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Evaluation of Oil Extraction on Corn Dry-Milling Byproducts in Growing and Finishing Cattle Diets

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EVALUATION OF OIL EXTRACTION ON CORN DRY-MILLING BYPRODUCTS IN GROWING AND FINISHING CATTLE DIETS

by

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Dry-milling ethanol plants produce distillers grains (DG) and condensed distillers solubles (CDS). Before thin stillage is evaporated to CDS, corn oil is removed via centrifugation, producing de-oiled CDS. Depending on plant availability, CDS can be marketed or combined with DG to produce de-oiled distillers grains plus solubles (DGS). Currently, there are no data available on animal performance when corn oil is removed via centrifugation of the solubles stream. Therefore, two finishing experiments, a metabolism experiment, and a growing experiment were conducted to evaluate the effects of corn oil removal on cattle performance, carcass characteristics, and the effects on nutrient digestibility. Oil concentration had no effect on DMI, ADG, G:F, and carcass characteristics in finishing cattle fed de-oiled or normal DGS or CDS. Regardless of oil concentration, steers fed DGS or CDS had greater ADG and were more efficient than the corn-based control. Diets containing normal CDS had greater fat digestibility compared to de-oiled CDS, while there was no difference for DGS. The growing experiment suggested that there were no differences in ending BW, DMI, or ADG for the main effects of oil concentration. At lower concentration of dietary CDS, G:F improved 13.6% for normal CDS compared to de-oiled CDS. However, when CDS increased to 40% inclusion, G:F differed by only 1% which could be a result of hindered fiber digestion for

normal CDS. In finishing diets, oil removal via centrifugation had no effect on animal performance or carcass characteristics. However, in growing trials, normal CDS fed at low inclusions resulted in improved G:F compared to de-oiled CDS with no difference observed at greater inclusions.

Key Words: Centrifugation, Condensed distillers solubles, Corn oil, Distillers grains plus solubles, Extraction

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Chapter 1

Introduction

The concept of fermentation of cereal grains to produce ethanol has been in existence since the 1800's with the first use for an internal combustion engine in 1826 (ICM, 2012). In 1920, Henry Ford believed that the success of his automobiles rested in renewable resources which resulted in an ethanol biorefinery built in the Midwest to supply fuel (ICM, 2012). In 1970, the Arab oil embargo resulted in the increased use of "gasohol", a fuel extender, which is comprised of one part corn ethanol with nine parts gasoline (E-10; ICM, 2012). Since gasohol is made with ethanol, it is a way for the United States to reduce dependency on foreign oil. Today, ethanol represents approximately 10% of the nation's gasoline supply at 14 billion gallons produced (Renewable Fuels Association, 2013a).

The increase in ethanol production has resulted in an increase in by-product feeds (distillers grains, distillers solubles, corn gluten feed, and corn gluten meal) produced for livestock feeds. For every bushel of corn used for ethanol production, 2.8 gallons of ethanol and 17-18 pounds, on an as-fed basis, of by-product feed are produced (RFA, 2012a). This resulted in more than 39 million metric tons of feed for the livestock industry in 2011 with 35.7 million metric tons coming from distillers grains (RFA, 2012a).

There are two primary processes associated with producing ethanol: wet milling and dry milling. The wet milling industry accounts for 11% of current operating capacity (RFA, 2012b) and contributes to several by-products such as corn germ meal, corn oil,

corn bran and steep liquor which are typically mixed together to produce wet corn gluten feed (WCGF). The nutrient composition of WCGF depends on the ratio of steep liquor to corn bran and can be variable between ethanol plants. Wet corn gluten feed with increased levels of steep liquor results in greater crude protein content, decreased NDF, and ultimately improved feed efficiencies because steep liquor contains more energy than corn bran (Stock et al, 2000). Corn gluten feed can be marketed as being wet (40 to 60% DM) and sold to surrounding dairies and feedlots or dried, pelleted, and shipped overseas (Stock et al, 2000).

The dry milling industry represents 89% of current operating capacity (RFA, 2012b) and results in two by-products for livestock feed: distillers grains (DG) and condensed distillers solubles (CDS). Dry milling has the flexibility in the grain type that can be utilized in the fermentation process. Corn, wheat, barley, grain sorghum, or a mixture of grains can be used, but corn is the grain source predominately utilized because of the abundant supply (Stock et al., 2000). The nutrient composition of DG are concentrated three-fold compared to the grain used in the fermentation process making DG an excellent energy and protein feed source for growing and finishing cattle (Klopfenstein et al., 2008).

Chapter II

Review of Literature

Dry Milling

Process. The first step in the dry milling process is to remove any debris from the corn grain (i.e. corn stalk) using a process of screens (ICM, 2012). The entire grain kernel (fermentable and non-fermentable components) is sent through a hammer mill to be ground into course flour. Once the grain is ground, the corn is mixed with processed water to produce a slurry mixture. The alpha-amylase enzyme is added to convert starch to dextrose, the pH is adjusted to 5.8 with sulfuric acid, and controlled by the use of ammonia (ICM, 2012; RFA, 2012b). The mixture is then heated to 82-88°C to control bacteria and maintained for 30-45 minutes.

Once the slurry has been heated, it is sent through a pressurized jet cooker at 105°C for 5 minutes and then transferred to liquefaction tanks where it is held for 1-2 hours at 82-88°C (ICM, 2012). During this process the alpha-amylase is given time to break down starch to produce short chain dextrin's. Once this has occurred, the temperature and the pH are adjusted and a second enzyme, glucoamylase, is added to convert the short chain dextrin's to simple sugars (ICM, 2012).

The slurry is now referred to as mash and is allowed to ferment for 50-60 hours. Yeast is added to convert the simple sugars to ethanol and carbon dioxide. The carbon dioxide can be captured and marketed for carbonating soft drinks and manufacturing dry ice or released into the atmosphere (ICM, 2012; RFA, 2012b). Once the fermentation

process is complete, the mash contains approximately 15% ethanol, yeast, and solids from the grains.

After fermentation, the alcohol needs to be removed. This is referred to as the distillation step. The mash is transferred into the distillation columns where the ethanol is removed producing whole stillage. The whole stillage contains yeast cells that were used during fermentation and increased amounts of sulfur from sulfuric acid used to manage pH and sterilization of parts of the ethanol plant. The whole stillage is transported to a centrifuge where it is separated into thin stillage (5-10% DM) and wet distillers grains. The thin stillage goes through an evaporation system to produce a syrup-like by-product known as condensed distillers solubles which contains 20-35% DM (Stock et al, 2000). The wet distillers grains can be sold as wet distillers grains (WDG) or dried to produced dried distillers grains (DDG). Condensed distillers solubles can be added back to the distillers grains to produce wet distillers grains plus solubles (WDGS), dried with distillers grains to approximately 90% DM to produce dried distillers grains plus solubles (DDGS), partially dried to approximately 42-48% DM to produce modified distillers grains plus solubles (MDGS), or marketed as a separate feed ingredient (Stock et al, 2000; Bremer et al., 2011).

Nutrient Composition. Approximately two-thirds of the corn grain is comprised of starch. Once the starch is removed, all other nutrients (protein, fat, phosphorus, and fiber) can be recovered in the stillage and are increased three-fold compared to the original grain (Stock et al, 2000). The protein content increases from 10 to 30%, fat from 4 to 12%, P from 0.3 to 0.9%, and NDF from 12 to 36% of DM (Klopfenstein et al., 2008).

There are three types of distillers grains that are marketed: WDGS, MDGS, and DDGS. The three types are based on the plants ability of drying the product. Holt et al. in 2004 conducted a study to evaluate the nutrient composition of by-products from dry milling ethanol plants. Nutrient composition was determined for WDGS, MDGS, and DDGS. Four regional plants were utilized and samples were collected four times per day over four consecutive days during March, April, and May 2002. The by-products were sampled from the truck to simulate the product being received by the producer. They determined that WDGS ranged from 29.5-36.5% DM, 34.4-36.6% CP, 11.0-13.1% fat, 36.1-48.1% NDF, 9.8-16.9% ADF, and 2.8-4.2% ash. Dried distillers grains plus solubles ranged from 89.4-90.9% DM, 30.7-36.7% CP, 10.4-14.2% fat, 37.3-48.9% NDF, 10.9-16.0% ADF, 0.66-0.83% P, and 3.9-4.2% ash. Modified distillers grains plus solubles was determined to average 58.9% DM, 29.7% CP, 16.7% fat, 34.9% NDF, 10.9% ADF, and 5.3% ash. A later study conducted by Buckner et al. (2011) found similar results to the nutrient composition of dry milling by-products. By-product was sampled from 6 ethanol plants with 10 samples taken across a day for 5 consecutive days. This process was repeated over four months throughout the year. It was determined that DG averaged 31.0% CP and 11.9% fat which are in the ranges given by Holt et al. (2004).

The nutrient composition of CDS can vary within and across plants similar to DG. Lardy (2007) reported that CDS ranged from 23-45% DM, 20-30% CP, 9-15% fat, 1.30-1.45% P, and 0.37-0.95% S. The fat content of CDS has been reported to be greater than Lardy et al., (2007) averages at 18.6% (Pesta, 2013) or even higher at 34.4% (Cao et al., 2009). The increased fat content in CDS as reported by Pesta, 2013 and Cao et al., 2009

can be a concern if the dietary fat is greater than 8% DM which can result in decreased cattle intakes (Vander Pol et al., 2009). Along with increased fat, CDS also contains increased phosphorus and sulfur which can lead to health issues if improperly managed. Increased levels of phosphorus can cause an imbalance in the ratio of calcium to phosphorus resulting in urinary calculi (Lindley et al, 1953). Increased amounts of sulfur in the diet (above 0.4%; NRC, 1996) can lead to increased incidence of polioencephalomalacia (PEM or polio). The excess sulfur is a result of sulfuric acid added during the distillation step for managing pH and sanitation of plant parts which remains in the by-product feed.

Distillers grains are relatively high in crude protein making them an excellent protein source for beef cattle (Lardy, 2007). Crude protein in DG is relatively high in undegradable intake protein (UIP). Undegradable intake protein is not fermented by the microbes in the rumen allowing the protein to escape the rumen to the small intestine where it can be digested and utilized by the animal. Lardy (2007) estimated the UIP% of distillers grains plus solubles to be 47 to 57% of CP while the UIP% of CDS was lower at 20% of CP. Condensed distillers solubles may be lower in UIP but it is relatively high in degradable intake protein (DIP) with a DIP value of 80% of CP while DG are in the range of 43-53% DIP of CP.

Method of Reducing Fat in CDS

Pre-Fractionation Process. Fractionation is the process that separates the three main components of the corn kernel: the endosperm, germ, and the bran. Pre-fractionation processing occurs at the initiation of ethanol production process by using

coarse grinders to extract the starch component. The corn kernel is approximately 82% endosperm which contains 98% of the starch, 12% germ, and 6% bran (Cereal Process Technologies, 2012). For the most efficient production of ethanol, the endosperm needs to yield 82 to 83% starch, which can increase the ethanol yield per batch by 18% (Cereal Process Technologies, 2012; Applied Milling Systems, 2006). With the bran and germ removed, the starch becomes more accessible to enzymes during the fermentation process resulting in a quicker conversion of starch to ethanol and reduces the amount of enzymes used in the process. With the attempt of increased endosperm yield above 83%, oil and fiber levels start to increase. This results in the germ and bran entering into the starch stream which decreases fermentation efficiency (Cereal Process Technologies, 2012). With the components of the corn kernel separated, the non-fermentable components (i.e. corn germ and bran) are not introduced into the fermentation process and corn oil can readily be extracted.

Feeding Pre-Fractionated DGS. Limited research has been conducted to determine the effect of feeding a de-oiled DGS by-product from pre-fractionation. In a finishing trial, Depenbusch et al. (2008a) compared a traditional-grind DGS (12% crude fat, TRAD) to a pre-fractionated DGS (4% crude fat, FRAC) at 13% inclusion in a steam flaked corn (SFC) diet on growth performance and carcass characteristics in yearling heifers. There was an effect on DMI with heifers receiving TRAD consuming 4.5% more feed then heifers fed FRAC. This could be contributed to a degradable intake protein deficiency in heifers fed FRAC because degradable intake protein was limited. Regardless of treatment, cattle performance (average daily gain and feed efficiency) and carcass characteristics (hot carcass weight, dressing percentage, LM area, KPH fat, and

12th rib fat) were not different. This suggests that cattle fed 13% DGS produced from a traditional dry-grind or pre fractionation process results in similar performance in diets with SFC.

Godsey et al., (2010) fed E-Corn, a type of pre-fractionated DGS, at 0, 20, 40, and 60% inclusion in diets containing 35% WDGS. The treatments that contained E-Corn replaced DRC. No response in ADG ($P > 0.21$) was observed as E-Corn was increased up to 60% inclusion. A cubic response ($P = 0.02$) was reported for G:F. Cattle fed 20 and 60% had the greatest G:F, controls were intermediate, and cattle fed 40% had the lowest G:F. E-Corn concentration had no effect ($P > 0.23$) on HCW, however, a linear decrease ($P < 0.01$) was observed for marbling score, 12th rib fat, and calculated YG. The authors reported that the optimum performance of E-Corn was at 20% inclusion when fed in combination with 35% WDGS.

Gigax et al. (2011) evaluated feeding pre-fractionated DGS in finishing cattle diets. Treatments consisted of low-fat (6.7% fat) and normal-fat (12.9% fat) WDGS at 35% inclusion in a 1:1 blend of dry-rolled and high-moisture corn diets. Normal fat WDGS resulted in heavier carcass adjusted final BW, HCW, and greater ADG ($P < 0.05$) compared to low-fat WDGS and controls. Ironically, low-fat and controls had identical final BW, ADG, and HCW. No difference ($P = 0.12$) was observed for G:F between low and normal-fat WDGS, however steers fed normal-fat WDGS had numerically greater G:F compared to low-fat WDGS. This experiment suggests that low-fat WDGS have a lower energy value than normal-fat WDGS and would result in similar cattle performance to a corn-based diet.

In two finishing experiments, Veracini et al. (2013) analyzed feeding pre-fractionated DGS (6.92 ± 1.84% ether extract) in whole shelled corn diets at 25, 40, and 70% inclusion in the diet DM on growth performance and carcass characteristics. In Exp. 1, over the entire feeding period, no differences ($P > 0.26$) were observed for final BW, DMI, ADG, and G:F. This is similar to observations reported by Atkinson et al. (2012), who did not detect a difference in animal performance in steers fed reduced fat DGS at 40 and 70% inclusion in the diet DM. Veracini et al. (2013) observed no differences ($P > 0.37$) in carcass characteristics when reduced fat DGS were fed at increased inclusions. In Exp 2, the authors included a control diet (DGS not included) to the treatment group. Over the entire feeding period, DMI increased ($P < 0.01$) as the inclusion of reduced-fat DGS increased in the diet. A meta-analysis conducted by Bremer (2011) reported that DMI increased when DGS increased up to 30% in the diet DM. Steers fed 70% DGS had lower ($P < 0.01$) ADG and a trend for lower final BW ($P = 0.09$) compared to other treatments. Neville et al. (2012) observed a quadratic decrease in ADG as DGS increased in the diet up to 60% inclusion. Unlike Exp. 1, Veracini et al. (2013) observed a difference ($P < 0.01$) for G:F in Exp. 2. As the inclusion of DGS increased in the diet, G:F decreased with steers fed control diet being the most efficient. However, Atkinson et al. (2012) in two experiments observed no difference ($P > 0.22$) for G:F as DGS increased up to 70% in the diet DM. In whole corn diets, reduced fat DGS from the pre-fractionation process had no effect on G:F (Veracini et al. 2013; Atkinson et al.,, 2012) or reduces G:F (Veracini et al. 2013).

Post-Fractionation Process. The removal of corn oil, via centrifugation, occurs during the post-fermentation process before thin stillage is evaporated to produce CDS

(U.S. Grains Council, 2012). It is only in this phase that the corn oil that is not encapsulated with fiber particles can be removed. The corn oil is routed to storage tanks where it can be marketed to the biodiesel industry. Once CDS is added back to distillers grains, it produces a de-oiled by-product of approximately 8% ether extract instead of 12%. Currently, there are no data available on the effects of feeding DGS with corn oil removed using this process.

Fats and Lipids

Introduction. The three main sources of lipids that are often supplied in feedlot cattle diets are in the form of triglycerides, phospholipids, and galactolipids (Jenkins et al., 2008). A triglyceride contains a 3-carbon glycerol backbone attached with an ester bond to three fatty acid molecules. Phospholipids and galactolipids are made up of a 3-carbon glycerol backbone that is bound to two fatty acid molecules and a phosphate group or a galactose molecule, respectively. Once in the rumen, lipids undergo lipolysis where microbial lipases (bacterial or protozoal) rapidly hydrolyze the ester linkages releasing fatty acids from glycerol (Jenkins et al., 2008). The glycerol can then be broken down into volatile fatty acids, mainly propionate and butyrate, which are absorbed and used as energy (Doreau and Ferlay, 1994). Once the fatty acids are cleaved from the glycerol, microbes act on any unsaturated fatty acids to immediately undergo biohydrogenation.

The rate of lipolysis and biohydrogenation are dependent on factors such as type and amount of dietary fat and ruminal pH. For lipids that are not protected against biohydrogenation, the extent of lipolysis is very high ranging from 85 to 95% (Bauchart

et al., 1990). Beam et al., (2000) analyzed the effect of differing amounts of dietary fat on in vitro rate of lipolysis at 0, 3, 6, 9, 12, 24, and 48 h of incubation. Different inclusions of soybean oil were added at 0, 2, 4, 6, 8, and 10%, wt/wt of the ground grass hay substrate. As the concentration of soybean oil increased, the rate of lipolysis decreased with 10% soybean oil having the lowest rate of 22.6%/h and 2% having the greatest rate at 41.4%/h. Similar to lipolysis, the hydrogenation rate of 18:2 decreased as the concentration of soybean oil increased. The authors concluded that dietary concentration was the primary factor that affected the rate of lipolysis and biohydrogenation of soybean oil. Van Nevel and Demeyer (1996) evaluated pH effect on lipolysis and biohydrogenation with soybean oil as the sole substrate. The authors observed that lipolytic activity was inhibited at a pH $\leq$ 6.0 with the intensity of inhibition being increased with larger amounts of soybean oil. In the rumen, lipolytic activity appeared to be more sensitive to changes in pH than biohydrogenation meaning that reduced biohydrogenation only results from inhibited lipolysis. When high concentrate diets are fed to finishing cattle, a reduction in ruminal pH is typically observed. If a reduction in pH results in a decrease in lipolysis and biohydrogenation, then feeding high concentrate rations could be a way of protecting unsaturated lipids from biohydrogenation due to less lipolysis. Unsaturated fatty acids can then reach the small intestine, be absorbed, and utilized by the body.

Biohydrogenation. Biohydrogenation reduces double bonds within an unsaturated fatty acid resulting in a saturated fatty acid, of the same carbon length, by the addition of hydrogen ions. Biohydrogenation is an important mechanism where microbes can dispose of hydrogen which potentially could have been utilized for methane

production (Zinn, 1989). While most unsaturated fatty acids undergo biohydrogenation, normally saturation is incomplete (Beam, et al., 2000). Incomplete biohydrogenation results in unsaturated fatty acids reaching the duodenum which can be attributed to factors such as changes in pH, particulate matter present, and inhabitant microbial populations present (Church and Pond, 1988).

A review by Lock et al. (2005) shows the significance of biohydrogenation. The authors indicated that in most dairy diets, linoleic acid (18:2) is the most common unsaturated fatty acid present. However, very little of the linoleic acid consumed (mean 272 g/d) reaches the duodenum and is available for absorption (mean duodenal flow 56 g/d). Doreau and Ferlay (1994) reported that the percentage of biohydrogenation for linoleic acid ranges from 70 to 95%, with an average of 80%. Doreau and Ferlay (1994) reported that the extent of hydrogenation of linolenic acid (18:3) is virtually complete with percentages between 85 to 100% (average of 92%). With this said, very little stearic acid (18:0) is consumed from the diet (mean 52 g/d) but there is a dramatic increase in stearic acid that reaches the duodenum (mean 397 g/d; Lock et al., 2005). This can be expected since stearic acid is the end product of biohydrogenation of all 18-carbon polyunsaturated fatty acids.

Research by Vander Pol et al. (2009) suggested that fatty acids from WDGS are not biohydrogenated to the same extent as fatty acids from corn oil. A duodenal fatty acid profile was analyzed from steers fed 40% WDGS, a composite of corn bran and corn gluten meal, the composite diet plus corn oil, a dry rolled corn (DRC) based control, and the control plus corn oil. Results concluded that steers fed diets that were supplemented with corn oil had greater proportions of 18:0 fatty acids reaching the duodenum

compared to cattle fed WDGS, which had the least amount. However, cattle fed WDGS had the greatest proportion of 18:1 *trans*, 18:1, and 18:2 reaching the duodenum relative to all other diets. Cattle supplemented with corn oil had the least unsaturated fatty acids reaching the duodenum. This is similar to Bremer (2010) who reported that cattle fed WDGS had greater proportions of 18:1 and 18:2 reaching the omasum compared to diets containing tallow, corn oil, or CDS as a fat source. Even though WDGS and CDS originate from corn, there is a difference in the extent of biohydrogenation. The unsaturated:saturated ratio was 0.83 and 0.52 for WDGS and CDS, respectively.

Intestinal Digestion of Fatty Acids. Once biohydrogenation occurs, the lipid material that exits the rumen is comprised of free fatty acids that are highly saturated with approximately 80-90% of the free fatty acids attached to feed particles (Doreau and Chilliard, 1997). The saturated fatty acids consist of approximately ⅓ palmitic acid (16:0) and ⅔ stearic acid (18:0; Lock et al., 2005). Before absorption can occur, bile and pancreatic secretions, bile salts and lysolecithin, need to desorb the fatty acids from bacteria and feed particles allowing the formation of a micelle (Lock et al., 2005). Once the formation of micelles have occurred, micelles facilitate the transfer of water-insoluble lipids across the water layer of intestinal epithelial cells of the jejunum, where the fatty acids are absorbed (Lock et al., 2005). Fatty acid absorption is dependent on the formation of micelles. It is the interactions between bile salts and lysolecithin, an amphiphile or swelling agent, which increase micelle surface area resulting in increased fat digestibility (Zinn et al., 2000). Moore and Christie (1984) reported in sheep that when the bile salt/lysolecithin complex was blocked in the duodenum, absorption of fatty acids was virtually eliminated.

In terms of fatty acid digestibility, Lock et al. (2005) reported that absorption was relatively constant and gradually increased when fatty acid duodenal flow increased. Total fatty acid digestibility averaged 74% with a 95% confidence interval of 58-86%. This is in agreeance with Doreau and Ferlay (1994) who reported digestibility values ranging from 55-92%. Individual fatty acid digestibilities varied slightly with unsaturated fatty acids having greater digestibilities (80, 78, and 77% for 18:1, 18:2 and 18:3) compared to saturated fatty acids (75 and 72% for 16:0 and 18:0). This is in agreement with Doreau and Ferlay (1994) who reported mean digestibilities of 77, 85, 83, and 77% for 18:0, 18:1, 18:2 and 18:3, respectively. Lock et al. (2005) concluded that the difference in digestibilities among individual fatty acids reflects differences among individual experiments which relates to different experimental approaches and analytical techniques. In addition, variation that was observed can reflect differences in specific feed ingredients and overall diets.

Fat Sources. Rendered animal products are used in various industries and products throughout the world. More than 6.8 million tonnes of animal fat is produced worldwide with more than half being produced in North America (National Renderers Association, 2003). There are five major sectors that utilize animal fat. Livestock and aquaculture production, the most important sector, utilizes animal fat to produce higher energy rations. The second sector for rendered animal products is for industrial usage. More than 3,000 industrial products utilize lipids for products included in the chemical, rubber, and metal industries. Next, manufacturing soaps utilizes tallow as the main ingredient in producing hand and laundry soaps. The fourth sector is the food industry which uses edible tallow and other edible animal by-products. Lastly, the biodiesel

industry utilizes animal fat for the production of biodiesel (National Renderers Association, 2003).

Historically, fat has mainly been fed in swine or poultry diets but has become increasingly popular over the years in cattle diets. Supplemental fats are an excellent source of energy containing 2.5 to 3 times the NE_g compared to carbohydrates making it a valuable feed resource (Zinn, 1989; NRC, 1996). Dietary fat not only increases the energy density of the diet but it acts as a binding agent to hold the total mixed ration together.

Fat supplements for cattle diets can consist of animal fat (tallow or choice white grease), feed grade vegetable oil, blends of animal and vegetable fats, yellow grease, and oilseeds. Tallow or choice white grease is produced through a process called rendering which converts beef or pork fat tissue into a usable feed product. The process of dry rendering, which is utilized today, uses steam to heat fat tissue to approximately 115 to 145°C in jacketed containers. Mechanical agitation and increased pressure is applied to evaporate remaining moisture producing tallow or choice white grease (National Renderers Association, 2003). Rendering companies obtain material from packinghouse by-products which include offal and organ fat, meat market trimmings such as adipose and inter-muscular fats, as well as dead animals. Feed grade vegetable oil is obtained from extracting oil from seeds that are processed for edible use. The predominate vegetable oils utilized in cattle diets are soybean or corn oil. Yellow grease consists of used cooking grease from restaurant deep fat fryers. Lastly, oilseeds such as whole canola or cotton seeds which contain approximately 20 to 45% lipid can provide additional fat for cattle diets (Doreau and Ferlay, 1994).

Fat Supplementation in Finishing Diets. The addition of supplemental fat in finishing diets containing sorghum or barley have shown to improve ADG and G:F (Brandt and Anderson, 1990; Brandt et al., 1992; Zinn, 1989). However, when supplemental fat was added in corn based diets, G:F increased (Gramlich et al., 1990; Krehbiel et al., 1995b; Zinn, 1992), decreased (Krehbiel et al., 1995a; Zinn, 1994), or remained unchanged (Hatch et al., 1972; Huffman et al., 1990;). Historically, total dietary fat in finishing diets should be limited to 5% or less to maximize production and prevent negative effects that fat can have on rumen function (Zinn, 1989a; Zinn, 1989b). These negative effects can be physically coating fiber particles preventing digestion or causing toxic effects on fiber digesting protozoa and cellulolytic bacteria in the rumen (Zinn, 1989b). Zinn (1994) reported that the maximum lipid intake provided by the diet should not exceed 1.6 g/kg of BW in order to maximize production, which for a 500-kg animal equates to a maximum dietary lipid consumption of 8% of the diet DM at 2.0% of BW. Dietary fat above 1.6 g/kg of BW decreases rumen digestion function and the small intestines ability to digest lipids resulting in detrimental effects on growth performance (Zinn, 1994).

With the addition of various fat sources in finishing diets, consulting nutritionists recommend a total maximum dietary fat of 7.6% (Vasconcelos and Galyean, 2007). Vander Pol et al. (2009) replaced corn with 20% WDGS or 2.5% corn oil which created diets that contained 6.37% total dietary fat. Using average initial and final BW and 6.37% total dietary fat, this equated to 1.35 and 1.34 g/kg of BW of lipid consumed for 20% WDGS and 2.5% corn oil, respectively which is below the maximum lipid intake of 1.6 g/kg of BW report by Zinn (1994). When comparing animal performance, both the

20% WDGS and 2.5% corn oil diets resulted in similar cattle performance relative to controls. Within the same trial, the total dietary fat was increased to 8.76% total dietary fat with the addition of 40% WDGS or 5% corn oil. Dietary lipid consumption values were 1.83 and 1.74 g/kg of BW for 40% WDGS and 5% corn oil, respectively. These values both exceed the maximum lipid intake reported by Zinn (1994). The 5% corn oil treatment resulted in depressed ADG and G:F relative to controls. However, the 40% WDGS treatment had improved ADG and G:F compared to controls, suggesting that at greater concentrations of fat provided from WDGS or corn oil do not result in similar cattle performance.

Vander Pol et al. (2009) analyzed DDGS or tallow as a fat source in finishing diets. Corn was replaced by tallow at 1.3 or 2.6% and DDGS at 20 or 40% in diets that contained 20% wet corn gluten feed (WCGF) to control subacute acidosis. Diets that contained 1.3% tallow or 20% DDGS and 2.6% tallow or 40% DDGS were formulated to provided similar dietary fat, respectively. The authors reported that there were no statistical differences in ADG or G:F across all treatments. The maximum dietary fat was 5.98 and 5.00% for tallow and DDGS, respectively. The levels of dietary fat are below the threshold of 8.0% reported by Zinn (1994), which could possibly explain why there were no differences observed. Krehbiel et al. (1995) evaluated feeding tallow in finishing diets that replaced dry rolled corn (DRC) at 0, 2 or 4% inclusion on a DM basis. The authors reported that G:F increased linearly which resulted in a 6.5 and 10.8% improvement in efficiency when 2 and 4% tallow were included in the diet, respectively. Similarly, Gramlich et al. (1990) observed improved G:F with the addition of 4% tallow

in DRC-based diets. However, Huffman et al. (1990) reported that as tallow increased up to 6% inclusion in an all concentrate finishing diet, G:F decreased linearly.

Along with tallow, yellow grease and vegetable oils are commonly utilized in finishing diets as sources of supplemental fat. Zinn (1989) evaluated the effect of level of fat supplementation of yellow grease (YG) and blended animal-vegetable fat (BVF) on finishing performance. Yellow grease and BVF replaced SFC in a combination steam-flaked barley and SFC-based diets at 0, 4, or 8% inclusion. Regardless of fat source, empty BW gains and G:F increased linearly. Brandt and Anderson (1990) fed soybean oil, tallow, or yellow grease at 3.5% inclusion in flaked milo diets. The authors observed that cattle fed a supplemental fat treatment had improved G:F compared to controls. In a separate experiment, Brandt et al. (1992) fed 0 or 4% yellow grease in steam-flaked grain sorghum and SFC based diets. Including supplemental fat in the diets improved G:F by 4.9 and 7.1% in steam-flaked grain sorghum and SFC diets, respectively.

Cranston et al. (2006) analyzed feeding whole cottonseed (WC) in SFC based diets. In Exp. 1, WC replaced tallow, cottonseed meal, and corn. Total dietary fat was 9.93 and 10.79% for the SFC control and WC treatments, respectively. Cattle fed WC resulted in numerically lower gains and decreased G:F compared to controls. The authors attributed this difference to the control diet having greater energy content than the WC diet (3.14 vs. 3.10 Mcal/kg of ME, respectively). Using animal performance, dietary energy content was calculated and the difference was even greater (3.50 Mcal/kg for the control vs. 3.17 Mcal/kg for the WC treatment). In Exp. 2, 15% WC or FuzZpellet (Buckeye Technologies, Memphis, TN) cottonseed replaced tallow, cottonseed meal, and SFC. All diets were formulated to be isonitrogenous and contain similar percentages of

fat and NDF from roughages. Across all treatments, ADG was not different. Although not significant, cattle fed either cottonseed treatment had greater G:F than controls. The authors reported greater ME concentrations for both cottonseed diets than the controls (3.29 vs. 3.15 Mcal/kg, respectively).

Overall, the addition of supplemental fat in finishing diets increases G:F compared to diets without supplemental fat regardless of fat source. Dietary fat above 1.6 g/kg of BW or 8% inclusion on a DM basis, results in a decrease in cattle performance.

Dry Milling By-Products in Finishing Diets

Feeding Distillers Grains Plus Solubles. The primary energy source that is utilized in finishing cattle diets is corn (Vasconcelos and Galyean, 2007). With the increase in ethanol production, the demand for corn by the ethanol industry has increased. One option to displace corn for cattle producers is the use of DGS to replace corn in finishing rations. The corn kernel is comprised of two thirds starch. Once the starch is removed during the dry milling process, the remaining nutrients are increased three-fold making DGS an excellent protein and energy source (Klopfenstein et al., 2008). Distillers grains plus solubles are utilized as a protein source in finishing diets when included in diets at 15-20% of diet DM or less, but at concentrations above 15-20%, DGS serve as a protein and energy source for the animal (Corrigan et al., 2006). The remainder of this review will focus on feeding DGS as an energy source in finishing diets.

Wet Distillers Grains Plus Solubles. An increase in ethanol production results in an increase in by-products available to producers. After the CDS are added back to the distillers grains, the WDGS product, approximately 30-35% DM, can be delivered to feedlots or dairies in close proximity to the ethanol plant. With distillers grains usage increasing throughout the United States, it is important to evaluate the value of distillers grains in diets that are specific to various regions of the country. The method of corn processing differs throughout the country with dry-rolled and high moisture corn predominantly fed in finishing rations in the Midwest and Northern Plains while steam flaked corn is predominantly fed in the Southern Plains region. Cattle fed WDGS perform differently when fed with different processing method of corn.

Larson et al. (1993) reported two finishing studies evaluating the effects of WDG replacing protein and DRC in calf-fed and yearling steers. Wet distillers grains was fed in the diet at 5.2%, 12.6% and 40.0% DM. As WDG increased in the diet, DMI decreased and ADG increased resulting in a 19.4% and 25.7% improvement in G:F for calf-feds and yearlings, respectively. Similar findings for G:F were reported by Ham et al. (1994), Godsey et al. (2009a), and Corrigan et al. (2009) of 18.8, 16.5, and 13.5% improvement compared to controls (respectively) when 40% WDGS were fed and replaced DRC. When replacing cracked corn with 40% WDGS, similar results were observed for G:F with an improvement of 11% (Trenkle, 1996). Ham et al. (1994) conducted two metabolism experiments evaluating the effects of WDG on nutrient digestibility, ruminal pH, and VFA parameters. Cattle fed WDG had similar OM intakes and digestibilities compared to cattle fed DRC. However, as expected, WDG resulted in greater NDF intakes and digestibilities compared to DRC. Ruminal pH and the acetate to

propionate ratio were similar for cattle fed WDG and DRC. Vander Pol et al. (2009) replaced 40% DRC with WDGS in a metabolism experiment. The authors reported that cattle fed WDGS had similar DM, OM, and NDF digestibilities compared to cattle fed DRC. Similarly to Ham et al. (1994) ruminal pH was similar between WDGS and DRC treatments. However, cattle fed WDGS had reduced acetate and increased propionate resulting in an improved acetate:propionate ratio for WDGS compared to DRC.

Corrigan et al. (2009) evaluated the effects of WDGS replacing high moisture corn (HMC). Wet distillers grains plus solubles was included in the diet at 0, 15, 27.5, and 40% on a DM basis. In response to increasing concentration of WDGS in the diet, final BW, DMI, and ADG increased quadratically while G:F increased linearly. Cattle fed 27.5% WDGS with HMC had a 7.8 and 7.7% improvement in ADG and G:F, respectively compared to cattle fed the control diet. At 40% inclusion of WDGS, improvements in ADG and G:F were 4.8 and 6.0%, respectively. Differences in improvement between DRC and HMC when feeding WDGS can be attributed to the difference in ruminal starch fermentation associated with corn processing. Processing methods that reduce particle size and/or causes gelatinization increases the availability of the starch granules resulting in an increase in the rate of ruminal starch fermentation (Stock and Erickson, 2006). Corn harvested at increased moisture (greater than 24%), ground and stored in a bunker has faster rates of ruminal starch digestion than dry rolled corn which increases the possibility of acidosis (Stock and Erickson, 2006). Acidosis can affect the efficiency of utilization of the corn fed. An option to overcome this issue is by feeding a combination of processed grains, one with a slower rate of starch fermentation with a second with a rapid rate of starch fermentation (Stock and Erickson, 2006).

Replacing WDGS with a 1:1 blend of HMC and DRC (BLEND) has been reported. Godsey et al. (2009b) replaced BLEND with 20 or 40% WDGS and observed a 5.1 and 5.7% improvement in ADG, respectively. Feed efficiency was improved by 5.5 and 8.1% when 20 or 40% WDGS, respectively, replaced BLEND. Similar to Godsey et al. (2009b), Vander Pol et al. (2009) observed a 5.8% improvement in G:F when WDGS replaced 40% of BLEND in the diet. Meyer et al. (2013) reported a 6.5 and 6.9% improvement in ADG and G:F when 25% WDGS replaced BLEND. Loza et al. (2010) fed 30% WDGS in a BLEND diet and observed a 15% increase in ADG and 8.7% increase in G:F compared BLEND control diet. Vander Pol et al. (2006) replaced BLEND with 10, 20, 30, 40, and 50% WDGS. As inclusion level of WDGS increased, ADG increased quadratically with cattle fed 30% WDGS having the greatest ADG. Similarly, G:F increased quadratically with optimum efficiency observed when 40% WDGS replaced BLEND.

The process of producing steam flaked corn (SFC) involves the use of moist heat (steam) to gelatinize the starch granules followed by a reduction in particle size which increases the energy availability and starch digestion of the corn grain (Zinn et al., 2002). A review by Owens et al. (1997) reported that steam flaking resulted in corn containing 14.2 and 17.3% more NE_m and NE_g than DRC. This increase in energy from flaking improved G:F by 12% compared to feeding DRC in a corn based diet (Owens et al., 1997). When WDGS replaces SFC in finishing rations, the performance response does not appear to be as great when WDGS replaces DRC, HMC, and BLEND. An explanation could be that the WDGS contains less energy than the SFC that it replaces resulting in a decrease in performance.

Daubert et al. (2005) replaced SFC in increments of 8 percentage units with a maximum concentration of sorghum WDGS of 40%. The authors reported a quadratic effect for ADG and G:F. Maximum daily gain was achieved when 8% WDGS replaced SFC and G:F was optimized at 16% WDGS, followed by reductions in both as inclusion of WDGS increased. The authors indicated that WDGS should not be included beyond 15% to obtain optimal efficiency. However, Depenbusch et al. (2009) replaced SFC with 12.8% WDGS and did not observe a response for ADG or G:F compared to the SFC control diet. In a previous trial, Depenbusch et al. (2008b) fed 25% WDGS in a SFC diet and observed a 9.1 and 7.1% reduction in ADG and G:F, respectively. Similar to findings by Depenbusch et al. (2008b), May et al. (2010) observed an 8.3% decrease in ADG and 3.9% decrease in G:F when SFC was replaced by 30% WDGS. Luebbe et al. (2012) conducted a study analyzing the effects of titrating WDGS in SFC rations. Wet distillers grains plus solubles replaced 15, 30, 45, or 60% of the SFC. The authors reported that ADG, G:F, and the feeding value of WDGS decreased linearly as the concentration of WDGS increased. Overall, cattle performance tends to decrease when WDGS is included in SFC rations at inclusions greater than 25%.

Wet distillers grains plus solubles is an excellent source of energy in cattle diets. When WDGS are fed in combination with a grain that is slower in ruminal starch digestion (DRC), significant improvements in animal performance have been reported (Larson et al., 2007; Ham et al., 1994; Godsey et al., 2009; Corrigan et al., 2009). Diets that contain WDGS and a grain that is more rapidly fermented does not produce improvements in animal performance as great as DRC (Corrigan et al., 2009; Daubert et al., 2005; Depenbusch et al. 2008b; Depenbusch et al., 2009; May et al., 2010; Luebbe et

al., 2012). This issue brings about the concept of feeding a combination of processed grains trying to reduce the potential of acidosis which will hinder animal performance. Wet distillers grains plus solubles fed with different corn processing methods will result in different optimum inclusions. Overall, optimum ADG and G:F resulted for 40% in DRC based diets, 27.5% in HMC based diets, 30-40% in BLEND diets, and 15% in SFC based diets (Erickson et al. 2010). From a producer standpoint, if the price of corn far exceeds the price of WDGS then economic advantages of replacing a portion of corn with WDGS may overcome any loss in animal performance.

Modified Distillers Grains Plus Solubles. Modified distillers grains plus solubles (MDGS) are distillers grains that have been partially dried to approximately 45% to 50% DM. Bremer et al. (2011) conducted a meta-analysis comparing 4 finishing trials with 85 pens that represented 680 steers (Adams et al., 2010; Huls et al., 2008; Luebbe et al., 2012; Nuttelman et al., 2011). All studies were conducted at the same research feedlot under similar conditions with MDGS replacing DRC or BLEND. The authors observed a quadratic response for DMI, ADG, and G:F as the concentration of MDGS increased. Maximum DMI was reported for 20 to 30% MDGS inclusion, ADG was maximized at 30% MDGS inclusion, and the maximum G:F was observed for 40% MDGS inclusion. Huls et al. (2008) compared feeding 0 to 50% MDGS, in increments of 10% units, in finishing diets that replaced BLEND. Intakes increased quadratically with 20% MDGS having the greatest intakes. A quadratic response was observed for ADG with 20% and 30% having the greatest gains. A linear response was observed for G:F as the inclusion of MDGS increased. Nuttelman (2013) fed 0, 20, 30, and 40% MDGS that replaced BLEND and observed a quadratic response for DMI. A quadratic effect was

observed for ADG with steers fed 20 and 40% MDGS having the greatest gains, 30% was intermediate, and controls had the lowest gains. A linear response was observed for G:F. It was reported that there was a 6-10% improvement in G:F when cattle were fed MDGS compared to corn based controls. Trenkle, (2008) fed 0, 20, 40, and 60% of MDGS in finishing diets. The author observed no difference for DMI when steers were fed 20% or 40% MDGS, however, steers fed 20% had numerically greater intakes than steers fed 40% MDGS which agrees with previous research (Bremer et al., 2011; Huls et al., 2008). There was no difference for ADG and G:F when cattle were fed 20 or 40% MDGS, but cattle fed 60% MDGS produced the lowest gains and were less efficient.

Dried Distillers Grains Plus Solubles. Dry distillers grains plus solubles (DDGS) are distillers grains that have been dried to approximately 90% DM. This allows producers that are a greater distance away from ethanol plants to incorporate DGS into finishing rations by decreasing shipping and storage costs due to the decreased moisture content of the DGS.

Bremer et al. (2011) conducted a meta-analysis which evaluated replacing corn with increasing concentrations of DDGS. Dried distillers grains plus solubles were fed from 0 to 40% in increments of 10 percentage units. Four finishing trials were evaluated, containing 66 pens which represented 581 steers. The author observed a quadratic response for DMI with 30 and 40% inclusions having the greatest DMI. There was a linear increase for ADG and G:F resulting in 40% DDGS having the greatest ADG and G:F. Nuttelman (2013) replaced BLEND with 0, 20, 30, and 40% DDGS and observed a linear increase in DMI as the concentration of DDGS increased. There was a linear response for ADG and G:F similar to Bremer et al. (2011). Neville et al. (2012) fed 20,

40 and 60% DDGS to finishing steers and observed a quadratic decrease for DMI and ADG, whereas G:F decreased linearly as the concentration of DDGS increased.

Buckner et al. (2008) evaluated the effects of replacing DRC with increasing concentrations of DDGS from 0 to 50% in increments of 10 percentage units. Due to issues associated with polioencephalomalacia, cattle on the 50% treatment were removed from the study resulting in treatments of 0 to 40% DDGS being reported. There were no differences observed for DMI between treatments. The authors observed a quadratic response for ADG. Using the quadratic prediction equation, ADG was maximized at 23.5% inclusion of DDGS but any concentration of DDGS produced greater gains than the DRC control. Feed efficiency, although not significant, approached a significant quadratic trend for increasing concentrations of DDGS. Using the quadratic prediction equation, G:F was maximized at 24.7% inclusion. Cattle fed the control diet had the poorest G:F while steers fed 30 and 40% were intermediate to 10 and 20%.

Condensed Distillers Solubles. Compared to DGS, there is limited data on the use of condensed distillers solubles (CDS) fed in finishing diets as the sole by-product. Ethanol plants will add a portion of CDS back onto distillers grains to produce distillers grains plus solubles. However, many times not all CDS can be added back to WDGS requiring ethanol plants to market CDS as a separate by-product to producers.

Rust et al. (1990) fed CDS that was soaked onto the feed and free choice, with and without access to water to steers in a metabolism trial. It was observed that when CDS was allowed free choice without water, steers consumed 22% of their daily DMI from CDS as opposed to 6.7% when CDS was soaked onto the feed. Daily gains did not differ among treatments. Cattle fed free choice CDS had a 35.5% improvement in G:F

compared to controls. Trenkle et al. (1997, 2002, and 2004) conducted three trials which analyzed replacing dry-rolled corn with CDS. In Exp. 1, CDS was fed at 6.5% inclusion with 10% soybean meal. Compared to the soybean meal control, ADG and G:F were improved by 5.3 and 4.1%, respectively. In Exp. 2, CDS was included in a finishing diet at 0, 4, or 8%. Although not significant, feeding 4% CDS improved ADG and G:F by 3.2 and 5.2% compared to controls, whereas 8% CDS decreased ADG by 6.4% and improved G:F by 1.5%. In Exp. 3, CDS was fed at 0, 4, 8, or 12% inclusion and replaced dry rolled corn and urea. Animal performance (ADG and G:F) was not affected by the addition of CDS up to 12% inclusion in the diet.

Resent research at the University of Nebraska has evaluated feeding CDS in finishing diets. Pesta et al. (2013) fed 0, 9, 18, 27, and 36% CDS which replaced BLEND and urea. As CDS increased in the diet, DMI decreased linearly and ADG increased quadratically which resulted in a quadratic increase in G:F. Using the quadratic prediction equation, ADG was maximized at 20.8% inclusion of CDS while G:F was maximized at 32.5% CDS. It was observed that 27% inclusion of CDS was near optimal as it maximized both ADG and G:F. In a metabolism trial conducted by Pesta et al. (2012) evaluated the effect of feeding 27% CDS in place of BLEN on nutrient digestibility, ruminal pH, and VFA parameters. The authors reported that the addition of CDS had no effect ($P \geq 0.46$) on DM, OM, NDF, and fat total tract digestibility. Average ruminal pH was statistically similar between the corn based diet and CDS. Cattle that were fed 27% CDS produced statistically less ($P = 0.09$) acetate compared to cattle fed the corn based control.

Titlow et al. (2013) evaluated replacing 15 or 30% CDS in dry rolled corn and steam flaked corn diets. In dry rolled corn diets, a quadratic response was observed for ADG and G:F. When 15% CDS was fed with DRC, a 14.6% improvement in G:F was observed compared to controls. However, when CDS increased from 15 to 30%, a small improvement of 4.3% in G:F was observed. In steam-flaked corn diets, ADG increased linearly as the inclusion of CDS increased. A quadratic response was observed for G:F. As CDS inclusion increased from 0-15%, a 5% increase in G:F was reported. An additional 12% improvement in G:F was observed when CDS increased from 15-30%. The authors concluded that corn processing does interact with CDS concentration in finishing diets. Increasing the inclusion of CDS did not hinder ADG and G:F in SFC diets, which is quite different than the response to feeding WDGS in SFC diets.

Calculated Feeding Value of Distillers Grains Plus Solubles. Typically when DGS are included in a finishing diet, corn is the ingredient that is replaced. The feeding response depends on the type of corn that is replaced and the type and inclusion of DGS included in the diet. To calculate the feeding value of DGS, G:F for both DGS and corn diets need to be compared. This is accomplished by finding the difference in G:F between DGS and corn diets, within the same study, divided by the inclusion of DGS to determine the feeding value of DGS relative to corn (Klopfenstein et al., 2008).

Godsey et al. (2009) replaced DRC with 20 or 40% WDGS and calculated a feeding value of WDGS to be 185 and 141%, respectively. Similarly, Ham et al. (1994) replaced DRC with 40% WDGS and observed a feeding value of 147% for WDGS to that of DRC. Corrigan et al. (2009) fed WDGS at 15, 27.5 and 40% inclusion and observed feeding values of 129, 140, and 134%, respectively.

Corrigan et al. (2009) evaluated replacing HMC with WDGS at 15, 27.5, and 40% inclusion. The authors reported feeding values of WDGS to be 122, 128, and 115%, respectively, compared to HMC. When WDGS replaced HMC, the feeding value of WDGS was less than the feeding value of WDGS when it replaced DRC in the same study.

The feeding value of WDGS when replacing a blend of HMC and DRC (BLEND) has been reported. Vander Pol et al. (2006) replaced BLEND with 10, 20, 30, 40, and 50% WDGS with the feeding values of WDGS being 178, 138, 144, 137, and 121%, respectively. Godsey et al. (2009b) replaced BLEND with either 20 or 40% WDGS and observed a feeding value of 127 or 120%, respectively. Meyer et al. (2013) observed a feeding value for WDGS of 128% when 25% WDGS was fed. Similarly, Loza et al. (2010) fed 30% WDGS and reported a feeding value of 129% to that of BLEND.

Research has suggested that the feeding value of WDGS when fed in SFC-based diets is equal to or less than that of the corn; however it has also been shown to be greater than SFC. Luebbe et al. (2012) evaluated feeding 15, 30, 45, and 60% WDGS which replaced SFC. The authors observed a linear decrease in the feeding value of WDGS as the concentration of WDGS increased in the diet. Depenbusch et al. (2008b, 2009) conducted two separate trials replacing SFC with 12.8 and 25% WDGS. It was reported that feeding 12.8 and 25% WDGS with SFC resulted in a feeding value for WDGS to be 100% and 73% that of SFC, respectively. Similarly, May et al. (2010) reported a feeding value of 100% and 88% for WDGS when WDGS was fed at 15 and 30% inclusion in a SFC diet. However, Godsey et al. (2009) replaced 20 and 40% SFC with WDGS and observed the feeding value to be 135% and 111%, respectively, that of SFC. Corrigan et

al. (2009) fed 15, 27.5, and 40% inclusion of WDGS and observed the feeding value to be 115, 100, and 101%, respectively. The difference in feeding value when WDGS are fed with SFC compared to DRC or HMC can be attributed to different corn processing methods. It has been suggested that replacing SFC with WDGS reduces the energy concentration of the diet resulting in reduced cattle performance (Zinn et al., 1995; Depenbusch et al., 2008b).

The feeding value of distillers grains decreases as the moisture content decreases (Bremer et al., 2011). Modified distillers grains plus solubles contains approximately 50% DM which is drier than WDGS at approximately 30-35% DM. From the previous statement made by Bremer et al. (2011), MDGS should have a decreased feeding value compared to WDGS. The studies that have analyzed MDGS have utilized DRC and/or HMC as the corn source. Huls et al. (2008) replaced BLEND with MDGS at inclusions of 0 to 50% in increments of 10 percentage units. The feeding value of MDGS ranged from 128 to 112% as MDGS increased in the diet. A meta-analysis conducted by Bremer et al. (2011) analyzed the feeding value of MDGS. At MDGS concentrations of 10, 20, 30, and 40% the feeding value for MDGS was reported to be 128, 124, 120, and 117%, respectively, that of the corn it replaced. However, Trenkle (2008) reported decreased feeding values for MDGS as MDGS replaced DRC at 20, 40, and 60% inclusions.

With the three methods for DGS, DDGS, having a DM percentage of approximately 90%, should have the lowest feeding value because it contains the lowest moisture content. Energy within DGS is lost as the drying time is increased to produce MDGS and DDGS compared to WDGS. Buckner et al. (2008) fed DDGS from 0 to 40% in increments of 10 percentage units while replacing DRC. The authors reported the

feeding value of DDGS to be 127, 128, 106, and 105% that of DRC when fed at 10, 20, 30, and 40% inclusion, respectively. Bremer et al. (2011) conducted a meta-analysis of finishing performance when fed DDGS at inclusions of 10, 20, 30, and 40% in the diet. The authors observed the feeding value of DDGS to be 112% that of corn for all concentrations of DDGS. Similarly, Nuttelman (2013) replaced BLEND with 20, 30, and 40% DDGS and reported the feeding value for DDGS to be 110, 107 and 110%, respectively.

Data regarding the feeding value of CDS are limited. A trial conducted by Pesta et al. (2013) replaced BLEND with 9, 18, 27, or 36% inclusion of CDS and observed feeding values of CDS relative to BLEND of 211, 166, 142, or 139%, respectively. Titlow et al. (2013) replaced DRC with either 15 or 30% CDS, and observed a feeding value for CDS to be 197 or 165% that of DRC, respectively. In the same trial, Titlow et al. (2013) replaced SFC with either 15 or 30% CDS, and observed a feeding value for CDS to be 133 or 159% that of SFC, respectively. The increase in feeding value of CDS can be partially attributed to the fat content of CDS.

Objectives

Research has shown that dry milling byproducts are a viable option to replacing corn as an energy and protein source in finishing diets. Along with providing energy and protein, distillers grains plus solubles contain three times the concentration of fat relative to the corn grain it originated from. The dry milling industry is investing in the technology of separating corn oil from the thin stillage, which becomes CDS. According to Renewable Fuels Association (2012b), approximately 50% of the nation's

ethanol biorefineries are removing corn oil with an estimated 1.5 billion pounds of corn oil captured in 2011. Approximately two thirds of the fat that is located in thin stillage is not bound to grain particles making removal through centrifugation possible. If CDS are added back to the grains to produce wet distillers grain plus solubles (WDGS), the centrifugation process reduces the fat content from approximately 12 to 8%. Based on the greater caloric density of fat versus starch and protein, it is believed that the removal of fat will hinder the feeding value of these by-products and ultimately affect the gains and efficiencies of growing and finishing cattle. Therefore, four experiments were conducted to address several objectives:

1. Examine the effects of feeding de-oiled CDS and MDGS on performance and carcass characteristics in finishing steers
2. Examine the effects of de-oiled CDS and MDGS on digestion and metabolism in finishing steers.
3. Examine the effects of feeding increasing levels of de-oiled WDGS on performance and carcass characteristics in finishing steers
4. Examine the effects of de-oiled CDS at differing levels and feeding de-oiled CDS with different forages on the performance of growing steers

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Chapter II

Finishing performance and metabolism characteristics of feedlot steers receiving dry milling by-products with and without oil extraction

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ABSTRACT

Three experiments evaluated the effects of corn oil removal, using centrifugation, in dry milling by-products on animal performance and digestion characteristics of finishing cattle. In Exp. 1, 225 crossbred steers (300 ± 9.1 kg) were utilized in a randomized block design with a 2 x 2 + 1 factorial arrangement of treatments. Factors consisted of oil concentration [de-oiled (DO) or normal (NORM)] and by-product type [27% condensed distillers solubles (CDS) or 40% modified distillers grains plus solubles (MDGS)] with a plus one control (CON). Ingredient fat concentration was 6.0% for DO CDS, 21.1% for NORM CDS, 9.2% for DO MDGS and 11.8% for NORM MDGS. There were no oil concentration by by-product type interactions ($P > 0.34$). There were no differences in DMI, ADG, or G:F between DO and NORM CDS ($P \geq 0.29$) and MDGS ($P \geq 0.58$). No differences ($P > 0.20$) due to oil concentration were observed for carcass characteristics. Experiment 2 was a 5 x 5 Latin Square design digestion trial that mimicked the treatments in Exp. 1. Fat concentration was 8.7% for DO CDS, 15.4% for NORM CDS, 9.2% for DO MDGS and 12.3% for NORM MDGS. Percentage of fat and NDF digestibilities were greater ($P < 0.05$) for NORM CDS compared to DO CDS. Average ruminal pH for cattle fed NORM MDGS was greater than DO MDGS ($P = 0.06$). There was no difference for average ruminal pH between DO and NORM CDS ($P = 0.74$). In Exp. 3, 336 yearling, crossbred steers (352 ± 19 kg) were utilized in a randomized block design with a 2x3+1 factorial arrangement of treatments. Factors included oil concentration (DO or NORM) and inclusion level [35, 50, and 65% wet distillers grains plus solubles (WDGS)] along with a corn based control (CON). The fat concentrations of DO and NORM WDGS were 7.9 and 12.4%, respectively. A linear interaction ($P < 0.01$) was observed for DMI which produced different slopes for DO and

NORM WDGS. No linear or quadratic interactions were observed for final BW, ADG, or G:F ($P \geq 0.31$). For the main effect of oil concentration, there were no statistical differences ($P \geq 0.19$) for final BW, ADG, or G:F. No statistical differences were observed for all carcass traits ($P \geq 0.34$). Corn oil removal via centrifugation had minimal impact on finishing performance suggesting that cattle fed DO by-products will have similar performance to cattle fed NORM oil by-products.

Key Words: by-products, distillers grains plus solubles, solubles corn oil, extraction

INTRODUCTION

Distillers grains plus solubles (DGS) is an excellent feedstuff for the cattle industry as DGS are a good source of energy and protein (Klopfenstein et al., 2008; Buckner et al., 2011). The ethanol industry has developed techniques to extract the oil, which can be marketed to the biodiesel industry or other feed markets. There are two processes utilized for oil extraction: front-end fractionation and back-end oil extraction. Front-end fractionation involves separating the germ, endosperm, and bran fractions before fermentation while back-end extraction removes oil from thin stillage via centrifugation after fermentation has occurred (U.S. Grains Council, 2012). Back-end oil extraction is widely utilized today with more than 80% of all U.S. ethanol plants utilizing this process (U.S. Grains Council, 2012).

The ethanol production process consists of converting starch from corn grain into ethanol, which is removed by distillation, producing whole stillage (Stock et al., 2000). The whole stillage is centrifuged to yield wet distillers grains and thin stillage. The thin stillage phase, which contains approximately 30% of the oil, is the only location that can

undergo centrifugation to remove corn oil, producing de-oiled solubles following evaporation (U.S. Grains Council, 2012). If de-oiled CDS are added back onto distillers grains, the fat concentration of the DGS will be reduced from approximately 12 to 8% fat (U.S. Grains Council, 2012). Our hypothesis was that a 4% unit decrease in energy would result in a decrease in animal performance. However, there are no data available on animal performance when this centrifugation process is used to remove corn oil from CDS. Therefore, 3 experiments were conducted to evaluate animal performance, carcass characteristics, and rumen digestion in steers fed finishing diets containing DGS or CDS produced from either a traditional dry-grind (normal) or have undergone oil extraction via centrifugation (de-oiled).

MATERIALS AND METHODS

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

Experiment 1

A 179-d finishing experiment was conducted using 225 crossbred, calf fed steers (initial BW = 300 ± 9.1 kg) in a randomized block design, with a 2 x 2 + 1 factorial arrangement of treatments. Steers were received at the University of Nebraska's Agricultural Research and Development Center (research feedlot near Ithaca, NE) in the fall of 2011.

Initial processing included vaccination with a modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health, Madison, NJ), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health), and administered an injectable dewormer (Dectomax

Injectable, Zoetis Animal Health). Approximately 27 d later, cattle were revaccinated with a modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health), and pinkeye vaccine (Piliguard Pinkeye + 7, Merck Animal Health, Desoto, KS). Steers were implanted with Revalor-IS (80mg of trenbolone acetate and 16mg estradiol; Merck Animal Health) on d 1 and reimplanted with Revalor-S (120mg of trenbolone acetate and 24mg of estradiol; Merck Animal Health) on d 83.

Steers were limit fed a 1:1 blend (DM basis) of alfalfa hay and wet corn gluten feed (Sweet Bran®, Cargill, Blair, NE) for 5 days at 2% of BW prior to the initiation of the trial and weighed on two consecutive days (0 and 1) to determine initial BW (Watson et al, 2013; Stock et al., 1983). Steers were blocked by initial BW into a light or heavy block with 2 and 3 replication of each treatment, respectively. Steers were stratified by BW within each block, and assigned randomly to pen using d 0 BW. Pens were assigned randomly to one of five treatments with nine steers per pen and five pens per treatment.

Dietary treatments (Table 1) were arranged in a 2 x 2 + 1 factorial treatment design with factors including by-product type [CDS or modified distillers grains plus solubles (MDGS)] and oil concentration (de-oiled or normal); and a corn based control diet. Basal ingredients consisted of a 1:1 blend of dry rolled and high moisture corn, 7.5% sorghum silage, and 5% dry supplement (DM basis). Modified DGS were procured at the initiation of the experiment from Green Plains LLC (Central City, NE) on two different weeks when the process was running to remove oil or not. Condensed distillers solubles were sourced from the same plant and received approximately every 3 weeks throughout the experiment on alternating weeks, with or without the oil process operating

in the plants. The de-oiled CDS utilized in this experiment contained 6.0% fat, 29.6% CP, and 1.26% S, DM basis; normal oil CDS contained 21.1% fat, 27.0% CP, and 0.78% S, DM basis; de-oiled MDGS contained 9.2% fat, 33.7% CP, 0.65% S, and 29.4% NDF, DM basis; normal oil MDGS contained 11.8% fat, 33.0% CP, 0.56% S, and 31.9% NDF, DM basis. Dietary fat consisted of 4.7, 8.8, 6.1, 7.2, and 4.4% for de-oiled CDS, normal CDS, de-oiled MDGS, normal MDGS, and CON, respectively. Soypass (Borregaard LignoTech, Sarpsborg, Norway) was included in the control and CDS diets for 38 and 60 days, respectively, to meet or exceed MP requirements (NRC, 1996). Urea was included in the control treatment at 1.52% of the diet on a DM basis. All diets contained 5% supplement which was formulated for 30 g/ton of DM of monensin (Elanco Animal Health) and to provide 90 mg per steer daily of tylosin (Elanco Animal Health).

Cattle were fed once daily at approximately 0800. Feed bunks were managed to contain crumbs of feed remaining at feeding time. When needed, refused feed was removed from feed bunks, weighed, and dried in a forced-air oven for 48 h at 60°C to determine DM for accurate DMI.

Samples of each feed ingredient were collected weekly to form a monthly composite which were analyzed for DM (Association of Analytical Chemist [AOAC], 1999 method 4.1.03), CP (AOAC, 1999 method 990.03) using a combustion-type N analyzer (Leco FP 528 Nitrogen Autoanalyzer, St. Joseph, MI), sulfur (TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI), ether extract, and NDF (Van Soest et al., 1991) incorporating heat stable α-amylase (Ankom Technology, Macedon, NY) at 1 ml per 100 ml of NDF solution (Midland Scientific, Omaha, NE) along with the addition of 0.5 g of Na_2SO_3 to the NDF solution. The NDF procedure was conducted

after ether extract had been extracted from the byproduct samples. Ether extract was determined by performing a biphasic lipid extraction procedure described by Bremer (2010). Ingredient samples are heated for 9 hours with a 1:1 mixture of hexane and diethyl ether. After 9 hours, diluted HCl is added and the sample is centrifuged to separate out the lipid layer which is pipetted into a separate tube. The procedure is repeated to ensure all lipid is extracted. Heat is then used to evaporate remaining solvent resulting in the fat for the ingredient.

Before shipping to slaughter, final live BW was measured by weighing steers by pen and applying a 4.0% pencil shrink. All animals were harvested on d 180 at a commercial abattoir (Greater Omaha Packing, Omaha, Neb.) with HCW and liver abscesses recorded at that time. Following a 48-h chill, carcass 12^{th} rib fat, LM area, and USDA marbling score were captured by cameras within the plant and recorded at time of grading. Yield grade was calculated using the USDA YG equation: YG = 2.5 + 6.35 (Fat thickness, cm) – 2.06 (LM area, cm^2) + 0.2 (KPH fat, %) + 0.0017 (HCW, kg). Calculated final BW, ADG, and G:F were calculated using HCW adjusted to a common dressing percentage of 63%.

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a randomized block design with pen as the experimental unit. The model included block as a fixed effect and treatment. Pair-wise comparisons for treatments, including the control, were determined by Fishers's LSD method when the F-Test statistic was significant. Two pre-planned contrasts were used to evaluate the effect of oil removal when 27% CDS or 40% MDGS were fed.

Experiment 2

A 111-d metabolism experiment utilized six ruminally fistulated crossbred steers (BW = 591 ± 20 kg) in a 5 x 5 Latin Square design with five periods and five treatments. A 2 x 2 + 1 factorial arrangement of treatments were used which are similar to those fed in Exp. 1. All diets contained a 1:1 blend of dry rolled and high moisture corn which was replaced by either CDS or MDGS, 12% corn silage, and a 5% supplement (Table 2). The by- products utilized in the trial were procured from Green Plains LLC (Central City, NE). The de-oiled CDS utilized in this experiment contained 8.7% fat, 29.9% CP, and 1.26% S; normal oil CDS contained 15.4% fat, 25.5% CP, and 0.78% S; de-oiled MDGS contained 9.2% fat, 33.9% CP, 0.65% S, and 29.7% NDF; normal oil MDGS contained 12.3% fat, 32.4% CP, 0.56% S, and 36.4% NDF. Dietary fat consisted of 5.2, 7.0, 5.9, 7.2, and 4.0 for de-oiled CDS, normal CDS, de-oiled MDGS, normal MDGS, and CON, respectively. Nutrients analyzed the same as Exp. 1. Steers were adapted to a high grain diet by utilizing RAMP (a complete-feed starter ration consisting of Sweet Bran and a small portion of alfalfa hay; Cargill Corn Milling, Blair, NE).

Steers were housed in 2.4 x 1.5 m^2 individual concrete slatted pens, in a temperature controlled room (25°C) with ad libitum access to feed and water. Cattle were fed once daily at 0800 and refused feed was removed from bunks prior to feeding. Ingredient samples were taken during the collection period at time of mixing, composited by period and frozen at -20°C. Refused feed was collected daily before time of feeding during the collection period, composited by period, and stored frozen at -20°C. A subsample of each d feed refusals (10%) were collected and dried for 48 h in a 60°C forced air over to determine DM and adjust for DMI. At the completion of each period,

ingredients and refused feed composites were freeze dried and ground through a 1-mm screen of a Willey Mill (Thomas Scientific, Swedesboro, NJ).

Period duration was 21-d, which consisted of a 16-d adaptation phase and 5-d collection period. During the 5-d collection (d 17 through 21) fecal samples and pH data were collected. Beginning on d 10 of each period, the titanium dioxide was administered to provide an estimate of fecal output (Meyer et al., 2004). Titanium dioxide, an indigestible marker, was dosed intraruminally 2x daily at 0800 and 1600 h to provide a total of 20 g/d. On d 17 to 21, fecal grab samples were collected 3 times/d at 0800, 1200, 1600, composited (wet basis), and immediately frozen at -20°C. At the end of each period, fecal samples were freeze dried, ground through a 1-mm screen of a Wiley Mill (Thomas Scientific), and composited by period.

Ruminal pH was measured continuously from d 17 to 21 with submersible wireless pH probes (Dascor, Inc., Escondido, CA). Ruminal pH measurements were recorded every minute (1,440 measurements/d) and downloaded after total rumen evacuations on d 21 of each collection period. Measurements for pH include average ruminal pH, minimum and maximum pH, and magnitude. Ruminal pH variance and time and area below 5.6 were calculated as described by Cooper et al. (1999).

Feed ingredients and fecal sample analysis consisted of DM, OM (AOCC, 1999; method 4.1.03) CP, NDF, and fat as described for Exp. 1. Fecal samples were analyzed for titanium dioxide using the procedure described by Myers et al (2004), plated, and analyzed using a SpectraMAX 250 (Harlow Scientific, Arlington, MA).

Digestibility and intakes were analyzed using the MIXED procedure of SAS (SAS Inst. Inc.). Included in the model were the fixed effects of treatment and period

while steer was treated as a random effect for all analyses. Ruminal pH data were analyzed using the GLIMMIX procedure of SAS (SAS Inst. Inc.) as a crossover design. An autoregressive (AR-1) covariance structure was utilized for pH data with day as a repeated measure. A Kenward-Rogers denominator degrees of freedom adjustment was used with steer treated as a random effect. Treatment differences were considered significant at $P < 0.10$.

Experiment 3

A 147-d finishing experiment was conducted using 336 crossbred, yearling steers (initial BW = 352 ± 19 kg) in a randomized block design, with a 2 x 3 + 1 factorial arrangement of treatments. Steers were received at the University of Nebraska's Agricultural Research and Development Center (Ithaca, NE) in the fall of 2011 and backgrounded on corn stalks for the winter. Initial processing and re-vaccination was similar to Exp. 1. Steers were implanted on d 1 with Revalor-XS (4 mg of estradiol and 20 mg of trenbolone acetate; Merck Animal Health).

Limit feeding and initial weigh procedures were the same as Exp. 1. Steers were blocked by BW into a light, medium, or heavy weight block with 2, 3, and 1 replication per treatment, respectively. Steers were stratified by BW within each block and assigned randomly to pen based on d 0 BW. Pens were then assigned randomly to one of seven treatments with six pens per treatment and eight steers per pen.

A 2 x 3 + 1 factorial arrangement of treatments was used, with factors being oil concentration (de-oiled or normal) by concentration of WDGS in the diet (35%, 50%, 65%) plus a corn based control (Table 3). Wet distillers grains plus solubles was sourced from KAAPA Ethanol, LLC (Minden, NE) and received approximately every 3 weeks

throughout the experiment. Feed ingredients were analyzed for DM, CP, NDF, S, and fat according to the procedures outlined in Exp. 1. The de-oiled WDGS contained 7.9% fat, 30.5% CP, 48.0% NDF, and 0.76% S and normal oil WDGS contained 12.4% fat, 29.3% CP, 51.5% NDF, and 0.73% S. Dietary fat concentrations are included in Table 3. Urea was included in the control treatment at 1.58% of the diet on a DM basis. All diets contained a 1:1 blend of dry rolled and high moisture corn, 12% corn silage, and 5% supplement which was formulated to contain 30 g/ton of monensin (DM basis, Elanco Animal Health) and provide 90 mg per steer daily of tylosin (Elanco Animal Health).

All animals were harvested on d 148 at a commercial abattoir (Greater Omaha Packing, Omaha, Neb.). Carcass data collection procedures were the same as Exp. 1.

Data were analyzed using the GLIMMIX procedure of SAS as a randomized block design. Pen was the experimental unit and BW was treated as a fixed effect. The 2x3 factorial treatment design was analyzed for a fat (de-oiled, normal) by inclusion level (0, 35, 50, 65%) interaction. PROC IML was used to determine appropriate coefficients due to unequal spacing of WDGS inclusion level. Using the control as the common intercept, orthogonal contrasts were developed.

RESULTS AND DISCUSSION

Experiment 1

Cattle fed CDS, regardless of oil concentration, had significantly ($P = 0.01$) lower DMI than cattle fed MDGS or CON. Dietary fat for de-oiled and normal CDS was 4.72% and 8.80%, respectively. Even though dietary fat for normal CDS was double that of de-oiled CDS, DMI was 8.8 kg/d for both treatments. Pesta (2013) reported a dietary

fat of 7.96% in a 27% CDS finishing diet. No difference was observed for DMI between de-oiled and normal MDGS ($P > 0.58$) when dietary fat was 6.12 and 7.19%, respectively. A reduction in DMI is typically the most consistent negative effect that is observed with increased fat supplementation (Hatch et al., 1972) which was not observed in the current experiment. When supplemental fat was supplied by tallow or yellow grease, DMI either decreased (Huffman et al., 1992; Zinn, 1994; Zinn and Shen, 1996) or remained unchanged (Brandt and Anderson, 1990; Vander Pol et al. 2009; Zinn 1988; Zinn 1989a). When fat was supplied by CDS, DMI decreased (Pesta, 2013; Trenkle, 2002; Rust, 1990; Titlow et al., 2013) or was not changed (Trenkle, 2004). However, a meta-analysis performed by Bremer (2011) observed that DMI increased when distillers grains plus solubles increased in the diet up to 30%. The increase in DMI can be attributed to the high NDF and low starch concentration of distillers grains which may have alleviated the risk of subacute acidosis.

There were no differences ($P \geq 0.29$) due to oil concentration of CDS and MDGS for ADG and G:F. Cattle fed CDS or MDGS had greater ADG ($P < 0.01$) and improved G:F ($P = 0.02$) compared to corn based controls. This agrees with previous research that cattle fed CDS (Pesta, 2013; Titlow et al., 2013) and DGS (Klopfenstein et al., 2008; Corrigan et al., 2009; Bremer et al., 2011) produce greater ADG and G:F compared to corn based diets without dry milling byproducts. Feeding values in the current study, calculated as described by Bremer et al. (2011), were 159 and 147% of corn for de-oiled and normal CDS, respectively. Pesta et al. (2013) reported a feeding value of 142% for CDS relative to corn when fed at 27% of the diet DM. The feeding values for MDGS were 130% of corn for both de-oiled and normal MDGS at 40% inclusion. Bremer et al.

(2011) conducted a meta-analysis and reported the feeding value of MDGS to be 117% when fed at 40% inclusion in a corn based finishing diet.

Regardless of oil concentration, cattle fed CDS or MDGS had greater ($P > 0.01$) HCW compared to CON. Hot carcass weight between de-oiled and normal CDS varied by only 4 kg while de-oiled and normal MDGS differed by only 2 kg. No other differences ($P \geq 0.13$) were observed for LM area, 12th rib fat thickness, calculated YG, or marbling score across all treatments.

Exp. 2

No treatment differences were observed for DMI or total tract DM digestibility ($P \geq 0.17$; Table 5). This is similar to the results of Pesta (2013) and Bremer (2010), where steers fed diets with 7.6 and 8.6% fat, respectively, had similar DMI and total tract DM digestibility compared to 4.2 and 3.6% dietary fat corn based control, respectively. However, steers fed WDGS have been reported to have a lower DMI and DM digestibility than corn based control diets (Bremer, 2010; Corrigan et al., 2009; Vander Pol et al., 2009).

There were no differences observed for OMI or OM digestibility when contrasting de-oiled and normal oil concentration for CDS and MDGS ($P > 0.30$). No effect of treatment ($P = 0.75$) was observed for OMI; however, a difference was observed for total tract OM digestibility ($P = 0.08$). Treatments that contained CDS had the greatest OM digestibility followed by de-oiled MDGS, CON, and normal MDGS. Similarly, Ham et al., (1994) reported thin stillage having greater OM digestibility compared to DRC, however, Pesta (2012) reported no difference in OM digestibility.

Similar to data reported by Ham et al. (1994), Vander Pol et al., (2009) reported WDGS to have comparable OM digestibility to a corn based diet.

A treatment effect was observed for NDFI ($P < 0.01$). Intake of NDF was greater for MDGS than CDS or CON because of the high NDF content of MDGS. No treatment difference was observed for total tract NDF digestibility ($P = 0.11$). However, the contrast between oil concentrations was significant for CDS ($P = 0.03$) with normal CDS having greater NDF digestibility than de-oiled CDS. This would suggest that the centrifugation process to remove corn oil also removes a portion of highly digestible NDF out of the thin stillage since normal CDS had both greater NDFI and digestibility compared to de-oiled CDS. Ham et al. (1994) reported thin stillage to be significantly greater in NDF digestibility than a DRC based diet. There was no difference between oil concentrations for MDGS ($P = 0.90$) on NDF digestibility. However, both MDGS treatments had numerically greater NDF digestibilities compared to CON which has been previously reported (Ham et al., 1994; Corrigan et al., 2009; Bremer, 2010). More typical sources of supplemental fat, yellow grease or blended animal-vegetable fats, will decrease NDF and ADF digestibility by physically coating fiber particles or inhibiting cellulolytic activity (Zinn, 1989b; Zinn et al., 2000). It appears that lipids from dry milling byproducts do not decrease fiber digestion like typical fat sources.

A treatment effect was observed for fat intake ($P < 0.01$). Fat intake was the greatest for normal MDGS (0.74 kg/d), intermediate for normal CDS (0.66 kg/d) and de-oiled MDGS (0.66 kg/d), and the least for de-oiled CDS (0.46 kg/d) and CON (0.41 kg/d). A treatment effect was observed for total tract fat digestibility ($P = 0.01$). Total

tract fat digestibility was greater for normal CDS, intermediate for de-oiled and normal MDGS, and the least for de-oiled CDS.

Average ruminal pH was greatest for cattle fed normal MDGS and lowest for CON and de-oiled CDS ($P < 0.01$). This is consistent with the findings of Pesta (2012) who observed an increase in average ruminal pH when steers were fed WDGS relative to CDS or CON diets. However, previous research would suggest that there is not a difference in average ruminal pH between WDGS and corn based control (Bremer, 2010; Ham et al, 1994; Corrigan et al, 2009). There was no statistical difference between de-oiled and normal CDS for average pH ($P = 0.74$). However, average pH for normal MDGS was greater than de-oiled MDGS ($P = 0.06$). No treatment differences were observed for minimum or maximum pH or pH magnitude or variance ($P > 0.19$). Steers fed CDS or CON spent more time and area with a pH below 5.6 than steers fed WDGS ($P < 0.02$). Likewise, steers fed CDS or CON spent more time and area with a pH below 5.3 than steers fed WDGS ($P < 0.10$).

Exp. 3

No linear or quadratic interactions were observed for ADG or G:F ($P > 0.31$; Table 7). There was a linear interaction ($P < 0.01$) for DMI producing different slopes for de-oiled and normal WDGS. As de-oiled WDGS increased in the diet from 0 to 50, DMI remained relatively constant from 11.4 to 11.6 kg/d, and as dietary inclusion increased from 50 to 65%, DMI decreased from 11.6 to 10.9 kg/d. However, as normal WDGS increased from 0 to 50% inclusion in the diet DM, DMI decreased from 11.4 to 10.9 kg/d, and as the dietary inclusion of WDGS increased from 50 to 65%, DMI

decreased further from 10.9 to 10.4 kg/d. This agrees with previous research that at high inclusions of WDGS (> 30% of DM), cattle tend to have decreased DMI relative to lower inclusions (Vander Pol et al., 2006; Larson et al., 1993; Klopfenstein et al., 2008).

For the main effect of oil concentration (Table 8), there were no differences ($P \geq 0.19$) for final BW, ADG, or G:F. Cattle fed de-oiled WDGS had numerically greater final BW and ADG. However, cattle fed normal WDGS had lower DMI ($P < 0.01$) which resulted in a 2.5%, non-significant ($P = 0.19$) improvement in G:F compared to cattle fed de-oiled WDGS.

There was no effect on final BW or ADG ($P > 0.17$) as WDGS increased in the diet (Table 9). Vander Pol et al., (2006) observed a quadratic response ($P < 0.01$) for final BW and ADG as WDGS increased up to 50% in the diet. In their study, feeding 50% WDGS increased ADG and final BW compared to 0% WDGS. Similarly, Corrigan et al. (2009) and Bremer et al. (2011) observed a quadratic response for ADG as the inclusion of WDGS was fed up to 40% inclusion in the diet. In the current study, cattle fed 65% inclusion had similar ADG and final BW compared to CON ($P > 0.17$). A linear increase was observed for G:F as the inclusion of WDGS increased up to 65% in the diet DM. Firkins et al., (1985) observed a similar linear response for G:F as WDGS increased from 0 to 50% in the diet DM. However, several studies have reported a quadratic response for G:F with 40% inclusion of WDGS having the most improved G:F (Bremer et al., 2011; Corrigan et al., 2009; Vander Pol et al., 2006).

No effect of oil concentration or WDGS concentration ($P > 0.08$) were observed for HCW, LM area, 12th rib fat thickness, calculated yield grade, or marbling score.

Based on this research, reducing the oil concentration, via centrifugation, in DGS or CDS does not hinder ADG or G:F in finishing steers. However, replacing corn with distillers grains plus solubles or condensed distillers solubles in finishing diets increased ADG and G:F. Feeding de-oiled CDS does appear to reduce NDF and fat digestibility; however, this did not appear to impact gain or efficiency.

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Table 1: Diet Composition on a DM basis fed to finishing steers (Exp. 1)

	Control	27% CDS		40% MDGS	
		De-Oiled[1]	Normal[1]	De-Oiled[1]	Normal[1]
Ingredient, % of DM[2]					
DRC	43.75	30.25	30.25	23.75	23.75
HMC	43.75	30.25	30.25	23.75	23.75
MDGS: De-Oiled	-	-	-	40	-
MDGS: Normal Fat	-	-	-	-	40
CDS: De-Oiled	-	27	-	-	-
CDS: Normal Fat	-	-	27	-	-
Sorghum Silage	7.5	7.5	7.5	7.5	7.5
Supplement[3]					
Fine ground corn	1.03	2.59	2.59	2.59	2.59
Limestone	1.47	1.89	1.89	1.89	1.89
Urea	1.52	-	-	-	-
Potassium chloride	0.48	-	-	-	-
Salt	0.30	0.30	0.30	0.30	0.30
Tallow	0.13	0.13	0.13	0.13	0.13
Beef trace mineral[4]	0.05	0.05	0.05	0.05	0.05
Vitamin A-D-E[5]	0.02	0.02	0.02	0.02	0.02
Rumensin-90[6]	0.02	0.02	0.02	0.02	0.02
Tylan-40[7]	0.01	0.01	0.01	0.01	0.01
Analyzed Composition, %[8]					
CP	12.4	13.9	13.2	18.3	18.0
Fat	4.43	4.72	8.80	6.12	7.19
S	0.14	0.44	0.31	0.34	0.30

[1]De-Oiled CDS = 6.0% fat; Normal CDS = 21.1% fat; De-Oiled MDGS = 9.2% fat; Normal CDS = 11.8% fat

[2]DRC = Dry rolled corn; HMC = High moisture corn; MDGS = Modified distillers grains plus solubles; CDS = condensed distillers solubles

[3]Supplement formulated to be fed at 5.0% of diet DM.

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

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

[6]Formulated to contain 200 g/kg of monesin.

[7]Premix contained 88g/kg tylosin.

[8]Composition based on analyzed nutrients for each ingredient

Table 2: Diet Composition on a DM basis fed to finishing steers (Exp. 2)

	Control	27% CDS		40% MDGS	
		De-Oiled[1]	Normal[1]	De-Oiled[1]	Normal[1]
Ingredient, % of DM[2]					
DRC	41.5	28	28	21.5	21.5
HMC	41.5	28	28	21.5	21.5
MDGS: De-Oiled	-	-	-	40	-
MDGS: Normal Fat	-	-	-	-	40
CDS: De-Oiled	-	27	-	-	-
CDS: Normal Fat	-	-	27	-	-
Corn Silage	12	12	12	12	12
Supplement[3]					
Fine ground corn	1.03	2.59	2.59	2.59	2.59
Limestone	1.47	1.89	1.89	1.89	1.89
Salt	0.30	0.30	0.30	0.30	0.30
Tallow	0.13	0.13	0.13	0.13	0.13
Beef trace mineral[4]	0.05	0.05	0.05	0.05	0.05
Vitamin A-D-E[5]	0.02	0.02	0.02	0.02	0.02
Potassium chloride	0.48	-	-	-	-
Urea	1.52	-	-	-	-
Rumensin-90[6]	0.02	0.02	0.02	0.02	0.02
Tylan-40[7]	0.01	0.01	0.01	0.01	0.01
Analyzed Composition, %[8]					
CP	12.4	14.8	13.8	19.0	18.5
NDF	13.2	10.2	11.9	19.9	22.6
Fat	4.01	5.17	6.99	5.93	7.16
S	0.14	0.30	0.25	0.28	0.27

[1]De-Oiled CDS = 8.7% fat; Normal CDS = 15.4% fat; De-Oiled MDGS = 9.2% fat; Normal CDS = 12.3% fat

[2]DRC = Dry rolled corn; HMC = High moisture corn; MDGS = Modified distillers grains plus solubles; CDS = condensed distillers solubles

[3]Supplement formulated to be fed at 5.0% of diet DM.

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

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

[6]Formulated to contain 200 g/kg of monesin.

[7]Premix contained 88g/kg tylosin.

[8]Composition based on analyzed nutrients for each ingredient

Table 3: Diet Composition on a DM basis fed to finishing steers (Exp. 3)

	Control	35% WDGS		50% WDGS		65% WDGS	
		De-Oiled	Normal	De-Oiled	Normal	De-Oiled	Normal
Ingredient, % of DM[1]							
DRC	41.5	24	24	16.5	16.5	9	9
HMC	41.5	24	24	16.5	16.5	9	9
WDGS: De-Oiled	-	35	-	50	-	65	-
WDGS: Normal Fat	-	-	35	-	50	-	65
Corn Silage	12	12	12	12	12	12	12
Supplement [2]	5	5	5	5	5	5	5
Fine ground corn	1.46	2.54	2.54	2.54	2.54	2.54	2.54
Limestone	1.45	1.95	1.95	1.95	1.95	1.95	1.95
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Tallow	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Urea	1.58	-	-	-	-	-	-
Beef trace mineral[3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin A-D-E[4]	0.02	0.2	0.2	0.2	0.2	0.2	0.2
Rumensin-90[5]	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Tylan-40[6]	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Analyzed Composition, %[7]							
CP	12.8	16.2	15.8	19.4	18.8	22.6	21.9
NDF	13.5	26.6	27.8	32.3	34.0	38.0	40.2
Fat	4.47	5.49	7.06	5.98	8.22	6.39	9.31
Sulfur	0.09	0.32	0.31	0.42	0.41	0.52	0.51

[1]DRC = Dry rolled corn; HMC = High moisture corn; WDGS = Wet distillers grains plus solubles
[2]Supplement formulated to be fed at 5.0% of diet DM.
[3]Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.
[4]Premix contained 30,000 IU of Vitamin A, 6,000 IU of Vitamin D, 7.5 IU of Vitamin E per gram
[5]Formulated to contain 200 g/kg of monesin.
[6]Premix contained 88g/kg tylosin.
[7]Composition based on analyzed nutrients for each ingredient

Table 4: Effect of feeding de-oiled and normal fat CDS and MDGS on finishing performance (Exp. 1)

		27% CDS		40% MDGS			P-Value		
	Control	De-oiled	Normal	De-oiled	Normal	SEM[1]	F-Test	CDS[2]	MDGS[3]
Performance									
Initial BW, kg	300	300	301	300	300	1	0.39	0.07	0.68
Final BW[4], kg	567[a]	588[b,c]	580[a,b]	595[b,c]	599[c]	14	0.01	0.43	0.61
DMI, kg/d	9.5[a]	8.8[b]	8.8[b]	9.3[a]	9.5[a]	0.4	0.01	0.97	0.58
ADG[5], kg	1.49[a]	1.60[b,c]	1.56[a,b]	1.64[b,c]	1.67[c]	0.08	0.02	0.36	0.60
G:F	0.157[a]	0.182[b]	0.177[b]	0.176[b]	0.175[b]	0.004	<0.01	0.29	0.80
Carcass Characteristics									
HCW, kg	357[a]	370[b,c]	366[a,b]	375[b,c]	377[c]	9	0.01	0.43	0.61
LM area, cm^2	81.0	85.1	82.7	82.6	81.6	0.23	0.38	0.25	0.66
12^{th} rib fat, cm	1.27	1.27	1.19	1.35	1.42	0.03	0.28	0.47	0.47
Calculated YG	3.21	3.11	3.15	3.37	3.49	0.11	0.13	0.81	0.44
Marbling score[6]	570	579	575	594	599	14	0.50	0.85	0.77

[a,b,c]Means with different superscripts differ ($P < 0.05$)
[1]SEM = Standard error of the mean
[2]CDS = Pairwise, contrast of de-oiled vs. normal CDS
[3]MDGS = Pairwise, contrast of de-oiled vs. normal MDGS
[4]Calculated from hot carcass weight, adjusted to a common dressing percentage of 63.0%.
[5]Calculated using carcass adjusted final BW.
[6]Marbling score: 500 = Small00

Table 5: Effects of dietary treatment on intake and total tract digestibility of DM, organic matter, fat, and NDF. (Exp. 2)

		27 CDS[1]		40 MDGS[1]			*P*-Value		
Item	CON	De-Oiled	Normal	De-Oiled	Normal	SEM	F-Test[2]	CDS[3]	MDGS[4]
DM									
Intake, kg/d	9.25	9.30	9.48	9.21	10.25	1.5	0.79	0.84	0.29
Total tract digestibility, %	81.6	81.4	83.6	82.1	80.0	1.9	0.27	0.17	0.26
OM									
Intake, kg/d	8.90	8.88	8.84	8.89	9.98	2.2	0.75	0.97	0.37
Total tract digestibility, %	82.9^{a,b}	84.6^{b,c}	86.0^{c}	83.6^{a,b,c}	81.9^{a}	1.8	0.08	0.30	0.30
NDF									
Intake, kg/d	1.32^{a}	0.91^{b}	1.13^{c}	2.13^{d}	2.31^{e}	0.24	<0.01	0.02	0.08
Total tract digestibility, %	58.2	56.0	68.4	66.2	66.9	5.2	0.11	0.03	0.90
Fat									
Intake, kg/d	0.41^{c}	0.46^{c}	0.66^{a}	0.66^{a}	0.74^{b}	0.08	<0.01	<0.01	0.05
Total tract digestibility, %	87.3^{b}	89.6^{a,b}	93.1^{c}	91.2^{a,c}	90.6^{a}	1.3	0.01	0.02	0.68

^{a,b,c,d,e}Means with different superscripts differ ($P < 0.10$)

[1]CDS = Condensed distillers solubles; MDGS = Modified distillers grains plus solubles

[2]F-Test = Overall F-test representing variation due to treatment

[3]CDS = Contrast of de-oiled vs. normal CDS

[4]MDGS = Contrast of de-oiled vs. normal MDGS

Table 6: Effects of dietary treatment on ruminal pH with steers fed 27% CDS and 40% MDGS with (de-oiled) or without (normal) a portion of oil removed (Exp. 2)

		27 CDS		40MDGS			*P*-Value		
Item	CON	De-Oiled	Normal	De-Oiled	Normal	SEM	F-Test[1]	CDS[1]	MDGS[3]
Average pH	5.36[a]	5.38[a]	5.41[ab]	5.54[b]	5.72[c]	0.08	<0.01	0.74	0.06
Maximum pH	6.03	6.17	6.04	6.25	6.31	0.11	0.28	0.41	0.70
Minimum pH	4.87	4.92	5.01	5.07	5.07	0.08	0.19	0.35	0.98
pH magnitude	1.08	1.23	1.09	1.14	1.32	0.15	0.76	0.50	0.42
pH variance[4]	0.079	0.092	0.081	0.080	0.111	0.021	0.78	0.72	0.30
Time < 5.6, min/d[5]	958[a]	923[a]	902[a]	652[b]	494[b]	100	<0.01	0.87	0.22
Area < 5.6, min/d[6]	365[a,c]	356[a,c]	403[a]	238[b,c]	141[b]	71	0.02	0.58	0.23
Time < 5.3, min/d[7]	679[a]	575[a,c]	709[a]	368[b,c]	252[b]	127	0.03	0.40	0.46
Area < 5.3, min/d[8]	136[a,c]	129[a,c]	162[a]	86[b,c]	41[b]	41	0.10	0.48	0.33

[a,b,c]Means with different superscripts differ ($P < 0.10$)
[1]F-Test = Overall F-test representing variation due to treatment
[2]CDS = Contrast of de-oiled vs. normal CDS
[3]MDGS = Contrast of de-oiled vs. normal MDGS
[4]Variance of daily ruminal pH.
[5]Time < 5.6 = minutes that ruminal pH was below 5.6
[6]Area < 5.6 = ruminal pH units below 5.6 by minute
[7]Time < 5.3 = minutes that ruminal pH was below 5.3
[8]Area < 5.3= ruminal pH units below 5.3 by minute

Table 7: Linear and quadratic interactions for increasing concentration of de-oiled (DO) and normal (N) WDGS on finishing performance (Exp. 3)

		35%		50%		65%			*P*-Value	
	CON	DO	N	DO	N	DO	N	SEM	Lin Int[1]	Quad Int[2]
Performance										
DMI, kg/d	11.4	11.5	11.5	11.6	10.9	10.9	10.4	0.8	< 0.01	0.48
ADG, kg	1.76	1.81	1.88	1.88	1.78	1.87	1.84	0.12	0.31	0.64
G:F	0.155	0.158	0.164	0.163	0.164	0.172	0.178	0.007	0.38	0.89

[1]Lin Int = Linear interaction for byproduct type and oil concentration
[2]Quad Int = Quadratic interaction for byproduct type and oil concentration

Table 8: Main effect of oil concentration on performance and carcass characteristics (Exp. 3)

	De-Oiled	Normal	SEM	P-Value
Performance				
Final BW[1], kg	627	623	9	0.52
DMI, kg/d	11.4	10.9	0.2	< 0.01
ADG, kg	1.85	1.83	0.07	0.58
G:F	0.163	0.167	0.002	0.19
*Carcass Character*istics				
HCW, kg	394	393	6	0.68
LM area, cm^2	84.6	85.1	0.12	0.58
12^{th} rib fat, cm	1.42	1.42	0.01	0.93
Calculated YG	3.46	3.47	0.06	0.91
Marbling score[2]	565	576	8	0.34

[1]Calculated from hot carcass weight, adjusted to a common dressing percentage of 63.0%
[2]Marbling score: 500 = Small00

Table 9: Main effect of inclusion of WDGS on performance and carcass characteristics (Exp. 3)

	Control	35%	50%	65%	SEM	Linear[1]	Quadratic[2]
Performance							
Final BW[3], kg	614	626	624	626	36	0.23	0.46
DMI, kg/d	11.4	11.5	11.2	10.7	0.8	<0.01	<0.01
ADG, kg	1.76	1.84	1.83	1.85	0.12	0.17	0.60
G:F	0.155	0.161	0.163	0.175	0.006	<0.01	0.13
Carcass Characteristics							
HCW, kg	385	395	393	393	22	0.25	0.27
LM area, cm^2	86.4	85.1	85.9	85.1	0.20	0.53	0.97
12^{th} rib fat, cm	1.32	1.45	1.37	1.42	0.03	0.17	0.37
Calculated YG	3.24	3.49	3.38	3.49	0.12	0.08	0.42
Marbling score[4]	547	573	555	575	19	0.25	0.79

[1]Linear = Linear effect of treatment *P* – value with main effects of inclusion level of WDGS
[2]Quadratic = Quadratic effect of treatment *P* – value with main effects of inclusion level of WDGS
3Calculated from hot carcass weight, adjusted to a common dressing percentage of 63%
[4]Marbling score: 500 = Small00

Chapter III

Effect of feeding condensed distillers solubles with and without oil extraction on growing cattle performance

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ABSTRACT

An 84-d growing study utilized 60 individually fed steers (initial BW 241 ± 14.1 kg) to evaluate the effects of feeding condensed distillers solubles (CDS) with and without oil extraction at varying inclusions in two different forage quality diets. Based on initial BW, steers were stratified and assigned randomly to one of seven treatments. Of the seven treatments, five were designed as a 2 x 2 + 1 factorial consisting of 20 or 40% de-oiled or normal CDS and a control (CON) without CDS. Diets contained an 80:20 blend of brome hay and sorghum silage (GRASS). The last two treatments were designed as a 2 x 2 factorial comparing CDS fat concentration (de-oiled or normal) and forage type [GRASS (previous diets) or wheat straw (WS)] at 40% inclusion of CDS (DM basis). Dietary fat was 2.4% for 20% de-oiled CDS, 3.2% for 20% normal CDS, 5.2% for 40% de-oiled CDS, 8.8% for 40% normal CDS, 2.9% for 40% de-oiled WS, 8.4% for 40% normal WS, and 1.5% for CON. Ending BW, DMI, and ADG increased linearly with increasing concentration of CDS ($P < 0.01$), but oil content of CDS had no effect ($P > 0.21$). There was a tendency for an interaction for G:F ($P = 0.14$). At 20% inclusion, G:F improved 13.4% for normal CDS compared to de-oiled, but at 40% inclusion, G:F differed only 1%. This suggests oil may have reduced fiber digestion at 40% CDS inclusion. An interaction was observed between diets varying in forage quality and CDS oil content for DMI ($P = 0.06$) and a tendency for ADG ($P = 0.13$). Intakes were greatest for GRASS treatments, de-oiled CDS with wheat straw intermediate, and normal CDS with wheat straw had the lowest DMI. Gains and G:F were greater for GRASS diets compared to WS ($P < 0.01$), regardless of fat content ($P > 0.40$). At low concentrations of CDS, normal oil improved feed efficiency while with higher inclusions of CDS, removing oil resulted in little effect on performance. This may

suggest that high inclusions of normal CDS will result in a negative effect on fiber digestion in forage based growing diets.

Key Words: Condensed Distillers Solubles, Oil removal, Growing Cattle

INTRODUCTION

The increase in dry-milling ethanol production has produced an increase in by-product feeds (distillers grains and condensed distillers solubles) available to cattle producers. Depending on an ethanol plant's storage capacity for liquid feeds, condensed distillers solubles (CDS) can be added back to distillers grains to produce distillers grains plus solubles or marketed as a sole by-product. The increased fat and rumen degradable protein in CDS complement the nutrients available in low-quality forage diets which make CDS an appealing ingredient for forage based growing diets (Stalker et al., 2010).

Three reports have been conducted to evaluate CDS in forage-based growing diets. Wilken et al. (2009) fed CDS that were mixed with corn stalks at 15, 20, 25, and 30% of the diet DM. Steers fed 30% CDS had numerically greater intakes than all other treatments. Gains increased linearly ($P < 0.01$) as concentration of CDS increased in the diet, while G:F responded cubically ($P = 0.03$) with cattle consuming 25% CDS being the most efficient. Similarly, Warner et al. (2013) observed a linear increase in DMI, ADG, and G:F when 0, 15 or 30% CDS are fed with ground hay in a forage-based growing diet. Peterson et al. (2009) mixed CDS with wheat straw at 25, 35, and 45% inclusion of the diet, DM basis. Intakes, ADG, and G:F were numerically greatest for steers fed CDS at 45% of the diet DM. These experiments suggest that CDS can be fed with low quality forages in growing diets and increase ADG and G:F.

During the ethanol production process, whole stillage is produced when ethanol is removed by distillation. The whole stillage undergoes centrifugation to separate wet distillers grains and thin stillage which contains approximately 5-10% DM, protein, corn oil, and yeast cells (ICM, 2012). Once the thin stillage is separated from whole stillage, it passes through a centrifuge to remove corn oil, producing a de-oiled product. There are no data available feeding de-oiled CDS in forage based growing diets when this centrifugation process is utilized to remove corn oil. Therefore, the objective of this study was to determine the effects of feeding de-oiled and normal oil CDS at increasing levels and with different forage types on growing cattle performance.

MATERIALS AND METHODS

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

An 84-d growing trial utilized 60 crossbred steer calves (initial BW = 240 ± 14 kg) that were individually fed using the Calan electronic gate system (American Calan Inc., Northwood, NH). Upon arrival at the feedlot, steers were vaccinated with a modified modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health, Madison, NJ), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health), and administered an injectable dewormer (Dectomax Injectable, Zoetis Animal Health). Steers were revaccinated with with modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health), and pinkeye vaccine (Piliguard Pinkeye +7, Merck Animal Health) approximately 16 d following initial processing.

Prior to initiation of the trial, steers were limit fed 47.5% wet corn gluten feed, 47.5% grass hay, and 5% supplement at 2% of BW for five d to minimize gut fill, and weighed on three consecutive d to determine initial BW (Watson et al, 2013; Stock et al., 1983). Based on initial BW, steers were stratified by BW and assigned randomly to one of seven treatments within strata. Of the seven treatments (Table 1), five of the treatments were designed as a 2 x 2 + 1 factorial consisting of 20% or 40% de-oiled or normal CDS and a control diet (CON) with no CDS (+1). The six treatments containing CDS consisted of 8 steers per treatment with the control diet utilizing 12 steers. These diets contained an 80:20 blend of brome hay and sorghum silage (HAY; DM basis) replaced by CDS. The last two treatments were designed as a separate 2 x 2 factorial comparing de-oiled and normal fat CDS with different forage bases of either wheat straw or the HAY diet in the previous treatments with 40% de-oiled or normal CDS. All diets were formulated to meet or exceed MP requirements using the 1996 NRC model.

Feed refusals were sampled weekly, weighed, and then dried in a 60°C forced air oven for 48 hours to calculate DMI. Feed bunks were evaluated and feed offered was adjusted daily to maintain *ad libitum* intake. After 84-d, steers were limit fed for five days receiving the 47.5% wet corn gluten feed, 47.5% grass hay, and 5% supplement diet. Steers were weighed on three consecutive d and averaged to determine ending BW. All diets were formulated to provide 200 mg/steer daily of monensin (Rumensin, Elanco Animal Health, Indianapolis, IN).

Feed ingredients were analyzed to determine DM (Association of Analytical Chemist [AOAC], 1999 method 4.1.03), CP (AOAC, 1999 method 990.03) using a combustion-type N analyzer (Leco FP 528 Nitrogen Autoanalyzer, St. Joseph, MI), sulfur (TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI), NDF (Van Soest et al., 1991) incorporating heat stable α-amylase (Ankom Technology, Macedon, NY) at 1 ml per 100 ml of NDF solution

(Midland Scientific, Omaha, NE) along with the addition of 0.5 g of Na_2SO_3 to the NDF solution, and ether extract. Ether extract was determined by utilizing a biphasic lipid extraction procedure described by Bremer (2010). Four mL of a 1:1 mixture of hexane and diethyl ether was added to a test tube with a 0.5 g byproduct sample and heated for 9 hours. After 9 hours, 3 ml of diluted HCl (1 drop HCl/40 ml ddH_20) was added and the sample was centrifuged to separate out the lipid layer, which was subsequently pipetted into a separate tube. The procedure was repeated with 2 ml of the hexane diethyl ether mixture to ensure all lipid was extracted. Tubes were heated to evaporate remaining solvent resulting in the fat for the ingredient. The de-oiled CDS (Table 2) utilized in this experiment contained 6.3% fat, 28.0% CP, and 0.99% S; normal oil CDS contained 20.1% fat, 26.4% CP, and 0.83% S, DM basis. In the GRASS diets, dietary fat was 2.4% for de-oiled 20%, 3.2% for normal 20%, 5.2% for de-oiled 40%, and 8.8% for normal 40% CDS compared to 1.5% for CON. In the wheat straw diets, dietary fat was 2.9% for de-oiled CDS at 40% and 8.4% for normal CDS at 40%. .

Data were analyzed using MIXED procedures of SAS (SAS Inc., Cary, NC) as a completely randomized design with animal serving as the experimental unit (n = 60). The 2 x 2 + 1 factorial design was analyzed for an oil concentration (de-oiled, normal) by CDS level (20, 40) interaction. Using the control, orthogonal contrasts were used to evaluate level of either de-oiled or normal CDS. The other 2x2 factorial design was analyzed for a fat (de-oiled, normal) by forage type (GRASS or wheat straw) interaction.

RESULTS AND DISCUSSION

No oil concentration by CDS level interaction was observed for ending BW, DMI, or ADG. However, there was a trend ($P = 0.14$) for an interaction for G:F (Table 2). When CDS was fed at 20% in a GRASS diet, G:F improved 13.6% for normal CDS compared to de-oiled

CDS. When CDS increased in the diet to 40% inclusion, G:F differed by only 1% between normal and de-oiled CDS. When analyzed including the control, the concentration response for de-oiled CDS showed a linear ($P < 0.01$) increase in G:F while normal CDS tended to be quadratic ($P = 0.10$). Warner et al. (2013) fed CDS at 15 or 30% with ground hay and observed a linear increase ($P < 0.01$) in G:F. Wilken et al. (2009) evaluated growing performance in calves fed increasing levels (15, 20, 25, 30% inclusion) of CDS in a corn stalk diet. The author reported that G:F responded in a cubic ($P = 0.03$) manner with cattle consuming 25% CDS being the most efficient compared to all other treatments. A decrease in efficiency was observed when cattle were fed 30% CDS in a corn stalk diet.

For the main effect of oil concentration, there were no statistical differences for ending BW, DMI, and ADG ($P \geq 0.21$). For ending BW, de-oiled and normal CDS increased linearly ($P < 0.01$) with increasing concentration of CDS in the diet. Intakes for de-oiled CDS increased linearly ($P < 0.01$) and tended to increase quadratically ($P = 0.14$), however, normal CDS increased linearly ($P < 0.01$). The greatest dietary fat was calculated at 40% inclusion of normal CDS which was 8.8% dietary fat. This concentration of fat in the diet was not enough to negatively impact DMI which is the most predictable detrimental effect associated with fat supplementation (Zinn, 1989). Warner et al. (2013) observed similar results with a linear ($P < 0.01$) increase in DMI as concentration of CDS increased up to 30% in the diet. This significant linear response is in contrast to data observed from Wilken et al. (2009) who reported a small numerical increase in DMI. Gilbery et al. (2006) observed that supplementation of CDS with low quality hay diets tended to increase total DMI ($P = 0.11$). Feeding both de-oiled and normal CDS increased ADG linearly ($P < 0.01$) with increasing level of CDS. Wilken et al. (2009) and

Warner et al. (2013) observed similar results with ADG increasing linearly as the inclusion of CDS increased to 30%.

A forage type by oil concentration interaction was observed ($P = 0.06$) for DMI and a tendency ($P = 0.13$) for ADG (Table 3). All treatments analyzed contained 40% CDS in the diet. Intakes were greatest for GRASS treatments regardless of oil concentration, de-oiled CDS with wheat straw was intermediate, and normal CDS with wheat straw had the lowest DMI. The main effect of oil concentration was not different ($P > 0.40$) for ending BW, ADG, and G:F. However, steers fed normal CDS in HAY based diet, had numerically greater ending BW, ADG, and G:F compared to de-oiled CDS. Steers fed de-oiled CDS in wheat straw diets had numerically greater ending BW and ADG compared to normal CDS. However, de-oiled CDS had greater DMI ($P = 0.06$) than normal CDS which resulted in de-oiled CDS having numerically lower G:F compared to normal CDS. The main effect of forage was significant ($P < 0.01$) for ending BW, ADG, and G:F with steers consuming GRASS having greater ending BW, ADG, and G:F compared to wheat straw diets. Peterson et al. (2009) fed 25, 35, and 45% CDS in wheat straw diets and observed numerically greater DMI, ADG, and G:F for steers consuming 45% CDS. The authors reported dietary fat to be 5.17, 6.92. and 8.69% for 25, 35, and 45% CDS diets, respectively. This is similar to the dietary fat for normal CDS in the current experiment of 8.83 and 8.42 in GRASS and wheat straw diets, respectively. However, when steers were fed wheat straw diets, DMI was reduced in normal CDS diets suggesting that oil concentration potentially could have hindered fiber digestion by either physically coating fiber particles or having toxic effects on rumen microorganisms (Zinn et al., 2000). In spite of this, oil concentration had no effect ($P > 0.40$) on ADG and G:F.

Our data indicate that CDS can be fed in forage based growing diets while improving ADG and G:F. The oil concentration of CDS impacted G:F when steers were fed 20% CDS, with steers fed normal CDS being 13.6% more efficient than steers fed de-oiled CDS. However, at 40% inclusion of CDS, there was no difference between de-oiled and normal CDS. This response in G:F due to CDS inclusion could be related to the increased oil concentration hindering fiber digestion in forage based diets.

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Table 1: Diet Composition on a DM basis fed to growing steers

	Control	De-oiled CDS[1]		Normal CDS[1]		De-oiled WS[1]	Normal WS[1]
Ingredient, % of DM	0	20	40	20	40	40	40
Brome Hay	77.1	59.6	42.2	59.6	42.2	-	-
Sorghum Silage	19.3	14.9	10.5	14.9	10.5	-	-
Wheat Straw	-	-	-	-	-	55.2	55.2
CDS: De-Oiled	0	20	40	-	-	40	-
CDS: Normal Fat	0	-	-	20	40	-	40
Supplement	3.7	5.5	7.3	5.5	7.3	4.8	4.8
Corn gluten meal[2]	2.043	3.695	4.796	3.695	4.796	2.474	2.474
Limestone	0.803	1.682	2.000	1.682	2.000	1.792	1.792
Urea	0.300	0.120	-	0.120	-	0.030	0.030
Salt	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Tallow	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Beef trace mineral[3]	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Vitamin A-D-E[4]	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Rumensin-90[5]	0.0138	0.0138	0.138	0.0138	0.138	0.0138	0.0138
Analyzed Composition, %[6]							
Fat	1.47	2.39	3.32	5.15	8.83	2.91	8.42
CP	13.5	13.8	18.5	13.2	17.5	15.3	14.2

[1]CDS = Condensed Distillers Solubles; WS = Wheat Straw

[2]Corn gluten meal was added to balance MP requirements

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

[4]Premix contained 30,000 IU vitamin A, 6,000 IU vitamin D, 7.5 IU vitamin E per gram.

[5]Premix contained 200 g/kg monensin (Elanco Animal Health, Greenfield, IN).

[6]Composition based on analyzed nutrients for each ingredient.

Table 2: Effects of de-oiled and normal fat CDS fed at 20 or 40% in HAY diets

		De-Oiled		Normal					De-Oiled		Normal	
	0	20	40	20	40	SEM[1]	Int[2]	Fat[3]	Lin[4]	Quad[5]	Lin[4]	Quad[5]
Initial BW, kg	241	242	240	241	240	11	0.94	0.99	0.98	0.76	0.78	0.94
Ending BW, kg	290	319	350	324	356	15	0.93	0.54	<0.01	0.99	<0.01	0.99
DMI, kg/d	5.7	7.0	7.5	6.5	7.8	0.6	0.16	0.85	<0.01	0.14	<0.01	0.36
ADG, kg	0.58	0.92	1.31	0.98	1.38	0.10	0.94	0.21	<0.01	0.66	<0.01	0.93
G:F	0.102	0.132	0.175	0.150	0.177	0.005	0.14	0.07	<0.01	0.56	<0.01	0.10

[1]SEM = Standard error of the mean
[2]Int = Effect of CDS level and oil concentration interaction
[3]Fat = Main effect of oil concentration
[4]Lin. = Contrast for the linear effect of treatment *P*-value with main effects of CDS inclusion
[5]Quad =Contrast of the quadratic effect of treatment *P*-value with main effects of CDS inclusion

Table 3: Effect of forage and 40% distillers solubles (CDS) with or without oil on growing performance

	40 HAY		40 Wheat Straw			*P*-values		
	De-Oiled	Normal	De-Oiled	Normal	SEM[1]	Int[2]	Fat[3]	Forage[4]
Initial BW, kg	240	240	240	240	11	0.94	0.89	0.97
Ending BW, kg	350	356	312	306	15	0.43	0.97	<0.01
DMI, kg/d	7.5[a]	7.8[a]	6.1[b]	5.3[c]	0.6	0.06	0.41	<0.01
ADG, kg	1.31	1.38	0.86	0.78	0.10	0.13	0.92	<0.01
G:F	0.175	0.177	0.141	0.147	0.005	0.84	0.40	<0.01

[a,b,c] Within a row, means without a common superscript differ
[1]SEM = Standard error of the mean
[2]Int = Effect of oil concentration and forage type interaction
[3]Main effect of oil concentration
[4]Main effect of forage type