40% of diet DM where WDGS cattle were numerically more efficient making the slopes of the linear comparisons different ($P = 0.06$). Hot carcass weight linearly increased with increased inclusion of BRAN+SOL and WDGS ($P < 0.01$). Bran + Solubles improved feed efficiency compared to corn by 6.6% for yearling steers. Calculated NE_g was 1.80 and 1.67 Mcal/kg at 20% and 40% of Bran + Solubles as an ingredient, respectively giving it energy values of 120% and 111% that of corn.

Overall, performance appears to be similar between BRAN+SOL and WDGS for finishing cattle, but performance varies with inclusion.

Key Words: bran, distillers grains, finishing, performance, solubles,

INTRODUCTION

Using byproducts from the refining process, particularly distillers grains (DGS), to feed cattle has been done for a number of years. Technological advancements in the dry milling industry are focusing on fractionation of the corn kernel. Fractionation is perceived to allow ethanol plants to capture more valuable feed products by separating protein, fiber, and starch. The result is the output of new feed byproducts with differing nutrient composition than distillers grains plus solubles (Berger and Singh, 2010; Bremer et al., 2015; Buckner et al., 2011). Fiber and protein have been reported to contribute the greatest proportion of the positive performance results observed when feeding distillers grains plus solubles (Conroy et al., 2016; Oglesbee et al., 2016). In a study conducted by Conroy et al. (2016), steers were more efficient when 14% of dietary DRC was replaced by corn bran, resulting in a 118% feeding value for the corn bran compared to corn. Wet distillers grains had a feeding value of 136% in this experiment, therefore approximately 75% of the response observed was due to the fiber portion.

Previous research by Buckner et al. (2011) studied the effect of feeding a combination of corn bran and condensed distillers solubles (CDS) to yearling steers compared to DDGS. Final BW, ADG, G:F, and HCW increased linearly with increased inclusion of Dakota Bran (POET Nutrition, Sioux Falls, SD). Larson et al. (2007) reported a linear decrease in G:F with inclusion of Dakota Bran up to 70%. Final BW and ADG were not affected by treatment with high inclusion of Dakota Bran. A corn bran and CDS blend appears to positively effect ADG while having varying effects on efficiency. Therefore, the objective of this study was to establish a feeding value for Bran + Solubles, a new byproduct resulting from a pre-fermentation fractionation process using

Fiber Separation Technology™ (ICM Inc., Colwich, KS), and to compare the effect of feeding Bran + Solubles at differing inclusions to conventionally fed WDGS.

MATERIALS AND METHODS

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

Bran + Solubles Production

The new feed byproduct used in this trial was produced using a counter-current washing system (Fiber Separation Technology™, ICM, Inc., Colwich, KS) to separate the bran from starch during the dry-grind ethanol process. The starch is then further processed to produce ethanol. Separated fiber (bran) is combined with condensed distillers solubles (CDS) in approximately a 50:50 blend to make Bran + Solubles. The dry matter (DM) and crude protein (CP) content of Bran + Solubles used in this study was 36.3% and 23.4%, respectively. Wet distillers grains plus solubles (WDGS) were sourced from Green Plains Ethanol (York, NE).

Experimental Procedure

Crossbred yearling steers (n=300; initial BW = 414 kg; SD = 36 kg) were utilized in a 120-d finishing study conducted at the University of Nebraska—Lincoln Eastern Nebraska Research and Extension Center near Mead, NE. Steers were received as calves in the fall of 2016 and, upon arrival into the feedlot, animals were individually identified, weighed, and vaccinated for protection against BVD Type I and II, IBR, PI_3, BRSV, *Mannhemia haemolytica*, and *Pasteurella multocia* (Bovi-Shield Gold 5, Zoetis, Inc., Kalamazoo, MI), *Heamophilus somnus* (Sumobac, Zoetis, Inc.), and parasite control

(Dectomax, Zoetis, Inc.). Approximately 14 d following initial vaccination animals were revaccinated for *Heamophilus somnus* (Ultrabac-7, Zoetis, Inc.) and *Mannhemia haemolytica* (Bovi-Shield Gold One Shot, Zoetis, Inc.). Animals were mass-treated for bovine respiratory disease (Micotil, Elanco Animal Health, Greenfield, IN) and wintered on corn stalks. Steers then grazed smooth bromegrass pastures through spring and summer. Additionally, prior to initiation of the trial, steers were limit fed (Watson et al., 2013) a diet containing 50% wet corn gluten feed (Sweet Bran, Cargill Corn Milling, Blair, NE) and 50% alfalfa hay (DM basis) at 2.0% of BW for 5 d to equalize gut fill. Steers were weighed on d 0 and d 1 to establish initial BW (Stock et al., 1983). Animals were blocked into one of 4 blocks by initial BW, stratified by BW within block, and assigned randomly to one of 30 pens within block. Steers were implanted (200 mg TBA, 20 mg E; Component TE-200, Elanco Animal Health, Greenfield, IN) on d 22 to allow maximum payout of the implant.

Pens within block were assigned randomly to one of 5 dietary treatments (Table 3.1) with 6 replications per treatment and 10 steers per pen. The light and heavy blocks contained 1 replication each and the two middle BW blocks contained 2 replications each. Treatments were arranged in a 2 × 2 + 1 factorial arrangement. The factors included two byproduct types (BRAN+SOL or WDGS) and two inclusions (20% or 40% of diet DM). Byproducts were compared to a dry-rolled corn (DRC) and high-moisture corn (HMC) based control diet (CON). All diets contained 7% grass hay and 5% supplement. Supplements were formulated to provide 33.0 mg/kg monensin (Rumensin, Elanco Animal Health, Greenfield, IN) and 9.7 mg/kg tylosin (Tylan, Elanco). All diets were formulated to meet or exceed metabolizable protein (MP) requirements using the NRC

(1996). Steers were adapted to diets over a 21-d step-up period. Byproduct inclusions were held constant while the corn blend replaced grass hay. Grass hay was initially included at 45% DM and stepped down while corn was stepped up in a series of five steps.

Cattle were fed *ad libitum* and feed bunks were evaluated daily at approximately 0530 h for refusals so that trace amounts of feed were left in the bunk at the time of feeding. Feed was delivered with a truck mounted mixer and delivery unit (Roto-Mix, Dodge City, KS) daily at 0800 h. All feed refusals were subsampled and dried for 48-h in a 60ºC forced-air oven for DM analysis and calculation of refusal DM weight (AOAC, 1999 method 4.1.03). Dietary ingredients were sampled weekly for DM determination. Dietary as-fed ingredient inclusions were adjusted on a weekly basis. Steers were fed for 120 d and harvested at a commercial abattoir (Greater Omaha, Omaha, NE). Hot carcass weight and liver scores were collected on the d of harvest. Hot carcass weight was used to adjust final BW, ADG, and G:F using a 63% dressing percentage. Marbling score, 12th rib fat thickness, and LM area were collected after a 48h chill.

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a randomized block design. Pen was used as experimental unit while block (n = 4) was analyzed as a fixed effect. Byproduct and inclusion, as well as the interaction between byproduct and inclusion were included as fixed effects. Because the interaction term was not significant for most variables, orthogonal contrasts were used to compare the slopes of linear and quadratic lines including 0%, 20%, and 40% of BRAN+SOL and WDGS for ADG, DMI, and G:F. Dead steers were removed from analysis. Two animals, both from the WDGS20 treatment, were removed due to death from respiratory infection.

Treatment differences were considered significant when $P \leq 0.05$ and tendencies were considered between $P > 0.05$ and $P \leq 0.10$. *P*-values of ≤ 0.10 were considered significant for orthogonal contrasts of byproduct inclusion including control. Feeding values were calculated based on feed efficiency (G:F) using the following equation: {(((G:F_{TRT} – G:F_{CON})/G:F_{CON}) / byproduct inclusion, %) + 1} * 100. Feed efficiency of treatment is denoted as G:F_{TRT}, and G:F_{CON} represents the feed efficiency of the control treatment. Dietary NEm and NEg values were calculated for each treatment based on intake and performance of steers using equations from the NRC (1996) as described by Vasconcelos and Galyean (2007). The net energy (NE) modifier was set at 80.2 to predict control values and an average final BW of 650 kg was used for all treatments. Byproduct NEm and NEg values were calculated by changing the energy value of byproduct until expected performance matched observed ADG with average treatment intake.

RESULTS AND DISCUSSION

Byproduct Type by Inclusion Interaction

A byproduct type by inclusion interaction was observed for marbling ($P < 0.01$) and DMI ($P = 0.02$; Table 3.2). Marbling score was higher for BRAN+SOL at 20% inclusion, but decreased at 40% inclusion. The inverse occurred for WDGS, which was lower at 20%, but increased at 40% inclusion. Intakes steadily increased with inclusion of BRAN+SOL (Linear $P < 0.01$). Intakes increased to 20% WDGS and then decreased at 40% inclusion for WDGS (Quadratic $P < 0.01$). There were no other interactions for performance or carcass characteristics ($P \geq 0.12$).

Effect Curves

Dry matter intake quadratically ($P < 0.01$) increased with greater inclusion of WDGS, and tended ($P = 0.08$) to increase quadratically when BRAN+SOL inclusion was increased (Table 3.2). The slope of the lines, while both quadratic, appear to be different ($P = 0.07$). In Figure 3.1 we observed that steers fed 20% WDGS numerically had the greatest DMI, but intake drops off at 40% WDGS. Steers fed BRAN+SOL had similar DMI at both 20% and 40% inclusion while both were greater than 0%, making the quadratic effect less apparent. Inclusion of both WDGS and BRAN+SOL quadratically increased ADG ($P \leq 0.10$). The slope of the lines were not different between BRAN+SOL and WDGS for the linear ($P = 0.66$) and quadratic ($P = 0.80$) comparison, and both byproducts resulted in better gains than corn alone (Figure 3.3). A linear ($P < 0.01$) improvement in G:F was observed with increasing inclusion of WDGS while a tendency ($P = 0.10$) for a linear increase occurred with increasing inclusion of BRAN+SOL (Figure 3.2). Differences in DMI with inclusion of each byproduct were observed while no differences were observed for ADG with inclusion of either byproduct. This resulted in a difference ($P = 0.06$) in the slopes of the linear comparison of G:F between cattle fed increasing levels of BRAN+SOL compared to WDGS. Feed efficiency linearly increased and was numerically maximized at 40% WDGS while the increase in the slope of BRAN+SOL inclusion was smaller (Figure 3.3).

Hot carcass weight linearly ($P < 0.01$) increased with inclusion of both BRAN+SOL and WDGS. Carcass weights increased from 0 to 20% WDGS, but then appeared to level off between 20% and 40% (410 kg v. 412 kg). Marbling score was numerically greatest with the 40% WDGS treatment, but was not different ($P > 0.11$) than the control or 20% BRAN+SOL treatments. Byproduct-fed cattle tended to ($P = 0.09$) have more back fat

than CON cattle although CON steers were not statistically different ($P > 0.24$) than either of the BRAN+SOL treatments. These results are consistent with results from a meta-analysis of byproduct feeds conducted by Klopfenstein et al. (2008). Because cattle tend to gain weight faster when fed byproducts, they are fatter when fed to equal days on feed. Due to increased back fat, calculated yield grade was greater for byproduct-fed cattle as well. Calculated YG was greatest for the 20% WDGS treatment, but not significantly different ($P > 0.18$) than 40% WDGS or 20% BRAN+SOL treatments. Control cattle had the lowest calculated YG ($P < 0.04$) of all treatments and 40% BRAN+SOL cattle were intermediate. Longissimus muscle area was not affected ($P = 0.36$) by dietary treatment.

Wet distillers grains plus solubles used in this study resulted in performance similar to previous research. The feeding value of WDGS at 20% DM was slightly lower than the 143% reported by Bremer et al. (2011), but the feeding value of 125% at 40% inclusion in the current trial was consistent with the 130% reported in their meta-analysis of DGS. The improvement in feed efficiency with increased inclusion of WDGS observed in the current study was consistent with previous research when fed up to 40% of diet DM (Corrigan et al., 2009; Watson et al., 2014). In this study, WDGS as an ingredient had a NE_m value of 2.40 and 2.57 Mcal/kg when fed at 20% and 40% of the diet (DM), respectively. These values give WDGS energy values 11% and 18% greater than corn grain, respectively. These values are similar to the 2.11 and 2.23 Mcal/kg reported by Watson et al. (2014) and the trend remains that greater inclusion of WDGS results in improved performance.

Previous research regarding the use of bran and CDS does not provide consistent performance results, primarily due to the differing nature of corn bran. Corn bran from wet milling fed at 30% of diet DM resulted in a NE_g of 1.33 Mcal/kg. The addition of 15% steep to 30% bran improved the NEg to 1.45 Mcal/kg (Sayer et al., 2013). Additionally, Buckner et al. (2011) reported a linear increase in G:F when Dakota Bran, a combination of corn bran and CDS from dry milling, was increased from 0% to 45% of diet DM. Larson et al. (2007), however, observed no difference in G:F between 0% and 40% Dakota Bran, but a linear decrease in G:F when Dakota Bran was increased from 40% to 70% of diet DM. It is logical that the addition of CDS to diets containing corn bran would result in increased performance given the NE_g of CDS in corn-based diets is approximately 1.38 Mcal/kg (Pesta et al., 2015). The NE_m of Bran + Solubles as an ingredient in this study was calculated to be 2.54 and 2.38 Mcal/kg for 20% and 40% inclusion, respectively, while NE_g was 1.80 and 1.67 Mcal/kg, respectively, indicating that greater inclusion slightly reduces the energy value of Bran + Solubles.. Dietary NE_m averaged 1.88 and 1.91 Mcal/kg for BRAN+SOL and WDGS, respectively while dietary NE_g averaged 1.14 and 1.17 Mcal/kg, respectively.

In summary, feeding BRAN+SOL and WDGS resulted in similar performance and carcass characteristics measurements. Based on feed efficiency, BRAN+SOL has a feeding value of 129% and 118% that of corn when fed at 20% and 40% of diet (DM), respectively. As an ingredient, Bran + Solubles has energy values of 120% and 111% that of corn when fed at 20% and 40%, respectively. The energy in CDS and fiber of corn bran appear to have a synergistic effect when fed in combination to finishing cattle.

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Table 3.1. Composition of dry-rolled and high-moisture corn finishing diets with corn bran plus solubles (BRAN+SOL) or wet distillers grains (WDG) at 20 or 40% DM inclusion

	Treatment[1]				
	CON	20BRAN+SOL	40BRAN+SOL	20WDGS	40WDGS
Ingredient[2]					
HMC	44	34	24	34	24
DRC	44	34	24	34	24
Grass Hay	7	7	7	7	7
WDGS	-	-	-	20	40
Bran + Solubles	-	20	40	-	-
Supplement					
FGC	1.552	2.152	2.752	2.152	2.752
Limestone	1.730	1.730	1.730	1.730	1.730
Tallow	0.125	0.125	0.125	0.125	0.125
Urea	1.200	0.600	-	0.600	-
Salt	0.300	0.300	0.300	0.300	0.300
Beef Trace. Min.[3]	0.050	0.050	0.050	0.050	0.050
Vit. ADE[4]	0.015	0.015	0.015	0.015	0.015
Rumensin-90	0.017	0.017	0.017	0.017	0.017
Tylan-40	0.011	0.011	0.011	0.011	0.011
Nutrient Composition[5]					
DM	77.69	69.80	61.87	69.61	61.48
CP	11.34	12.67	14.00	13.81	16.29
NDF	10.69	16.89	23.20	19.07	21.56
S	0.12	0.19	0.26	0.21	0.31
Ca	0.85	0.88	0.90	0.89	0.91
P	0.26	0.44	0.63	0.42	0.59
K	0.47	0.70	0.94	0.69	0.91

[1] Treatments included CON-control; 20BRAN+SOL-20% Bran+Solubles; 40BRAN+SOL-40% Bran+Solubles; 20WDGS-20% WDGS; 40WDGS-40% WDGS included on a DM basis
[2]DRC = dry-rolled corn, HMC = high-moisture corn, WDGS = wet distillers grains plus solubles, FGC = fine-ground corn
[3]Premix contained 10% Mg, 6% Zn, 4.5% Mn, 0.5% Cu, 0.3% I, and 0.05% Co
[4]Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, and 3.7 IU of vitamin E per g
[5]Nutrient composition expressed on a DM basis

Table 3.2. Performance and carcass characteristics for yearling steers fed a corn-based control (CON), corn bran plus solubles (BRAN+SOL) or wet distillers grains (WDG) at 20 or 40% DM inclusion in finishing diets

	Treatment[1]						*P* - values				
							BRAN+SOL			WDG	
	CON	20BRAN+SOL	40BRAN+SOL	20WDGS	40WDGS	SEM	F-test	Int.	Lin.	Quad.	Lin.	Quad.
Performance												
Initial BW, kg	415	415	415	416	415	0.6	0.34	0.43	0.39	0.92	0.93	0.14
Final BW, kg	618	645	648	648	651	5.5	<0.01	0.94	<0.01	0.10	<0.01	0.05
DMI, kg/d	12.3	13.2	13.3	13.5	12.9	0.16	<0.01	0.02	<0.01	0.08	0.01	<0.01
ADG, kg	1.69	1.92	1.95	1.93	1.97	0.045	<0.01	0.97	<0.01	0.10	<0.01	0.06
G:F	0.137	0.145	0.147	0.143	0.153	0.0032	0.07	0.21	0.10	0.42	<0.01	0.62
Feeding Value, %[6]	-	129	118	122	129	-	-	-	-	-	-	-
Dietary Energy Values												
NE_m, Mcal/kg[2]	1.80	1.87	1.89	1.85	1.96	-	-	-	-	-	-	-
NE_g, Mcal/kg[3]	1.10	1.14	1.14	1.12	1.21	-	-	-	-	-	-	-
Byproduct Energy Values												
NE_m, Mcal/kg[4]	2.18[7]	2.54	2.38	2.40	2.57	-	-	-	-	-	-	-
NE_g, Mcal/kg[5]	1.50	1.80	1.67	1.68	1.82	-	-	-	-	-	-	-
Carcass characteristics												
HCW, kg	391	406	412	410	412	3.6	<0.01	0.59	<0.01	0.27	<0.01	0.06
Marbling [8]	507	524	499	489	535	12.4	0.09	<0.01	0.64	0.17	0.12	0.04
Fat depth, cm	1.27	1.40	1.40	1.50	1.47	0.042	0.07	0.81	0.29	0.62	0.03	0.06
LM Area, cm^2	83.2	81.9	84.5	81.2	83.2	1.23	0.36	0.84	0.88	0.09	0.77	0.27
Calc YG [9]	3.27	3.58	3.51	3.73	3.64	0.078	<0.01	0.87	0.04	0.06	<0.01	<0.01

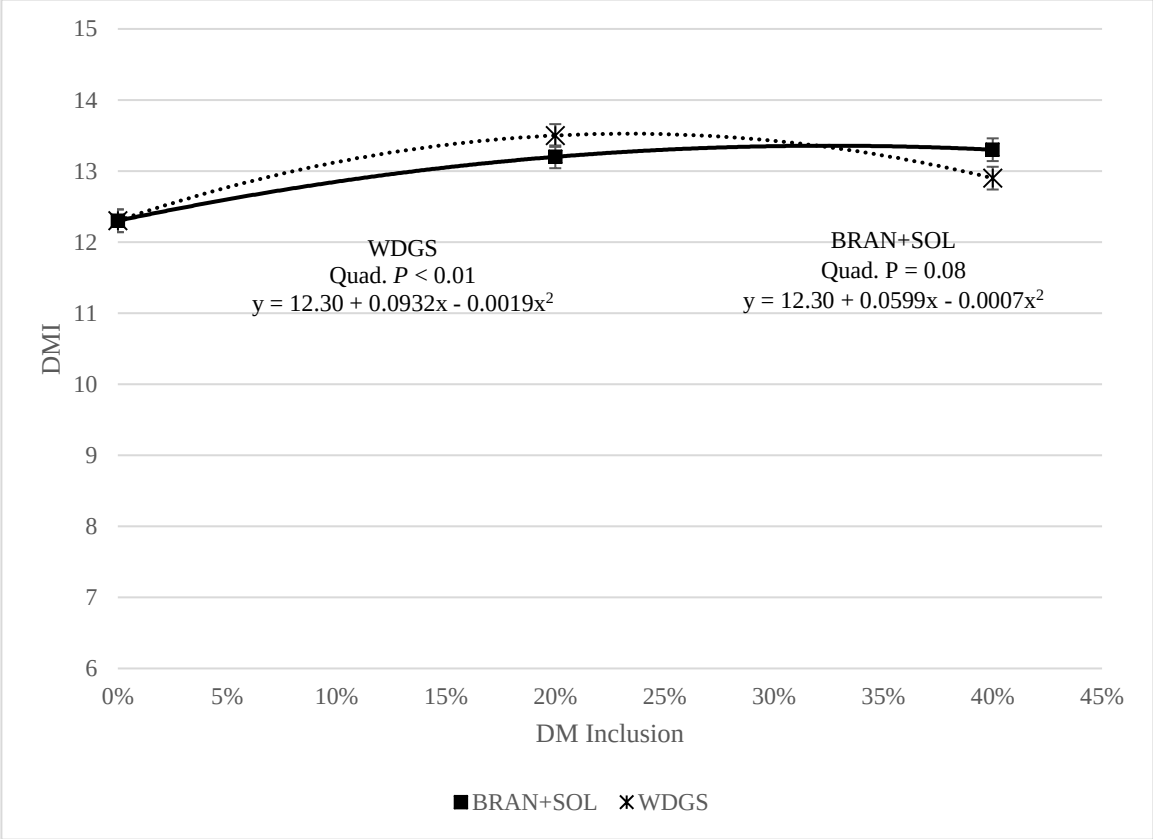
[abc] Values within rows with unique superscripts are different ($P \leq 0.05$)

[1] Treatments included CON-control; 20BRAN+SOL-20% Bran+Solubles; 40BRAN+SOL-40% Bran+Solubles; 20WDGS-20% WDGS; 40WDGS-40% WDGS included on a DM basis

[2] Predicted NEm values for diets calculated using NRC (1996) equations, assumed TDN value of corn (88%)

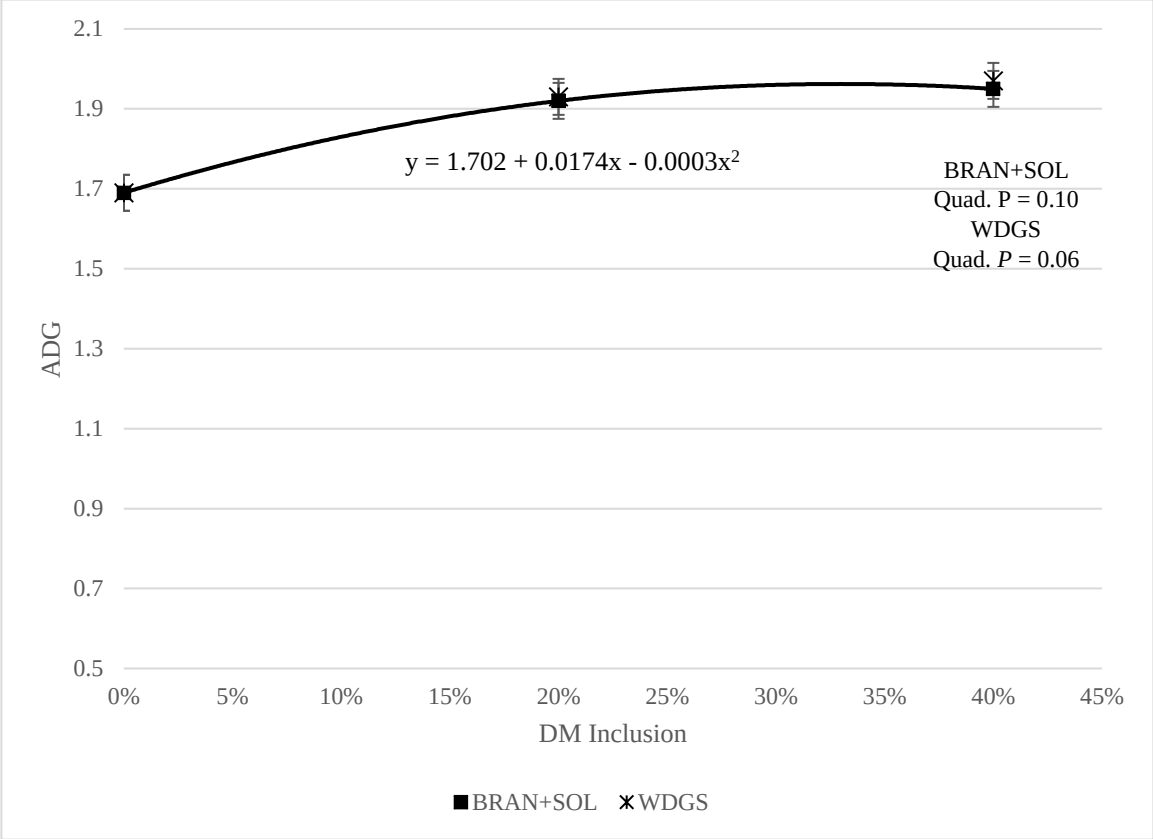
[3] Predicted NEg values for diets calculated using NRC (1996) equations, assumed TDN value of corn (88%)
[4] Predicted NEm values for byproducts calculated using NRC (1996) equations, assumed TDN value of corn (88%)
[5] Predicted NEg values for byproducts calculated using NRC (1996) equations, assumed TDN value of corn (88%)
[6] Feeding value = % change in feed efficiency/ % inclusion of byproduct
[7]NEm and NEg values for corn grain, dry-rolled
[8]300 = Slight, 400 = Small, 500 = Modest
[9]Calculated as $2.5 + (0.9843 \times 12^{th}$ rib fat, cm) + (0.2 × 2.5(KPH, %)) – (0.0496 × LM Area, cm^2) + (0.0084 × HCW, kg)

Figure 3.1. Simple effects of DM inclusion of Bran + Solubles and WDGS on DMI of steers



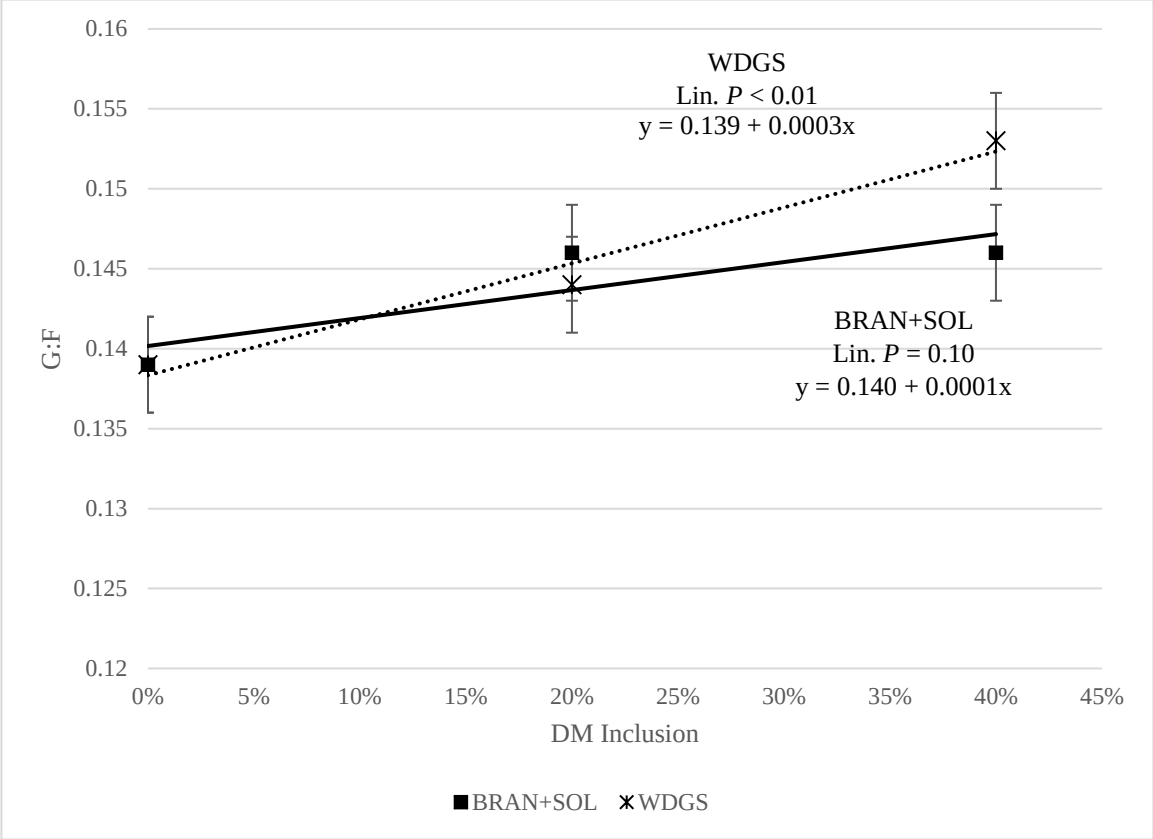
Description: Treatments included a corn control (0%), Bran + Solubles at 20% and 40% of diet DM (BRAN+SOL20 & BRAN+SOL40), wet distillers grains at 20% and 40% of diet DM (WDGS20 & WDGS40). The slope of both the linear (P = 0.01) and the quadratic (P = 0.07) terms are significantly different for DMI.

Figure 3.2. Main effects of DM inclusion of Bran + Solubles and WDGS on ADG of steers



Description: Treatments included a corn control (0%), Bran + Solubles at 20% and 40% of diet DM (BRAN+SOL20 & BRAN+SOL40), wet distillers grains at 20% and 40% of diet DM (WDGS20 & WDGS40). Neither the slope of the linear or quadratic terms are significantly different ($P \geq 0.66$) for ADG.

Figure 3.3. Simple effects of DM inclusion of Bran + Solubles and WDGS on G:F of steers



Description: Treatments included a corn control (0%), Bran + Solubles at 20% and 40% of diet DM (BRAN+SOL20 & BRAN+SOL40), wet distillers grains at 20% and 40% of diet DM (WDGS20 & WDGS40). The slope of the linear lines appear to be different (P = 0.06); however the slope of the quadratic lines were not different (P = 0.46) for G:F.