Changing distillers grains: Implications for cattle performance and management

by

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A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Animal Science

Program of Study Committee:
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Iowa State University
Ames, Iowa
2015

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<td>acid detergent fiber</td>
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<tr>
<td>ADG</td>
<td>average daily gain</td>
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<td>BF</td>
<td>12th rib back fat</td>
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<tr>
<td>bu</td>
<td>bushel</td>
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<tr>
<td>BW</td>
<td>body weight</td>
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<tr>
<td>CCDS</td>
<td>corn condensed distillers solubles</td>
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<td>CP</td>
<td>crude protein</td>
</tr>
<tr>
<td>CV</td>
<td>coefficient of variation</td>
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<tr>
<td>C-WDG</td>
<td>cellulosic wet distillers grains</td>
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<tr>
<td>d</td>
<td>day</td>
</tr>
<tr>
<td>DDG</td>
<td>dried distillers grains</td>
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<tr>
<td>DDGS</td>
<td>dried distillers grains plus solubles</td>
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<tr>
<td>DG</td>
<td>distillers grains</td>
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<tr>
<td>DM</td>
<td>dry matter</td>
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<tr>
<td>DMI</td>
<td>dry matter intake</td>
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<tr>
<td>DP</td>
<td>dressing percentage</td>
</tr>
<tr>
<td>DRC</td>
<td>dry-rolled corn</td>
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<tr>
<td>EE</td>
<td>ether extract</td>
</tr>
<tr>
<td>FBW</td>
<td>final body weight</td>
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<tr>
<td>FGC</td>
<td>finely ground corn</td>
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<tr>
<td>g</td>
<td>gram</td>
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<tr>
<td>G:F</td>
<td>gain to feed ratio</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<td>--------------</td>
<td>------------------------------------------</td>
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<tr>
<td>HCM</td>
<td>high moisture corn</td>
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<td>HCW</td>
<td>hot carcass weight</td>
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<td>IMF</td>
<td>intramuscular fat</td>
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<tr>
<td>kg</td>
<td>kilogram</td>
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<tr>
<td>L</td>
<td>liter</td>
</tr>
<tr>
<td>LAS</td>
<td>liver abscess score</td>
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<tr>
<td>LM</td>
<td>longissimus muscle</td>
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<tr>
<td>Mcal</td>
<td>megacalorie</td>
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<tr>
<td>MDG</td>
<td>modified distillers grains</td>
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<tr>
<td>MDGS</td>
<td>modified distillers grains plus solubles</td>
</tr>
<tr>
<td>ME</td>
<td>metabolism energy</td>
</tr>
<tr>
<td>N</td>
<td>nitrogen</td>
</tr>
<tr>
<td>NDF</td>
<td>neutral detergent fiber</td>
</tr>
<tr>
<td>NEg</td>
<td>net energy required for gain</td>
</tr>
<tr>
<td>NRC</td>
<td>National Research Council</td>
</tr>
<tr>
<td>OM</td>
<td>organic matter</td>
</tr>
<tr>
<td>OMI</td>
<td>organic matter intake</td>
</tr>
<tr>
<td>P</td>
<td>phosphorus</td>
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<tr>
<td>PEM</td>
<td>polioencephalomalcia</td>
</tr>
<tr>
<td>PUN</td>
<td>plasma urea nitrogen</td>
</tr>
<tr>
<td>QG</td>
<td>quality grade</td>
</tr>
<tr>
<td>WC</td>
<td>whole-shelled corn</td>
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<tr>
<td>WCGF</td>
<td>wet corn gluten feed</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
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<td>---------------------------------------</td>
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<tr>
<td>WDG</td>
<td>wet distillers grains</td>
</tr>
<tr>
<td>WDGS</td>
<td>wet distillers grains plus solubles</td>
</tr>
<tr>
<td>S</td>
<td>sulfur</td>
</tr>
<tr>
<td>SD</td>
<td>standard deviation</td>
</tr>
<tr>
<td>SEM</td>
<td>standard error of the mean</td>
</tr>
<tr>
<td>SFC</td>
<td>steam-flaked corn</td>
</tr>
<tr>
<td>TMR</td>
<td>total mixed ration</td>
</tr>
<tr>
<td>TTSD</td>
<td>total tract starch digestibility</td>
</tr>
<tr>
<td>T-WDG</td>
<td>traditional wet distillers grains</td>
</tr>
<tr>
<td>YG</td>
<td>yield grade</td>
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I would like to thank my major professors for the privilege to work with them during my time at Iowa State University. Thank you, Dr. Dan Loy, for the endless opportunities you offered me while serving as an extension assistant for the Iowa Beef Center and sharing my passion for making the connection between research and industry. My graduate experience would not have been the same without your guidance and support. To Dr. Stephanie Hansen, thank you for the opportunities and countless hours of encouragement and advice you have given me over the past six years. Thank you for exposing me to the rewarding aspects of research and encouraging me to do my best in the classroom and in my professional career. Thank you to my committee member, Dr. Lee Schulz, for your guidance and feedback throughout the course of this research. In addition, I would like to thank Dr. Patrick Gunn for your mentorship during my time serving as a teaching assistant.

I am grateful to have had the opportunity to work with so many great people during my time at Iowa State University, especially those within the Hansen lab group. To Olivia, Sara, Danielle, Jason, and Taylor, I appreciate your valuable discussions and willingness to answer my never-ending questions, but more importantly your friendships over the years. Brady, Mick, Bailey, and Anthony deserve a special thanks for your hard work, reliability, and entertainment during the long hours of sheep collection. I would like to also extend my gratitude to the Beef Nutrition Farm staff for aiding in completion of my steer trial. Without your dedication and management, the success of this trial would not be possible.
Words cannot express my overwhelming gratitude towards my family. To my sisters, Shannon and Sara, thank you for your endless encouragement and pep talks even though you never quite understood what I was talking about. To Ethan, thank you for your patience and support. Finally, my parents, Gary and Cindy, deserve the biggest thank you for your ceaseless encouragement, support, and love. You have instilled in me the value of an education and strong work ethic that has gotten me where I am today. Thank you for believing that I could achieve anything when I set my mind to it.
ABSTRACT

In the past decade, the ethanol industry has begun changing their production processes to capture more value from the corn kernel, altering the nutrient profile of distillers grains (DG). One of the first methods of value extraction includes partial removal of corn oil, resulting in a decreased oil or fat content of DG. Although the majority of ethanol plants are currently extracting oil from DG, limited research has been conducted regarding the use of new generation DG in finishing cattle diets. Previous research with decreased fat DG has shown varying results in cattle performance when compared to traditional DG. The inconsistency in performance results could be attributed to variation in oil extraction methods and thus, variation in the nutrient profile of new generation DG. Likewise, research evaluating the interaction of corn processing methods and decreased fat DG is limited. Therefore, this research was designed to determine: 1) if feeding moderate levels of wet DG (WDG) plus solubles (WDGS) would decrease the acidosis risk associated with further grain processing and allow fine grinding of corn to improve starch utilization and cattle performance and 2) the impact of feeding WDG produced from a novel cellulosic ethanol process for conversion of corn kernel fiber into cellulosic ethanol (C-WDG) on nutrient digestibility and feedlot performance of ruminants compared to traditional WDG (T-WDG). In experiment 1, it was hypothesized that because WDGS are low in starch concentration, increasing corn surface area would allow for improved starch digestibility while inclusion of WDGS would moderate the risk of acidosis. In diets containing 35% WDGS, apparent total starch digestibility was improved for steers fed finely ground corn (500 microns) compared to
steers fed a traditional, dry-rolled corn (2350 microns). However, improved starch digestibility did not translate into improved performance with steers finished on finely ground corn having lighter final BW and decreased DMI and ADG. More recently, the ethanol industry is going beyond oil extraction moving towards fiber extraction. Therefore, a digestibility study utilizing lambs and a steer feedlot study to determine performance were designed to answer the second objective of this thesis. In the first experiment, DM digestibility was lesser in C-WDG compared to T-WDG at both the 30% and 45% inclusions of WDG. While NDF digestibility did not differ across treatments, ADF digestibility was not different between 30% T-WDG, 30% C-WDG, or 45% C-WDG. However, ADF digestibility was greater in lambs fed 45% T-WDG compared to other treatments, suggesting that the secondary fermentation process may be hindering the bioavailability of some portion of the remaining fiber in the C-WDG. In the performance study, steers fed T-WDG had similar final BW and ADG compared to C-WDG. However, steers fed C-WDG had an increased DMI and thus, less efficient G:F which could be explained by the differences in DM digestibility noted in the lamb study. Based on cattle performance, the estimated energy value of C-WDG was decreased by 25% compared to T-WDG. However, based on an economical simulation, the break-even price of C-WDG is similar to T-WDG when calculated based on cattle performance in this study. While digestibility was not evaluated, the addition of corn condensed distillers grains (CCDS) to C-WDG in the feedlot trial resulted in similar feed efficiency while DMI and ADG were decreased compared to C-WDG–fed steers. In summary, new generation DG still added value to finishing diets compared to corn-based diets. These data suggest that feeding 35% WDGS when feeding finely ground corn results in
increased starch utilization; however, additional research is needed to determine the optimal particle size and WDGS inclusion to maximize feedlot cattle performance. Furthermore, although WDG produced from secondary fermentation process for converting corn kernel fiber into cellulosic ethanol did result in decreased DM digestibility in lambs, final BW and ADG of steers were still similar to steers fed T-WDG. Overall, addition of new generation WDG in finishing diets maintained an advantage over a corn-based control diet based on cattle growth performance.
CHAPTER 1.

GENERAL INTRODUCTION

While ethanol has proven to be a renewable fuel resource, the production process has also created co-products, such as distillers grains (DG), which are nutritious feedstuffs for cattle. Because DG are rich in protein and energy, DG are often an attractive addition to corn in finishing diets to cattle feeders. In the last decade, ethanol plants have diversified their product streams in an effort to increase efficiency and profit margins (Richardson et al., 2014) through extracting more value from the corn kernel, with the first method being corn oil extraction. Because of these advancements in the ethanol production process, the nutrient profile of DG has begun to change. Removing corn oil during ethanol production has resulted in decreased fat content of DG, and thus, is thought to decrease the energy content of the DG. Though limited, previous research with new generation DG have shown variation in cattle performance, ranging from no impact to a depression in performance, compared to traditional process DG (Depenbush et al., 2008; Gigax et al., 2011; Jolly et al., 2013). Variation in oil extraction methods across ethanol plants results in large variations in nutrient profiles of DG (Berger and Singh, 2010). Removal of corn oil also concentrates the remaining nutrients, and increased S content in DG can present a problem to ruminants as excessive S intake can lead to decreased performance (Richter et al., 2012; Pogge and Hansen, 2013). The variation in nutrient components of DG, particularly S and fat, can result in a large difference in cattle performance.
Because of the changing nutrient composition of DG, potential changes in inclusion of DG based on economics and the resultant lower overall starch concentration of the diet, corn processing methods could be altered to optimize cattle performance during the finishing phase. While decreasing corn particle size is an effective way to increase starch utilization and improve performance (Huntington, 1997), decreasing particle size too finely often results in rapid fermentation in the rumen, leading to acidosis contributing to decreased performance (Owens et al., 1998). Because starch, the main component in corn, is fermented for ethanol production, DG are relatively low in starch and can help alleviate acidosis risk often associated with feeding high levels of rapidly fermentable grains (Stock et al., 2000). When DG replace corn in finishing diets, starch concentration of the diet is decreased. Thus, it is hypothesized that feeding decreased corn particle size with DG may moderate the risk of acidosis while increasing starch digestion. Previous research with finely ground corn and traditional DG has been less successful due to acidosis concerns (Vander Pol et al., 2008). However, the effect of reduced-fat DG and corn particle size on starch digestibility and cattle performance has not been investigated.

More recently, the ethanol industry has begun exploiting fiber extraction as another method to add value to the corn kernel. Contrary to the typical cellulosic ethanol processes that utilize fiber from biomass feedstocks such as trees and grasses (Solomon et al., 2007; Dwivedi et al., 2009), the newest process utilizes cellulose from corn kernel fiber to produce additional ethanol. Therefore, the impact on the feeding value of the co-product produced from this process was evaluated in a series of studies discussed in this thesis. The resulting co-product has greater CP, and decreased starch and fat
concentrations compared to traditional DG. To date, no previous research has been conducted to investigate the impact of cellulosic ethanol wet DG (WDG) produced from fermentation of corn kernel fiber on cattle performance. Therefore, this series of studies were designed to determine the effects of new generation DG and corn particle size on starch digestibility and cattle performance as well as the influence of DG produced from novel cellulosic process on nutrient digestibility and feedlot performance compared to traditional DG.

**Thesis organization**

The following chapter (Chapter 2) contains a review of the literature relating to the ethanol production process and feeding new generation DG in finishing diets of cattle. More specifically, the processing methods of new generation DG and effects on cattle performance, changing nutrient composition of DG, S toxicity concerns when feeding DG, as well as the interaction between grain processing methods and DG will be discussed. The next two chapters present recent research conducted in these subject areas. Chapter 3 has been submitted to the *Professional Animal Scientist* and evaluates starch digestibility and performance of steers fed varying corn particle sizes with moderate inclusions of WDG plus solubles (WDGS). Chapter 4 has been accepted into the *Journal of Animal Science*. This chapter includes research conducted to determine nutrient digestibility in lambs, and feedlot performance and carcass characteristics of steers, fed a novel WDG resulting from a process for converting corn kernel fiber into cellulosic ethanol compared to traditional process WDG. The final chapter (Chapter 5)
concludes this thesis providing a summary of the research, implications, and suggestions for future areas of research with new generation DG.
CHAPTER 2.

REVIEW OF THE LITERATURE

Ethanol and Co-product Production

Dry milling industry process and products

Following rapid expansion in the 1990’s and 2000’s, the Midwestern ethanol industry is continuing to evolve. Ethanol production has also lead to a steady supply of high quality co-products of the ethanol industry known as distillers grains (DG) and solubles, corn gluten feed, and corn gluten meal which have proven to be a valuable replacement to corn in finishing cattle diets (Klopfenstein et al., 2008). While the wet milling industry, which produces corn gluten feed and corn gluten meal, once was the dominant ethanol production process in the U.S., the dry milling industry now accounts for nearly 90% of the ethanol plants in the U.S. (Renewable Fuels Association, 2012).

The main products of the dry milling industry are DG and corn condensed distillers solubles (CCDS). Starch is the primary nutrient in corn grain and is the main substrate for alcohol fermentation. The corn kernel is first ground through a hammer mill into a flour substance, and water is added to create a slurry mixture (ICM, 2012). Enzymes are then added to the slurry to begin the breakdown of starch into a less complex sugar, while ammonia helps maintain the desired pH of the slurry (Renewable Fuels Association, 2014b). The next step, liquefaction, involves heating the slurry to reduce the bacteria load prior to the fermentation process (ICM, 2012; Renewable Fuels Association, 2014b). During the 50 hour fermentation process, yeast is added and works
with enzymes to reduce starch to simple sugars for alcohol and carbon dioxide production. The product is then transferred to distillation columns where the alcohol is removed and the remaining product, known as whole stillage, undergoes centrifugation to remove the thin stillage, or liquid portion, from the DG (ICM, 2012). The thin stillage will go through an additional evaporation process to remove excess water to create a syrup-like substance known as CCDS (approximately 30% DM; Scott et al, 2000). The CCDS can be marketed separately or added back to the DG to be marketed as DG plus solubles. The ratio of CCDS added back to the DG can alter the nutrient profile of the DG plus solubles (Holt and Pritchard, 2004). The DG—with or without solubles—can be marketed as wet DG (WDG; 30%–40% DM), dried partially to create modified DG (MDG; 50% DM), or further dried for dried DG (DDG; 90% DM). For a reference of the dry milling process, see Figure 1 (Lundy and Loy, 2014a).

Figure 1. Dry milling process (Lundy and Loy, 2014a).

In the last decade, volatile corn prices have encouraged ethanol plants to be more efficient and extract more value from the corn kernel. The wet milling process differs from the traditional dry milling process in that the corn kernel is steeped, or soaked in
water, prior to beginning the ethanol process to break the kernel into the endosperm, germ, and bran components (Renewable Fuels Association, 2014b). The wet milling process is a more complex process and results in more end products—ethanol, corn starch, and sweeteners—and co-products—corn gluten meal and corn gluten feed (Figure 2; Lundy and Loy, 2014a). Historically, separation of the corn kernel components prior to ethanol production in the wet milling industry has resulted in higher marketing opportunities compared to products of the dry milling industry (Erickson et al., 2005). In an effort to capitalize on higher marketing value, the dry milling industry has begun mimicking the wet milling industry looking for additional methods of value extraction. The first and primary method has been through corn oil extraction resulting in a decreased oil or fat content of DG.

![Figure 2. Wet milling process (Lundy and Loy, 2014a).]

**Methods of value extraction from the corn kernel**

Corn oil extraction has become an industry standard with at least 85% of ethanol plants extracting oil (Renewable Fuels Association, 2014a). During the traditional ethanol process, one bushel of corn supports production of approximately 10.5 L of
ethanol and 8 kg of co-products (Renewable Fuels Association, 2013); however, oil extraction methods may decrease co-product yield by 10% (U.S. Grains Council, 2012).

The corn kernel can be divided into three main components: endosperm, germ, and bran. Corn is considered to be approximately two-thirds starch with the majority of the starch being found in the endosperm (U.S. Grains Council, 2012). Thus, removal of starch for ethanol production results in a three-fold increase in the remaining nutrients (Erickson et al., 2005; Klopfenstein et al., 2008). The germ contains primarily the corn oil and protein of the kernel. The bran, composed of the pericarp and tip cap of the kernel, is highly fibrous.

Oil extraction can occur at various stages during the ethanol process and the nutrient profile of the distillers grains will vary depending on the method of extraction used (Berger and Singh, 2010; U.S. Grains Council, 2012). Primarily, oil extraction can be divided into three categories: 1) pre-fermentation fractionation (also referred to as front-end fractionation), 2) back-end oil extraction, and 3) post-fermentation (U.S. Grains Council, 2012).

**Pre-fermentation fractionation distillers grains.** Pre-fermentation fractionation involves separate of the germ, endosperm, and bran prior to beginning the ethanol production process (U.S. Grains Council, 2012). In this process, only the endosperm is fermented for ethanol and results in a high protein DG that is typically 6%–8% lower in fat compared to the traditional ethanol process. The corn oil is extracted from the germ which contains approximately 45% of the oil found in the kernel. The remaining portions of the germ and bran, which do not go through the ethanol process, are often used in
production of other co-products and marketed as fibrous feedstuffs (Berger and Singh, 2010). Due to high capital investment costs and minimal margins for advancement of fermentation utilizing this technology, pre-fermentation fraction in the dry milling industry has become less common (U.S. Grains Council, 2012).

**Feeding pre-fermentation fractionation distillers grains.** In a finishing study, Depenbusch et al. (2008) compared performance and carcass characteristics of crossbred yearling heifers (347 ± 5 kg) fed diets containing 13% DDG plus solubles (DDGS) produced from a traditional process (12% fat; 4.8% dietary fat) or a pre-fermentation fraction process (4% fat; 3.9% dietary fat) in steam-flaked corn (SFC) diets. Average daily gain tended to differ between treatment groups with heifers fed traditional DDGS gaining 6% more (1.18 kg) than their counterparts being fed pre-fermentation fractionation DDGS (1.11 kg). While G:F were not different (0.126 and 0.124 for traditional and pre-fermentation fractionation DG diets, respectively), heifers fed traditional DG experienced almost a 5% increase in DMI (9.37 kg) compared to those fed pre-fermentation fractionation DG (8.94 kg). The authors speculated that in the pre-fermentation fractionation DG diet, degradable intake protein was limited thus reducing passage rate and DMI. No differences in carcass characteristics were observed.

Kelzer et al. (2011) finished Angus, calf-fed steers (230 ± 28 kg) on diets containing 35% traditional DDGS (10.9% fat; 5.96% dietary fat) or pre-fermentation fractionation DDG (5.1% fat; 3.53% dietary fat) in dry-rolled corn (DRC) diets to determine the effects of ethanol production process on performance and carcass characteristics. Distillers grains source had no effect on final BW (552 and 540 kg),
ADG (2.00 and 1.91 kg), or G:F (0.196 and 0.195 for traditional and pre-fermentation fractionation DG, respectively). Dry matter intake tended to be decreased by 4% when steers were fed pre-fermentation fractionation DG (9.8 kg) compared to steers fed traditional DG (10.2 kg), which the authors attributed to improved palatability of traditional DG.

Utilizing traditional WDG (12.9% fat; 6.91% dietary fat) and pre-fermentation fractionation WDG (6.9% fat; 4.72% dietary fat), Gigax et al. (2011) compared dietary inclusion at 35% WDG in diets containing 1:1 DRC to high moisture corn (HMC) to determine impact on performance of crossbred yearling steers (399 ± 52 kg). While DMI was not different across treatments (11.1 kg for both traditional and pre-fermentation fractionation WDG diets, respectively), traditional WDG-fed steers had 3% improvement in final BW (604 and 587 kg), 8% improvement in ADG (1.68 and 1.55 kg), and 8% improvement in G:F (0.152 and 0.140 for traditional and pre-fermentation fractionation WDG diets, respectively). Gigax et al. (2011) found that feeding pre-fermentation fractionation DG yielded similar performance results as cattle fed the corn-based control diet, concluding that pre-fractionated WDG have a decreased energy value and performance compared to traditional process WDG. In previous studies by Depenbusch et al. (2008) and Kelzer et al. (2011), performance was similar between cattle fed traditional DG or pre-fermentation fractionation DG, and cattle fed DG, regardless of source, had improved performance compared to cattle fed corn-based control diets.

Although limited research data are available, previous data indicate that cattle fed pre-fermentation fractionated DG maintained similar performance compared to cattle finished on traditional process DG at low to moderate dietary inclusions. Previous
research with pre-fermentation fractionated WDG showed decreased performance compared to the traditional process WDG, suggesting that the moisture content of DG could alter cattle performance in pre-fermentation fractionation DG. In the study by Gigax et al. (2011), dietary fat concentrations were also greater than those of Depenbusch et al. (2008) and Kelzer et al. (2011). Performance results by Gigax et al. (2011) may be confounded by the higher dietary fat concentrations or limited due to an interaction between dietary fat concentrations and the pre-fermentation fractionation process. Variation in fat content of traditional process and pre-fractionation fermentation DG, processing method of corn used in the diet, and DG dietary inclusion could alter cattle performance; therefore, additional research is needed to better understand optimal use of pre-fractionation fermentation DG in finishing diets.

**Back-end oil extraction distillers grains.** The most common method of oil extraction in the industry is through back-end extraction (U.S. Grains Council, 2012). This process involves an extra step during the traditional dry milling process where the thin stillage is centrifuged to remove up to 70% of available corn oil (Berger and Singh 2010; U.S. Grains Council, 2012). The decreased-oil thin stillage is then added back to the DG and the product is typically known as a de-oiled DG or low-fat DG. While the amount of oil recovered generally varies based on ethanol plants’ extraction methods, the cost of implementing back-end oil extraction and success of oil removal has made this method the most common amongst dry milling ethanol plants.
Feeding back-end oil extraction distillers grains. Jolly et al. (2013) conducted a finishing experiment utilizing co-products from a traditional process or back-end oil extraction process to determine effects on steer performance. Calf-fed steers (300 ± 10 kg) were fed diets containing 27% CCDS (21% fat; 8.8% dietary fat) or 40% modified DG plus solubles (MDGS; 6.0% fat; 4.72% dietary fat). Addition of CCDS, regardless of production method, resulted in no differences in final BW, DMI, ADG, G:F, or carcass characteristics. Similarly, feeding traditional fat MDGS (12% fat; 7.2% dietary fat) or de-oiled MDGS (9% fat; 6.1% dietary fat) did not have an effect on performance or carcass characteristics.

In a finishing study evaluating WDGS inclusions at 35%, 50%, and 65%, traditional (12% fat) or de-oiled (8% fat) WDGS were compared in finishing diets (Jolly et al., 2014). Regardless of inclusion concentration, fat content of the WDGS did not impact final BW (623 and 627 kg), ADG (1.83 and 1.85 kg), or G:F (0.167 and 0.163 for traditional and de-oiled WDGS, respectively). However, DMI was 4% greater for steers finished on de-oiled WDGS (11.4 kg) compared to those finished on traditional fat WDGS (10.9 kg). These results suggest that back-end oil extraction WDGS had minimal impact on performance (Jolly et. al., 2014).

Bremer (2014) conducted a series of finishing trials to evaluate the effects of feeding de-oiled DG on steer performance. In experiment 1, feeding diets containing 15% or 30% MDGS with varying oil content (12% fat for traditional MDGS; 7% fat for de-oiled MDGS) did not impact steer performance or carcass characteristics when fed in diets containing 1:1 DRC to HMC. De-oiled MDGS were also fed at 15%, 30%, 45%, and 60% of the diet on a DM basis, and cattle performance was not affected by the
varying inclusions. In experiment 2, the author compared the interaction of corn processing method (DRC or SFC) with de-oiled WDGS (8% fat) or traditional WDGS (11% fat) provided at 35% of the diet. The interaction of corn processing method and fat content of WDGS did not impact steer performance. The main effect of fat content of WDGS also had no influence on performance measures. Bremer (2014) concluded that although performance was not affected, feeding de-oiled WDGS resulted in a 4% reduction in dietary net energy value (NEg: 1.18 Mcal/kg) compared to traditional process WDGS (NEg: 1.24 Mcal/kg). In this summary of studies, de-oiled WDGS resulted in 90% of the feeding value compared to traditional process WDGS (Bremer, 2014).

Oil extraction from centrifugation of the solubles appears to have minimal impact on performance of finishing cattle fed diets utilizing de-oiled DG and still maintained a benefit in performance over corn-based control diets when fed at moderate amounts in the diet. Although de-oiled DG were successfully fed at up to 60% (Bremer, 2014) and 65% (Jolly et al., 2014) of the diet without negatively affecting cattle performance, S toxicity can become a concern when feeding DG at high dietary inclusions. Though research with de-oiled DG is limited, research conducted to date has been done with a 1:1 DRC to HMC. Therefore, feeding de-oiled DG with other corn types may result in differing performance results, as DG interact differently with varying corn processing types. The difference in oil content between traditional and back-end oil extraction DG used in these comparisons are between 3% to 4% compared to 6% to 8% difference in oil content between traditional and pre-fractionation fermentation DG. The lesser difference in oil content between the traditional and de-oiled DG minimizes the variation in dietary
fat concentrations within the treatment comparisons which could dilute some adverse effects of oil extraction, thus reducing the energy value of DG. Overall, decreased oil DG appear to be intermediate in energy value for cattle when compared to traditional DG and corn-based diets. However, further research is still need to quantify the performance impact of feeding de-oiled DG at varying inclusions and within different finishing diet types.

**Post-fermentation distillers grains.** The newest extraction method adopted by the ethanol industry involves post-fermentation processing of the whole stillage. This process involves the addition of specialized enzymes as well as a secondary fermentation to aid in extraction of fiber and additional corn oil before the thin stillage is separated from the DG (U.S. Grains Council, 2012). Therefore, the nutrient profile of DG produced from post-fermentation processing typically is lower in fat and higher in fiber compared to DG from the traditional ethanol process. While previous research with DG produced from pre-fermentation fractionation and back-end oil extraction has been evaluated, no data on feeding DG produced from post-fermentation process are available.

**Introduction of Cellerate™.** On July 2, 2014, Cellulosic Ethanol Technologies, LLC (Quad County Corn Processors, Galva, IA) and Syngenta (Wilmington, DE) commercialized the first secondary fermentation process from conversion of corn kernel fiber into cellulosic ethanol. This novel process includes a pretreatment with cellulosic enzymes and yeast to the whole stillage. After the pretreatment, the additional heat applied through the secondary fermentation process prior to centrifugation allows the
pretreatment to capitalize on capturing more of the cellulose, hemicellulose, and the vast majority of the residual starch. This process results in additional ethanol produced and almost 20% reduction in DG production compared to the traditional ethanol production process.

**Energy Value of Distillers Grains**

**Nutrient composition of distillers grains**

Almost two-thirds of the corn kernel is compromised of starch (Huntington, 1997). Thus, once starch is fermented during the ethanol production process, the remaining nutrients are concentrated approximately three-fold into DG and have proven to be a viable protein and energy alternative to feeding corn in finishing diets (Stock et al., 2000; Klopfenstein et al., 2008). For example, if corn is 10% CP (DM basis), DG are expected to be approximately 30% CP (DM basis). Neutral detergent fiber is expected to increase from about 11% in corn to 33% NDF in DG and fat from 4% to 12%. Several factors can alter the expected nutrient profile of the DG produced including moisture content of DG, amount of solubles added to the DG, and oil extraction technologies.

Dicostanzo and Wright (2011) reviewed published articles to summarize the nutrient composition of traditional process DG. Wet DG ranged from 30%–35% CP, 8%–12% fat, 30%–50% NDF, 0.5%–0.7% S, and 1.54–1.76 Mcal NEg/kg DM (Dicostanzo and Wright, 2011). Similarly, a survey of Midwestern ethanol plants found that WDG produced averaged 30% CP and 11% fat (Saunders and Rosentrater, 2009). Buckner et al. (2011) also surveyed six Midwestern ethanol plants over four months and
found CP to average 31% and fat to average 12% for WDGS and MDGS samples. Dried DG ranged from 25%−35% CP, 8%−10% fat, 40%−44% NDF, 0.48% S, and 1.48−1.54 Mcal NEg/kg DM (Dicostanzo and Wright, 2011). Dicostanzo and Wright (2011) found DDGS to be more variable in nutrient composition ranging from 26%−34% CP, 9%−12% fat, 30%−54% NDF, 0.12%−0.82% S, and 1.41−1.54 Mcal NEg/kg DM. Inclusion rate of CCDS to the DG plays a large role in variation of nutrient profile of DG (Berger and Singh, 2010; Buckner et al., 2011).

Because the nutrients in corn are concentrated into DG, the feeding value, defined as the percentage change in feed conversion (Bremer et al., 2011b), of DG is greater in relation to corn. In a meta-analysis by Bremer et al. (2011b), the feeding value of DG at 20%−40% dietary inclusion ranged from 110%−145% of the corn which DG replaced. Distillers grains are typically between 109%−147% energy value of corn (Stock et al., 2000). The further DG are dried, the greater loss in energy value; however, protein value of DG does not appear to be altered by drying (Stock et al., 2000).

**Effects of oil removal on feeding value and energy value of distillers grains**

Oil removal during the ethanol production process has altered the nutrient profile of the DG. Saunders and Rosentrater (2009) found the DDG produced from pre-fermentation fractionation process averaged 43% CP and 3% fat. More recently, DG samples were collected from Iowa ethanol plants and beef producers to quantify the nutrient profile of various DG from the dry milling industry (Lundy and Loy, 2014a). Samples were categorized based on DG moisture content (dried, modified, or wet) and fat content (normal, 9%−14%; low-fat, 5%−8%; or de-oiled, 2%−6%, as defined by NRC,
The authors reported 35% CP, 3% fat, 34% NDF, 1.76 Mcal NEg/kg DM for pre-fermentation fractionation WDG and 28% CP, 4% fat, 34% NDF, and 1.54 Mcal NEg/kg DM for pre-fermentation fractionation DDG. De-oiled WDG produced via back-end oil extraction averaged 33% CP, 8% fat, 31% NDF, and 1.76 Mcal NEg/kg DM, and de-oiled DDG averaged 31% CP, 7% fat, 27% NDF, and 1.54 Mcal NEg/kg DM (Lundy and Loy, 2014a).

The variation in cattle performance results from previous research creates a challenge to quantify the impact of oil removal from DG on feedlot performance. Therefore, Lundy and Loy (2014b) compiled performance data from 13 comparisons from 9 studies in an effort to better predict how decreased oil content of DG can affect the feeding and energy value in finishing diets (Table 1). To the authors’ knowledge, these are all of the studies conducted with decreased fat DG at the time of the publication (December 2014). In these comparisons, the oil content of the DG was the only difference between the comparisons—all other dietary ingredients were held constant. Feeding value was calculated based on the change in feed conversion within each comparison. The feeding value was then adjusted based on DG inclusion in the diet to represent the change in feeding value per 1% fat difference between the traditional and decreased fat DG used in each study comparison. Results from this summary indicate that the feeding value of decreased fat DG were decreased by 1.64% for each 1% decrease in oil content of the DG. For example, when comparing a traditional DG at 12% fat and a decreased fat DG at 7% fat, the decreased fat DG are expected to have a 8.2% reduction in feeding value (5, difference in fat content of DG, × 1.64 = 8.2). Therefore, cattle fed the decreased fat DG at 30% of the diet would experience approximately 2.46%
reduction in cattle performance compared to when fed a traditional fat DG (8.2 \times 0.30 = 2.46).

The energy value of each comparison was calculated utilizing the equation by Plascenia et al. (1999). This equation utilizes the means of cattle performance (DMI, ADG, and mean BW of cattle with on trial) to predict the dietary energy value of each treatment. Within a comparison, ME of each treatment was calculated and the difference between the decreased fat and traditional fat DG at the given inclusion of DG in the treatments were determined. The energy value was then adjusted to reflect the change in ME per 1% difference in oil content of DG used in the comparison. In summary, when the oil content of DG is decreased by 1%, the ME of DG is decreased by 0.27%. Thus, when two DG sources are being compared, such as 10% or 5% fat, the expected energy value of decreased fat DG is anticipated to be 1.35% lesser than traditional fat DG (5, difference in fat content of DG, \times 0.27 = 1.35). The average change in energy values shown in Table 1 are based on the average difference in energy value per unit change in oil content. This approach appears to be more conservative than the diet substitution method used to estimate energy values of coproducts reported in Lundy and Loy (2014a) with the method used to determine these values described in Lundy and Loy (2014b).

These calculated feeding and energy values can be a valuable asset to producers and nutritionists in the beef industry to aid in determining the value of decreased fat DG in finishing diets. While these numbers are an attempt to help quantify the effects of oil removal in DG on cattle performance, limited research with decreased fat DG is available. Other dietary differences across studies can have an impact on cattle performance, in particular, the method of corn processing used in the experiments. In the
nine studies utilized in this analysis, the most common corn processing method used was a 1:1 of DRC:HMC used in eight of the comparisons (Gigax et al., 2011; Jolly et al., 2013; Bremer et al., 2014b; Jolly et al., 2014). However, DRC was utilized in three comparisons (Kelzer et al., 2011; Anderson and Engel, 2014; Bremer et al., 2014a), and SFC was used in two comparisons (Depenbusch et al., 2008; Bremer et al., 2014a). As additional research is conducted with decreased fat DG, the feeding value and energy value could be altered to better predict the value of DG in finishing diets. However, this analysis is the first step in anticipating how cattle performance is impacted by oil removal of DG and the changing feeding value and energy value of decreased fat DG.
### Table 1. Effects of oil removal on distillers grain co-product feeding value\(^1\) and energy value\(^2,3\).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Oil content of treatment comparisons, %</th>
<th>Level(s) of inclusion, (%)</th>
<th>Change in feeding value per unit of oil content</th>
<th>Change in ME per unit of oil content</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>WDG(^4)</td>
<td>6.7 vs. 12.9</td>
<td>35</td>
<td>4.27</td>
<td>2.22</td>
<td>Gigax et al., 2011</td>
</tr>
<tr>
<td></td>
<td>7.9 vs. 11.3</td>
<td>26</td>
<td>4.53</td>
<td>0.31</td>
<td>Bremer et al., 2014a</td>
</tr>
<tr>
<td></td>
<td>7.9 vs. 12.4</td>
<td>35, 50, 65</td>
<td>1.13</td>
<td>1.05</td>
<td>Jolly et al., 2014</td>
</tr>
<tr>
<td>MDG(^5)</td>
<td>9.2 vs. 11.8</td>
<td>40</td>
<td>0.34</td>
<td>0.09</td>
<td>Jolly et al., 2013</td>
</tr>
<tr>
<td></td>
<td>7.2 vs. 12.0</td>
<td>15, 30</td>
<td>3.27</td>
<td>0.10</td>
<td>Bremer et al., 2014b</td>
</tr>
<tr>
<td>DDG(^6)</td>
<td>4.0 vs. 12.0</td>
<td>13</td>
<td>1.45</td>
<td>-0.09</td>
<td>Depenbusch et al., 2008</td>
</tr>
<tr>
<td></td>
<td>5.1 vs. 10.9</td>
<td>35</td>
<td>-0.19</td>
<td>0.32</td>
<td>Kelzer et al., 2011</td>
</tr>
<tr>
<td></td>
<td>5.5 vs. 13.0</td>
<td>19</td>
<td>-0.84</td>
<td>-1.09</td>
<td>Anderson and Engel, 2014</td>
</tr>
<tr>
<td>CCDS(^7)</td>
<td>6.0 vs. 21.1</td>
<td>27</td>
<td>0.76</td>
<td>-0.44</td>
<td>Jolly et al., 2013</td>
</tr>
<tr>
<td>Average(^8)</td>
<td></td>
<td></td>
<td><strong>1.64%</strong></td>
<td><strong>0.27%</strong></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Feeding value calculated based on change in feed conversion per unit of substitution for corn.

\(^2\)Energy value expressed as ME (Mcal/kg) calculated based on cattle performance using equation by Plascenia et al. (1999).

\(^3\)Table adapted from Lundy and Loy, 2014b.

\(^4\)Wet distillers grains.

\(^5\)Modified distillers grains.

\(^6\)Dried distillers grains.

\(^7\)Corn condensed distillers solubles.

\(^8\)Average change in feeding value or energy value per unit of oil content of distillers grains from 9 summaries with 13 comparisons.
Sulfur Considerations When Feeding Distillers Grains in Feedlot Diets

While DG have proven to be a valuable energy and protein addition to corn-based finishing diets, the S concentration of DG is one of the limiting factors to DG inclusion in cattle diets. Corn contains approximately 0.12% S (NRC, 2000), largely as S-containing amino acids and is concentrated by 3-fold during the traditional ethanol production process, and thus, DG are expected to contain approximately 0.36% S. However, DG commonly contain more than the predicted 0.36% S, and S concentrations of DG vary widely, primarily due to the use of sulfuric acid during the production process. Sulfuric acid is commonly added during distillation to maintain the pH as well as aid in sterilization of plant parts (Renewable Fuels Association, 2014b), resulting in increased S concentrations in the co-products (U.S. Grains Council, 2012).

In the rumen, sulfate reducing bacteria are responsible for reducing dietary sulfate into sulfide and hydrogen sulfide, and excessive concentrations of hydrogen sulfide is thought to cause S toxicity. Sulfuric acid is an inorganic source of S and is expected to be 100% available for reduction to sulfide by the ruminal sulfate reducing bacteria, unlike the organic source of S naturally found in corn. Organic sources of S, such as S derived from S-containing amino acids found in corn and DG, are only partially available to the rumen microorganisms due to the fact that approximately 45% of the CP in DDGS is expected to be degraded in the rumen (Meyer et al., 2012). Therefore, a large portion of CP bypasses the rumen as rumen undegradable protein, meaning some S-containing amino acids are unavailable to rumen microorganisms and unable to contribute to hydrogen sulfide production. The large variation in S content of DG can be contributed
to the inconsistent use of sulfuric acid across ethanol plants and can increase the risk of S toxicity because sulfuric acid is readily available to the rumen for reduction.

As the ethanol industry continues to adopt technological methods to extract more value from the corn kernel, S toxicity concerns for cattle in feedlots may increase as S variation becomes more prominent in new generation DG. Removal of oil from DG is known to further concentrate the remaining nutrients (U.S. Grains Council, 2012), including S (Anderson and Engle, 2014; Drewnoski et al, 2014; Jolly et al., 2014). Recent summaries of DG analyses have shown ranges in S concentrations to be 0.69%–1.06% (Buckner et al. 2011), 0.12%–0.82% (Dicostanzo and Wright, 2011), and 0.21%–1.26% (Lundy and Loy, 2014a). Compared to DG, CCDS have typically demonstrated even greater concentrations of S (Vanness et al., 2009; U.S. Grains Council, 2012). Samples of CCDS collected from ethanol plants and producers in Iowa during the summer of 2014 ranged in S concentration from 0.82%–2.10% (Lundy and Loy, unpublished data). Sulfur content in DG varies greatly depending on the amount of sulfuric acid added during ethanol production, the specific plant, and ratio of DG to CCDS. Buckner et al. (2011) noted that S content of DG had the greatest variation relative to DM, CP, fat, or P content in DG. Variation of S within a plant was reported to range from 3% to 13% within a single day (Bucker et al., 2011). These data reiterate the importance of routine analysis of DG because of the toxicity concerns associated with feeding high concentrations of S. With proper management, producers can adjust diets accordingly to manage risk associated with S toxicity concerns.
Ruminant sulfur requirements and toxicity

Sulfur is a macro mineral required by the body for biological functions by serving as a component of amino acids such as cysteine and methionine and as a pre-cursor for the B-vitamins, biotin and thiamine (NRC, 2000). Ruminants have a specific S requirement because the rumen bacteria, specifically cellulolytic bacteria, require S for normal growth and development (Spears et al., 1976). The NRC (2000) recommendation for dietary S concentration for growing beef cattle is 0.15% (DM basis) for adequate growth. The S requirement for smaller ruminants, such as growing lambs, is greater, 0.18% dietary S, to account for the increased S required for wool production (NRC, 2007).

Inadequate dietary S can lead to decreased appetite, weakness, weight loss, hair loss, emaciation, and death (Starks et al., 1953; Qi et al., 1994). Because ruminal bacteria require S, deficient diets can lead to a decrease in microbial population, nutrient digestion, microbial protein synthesis, and lactate utilization (Whanger and Matrone, 1966; NRC, 2000). Alternatively, excessive dietary S can also lead to decreased performance in addition to diarrhea, muscular twitching, and in more severe cases, polioencephalomalacia (PEM) and death (Gould, 1998; NRC, 2000). Sulfur induced PEM is a neurological disorder of ruminants often caused by excessive hydrogen sulfide production in the rumen following consumption of toxic amounts of S (Gould, 1998). In the rumen, sulfate reducing bacteria are responsible for reducing dietary sulfate into sulfide and hydrogen sulfide. The ratio of sulfide to hydrogen sulfide is dependent on ruminal pH, with an increase in hydrogen sulfide concentrations as the pH of the rumen decreases (Gould, 1998; Morine et al., 2014). When hydrogen sulfide concentrations are
increased and the ruminant eructates, a large portion of hydrogen sulfide is inhaled, likely causing the negative side effects of high S diets including PEM (Beaucamp et al., 1984; Gould 1998). Symptoms of PEM include disorientation, poor coordination, muscular twitching, head pressing, blindness, and breathlessness.

Because of S toxicity concerns, including PEM, the NRC (2005) recommends the maximum tolerable dietary S concentration to be 0.30% in diets with less than 15% roughage, and 0.50% S in diets with 40% roughage or more. Roughage increases chewing time and saliva production, which aids in moderating ruminal pH (Owens et al., 1998). Without the decrease in ruminal pH, the rate at which sulfate is reduced to hydrogen sulfide is decreased and the risk of S induced PEM is decreased. While typical finishing diets contain less than 8% roughage, research has shown that feeding roughage concentrations higher than the typical inclusion may decrease the risk of S toxicity (Vanness et al., 2009; Nichols et al., 2013). However, when calculating total S intake by cattle, both dietary S concentrations and water S concentrations should be considered, as some water sources can contain high sulfate concentrations (NRC, 2000).

**Sulfur toxicity concerns in finishing diets containing distillers grains**

While the NRC (2005) recommends 0.40% dietary S to be the maximum tolerable level of ruminants, supplementing excess roughage has been shown to lessen S toxicity risk and incidence of PEM (Vanness et al., 2009; Nichols et al., 2013; Drewnoski et al., 2014). Increasing the dietary roughage concentration allows for increased saliva production and buffering capacity to help stabilize ruminal pH (Owens et al., 1998), which in turn, can help lessen hydrogen sulfide production in the rumen. A meta-analysis
utilizing data from 16,760 steers by Nichols et al. (2013) was conducted to evaluate dietary S (0.12%–0.72% S) and NDF from forage (0%–8% added NDF from forage) concentrations on the incidence of PEM. The authors reported that at any given concentration of dietary S, the risk of PEM was decreased by nearly 20% as NDF concentration increased by 1%. Research by Morine et al. (2014) demonstrated that increasing dietary NDF from 3.5%–11.4% in a finishing diet containing 32% DDGS and 7% CCDS (0.46% dietary S) decreased hydrogen sulfide production without negatively impacting cattle ADG and G:F. Therefore, dietary roughage concentration can heavily influence the performance of ruminants fed high S diets.

Previous research has shown that diets containing greater than 0.40% S sourced from DDGS results in decreased DMI and ADG (Richter et al., 2012; DiCostanzo and Crawford, 2013). Pogge and Hansen (2013) fed calf-fed steers (341 ± 11 kg) diets containing 0.22% S, 0.34% and 0.55% dietary S with 9% roughage. To achieve these S concentrations, DDGS were included in the diet at 18%, 40%, or 40% DDGS plus 1.1% sodium sulfate for the 0.22%, 0.34%, and 0.55% dietary S treatments, respectively. Dry matter intake and ADG decreased by approximately 12% and 10%, respectively, for steers fed the 0.55% S diet compared to the other diets with less S. In another feedlot study by Veracini et al. (2013), steers (356 ± 42 kg) were fed diets containing 25%, 40%, and 70% MDGS (0.31%, 0.35%, or 0.53% total dietary S, respectively) with 15% corn silage. Dry matter intake was increased by 13% as MDGS inclusions increased in the diet from 25% to 70% while ADG was decreased by 11% in cattle fed the highest S concentration diet (0.53%) compared to 0.31% or 0.35% S diets. Jolly et al. (2014) fed yearling steers (350 ± 19.1 kg) diets containing 35%, 50%, or 65% WDGS,
corresponding to 0.31%, 0.42%, and 0.52% total dietary S respectively, with 12% corn silage as the roughage source. In agreement with Pogge and Hansen (2013), the authors noted a 7% decrease in DMI from 35% WDGS to 60% WDGS; however, in contrast to previous work, ADG was not affected by S concentrations of the diet and thus, feed efficiency was the greatest in the 0.52% S diet. The differences in performance responses observed by Veracini et al. (2013) and Jolly et al. (2014) might be explained by the moisture content of DG or corn processing method used in the diets as Veracini et al. (2013) fed whole-shelled corn (WC) whereas Jolly et al. (2014) fed a blend of DRC:HMC. Previous research has shown that starch utilization used to support animal performance is lesser in WC diets compared to corn that has been processed (Owens et al., 1986). Dietary fat concentrations also could have played a role, as diets fed by Jolly et al. (2014) ranged from 6.3%–7.9% fat compared to 5.1%–6.5% fat in the study by Veracini et al. (2013). While DMI was decreased, the increase in available fat as WDGS increased in the diet (Jolly et al., 2014) could have resulted in increased energy utilization of steers to maintain similar ADG across WDGS inclusion.

Lamb performance in response to S is more variable. Felix et al. (2012) fed lambs (27 ± 7.9 kg) 20%, 40%, and 60% DDGS corresponding to 0.18%, 0.29%, and 0.35% dietary S concentrations, respectfully. At 40% and 60% DDGS diets, ADG and G:F were decreased by approximately 15% and 11%, respectively, in comparison to 20% DDGS. While dietary S concentrations fed by Felix et al. (2012) were lesser compared to other studies, performance was still hindered. This could be attributed to insufficient roughage concentration as the only dietary fiber included was from the fiber in corn, soybean hulls, and DDGS. While diets were analyzed to have approximately 20% NDF,
effective fiber may have been limiting. In a digestibility study by Neville et al. (2011), lambs (37 ± 2.3 kg) were fed 20%, 40%, or 60% DDGS, corresponding to 0.52%, 0.70%, or 0.84% dietary S, respectively. Interestingly, DMI was not affected by dietary S concentrations, and though values were not reported, the authors indicated that performance was not altered by feeding high dietary S concentrations (Neville et al., 2011). In this study, no lambs expressed symptoms associated with PEM, which could in part be explained by lambs being fed 15% roughage and only consuming the finishing diets for 27 days. Schauer et al. (2008) fed 20%, 40%, or 60% DDGS (0.32%, 0.47%, and 0.55% dietary S, respectively) with 12.5% alfalfa hay to lambs and noted no difference in ADG. However, there was a 7% increase in DMI as concentrations of DDGS increased from 20% to 60% in the diet. In general, the negative effects associated with high dietary S concentrations appear to be more severe in cattle compared to lambs. This could be attributed to cattle having greater days on feed, lamb finishing diets containing higher roughage concentrations, or perhaps lambs having a higher S tolerance.

The incidence of S toxicity and PEM has increased in the recent decades due to the inclusion of DG in feedlot diets. The loss of performance associated with feeding high dietary S concentrations has restricted high inclusions of DG in finishing diets. As the ethanol industry continues to evolve and the variation of S within DG continues or even increases, the risk of S toxicity in the feedlot will remain a concern. Compared to DG, S concentration is greater in CCDS, and as oil is removed during ethanol production, S will be concentrated further. Thus, the greater the ratio of CCDS added back to DG, the greater the S concentration of DG plus solubles. However, DG can be successfully incorporated in finishing diets without hindering performance by adapting a few
management strategies. Because of the load-to-load S variation in DG, routine S analysis is critical. Diets can be adjusted to decrease the dietary DG, decreasing total S concentration. Managing for S through these methods can aid in successfully feeding DG and reducing the risk of S toxicity.

**Nutrient Digestibility of Distillers Grains in Finishing Diets**

Based on the previous review of energy value in this chapter, DG exceed corn in energy concentration, especially WDG, as energy value is lost during the drying process (Stock et al., 2000). While nutrients such as fat and CP in the corn kernel are concentrated into the DG (Klopfenstein et al., 2008), digestibility of individual nutrients could further explain why the energy value is greater in DG compared to corn. The differences in physical particle size between DG and corn could also contribute to variation in passage rates and total tract nutrient digestibility.

**Fat and fiber digestibility**

Traditional DG typically contain 10%–12% fat, large amounts on NDF (30%–35%; Lundy and Loy, 2014a) in relation to corn, and are generally low in lignin (<10%; NRC, 2000) and are therefore a readily digestible fiber source. However, feeding excess fat in the diet can suppress ruminal fiber and total tract DM digestibility due to lipids interfering with the growth of rumen microbes, particularly the cellulolytic bacteria (Jenkins, 1987; Zinn, 1989b). The decreased ability of cellulolytic bacteria to digest fiber has been shown to decrease feed intake and overall performance of feedlot cattle (Zinn,
1989a). Because DG contain a higher proportion of unsaturated fatty acids compared to corn oil, when dietary fat is sourced from DG instead of corn oil, performance is not as negatively affected (Vander Pol et al., 2009; Bremer et al., 2011b). Fat source, supplemental fat concentration, and particle size are components that suppress fiber digestion and rate of fermentation in the rumen, but the severity of fiber inhibition varies.

Vander Pol et al. (2009) conducted a finishing trial with yearling heifers (349 ± 34 kg) to compare performance of equal dietary fat concentrations sourced from WDGS or corn oil. Diets contained 0%, 2.5%, or 5% corn oil or 0%, 20%, or 40% WDGS to achieve 4.0%, 6.4%, and 8.8% dietary fat. Dry matter intake was not affected by dietary fat source or concentration. While ADG was not influenced by WDGS inclusions (1.40 kg), ADG was lesser in 5% corn oil (1.13 kg) compared to 0% or 2.5% corn oil (1.38 kg). Gain to feed was lesser in 5% corn oil (0.136) compared to all other treatments (0.155).

In a follow-up study designed to compare digestibility of fat sources, the authors fed ruminally cannulated steers a corn-based control (3.9% dietary fat), 40% WDGS replacing dry-rolled corn in the diet, or 3.4% corn oil added to corn-based diet to achieve the same dietary fat content as 40% WDGS diet (7.2% dietary fat). Between these treatments, DM and NDF digestibility were not different (81.1% and 78.6% for DM and NDF digestibility, respectively). However, fat digestibility was greater in WDGS diet (81.0%) compared to the control and corn oil treatment (72.7%). Based on the performance and digestibility results from both experiments, the authors speculated that corn oil in WDGS is protected from the rumen microbes because the germ contains the majority of oil in the corn kernel. Therefore, corn oil found in WDGS may not interfere
with fiber digestion in the rumen and may be more available for digestion in the small intestine compared to raw corn oil (Vander Pol et al., 2009).

Increasing traditional DDGS in lamb finishing diets up to 60% decreases DM digestibility, ranging from 85% digestibility in 0% DDGS to 80% digestibility in 60% DDGS diets (Neville et al., 2011) and 80% digestibility in 0% DDGS to 73% digestibility in 60% DDGS diets (Felix et al., 2012). In these studies, fat concentrations of the diets were also linearly increased in the diets as DDGS inclusions increased (Neville et al., 2011; Felix et al., 2012). While fat digestibility was not measured by Neville et al. (2011), fat digestibility was greater in 0% and 20% DDGS (87%) compared to 40% and 60% DDGS (76%; Felix et al., 2012). These data contradict Vander Pol et al. (2009) where feeding 40% WDGS resulted in a greater fat digestibility compared to corn-based control diet with no DG. However, Felix et al. (2012) also noted no difference in NDF digestibility across treatments (44.2%), and reported lesser NDF digestibility values than those reported by others (Corrigan et al., 2008; Vander Pol et al., 2009; Pritchard and Kleinhans, 2010). In the experiment by Felix et al. (2012), lambs were fed a complete pelleted feed with no additional roughage source, which may have resulted in an increased passage rate, thus altering nutrient digestibilities.

Because of the decreased fat content of DG due to oil extraction during the ethanol production process, it has been hypothesized that feeding low-fat DG could potentially help alleviate some of the negative effects associated with fiber digestion in high fat diets. However, Ceconi et al. (2012) found no difference in OM digestibility between 35% low-fat DDGS (4.5% dietary fat; 73% OM digestibility) and 35% traditional fat DDGS (6.7% dietary fat; 69.0% OM digestibility) of steers. Corrigan et al.
(2008) also conducted a study utilizing steers to determine the effects of 35% low-fat (6.9% fat) and 35% traditional (13.3% fat) DDGS on DM, OM, and NDF digestibility. In agreement with Ceconi et al. (2012), DM and OM digestibility were not different between the two DDGS regardless of fat concentration (67% and 69% for DM and OM digestibility, respectively). Neutral detergent fiber digestibility was not different between fat concentrations of DDGS (61%); however, NDF intake was greater in steers fed low-fat DDGS because NDF concentration was greater in the low-fat DDGS (36.8%) compared to traditional fat DDGS (29.3%).

In a digestibility study by Pritchard and Kleinhans (2010), increasing inclusions of a pre-fermentation fractionation DG from 0% to 30% resulted in a 7% decrease in DM digestibility of lambs. While fiber digestibility was not different across treatments (66% and 69% for average NDF and ADF digestibility, respectively), fat digestibility was least in the corn-based control diet (82%) and increased in the 10%, 20%, and 30% inclusion (88% fat digestibility). These data suggest that fat from the pre-fermentation fractionation DG are more available for the animal for utilization compared to fat from corn grain. Because fiber digestibility was not affected, it appears that digestion of fat from DG is limited in the rumen, and more available for digestion in the small intestine.

Studies with DG in the diets have shown NDF digestibility to range from 56%–79% (Corrigan et al., 2008; Vander Pol et al. 2009; Pritchard and Kleinhans, 2010). The variation in fiber digestibilities could be explained by DG inclusion, DG fat concentration, and dietary fiber supplied from other ingredients including the inclusion and quality of forage. Fiber digestibility is negatively impacted by diets containing greater than 8% dietary fat (Zinn 1989b; Vander Pol et al., 2009); however, the source of
fat plays a large role in how much fiber digestibility is decreased. For example, in
general, corn oil results in a greater depression in fiber digestibility compared to co-
products of the ethanol industry such as DG and CCDS when supplying equivalent
dietary fat.

**Nitrogen digestibility**

Meyer et al. (2013) conducted an *in situ* study to evaluate the protein digestibility
of DDGS at 3 fat concentrations (5.5%, 8.4%, and 12.5% fat). Nitrogen digestibility was
not different between the 3 concentrations of fat and averaged 63%. Likewise, Mjoun et
al. (2010) measured total digestible protein of 3 fat concentrations of DG (3.2%, 3.5%,
and 10.6% fat) *in vivo*, and also found no difference in N digestibility between varying
fat sources. However, total digestible protein was 96% for DG products (Mjourn et al.,
2010). These values reported by Mjourn et al. (2010) are greater than values reported by
Kleinschmit et al. (2007) which ranged from 71%–85% in DG products. The variation
could be attributed to nutrient composition of the DG used in the studies and laboratory
techniques. While the DG samples in the study by Meyer et al. (2013) ranged from
29%–32% CP, the CP of DG used by Mjoun et al. (2010) ranged from 30%–42%, which
may have impacted protein digestibility.

In a study using 10%, 20%, or 30% pre-fermentation fractionation DG, N
digestibility was not different between treatments (76.5%; Pritchard and Kleinhans,
2010). Nitrogen retention was similar between 0% and 10% pre-fermentation
fractionation DG (4.43 and 4.64 g/d for 0% and 10% DG, respectively) and lesser in 30%
(2.08 g/d), with 20% being intermediate (3.13 g/d). In another lamb digestibility study
utilizing 0%, 20%, 40%, or 60% traditional DDGS, N digestibility was similar in diets containing between 0%, 20%, and 40% DDGS (73%; Felix et al., 2012). However, at the 60% inclusion, N digestibility (78%) was greater than all of the treatments. Nitrogen retention was not different between treatments and averaged 4.74 g/d. Even though N digestibility and balance were similar between the two studies, CP concentrations of diets fed by Pritchard and Kleinhans (2010) averaged 12% for all diets whereas diets by Felix et al. (2012) were 14.5%, 13.5%, 16.5%, and 20.6% CP for 0%, 20%, 40%, and 60% DDGS, respectively. However, DMI was greater (1180 g) in the study by Felix et al. (2012) compared to Pritchard and Kleinhans (2010; 780 g). Therefore, passage rate could explain why N digestibility and balance were similar although the CP concentrations of the diets were different.

Diets high in dietary fat can decrease fiber and DM digestibility, thus decreasing performance in the feedlot. In in vitro cultures, increasing amounts of corn oil over 2% decreased NDF digestibility (Jenkins, 1987). Suppling dietary fat greater than 8% in the form of corn oil or vegetable oil has resulted in decreased feed intake and performance of cattle (Zinn 1989b; Vander Pol et al., 2009); however, supplying 8% dietary fat from DG did not result in a decrease in performance (Vander Pol et al., 2009). Because traditional DG are a readily digestible fiber source (Stock et al., 2000; Klopfenstein et al., 2008) and contain a higher proportion of unsaturated fatty acids compared to corn oil (Vander Pol et al., 2009; Bremer et al., 2011a), performance is not as negatively affected when dietary fat is sourced from DG. The increase in fat and N digestibilities of DG compared to corn could partially be explained by DG having a greater energy and protein value compared to corn. Other factors such as lessening the risk of acidosis, increased energy and protein
utilization, passage rate, and influence of other dietary ingredients could help explain the increased digestibility and performance of DG compared to corn in finishing diets.

**Corn Processing Methods and Distillers Grains Inclusions**

**Corn processing methods**

In finishing diets, grains are the primary energy source to support rapid growth and improved feed efficiency of cattle on feed. Starch is the primary energy source in grain and accounts for approximately 70% of the corn kernel (Huntington, 1997). To maximize starch digestion, processing corn using methods including steam flaking, grinding, ensiling, or dry rolling allow for increased rate of starch gelatinization, increasing the rate of starch fermentation in the rumen and small intestine (Owens and Soderlund, 2006). Therefore, decreasing corn particle size is an effective way to increase starch utilization, and thus improve performance of the animal (Owens et al., 1997; Huntington, 1997).

Grain processing typically involves damaging the corn kernel to increase surface area. Historically, DRC is the most common processing method in the Midwest. For feedlot cattle, DRC is typically ground or rolled to achieve a coarsely-cracked kernel yielding between four to ten components (Owens and Soderlund, 2006). Generally, dividing the corn kernel into three components results in a particle size of approximately 4,200 microns (Schwandt et al., 2014). Further reducing the particle size to less than 1,000 microns is generally considered finely ground corn (FGC; Dairyland Laboratories,
If harvested at a higher moisture content (typically 24%–35% moisture), ground or rolled corn can be ensiled to allow fermentation to occur prior to feeding and is known as HMC (Owens and Soderlund, 2006). Steam can also be added to moisten the kernel while being rolled to achieve SFC (Owens and Soderlund, 2006).

In a meta-analysis by Owens et al. (1997), performance data from over 16,000 cattle from 419 trials were summarized to determine the effects of grain processing on cattle performance. In general, decreasing corn particle size resulted in decreased DMI (DRC > HMC > SFC) and ADG (DRC and SFC > HMC), and improved G:F (SFC > DRC and HMC). Owens and Soderlund (2006) conducted a meta-analysis of starch digestion data from feedlot steers and heifers fed diets containing DRC, HMC, SFC, and unprocessed, WC. Total tract starch digestibility improved by 8% in cattle fed SFC or HMC (99.1% and 99.3%, respectively) compared to cattle fed DRC (91.0%). Total tract starch digestibility was the least in WC diets (87%). While decreasing particle size can effectively increase total tract digestion and can increase performance, the intensity of grain processing may also contribute to digestive disturbances (Owens et al., 1997; Owens et al., 1998). Decreasing the particle size of corn too finely often results in decreased ruminal pH and promotes the possibility of acidosis and subsequently, liver abscesses (Owens et al., 1998).

**Feeding processed corn with distillers grains**

In the ethanol production process, starch from the corn kernel is the primary substrate for alcohol production. Therefore, co-products from the dry milling industry have relatively low concentrations of starch. Thus, feeding DG in partial replacement of
corn in high concentrate diets appears to be an effective management strategy for reducing the risk of acidosis (Stock et al., 2000).

In a study by Vander Pol et al. (2008), 360 steers (318 ± 15 kg) were utilized to determine the effects of six different corn processing methods on steer performance when fed 30% WDGS. Diets contained 61.4% corn and 5.6% alfalfa hay. Corn processing methods included WC, DRC, DRC:HCM, HMC, SFC, and FGC listed in increasing order of degree of processing. Steers fed WC had the greatest DMI (10.5 kg), while DRC, DRC:HMC, and HMC were intermediate (10.3, 9.8, and 9.5 kg, respectively), and steers fed SFC or FGC had the lowest DMI (9.3 kg for both SFC and FGC). Steers fed DRC, DRC:HMC, or HMC had the greatest ADG (1.84, 1.78, and 1.77 kg, respectively) and best feed efficiency (0.179, 0.182, and 0.185 kg, respectively). While ADG was greater in WC fed steers (1.75 kg), feed efficiency was not different between WC (0.166) and FGC fed steers (1.53 kg and 0.166 for ADG and G:F, respectively). Steam-flaked corn was intermediate in ADG (1.63 kg) and G:F (0.176) compared to WC and FCG and DRC, DRC:HMC, and HMC. Based on these results, cattle fed finishing diets containing 30% WDGS had optimal performance when diets contained moderately processed DRC or HMC as opposed to unprocessed WC or extensively processed SFC or FGC.

Corrigan et al. (2009) utilized a 3 × 4 factorial design to determine the impact of corn processing method (DRC, HMC, or SFC) on inclusion of WDGS (0%, 15%, 27.5%, and 40% DM basis) on steer performance (n = 480, 314 ± 18 kg). Diets contained 7.5% alfalfa hay and WDGS were added at the expense of corn, resulting in diets containing 82.5%, 72.5%, 60%, and 47.5% corn for 0%, 15%, 27.5%, and 40% WDGS, respectively. A corn processing × WDGS inclusion interaction was observed for ADG.
and G:F. In DRC diets, ADG (1.65, 1.71, 1.76, and 1.78 kg for 0%, 15%, 27.5% and 40% WDGS, respectively) and G:F (0.163, 0.170, 0.181, and 0.185 for 0%, 15%, 27.5% and 40% WDGS, respectively) were linearly increased as WDGS increased in the diet. For HMC diets, increasing WDGS inclusions resulted in a quadratic affect in ADG (1.67, 1.80, 1.80, and 1.75 kg for 0%, 15%, 27.5% and 40% WDGS, respectively) and linear increase in G:F with 27.5% WDGS having the most efficient G:F (0.183, 0.189, 0.197, and 0.194 for 0%, 15%, 27.5% and 40% WDGS, respectively). In SFC diets, ADG was quadratically affected, with 15% SFC having the greatest ADG (1.66, 1.70, 1.63, and 1.56 kg for 0%, 15%, 27.5% and 40% WDGS, respectively). Gain to feed was not affected by WDGS inclusion in SFC diets (0.182, 0.186, 0.182, and 0.183 for 0%, 15%, 27.5% and 40% WDGS, respectively). Dry matter intake was greatest in DRC diets (9.9 kg), intermediate in HMC diets (9.2 kg), and lesser in SFC diets (9.0 kg). At the 27.5% inclusion, performance results (DMI, ADG, and G:F) of Corrigan et al. (2009) were consistent with results by Vander Pol et al. (2008) with DMI being greater for DRC compared to HMC and SFC, ADG being greater in DRC and HMC compared to SFC, and G:F greater in HMC, intermediate in DRC, and least in SFC. However, to achieve the optimal feed efficiency, WDGS inclusion in the diet varies based on corn processing method. Results from this study show that as corn particle size is further decreased (DRC > HMC > SFC), WDGS inclusion should be decreased to achieve maximum feed efficiency of cattle.

Contrary to previous results (Vander Pol et al., 2008; Corrigan et al., 2009), Nichols et al. (2012) found that final BW and ADG were not influenced by DRC or SFC in diets containing 35% WDGS. Diets contained 3.5% alfalfa hay, 7% corn silage, and
48.5% corn. For steers fed DRC, DMI was greater (11.4 and 11.1 kg for DRC and SFC, respectively), and thus, G:F was improved by 4% for SFC (0.193) compared to DRC (0.189). The flake density of SFC used in the study by Nichols et al. (2012) was more conservative (14.3 kg/bu) than the degree of processing used by Vander Pol et al. (2008; 11.8 kg/bu) and Corrigan et al. (2009; 12.7 kg/bu). Thus, the risk of acidosis would be lesser with the greater flake density (Nichols et al., 2012) which could explain the differences in performance results between the studies. Likewise, roughage concentration fed by Nichols et al. (2012) was greater than Vander Pol et al. (2008). The intensity of all grain processing methods used by Vander Pol et al. (2008) and low roughage concentration could have increased the risk of acidosis and hindered the performance of cattle on feed. Increasing roughage concentrations not only decreases the risk of acidosis but also hydrogen sulfide accumulation associated with S toxicity which can be a concern when feeding high concentrations of DG.

While the optimum inclusion of WDGS to maximize steer performance in finishing diets varies depending on the corn processing method (Klopfenstein et al., 2008; Vander Pol et al., 2008; Corrigan et al., 2009), the optimum inclusion of WDGS in finishing diets with new generation DG produced from various methods of oil extraction during the ethanol production process may be altered compared to traditional DG. To help answer this question, Bremer et al. (2014b) conducted a study with de-oiled WDGS (0%, 17.5%, and 35%, DM basis) and DRC or SFC utilizing 320 steers (398 ± 39 kg). Corn silage was included in all diets at 15%, and WDGS were added at the expense of corn. The authors reported no interactions between corn processing method and WDGS inclusion. However, steers fed DRC had increased DMI (12.4 kg) compared to those fed
SFC (12.1 kg). While ADG and final BW were not different, feed efficiency was improved in SFC (0.144) diets compared to DRC (0.137). For both DRC and SFC, increasing inclusions of WDGS resulted in increased G:F. While corn particle size was not reported by Bremer et al. (2014b), DMI data were similar to Vander Pol et al. (2008) and Corrigan et al. (2009) while G:F was in agreement with Nichols et al. (2012), suggesting that the optimal inclusion of de-oiled DG is different compared to optimal inclusion of traditional DG. However, additional research is needed to address these questions.

Liver abscesses

The development of liver abscesses has been attributed to aggressive feeding programs during the finishing phase, resulting in an economical loss to the industry (Brown and Lawrence, 2010). Compared to cattle with no liver abscesses, severe liver abscesses have shown to decrease cattle performance by as much as 15% decrease in ADG (Brink et al., 1990). Similarly, DMI can be decreased by as much as 0.5 kg/d and G:F decreased by 10% (Nagaraja and Chengappa, 1998). Severe liver abscesses alone can result in a 4% decrease in gross carcass value (Brown and Lawrence, 2010). Generally, cattle with less severe liver abscess scores have similar performance compared to cattle with no liver abscesses (Brink et al., 1990; Nagaraja and Lechtenberg, 2007; Rezac et al., 2014). Prevalence of liver abscesses in the feedlot industry generally ranges from 12%–32% of cattle on feed (Brink et al., 1990), but more recent data suggest the industry average is between 10%–20% (Elanco, 2014; Rezac et al., 2014). Incidences of liver abscesses are generally higher in SFC diets compared to DRC diets (Brink et al.,
1990; Nagaraja and Chengappa, 1998; Brown and Lawrence, 2010) as steam-flaking increases the rate of fermentation in the rumen compared to DRC. Feeding antimicrobials, such as tylosin (Tylan, Elanco Animal Health), can decrease the incidence of liver abscesses by 40% to 70% (Nagaraja and Chengappa, 1998). Feeding high-concentrate diets and grain processing methods, particularly SFC, HMC, and FGC, result in rapid-fermentation of the starch in the rumen leading to lactic acid production and decreased rumen pH, resulting in acidosis (Owens et al., 1998). Persistent acidosis will eventually lead to rumenitis, disrupting the integrity of the rumen wall allowing pathogens to pass through the rumen wall and enter the hepatic portal system (Jensen et al., 1954; Kleen et al., 2003). Once in the liver, infections are established to detoxify the foreign pathogens and eventually develop into abscesses (Nagaraja and Lechtenberg, 2007).

*Fusobacterium necrophorum* and *Arcanobacterium pyogenes* are the primary pathogens credited to liver abscesses (Nagaraja and Lechtenberg, 2007) with the prevalence of *Fusobacterium necrophorum* ranging from 80%–100% of abscesses and *Arcanobacterium pyogenes* from 0%–50% of abscesses (Nagaraja et al, 1999). Both bacteria are naturally found in the rumen, and because *Fusobacterium necrophorum* uses

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**Figure 3.** *Pathogenesis of liver abscesses in cattle fed a high-grain diet (Nagaraja and Chengappa, 1998).*
lactate as substrate, the population is increased in the rumen when cattle are fed high-grain diets compared to high-forage diets (Nagaraja and Lechtenberg, 2007). In acidic situations where the rumen pH is nearing 5.5, \textit{Fusobacterium necrophorum} population growth is inhibited and the bacteria may not be detected. However, it is thought that the bacteria remain close to the rumen wall in acidotic situations because the pH near the wall is near the optimal for bacterial growth, pH of 7.4 (Nagaraja and Lechtenberg, 2007). Thus, when the rumen wall is damaged, \textit{Fusobacterium necrophorum} is readily available for entry into the portal system.

While feeding tylosin decreases the prevalence of liver abscesses, tylosin does not completely prevent liver abscess development. Nagaraja et al. (1999) isolated \textit{Fusobacterium necrophorum} from 100% of liver abscesses collected from 36 cattle fed tylosin and 41 cattle which were not fed tylosin. Although the exact mechanism is unknown, antimicrobials such as tylosin are believed to inhibit the growth of \textit{Fusobacterium necrophorum} in the rumen (Nagaraja and Chengappa, 1998). While \textit{Arcanobacterium pyogenes} was only found in 10% of liver abscesses from cattle which were not fed tylosin, 53% of the liver abscesses from tylosin fed cattle contained \textit{Arcanobacterium pyogenes} (Nagaraja et al., 1999). Because \textit{Arcanobacterium pyogenes} is generally associated with \textit{Fusobacterium necrophorum} and not the primary organism isolated from liver abscesses, the two organisms are believed to have a synergistic relationship (Nagaraja et al., 1999).

Although liver abscess development on a live animal is hard to monitor, ultrasonography has proven to be a useful methodology for detection. However, visual appearance of the whole liver due to sheer size, liver location based on gut fill, and cost
of implementing the technology has limited research using ultrasonography to further evaluate the development of liver abscesses (Nagaraja and Lechtenberg, 2007). In a study reported by Nagaraja and Lechtenberg (2007), monthly ultrasonography of steers through the finishing phase indicated that liver abscess development occurs during the last 60 days on feed. During the transition period, less than 5% of steers developed liver abscesses when not fed antimicrobials, and the smaller, less severe abscesses appeared to dwindle in less than 60 days (Nagaraja and Lechtenberg, 2007). While no other research has been conducted to pinpoint a timeline for abscess development, potential reasons for development of liver abscesses during the last 60 days on feed could be attributed to highest concentrate diets being fed during the finishing phase and individual animal intake variation over time. Persistent exposure to high-concentrate diets during the finishing phase as days on feed increase could maximize subacute acidosis potential, assaulting the rumen wall until it eventually reaches its threshold creating rumenitis and thus, liver abscess development.
Literature Cited


CHAPTER 3.

EFFECT OF CORN PARTICLE SIZE WITH MODERATE AMOUNTS OF WET DISTILLERS GRAINS IN FINISHING DIETS ON STARCH DIGESTIBILITY AND STEER PERFORMANCE

A paper submitted to *The Professional Animal Scientist*


Abstract

Five hundred yearling steers (370 ± 30.0 kg, SD) were used to determine the effect of corn particle size in diets containing 35% wet distillers grains plus solubles (WDGS) on steer performance, carcass characteristics, and apparent total tract starch digestibility (TTSD). Treatments included 45% coarsely cracked corn (CON; 2350 microns) or finely ground corn (FINE; 500 microns) with 35% WDGS and were replicated in 4 pens/treatment with 60 or 64 steers/pen. Fecal samples were collected on days 71/72 (Fecal-1) and days 102/103 (Fecal-2). Final BW and HCW were heavier \( (P \leq 0.01) \) for steers finished on CON compared to steers finished on FINE. While G:F was not different \( (P = 0.22) \) between treatments, DMI and ADG were greater \( (P \leq 0.01) \) for CON-fed steers than FINE-fed steers. Liver abscess scores (LAS) were not influenced \( (P \geq 0.39) \) by treatment. Liver abscess scores tended \( (P = 0.10) \) to influence ADG over the trial, with steers having severe LAS gaining less compared to steers with no or mild LAS. A treatment by time effect \( (P < 0.01) \) was observed for TTSD. While TTSD of steers fed CON decreased over time (90.28% and 85.74% for Fecal-1 and Fecal-2, respectively),
TTSD of steers finished on FINE did not differ across the two sampling dates (97.95% and 97.55% for Fecal-1 and Fecal-2, respectively). Apparent starch digestibility was improved for steers fed finely ground corn with 35% WDGS; however, cattle performance was poorer compared to steers fed coarsely-cracked corn with 35% WDGS.

**Key words:** cattle, corn particle size, distillers grains, liver abscess, starch digestibility

**Introduction**

Expansion of the ethanol industry has led to a steady supply of high quality co-products, including wet distillers grains plus solubles (WDGS) and wet corn gluten feed (WCGF). These co-products have proven to be beneficial replacements for corn in finishing diets through improved ADG and feed efficiency (Klopfenstein et al., 2008). Because corn starch is the primary substrate of alcohol fermentation during the ethanol process, both WDGS and WCGF have relatively low concentrations of starch. As a result, co-products from both the dry and wet milling industries appear to moderate the risk of acidosis in finishing diets (Stock et al., 2000).

Decreasing corn particle size through grain processing is an effective way to increase starch utilization and thus improve performance of the ruminant animal (Owens et al., 1986; Huntington, 1997). However, grinding corn too finely often results in rapid rumen fermentation leading to acidosis. Persistent acidosis often results in decreased animal performance and liver abscesses, causing an economic loss to producers (Brown and Lawrence, 2010).
Adding co-products at the expense of corn often decreases dietary starch concentrations; therefore, decreasing grain particle size may allow for more complete starch digestion of what starch is present in the diet, potentially improving cattle performance. Previous research has shown that more extensive grain processing when feeding WCGF improves feed efficiency by 10.5% (Macken et al., 2006) to 12.5% (Scott et al., 2003). However, decreasing corn particle size in diets containing WDGS has given more variable results. Corrigan et al. (2009) noted up to 8% improvement in feed efficiency when assessed across multiple WDGS inclusions while Vander Pol et al. (2008) observed a 7% decrease in feed efficiency with decreased particle size in diets containing 30% WDGS. Therefore, the objective of this study was to determine if feeding moderate inclusions of WDGS would decrease the acidosis risk associated with further grain processing and allow fine grinding of corn to improve starch utilization and thus, cattle performance.

Materials and Methods

Procedures and protocols were approved by the Iowa State University Institutional Animal Care and Use Committee (9-13-7630-B).

Animals and experimental design. Six hundred crossbred steers were purchased from a single source and transported to a commercial feedlot (Mogler Stock Farms, Alvord, IA). Upon arrival, steers were housed in a concrete open lot and fed a series of four transition diets over 17 days to ensure all steers were prepared for a concentrate-based diet. Five days prior to the start of the trial, steers were vaccinated with Bovi-
Shield GOLD One Shot (Zoetis, New York, NY), Ultrabac CD (Zoetis), and Somubac (Zoetis) and implanted with Synovex Choice (Zoetis). Steers were treated for internal and external parasites with Dectomax Injectable (Zoetis) and ProMectin B Pour-on (Vedco, Inc., St. Joseph, MO). Weights were also collected on day -5, and 500 steers (370 ± 30.0 kg, SD) were selected to be used in the trial, blocked by weight, and randomly assigned to one of two diets: coarsely cracked (2350 microns) corn-based control diet (CON) or finely ground (500 microns) corn diet (FINE) with both treatments containing 35% WDGS (DM basis; Table 1). Diets were formulated to meet or exceed animal requirements (NRC, 2000).

At the initiation of the study, individual weights were collected prior to feeding. Steers were given a unique visual and electronic ID and sorted into their respective pens within a slotted confinement facility with rubber mats. Each treatment was replicated in 4 pens with 60 or 64 steers/pen, split equally across treatments, to maintain a similar pen density of 2.0 m²/steer.

On day 72, interim weights were collected, and steers were re-implanted with Revalor 200 (Merck Animal Health, Millsboro, DE). On day 106, steers were started on ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN) and fed at a rate of 300 mg·steer⁻¹·day⁻¹ for the last 21 or 22 days of the trial. Steers were harvested by pen weight blocks on day 127 or 128 at a commercial abattoir (Tyson Foods, Inc., Dakota City, NE). Throughout the trial, five steers were removed due to illness, injury, or death, for reasons unrelated to treatment (2 CON and 3 FINE), and data were excluded from analysis. It was assumed that steers were consuming the pen average DMI up until the day of removal or death.
**Corn particle size.** Both sources of corn were processed through a double pair roller mill (Model 12×52 Dual Ind, RMS, Harrisburg, SD) at the feedlot. To achieve a 500 micron finely ground corn, the top roller was adjusted to 0.02 cm, and the bottom roller was closed. For the coarsely cracked corn, the top rollers were set to minimally process 100% of corn kernels, and the bottom rollers were opened for full flow through. Batches of each corn source were processed back-to-back to provide uniformity of corn source. After processing, both coarsely cracked corn and finely ground corn were stored in bunkers under a covered roof until fed.

Samples of both sources of corn were taken four times throughout the duration of study for determination of corn particle size, which was determined using the method described by American Society of Agricultural and Biological Engineers (ANSI/ASAE, 2008, method ANSI/ASAE S319.4). Samples were shaken through a corn sieve (Tyler Equivalent Mesh, W.S. Tyler Industrial Group, Mentor, OH) using five screens (U.S. Sieve # 8, 12, 20, 30, and 40 for coarsely cracked corn and 20, 30, 40, 50, and 100 for finely ground corn). Particle size was determined by dividing the weight of sample retained on each sieve by the total sample weight (as fed basis) run through the series of sieves multiplied by the micron opening value given for each sieve (ANSI/ASAE, 2008). For each source of corn, the particle size of each sampling day was averaged and equivalent to 2350 microns for coarsely cracked corn and 500 microns for the finely ground corn.

**Sample collection and analytical procedures.** Steers were fed their respective diets twice daily on an *ad libitum* basis using a clean bunk management protocol.
Bunks were visually assessed each morning prior to feeding, and feed delivery was adjusted daily based on the amount of feed remaining. Daily feed delivery was recorded for each pen, and pen average DMI was calculated. Average daily gain and G:F were determined using pen total DMI and total BW gain of steers in the pen over the duration of the trial.

On day 71/72 and 102/103, fecal collections were taken for apparent total starch digestibility calculation. On each collection day, a pen composite of eight fresh samples, approximately 30 g/sample (wet basis), were collected randomly from the pen surface. Pen composites from each of the four days were sent to Dairyland Laboratories, Inc. (Arcadia, WI) for wet chemistry analysis of CP (AOAC, 1995, method 990.03) and fecal starch (Hall, 2009). Samples of each TMR were also collected on day 71 and 102 and sent to Dairyland for analysis of CP and starch using the same methods. Apparent total tract starch digestibility was estimated using the equation described by Zinn et al., (2007): starch digestion (expressed as a percentage of intake) is equivalent to 100 \left\{1 – \left[0.938 – 0.497 \times FN + 0.0853 \times FN^2\right]) \times FS ÷ DS\right\} where FN is fecal nitrogen concentration (% DM), FS is fecal starch concentration (% DM), and DS is dietary starch concentration (% DM). Starch digestion was averaged for each pen over the two consecutive days of collection (Fecal-1 for days 71/72 and Fecal-2 for days 102/103).

Individual camera carcass data were provided by Tyson Foods, Inc. Carcass data collected included: HCW, marbling score, 12th rib backfat thickness, ribeye area, liver abscess scores (LAS), YG, and QG. Liver abscess scores were facilitated by representatives from Elanco Animal Health, who were masked to treatments, using the Elanco Liver Check System (Greenfield, IN) on a 0, A, and A+ scale. Livers free of
abscesses were classified as a LAS of 0. Mild abscesses, up to 4 small abscesses less than 2.54 cm in diameter, were classified as LAS of A. Larger or more severe abscesses, with active areas of inflammation on the liver or when portions of the liver were attached to the diaphragm were classified as a LAS of A+. A 4% pencil shrink was applied to initial BW, and final BW (FBW) was calculated from HCW using the average DP of the cattle in this trial, 62.4%.

Statistical analysis. Data were analyzed by ANOVA in SAS 9.3 (SAS Institute, Inc., Cary, NC) as a complete block design with pen as the experimental unit (n = 4/treatment). The model included the fixed effects of treatment and block. Performance, carcass characteristics, and starch digestibility data were analyzed using the Mixed procedure of SAS. Treatment distributions of YG, QG, and LAS data were determined using PROC Glimmix of SAS. The effect of LAS on ADG was also tested using PROC Mixed with steer as the experimental unit (n = 495 steers). Significance was declared at P ≤ 0.05 and tendencies were declared from P = 0.06 to 0.10. Means reported are least square means (LSMEANS) ± SEM.

Results and Discussion

Performance and carcass results are presented in Table 2. While initial BW and interim BW (day 72) were not different (P ≥ 0.16) between treatment groups, FBW was heavier (P ≤ 0.01) for steers finished on CON compared to FINE. Dry matter intake and ADG were greater (P ≤ 0.01) for steers finished on CON compared to those finished on FINE. However, G:F was not different (P = 0.22) between treatment groups. Vander Pol
et al. (2008) also showed that fine ground corn (FGC) in a diet with 30% WDGS had negative effects on performance compared to a more traditional dry-rolled corn (DRC) diet with 30% WDGS, as demonstrated by a 17% decrease in ADG, 10% decrease in DMI, and 7% decrease in G:F over cattle fed diets of DRC and 30% WDGS. In a University report of the same study published earlier, Vander Pol et al. (2006) reported an increase in dietary roughage after 107 days on feed suggesting that steers being fed FGC experienced apparent acidosis, although it was not explicitly stated by the authors. This apparent acidosis may explain why cattle performance was poorer in the work by Vander Pol et al. (2008) in comparison to the current study.

Average HCW of CON-fed cattle was heavier ($P = 0.01$) than steers fed FINE. Ribeye area, backfat thickness, and YG were not different ($P \geq 0.38$) due to treatment. However, marbling scores of FINE cattle were lesser ($P = 0.04$) compared to cattle fed CON. Although distributions of USDA QG of average choice and higher and low choice were not affected by treatment ($P \geq 0.17$), the percentage of cattle grading select tended to be greater ($P = 0.07$) for cattle finished on FINE (Table 3). Lighter carcasses and decreased QG indicate that steers fed FINE treatment may not have reached the desired degree of finish by harvest. Yield grade distributions were not different ($P \geq 0.20$) by treatment.

Increased incidence of liver abscesses have been attributed to aggressive feeding programs of high concentrate diets leading to acidosis, with severe liver abscesses resulting in up to a 15% decrease in ADG (Brink et al., 1990). In this experiment, distribution of LAS was not influenced ($P \geq 0.39$) by treatment. However, there was a tendency ($P = 0.10$) for LAS to influence ADG over the duration of the trial (Table 4), as
steers with a LAS of A+ gained less compared to steers having a LAS of 0 or A. Interestingly, during Period 1 (days 0 – 72), LAS did not affect ADG ($P = 0.30$). However, during Period 2 (days 73 – 127 or 128), the ADG of steers that had a LAS of A+ was approximately 0.4 kg less than steers with LAS of 0 or A, indicating that negative performance associated with severe LAS occurs later in the feeding period. Other research has shown similar results where no difference in performance existed between steers with no LAS or mild LAS, but steers with severe LAS experienced a decrease in performance up to 16.6% loss of gain (Brink et al., 1990) or 0.22 kg/day decrease in gain (Rezac et al., 2014).

Prevalence of liver abscesses in the industry ranges from approximately 10%-20% of cattle on feed consuming steam-flaked corn diets (Brown and Lawrence, 2010; Rezac et al., 2014) with tylosin (Tylan, Elanco). When antimicrobials were not fed, occurrence of LAS was reported to be as high as 32% in DRC diets (Brink et al., 1990) and 43% in steam-flaked corn diets (Brown and Lawrence, 2010). While tylosin was not fed in this trial, only 10% of steers had LAS, indicating that acidosis was not a major issue in this experiment. However, previous research has shown steers with severe LAS typically have a 0.5 kg reduction in DMI (Brink et al., 1990; Nagaraja and Chengappa, 1998), which is consistent with decreased DMI of steers fed FINE compared to CON. During the first 21 days on feed, intakes varied between the two treatment groups. This is likely due to the FINE cattle experiencing sub-acute acidosis while making the transition to FGC from coarsely cracked corn. Steers on FINE experienced a decrease of approximately 1.1 kg in daily DMI from days 10-20 and continued to have an average DMI that was 0.3 kg less than CON fed steers for the remainder of the trial (Figure 1).
Although visible signs of acidosis were not observed during the study, measurement of rumen pH throughout the trial, especially the first 21 days, may have been an informative indicator of increased risk of rumenitis, which occurs prior to liver abscess development. Corrigan et al. (2009) found that the addition of 40% WDGS (DM basis) to DRC, high moisture corn, or steam-flaked corn-based diets did not impact rumen pH; however, Siverson et al. (2014) reported that feeding 30% WCGF (DM basis) in DRC or whole shelled corn-based diets aided in moderation of rumen pH and increased starch digestibility in growing diets, potentially due to differences in intestinal and ruminal digestion. Wet corn gluten feed generally contains less starch and has greater digestible fiber compared to WDGS (Stock et al., 2000), which may contribute to the variation in rumen pH results between the two studies.

Increased starch availability through grain processing often improves cattle performance (Huntington, 1997), and starch digestibility can be predicted based on fecal starch concentration (R²=0.96; Zinn et al., 2007). In this study, fine grinding of corn decreased fecal starch concentrations and improved apparent total tract starch digestibility. A treatment by time effect (P ≤ 0.01; Figure 2) was observed for fecal starch concentrations, where steers fed CON diets had increased concentrations (14.34% and 17.58% fecal starch for Fecal-1 and Fecal-2, respectively) over the two sampling dates compared to steers fed FINE diets which had consistently lesser concentrations (2.95% and 3.20% fecal starch concentrations for Fecal-1 and Fecal-2, respectively). While starch concentrations of the diets varied by less than 2% (Table 1), a treatment by time interaction (P ≤ 0.01; Figure 3) was also observed for apparent total tract starch digestibility of steers. Starch digestibility of steers fed CON diets decreased over time
(90.28% and 85.74% for Fecal-1 and Fecal-2, respectively). However, apparent total tract starch digestibility of steers fed FINE diets did not differ across sampling days (97.95% and 97.55% for Fecal-1 and Fecal-2, respectively).

Consistent with increased fecal starch concentrations of CON, Barajas and Zinn (1998) noted an increase in fecal starch concentrations ranging from 20.3% to 28.5% over an 8 week period in cattle fed a 75% DRC diet. Decreased starch digestibility as days on feed increased could be attributed to changes in microbial population, site of starch digestion, or DMI. Particle size of the grain plays a large role in retention time within the rumen (Owens et al., 1986). Although retention time was probably greater for CON, a greater portion of the starch most likely reached the small intestine, which does not have as extensive of digestion capacity in comparison to the rumen (Owens et al., 1986). While increased DMI would be thought to lead to more rapid passage rate and less utilization of starch, intakes in the present study were consistent between the two sampling dates for CON-fed steers. It is unclear why fecal starch concentrations decreased over time in the CON-fed steers.

Scott et al. (2003) observed a 1.8% decrease in fecal starch concentrations when 32% WCGF replaced DRC in the diet. Fecal starch concentrations in FGC diets with moderate inclusions of WCGF ranged from 7.1% (Scott et al., 2003) to 11.8% (Macken et al., 2006) and were greater than fecal starch concentrations of FINE-fed steers in current study, which averaged 3.1% over the duration of the trial. Vander Pol et al. (2008) found fecal starch concentrations in DRC diets with 30% WDGS to be consistent with FGC diets containing 30% WDGS (12.0% and 13.4% for DRC and FGC, respectively). The lack of difference in fecal starch concentrations found by Vander Pol
et al., 2008 compared to the present study could have been attributed to the amount of effective dietary fiber utilized in the two studies. In the present study, roughage concentration was 11.5%, which could have slowed passage rate, thus allowing for increased starch digestibility, compared to diets containing 5.6% roughage as fed by Vander Pol et al. (2008).

While fecal starch concentrations have been more extensively reviewed, apparent total tract starch digestibility of DRC diets has not been reported to the same extent. Others have observed apparent total tract starch digestibility of DRC diets to range from 91% to 96% (Cooper et al., 2002; Owens and Soderlund, 2006; Corrigan et al., 2009). Variation in fecal starch concentrations and apparent total tract starch digestibility amongst previous studies could be attributed to the variation of corn particle size used in the studies. In a recent survey of feedlots in the Midwest using DRC as the primary energy source, the average fecal starch concentration of 34 feedlots was 18.9%, ranging from 7.0% to 36.6%. The range of corn particle size reported varied from 1,165 to 6,823 microns with an average size of 4,201 microns (Schwandt et al., 2014). The CON diet utilized in the present study was 2,350 microns, which may help explain why the fecal starch concentrations of cattle in the present study were lesser than reported by others. When fecal starch concentrations are greater than 5%, it is often attributed to less than optimal starch digestibility due to insufficient grain processing (Owens and Soderlund, 2006), supporting that starch digestibility of FINE-fed steers was more favorable than steers fed CON. However, improved starch digestibility did not translate into improved performance of steers fed FINE. Further research is needed to evaluate the optimum particle size of corn in diets with moderate amounts of WDGS.
Implications

Although research with finely ground corn and WCGF has been successful, fine grinding of corn did not improve feed conversion and actually hindered DMI and ADG in this study compared to coarsely cracked corn when included in finishing diets with 35% WDGS. While indicators of acidosis such as LAS were not different between CON or FINE treatments, the decrease in DMI outweighed the increase in starch digestibility and therefore, limited cattle performance. As ethanol plants in the dry milling industry continue to extract more value, primarily corn oil and fiber, from distillers grains (Lundy and Loy, 2014), distillers grains may become more similar in nutrient value to co-products from the wet milling industry. Therefore, additional research should be conducted with the next generation of WDGS to determine the optimum inclusion of WDGS in finely ground corn diets to enhance cattle performance.

Acknowledgments

The authors thank Brian, Howard, and Ross Mogler of Mogler Stock Farms (Alvord, IA) for the opportunity to conduct this study at their feedlot as well as representatives of Elanco Animal Health for collection of liver abscess score data.
Literature Cited


Lundy, E. L. and D. Loy. 2014. Ethanol Coproducts for Beef Cattle: Changing distillers grains. Iowa Beef Center. Iowa State University Extension and Outreach Factsheet IBCR 200B.


# Table 1. Ingredient and nutrient composition of diets (% DM basis).

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>CON&lt;sup&gt;1&lt;/sup&gt;</th>
<th>FINE&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarsely cracked corn&lt;sup&gt;2&lt;/sup&gt;</td>
<td>45.0</td>
<td>–</td>
</tr>
<tr>
<td>Finely ground corn&lt;sup&gt;2&lt;/sup&gt;</td>
<td>–</td>
<td>45.0</td>
</tr>
<tr>
<td>Wet distillers grains plus solubles&lt;sup&gt;3&lt;/sup&gt;</td>
<td>35.2</td>
<td>35.2</td>
</tr>
<tr>
<td>Corn silage</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Corn stalks</td>
<td>6.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Liquid supplement&lt;sup&gt;4&lt;/sup&gt;</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Analyzed composition&lt;sup&gt;5&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>18.1</td>
<td>18.2</td>
</tr>
<tr>
<td>NDF</td>
<td>29.6</td>
<td>26.8</td>
</tr>
<tr>
<td>Starch</td>
<td>36.9</td>
<td>35.2</td>
</tr>
<tr>
<td>Ether extract</td>
<td>5.1</td>
<td>4.9</td>
</tr>
</tbody>
</table>

<sup>1</sup>Treatments: CON=coarsely cracked corn diet; FINE=finely ground corn diet.

<sup>2</sup>Coarsely cracked corn (2350 microns); finely ground corn (500 microns).

<sup>3</sup>Composite analysis: 35.5% crude protein, 8.7% ether extract, and 0.62% sulfur (DM basis).

<sup>4</sup>Liquid supplement includes 12.7% Ca, 5.7% salt, 1.6% K, 0.02% P, and 95,000 IU/kg of Vitamin A, and monensin sodium provided at 700 mg/kg (DM basis).

<sup>5</sup>Diets were analyzed by Dairyland Laboratories, Inc. (Arcadia, WI).
Table 2. Influence of corn particle size on steer performance and carcass characteristics.

<table>
<thead>
<tr>
<th></th>
<th>CON(^1)</th>
<th>FINE(^1)</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Growth performance(^2)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial BW, kg</td>
<td>368</td>
<td>371</td>
<td>1.54</td>
<td>0.20</td>
</tr>
<tr>
<td>Interim BW, kg (^3)</td>
<td>500</td>
<td>494</td>
<td>3.44</td>
<td>0.16</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td>624</td>
<td>605</td>
<td>1.79</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>11.76</td>
<td>11.07</td>
<td>0.10</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>2.01</td>
<td>1.84</td>
<td>0.03</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>G:F</td>
<td>0.161</td>
<td>0.156</td>
<td>0.003</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>Carcass characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCW, kg</td>
<td>390</td>
<td>378</td>
<td>1.58</td>
<td>0.01</td>
</tr>
<tr>
<td>Ribeye area, cm(^2)</td>
<td>86.6</td>
<td>85.8</td>
<td>1.20</td>
<td>0.56</td>
</tr>
<tr>
<td>Marbling score(^4)</td>
<td>434</td>
<td>417</td>
<td>4.63</td>
<td>0.04</td>
</tr>
<tr>
<td>Backfat thickness, cm</td>
<td>1.23</td>
<td>1.20</td>
<td>0.05</td>
<td>0.56</td>
</tr>
<tr>
<td>YG</td>
<td>3.2</td>
<td>3.1</td>
<td>0.09</td>
<td>0.38</td>
</tr>
</tbody>
</table>

\(^1\) Treatments: CON=coarsely cracked corn diet; FINE=finely ground corn diet; \(n=4\) pens/treatment.

\(^2\) A 4% pencil shrink was applied to all live BW. Final BW were calculated from HCW using a common DP of 62.4% which was used in calculation of DMI, ADG, and G:F over the duration of the trial.

\(^3\) Interim BW were collected on day 72.

\(^4\) Marbling score: 300=slight, 400=small, and 500=modest.
**Table 3.** Influence of coarsely cracked or finely ground corn in steer diets on distribution of quality and yield grades and liver abscess scores.

<table>
<thead>
<tr>
<th></th>
<th>CON (^1)</th>
<th>FINE (^1)</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality grade, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average choice and higher</td>
<td>16.3</td>
<td>10.8</td>
<td>2.21</td>
<td>0.17</td>
</tr>
<tr>
<td>Low choice</td>
<td>51.9</td>
<td>45.6</td>
<td>3.20</td>
<td>0.28</td>
</tr>
<tr>
<td>Select</td>
<td>28.9</td>
<td>41.1</td>
<td>3.14</td>
<td>0.07</td>
</tr>
<tr>
<td>Yield grade, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.0</td>
<td>3.5</td>
<td>1.34</td>
<td>0.37</td>
</tr>
<tr>
<td>2</td>
<td>33.0</td>
<td>38.3</td>
<td>3.07</td>
<td>0.31</td>
</tr>
<tr>
<td>3</td>
<td>55.4</td>
<td>48.1</td>
<td>3.20</td>
<td>0.20</td>
</tr>
<tr>
<td>4/5</td>
<td>8.6</td>
<td>8.9</td>
<td>1.80</td>
<td>0.90</td>
</tr>
<tr>
<td>Liver abscess score(^2), %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>91.3</td>
<td>88.8</td>
<td>1.90</td>
<td>0.42</td>
</tr>
<tr>
<td>A</td>
<td>6.0</td>
<td>6.8</td>
<td>1.56</td>
<td>0.74</td>
</tr>
<tr>
<td>A+</td>
<td>2.4</td>
<td>4.0</td>
<td>1.11</td>
<td>0.39</td>
</tr>
</tbody>
</table>

\(^1\)Treatments: CON=coarsely cracked corn diet; FINE=finely ground corn diet; \(n = 4\) pens/treatment.

\(^2\)Liver abscess score: 0=no abscesses; A=one or two small abscesses; A+=one or more large abscesses.
Table 4. Influence of liver abscess score on average daily gain of steers.

<table>
<thead>
<tr>
<th>ADG, kg/d</th>
<th>Liver abscess score&lt;sup&gt;1&lt;/sup&gt;</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>0.061</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Period 1&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.054</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Period 2&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.090</td>
<td>&lt;0.01</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>Liver abscess score: 0=no abscesses, n=445 steers; A=one or two small abscesses, n=33 steers; A+=one or more large abscesses, n=17 steers.

<sup>2</sup>Day 0 - 72 of trial.

<sup>3</sup>Day 73 - 127 or 128 of trial.

<sup>ab</sup>Means within a row without a common subscript differ (P ≤ 0.05).

<sup>xy</sup>Means within a row without a common subscript tend to differ (P ≤ 0.10).
Figure 1. Dry matter intake of steers fed coarsely cracked or finely ground corn in diets containing 35% wet distillers grains (DM basis). Treatments include: CON=coarsely crack corn diet, indicated by solid line, and FINE=finely ground corn diet, indicated by dashed line.
Figure 2. Fecal starch concentration of steers fed coarsely cracked (CON) or finely ground corn (FINE) with 35% wet distillers grains (DM basis). Each bar (CON=dark bar; FINE=light bar) represents fecal starch concentration taken at two time points: Fecal-1 (average concentration of days 71/72) and Fecal-2 (average concentration of days 102/103). Error bars indicate pooled SEM of 0.809. Means without a common superscript differ (P ≤ 0.05).
Figure 3. Apparent total tract starch digestibility of steers fed coarsely cracked (CON) or finely ground corn (FINE) with 35% wet distillers grains (DM basis). Each bar represents (CON=dark bar; FINE=light bar) total tract starch digestibility calculated at two time points: Fecal-1 (average digestibility of days 71/72) and Fecal-2 (average digestibility of days 102/103). Error bars indicate pooled SEM of 0.856. Means without a common superscript differ ($P \leq 0.05$).
CHAPTER 4.

INFLUENCE OF DISTILLERS GRAINS RESULTING FROM A CELLULOSIC ETHANOL PROCESS UTILIZING CORN KERNEL FIBER ON NUTRIENT DIGESTIBILITY OF LAMBS AND STEER FEEDLOT PERFORMANCE


Abstract

Two experiments evaluated the effects on animal performance of traditional wet distillers grains (T-WDG) compared to wet distillers grains (C-WDG) from a new process converting corn kernel fiber into cellulosic ethanol. The resulting co-product has greater CP and decreased starch and ether extract (EE) concentrations (34.0% CP, 1.6% starch, 7.3% EE) compared to T-WDG (32.5% CP, 5.1% starch, 7.7% EE). In Exp. 1, 10 wethers (34.1 ± 2.35 kg, SD) were used in a replicated 5 × 5 Latin square to evaluate digestibility of DM, fiber, EE, and N. Diets included a corn-based control with 7.5% T-WDG and 7.5% C-WDG (CORN); 30% or 45% inclusion of T-WDG; and 30% or 45% inclusion of C-WDG. Between CORN, 30% T-WDG, 45% T-WDG, or 45% C-WDG, DMI was not different (P ≥ 0.11), but lambs fed 30% C-WDG had decreased (P ≤ 0.05) DMI compared to other diets. Compared to CORN and 30% T-WDG, DM digestibility was lesser (P < 0.05) for 45% T-WDG or 30% C-WDG, while 45% C-WDG has lesser (P ≤ 0.05) DM digestibility than all other treatments. Digestibility of NDF was not affected by treatment
(P = 0.13), and ADF digestibility was not different (P ≥ 0.21) between CORN, 30% T-WDG, 30% C-WDG, or 45% C-WDG. However, digestibility of ADF tended to differ (P = 0.06) between 30% T-WDG and 45% C-WDG and was greater (P ≤ 0.05) in lambs fed 45% T-WDG compared to other treatments. In Exp. 2, 168 steers (421 ± 23.9 kg, SD) were used in a randomized complete block design to determine the impact of C-WDG or T-WDG on growth performance and carcass characteristics. Diets included a corn-based control (CON); 30% T-WDG (TRAD); 30% C-WDG (CEL); and 18% C-WDG and 12% condensed corn distillers solubles (CEL+CCDS; n = 7 pens of 6 steers/pen). Steers fed TRAD had improved (P ≤ 0.01) ADG, G:F, and HCW compared to steers fed the CON diet. No differences (P ≥ 0.16) in ADG and HCW were noted for steers fed CEL compared to TRAD; however, steers fed CEL had decreased (P = 0.01) G:F due to increased (P = 0.02) DMI compared to TRAD–fed steers. Steers fed CEL or CEL+CCDS did not differ (P = 0.50) in G:F, but CEL+CCDS–fed steers had lesser (P ≤ 0.01) DMI and ADG likely due to greater S content of the CEL+CCDS diet. Overall, while DM digestibility of lambs fed 30% C-WDG was lesser than 30% T-WDG, performance of steers finished on C-WDG was similar to those fed T-WDG. However, WDG from the secondary fermentation appeared to have lesser energy than T-WDG, while maintaining similar cattle performance to corn-fed controls.

**Keywords:** Beef cattle, cellulosic ethanol, corn fiber, digestibility, distillers grains
Introduction

Ethanol has proven to be a renewable resource (RFA, 2013), and distillers grains (DG) produced from the ethanol process provides a high quality, cost effective alternative to corn that is rich in protein and energy (Klopfenstein et al., 2008). An expanding trend for ethanol plants to extract corn oil during production is resulting in decreased oil content in DG. This is primarily accomplished through pre-fermentation fractionation, which involves separation of the corn kernel prior to fermentation of the endosperm, or through partial oil-removal from condensed corn DG (CCDS) via centrifugation after fermentation (U.S. Grains Council, 2012). Although it has been estimated that more than 85% of ethanol plants are currently extracting corn oil from DG (U.S. Grains Council, 2012), limited research has been conducted regarding the use of decreased fat DG in cattle diets. Due to variation in oil and fiber extraction methods the nutrient profile of DG varies greatly across ethanol plants (Berger and Singh, 2010). Previous research with new generation DG have shown varying results in cattle performance compared to traditional DG ranging from decreased performance (Depenbush et al., 2008; Gigax et al., 2011; DiCostanzo and Crawford, 2013) to no difference (Jolly et al., 2013).

With advancements in technology, the industry is moving beyond oil extraction towards cellulosic ethanol production. Unlike the typical cellulosic ethanol process which utilizes cellulose from biomass feedstocks such as trees, plants, and grasses (Solomon et al., 2007; Dwivedi et al., 2009), this novel process (Cellerate, Syngenta, Wilmington, DE and Cellulosic Ethanol Technologies, LLC, Galva, IA) utilizes corn kernel fiber to produce ethanol and results in a novel, cellulosic wet DG (C-WDG). Therefore, 2 experiments were designed to determine the effects of wet DG (WDG) from a secondary fermentation
process (C-WDG) compared to traditional WDG on nutrient digestibility in lambs and feedlot cattle performance.

**Materials and Methods**

All animal procedures and protocols were approved by the Iowa State University Institutional Animal Care and Use Committee (6-13-7590-B and 8-13-7623-B).

**Production of experimental distillers grains.** During the traditional ethanol process, after distillation or removal of the ethanol, the resulting product known as the whole stillage is centrifuged to separate the DG from the CCDS (Rosentrater et al., 2011). With this secondary fermentation process, cellulosic enzymes and yeast are added and additional heat is applied to the whole stillage prior to centrifugation. The enzymes are responsible for facilitating the use of more cellulose while the yeast aides in metabolizing additional sugar, thus the majority of the residual starch from the corn kernel is removed, resulting in additional ethanol production.

The WDG used in these studies were produced within two consecutive days at Quad County Corn Processors (Galva, IA) utilizing the same corn source to minimize variation between the two products. Each product was shipped the day after production to the Iowa State University Beef Nutrition Research Unit in Ames, Iowa, where it was bagged (Ag Bag, Up North Plastics, Hammond, WI) for storage until the initiation of the feedlot trial. At the time of arrival to the farm, WDG to be used in the lamb study was stored in barrels and sealed for storage until fed.
The nutrient profiles of the T-WDG and C-WDG fed in these experiments are shown in Table 1. While fiber is the primary substrate for additional ethanol production in the secondary fermentation process, the NDF and ADF concentrations between T-WDG and C-WDG are similar. The secondary fermentation process associated with C-WDG production results in approximately a 20% decrease in co-product yield compared to the traditional ethanol production process.

Exp. 1 was conducted in a controlled environment metabolism facility located on the campus of Iowa State University in Ames, Iowa. Exp. 2 was conducted at the Iowa State University Beef Nutrition Research Unit in Ames, Iowa.

**Experiment 1**

**Animals and experimental design.** Ten crossbred whiteface wethers (34.1 ± 2.35 kg, SD) were used in a replicated 5 × 5 Latin square design to determine the impact of increasing inclusion of T-WDG or C-WDG on total tract nutrient digestibility. There were 5 periods, 15 d in length, which included 10 d of diet adaptation and 5 d of total fecal and urine collection. Prior to the start of the trial, lambs were adapted to a concentrate-based diet and then allowed 5 d to adapt to the controlled-environment facilities. Each period, lambs received 1 of 5 diets: a corn-based control diet containing 7.5% T-WDG and 7.5% C-WDG to meet the protein needs of the lambs (CORN), and 30% or 45% inclusion of T-WDG (30% T-WDG or 45% T-WDG) or C-WDG (30% C-WDG or 45% C-WDG) on a DM basis (Table 2). Each WDG product replaced dry rolled corn within the diet (DM basis). For the first 3 d of each period, lambs on the same diet were paired in a pen (1.1 m²/lamb) to allow for adaptation to their respective diet prior to moving to individual
metabolism crates [123.2 cm (length) × 41.9 cm (width) × 93.4 cm (height)] for another 7
d of adaptation. Total fecal and urine collections were then conducted over a 5 d period.
This process was repeated for a total of 5 periods with 2 lambs·treatment⁻¹·period⁻¹ resulting
in 10 lambs/treatment in total.

**Sample collection and analytical procedures.** Lambs were fed once daily at 0800 h, and the previous day’s feed refusals, urine, and feces were removed at 0700 h daily. Feed was offered at 105% of the average intake from the previous 5 d. From d10 – 15 of each period, a composite of each total mixed ration (TMR) was made, representing samples collected daily. Total feed refusals were weighed each day, and a sample was taken during the collection period. To maintain urine pH below 3 and prevent volatilization of urine N, 200 mL of 6 N acetic acid was added daily to urine pans during the collection period. Total weight and volume were recorded for individual lamb urine output each day and a 10% aliquot (weight basis) was collected daily to create a composite sample for that period. During the collection period, urine composite samples were stored at 4°C, then frozen at -20°C for later analysis following the collection period. Total fecal output for each individual lamb was recorded daily with a 10% aliquot (wet weight basis) from each day collected for a composite. Approximately 10 mL of blood was collected via jugular vein in a heparinized vacutainer (158 IU of sodium heparin; Becton, Dickinson and Company, Franklin Lakes, NJ) 4 h post feeding (1200 h) on d 10 – 15 of each period. Blood samples were immediately placed on ice for transportation to the lab, centrifuged (1,200 × g, 4°C, 12 min), and plasma was extracted and stored at -80°C until analysis of plasma urea nitrogen (PUN).
Total mixed rations, feces, and feed refusals were initially dried in a 70°C convection oven for 96 h before TMR and feed refusals were ground through a 2-mm screen in a Wiley mill (Thomas Scientific, Swedesboro, NJ) and fecal samples were ground through a 2-mm screen in a Retsch ZM 100 grinding mill (Retsch GmbH, Haan, Germany). Dried and ground fecal and feed refusal samples were then composited by lamb per period on an equal DM weight basis for further analysis.

Individual animal DMI and digestibility of dietary DM, OM, fiber (NDF and ADF), ether extract (EE), and N were determined. True DM (105°C) and OM content, DMI, OM intake, and digestibility calculations of composited TMR, feed refusals, and fecal samples were determined as described by Pogge et al. (2014). Dried and ground samples of TMR, feed refusals, and feces were subjected to sequential analysis for determination of NDF (Van Soest et al., 1991) and ADF (Goering and Van Soest, 1970) concentrations utilizing an ANKOM\textsuperscript{200} Fiber Analyzer (ANKOM Technology, Macedon, NY), with alpha-amylase used during the NDF analysis procedure. A hay standard (Brome grass hay, average NDF was 63.1% and ADF was 33.25%) was included with each run to verify intra-assay accuracy (intra-assay CV of 1.1% for NDF and 1.2% for ADF). A sub-sample of TMR, feed refusals, and fecal composites were sent to the University of Arkansas Central Analytical Laboratory (Poultry Science Center, Fayetteville, AR) for EE analysis (AOAC, 1990). Dried and ground TMR samples from each period were prepared for S analysis by acid digestion (CEMS MarsXpress, Matthews, NC) prior to analysis using inductively coupled plasma optical emission spectrometry (Optima 700 DV; PerkinElmer, Waltham, MA) as previously described by Richter et al. (2012). Nitrogen analysis of TMR, fecal samples, feed refusals, and urine composites from each period was determined by
combustion (AOAC, 1990) using a Leco Tru-Mac (Leco Corporation, St. Joseph, MI). Crude protein was calculated as N × 6.25 and EDTA was used daily as a calibration standard. Plasma urea N concentration was determined using a commercially available assay (Stanbio Laboratory, Boerne, TX) utilizing a standard and pooled bovine plasma sample with each run as an intra-assay standard (intra-assay CV of 7.4%) and spectrophotometer (Eon Microplate Spectrophotometer, BioTek, Winooski, VT) at a wavelength of 600 nm.

Nitrogen balance (retention) was calculated as N intake minus N excreted and was expressed as the average daily retention in grams per d. Nitrogen intake is equivalent to the quantity of N offered (percentage of N of the feed offered times the quantity of feed offered) minus the quantity of N in feed refusals (percentage of N of the feed refused times the quantity of feed refused). Nitrogen excreted is defined as quantity of N in urine [the percentage of N in total urine times the quantity (mass) of urine excreted] and feces (percentage of N of in the fecal output times quantity of feces) during the collection period.

**Experiment 2**

**Animals and experimental design.** To evaluate the impact of C-WDG on steer growth performance and carcass characteristics during the finishing phase, Angus-influenced crossbreed steers (n = 168) were purchased from two sources and transported to the ISU Beef Nutrition Research Unit (Ames, Iowa). Upon arrival, steers from source one were vaccinated with Bovi-shield GOLD 5 (Zoetis, New York, NY) and dewormed with Ivomec Eprinex Pour-On (Merial Animal Health, Duluth, GA) and started on a growing diet. Steers from the second source were dewormed prior to arrival to the research
farm and vaccinated with Bovi-Shield GOLD 5 (Zoetis) and One Shot Ultra7 (Zoetis) upon arrival. All steers were fed a series of transition diets based on previous management to assure steers were prepared for a concentrate-based diet. Steers from source one were fed a series of two transition diets over 14 d while the second source was fed a series of four transition diets over a period of 21 d. The final transition diet for all steers consisted of 12% roughage, 53% corn, 30% WDG, with the remaining 5% including DG as the carrier for the micro-nutrients and was fed for 4 d prior to the start of the trial.

At the initiation of the study, BW were collected on 2 consecutive d prior to feeding (d 0 and 1). Steers were blocked by initial BW (421 ± 23.9 kg, SD), stratified by source, and randomly assigned to 1 of 4 dietary treatments (7 pens/treatment, 6 steers/pen): corn-based control with 13% T-WDG (CON), 30% T-WDG (TRAD), 30% C-WDG (CEL), and 18% C-WDG and 12% dietary CCDS (CEL+CCDS) on a DM basis (Table 3). For each treatment, T-WDG or C-WDG were added at the expense of dry rolled corn on a DM basis. Steers were housed in a partial-confinement building (7.5 m²/steer) with ad libitum access to water. Cattle were fed their respective diets once daily in the morning targeting a clean bunk management protocol (Pritchard and Bruns, 2003). Bunks were scored and feed calls were made at the same time each d prior to feeding, and a 5% increase (DM basis) in feed delivered was made after 3 consecutive d of clean bunk scores.

Throughout the duration of the trial, interim BW were collected prior to feeding on d 28, 56, and 66. Steers were implanted with Component TE-IS (donated by Elanco Animal Health, Greenfield, IN) on d 28 of the trial. On d 66, steers were started on ractopamine hydrochloride (Optaflexx, donated by Elanco Animal Health, Greenfield, IN) and fed at a rate of 300 mg steer⁻¹·d⁻¹ for the last 28 d of the trial. Consecutive d final BW were taken
at the end of the study (d 93 and 94), and steers were shipped to a commercial abattoir (Tyson Fresh Meats, Denison, IA) on d 94.

**Sample collection and analytical procedures.** Pen feed delivery and bunk scores were recorded daily, and DMI was calculated. Average daily gain and G:F were determined using pen DMI and BW gain over the duration of the trial. Based on the observed mean pen performance, the energy value (expressed as ME and NEg) was calculated using the equation described by Plascencia et al. (1999). Samples of individual ingredients and TMR were collected weekly, and pen feed refusals were collected monthly for DM determination. Samples were dried in a 70°C forced-air oven for 48 h to determine DM. Total mixed rations were ground through a 2 mm screen in a Wiley mill (Thomas Scientific, Swedesboro, NJ), and a sub-sample was sent to Dairyland Laboratories, Inc. (Arcadia, WI) for wet chemistry analysis of NDF (AOAC, 2005, method 2002.04), ADF (AOAC, 1995, method 973.18), starch (Hall, 2009), and EE (AOAC, 1995, method 920.39). Individual ingredients were sent to Dairyland Laboratories, Inc. for CP analysis (AOAC, 1995, method 990.03), and dietary CP concentrations were calculated based on ingredient CP analysis and inclusion in the diet. Dietary S concentrations of TMR samples were determined as described in Exp. 1.

At the initiation and completion of the study (d 0 and 94), all steers were scanned via real time ultrasound (Scanner 200, model 41480, Pie Medical, Masstricht, Netherlands) by a certified technician for LM area, percent intramuscular fat (IMF), and 12th rib backfat thickness (BF). Images were analyzed by Centralized Ultrasound Processing (CUP) Lab (Walter & Associates, LLC, Ames, IA). Steers were harvested on d 95 at a commercial abattoir, and HCW data were collected. Individual carcass data were collected after a 24 h
chill by representatives of Tri County Steer Futurity (Iowa State University Beef Extension, Lewis, IA) who were blind to treatments. Carcass data collected included: BF, LM area, marbling score, yield grade (YG), and quality grade (QG). A 4% pencil shrink was applied to initial BW and final BW (FBW) was calculated from HCW using the average dressing percentage of 63.55% to determine carcass-adjusted performance.

Statistical Analysis

**Experiment 1.** Data were analyzed by ANOVA using the Mixed procedure of SAS 9.3 (SAS Institute, Inc., Cary, NC) with lamb as the experimental unit (n = 10/treatment). The model included the fixed effects of treatment and lamb nested within square and the random effect of period. When the overall F-test was significant (P ≤ 0.05), treatment means were separated using the PDIF statement in SAS.

**Experiment 2.** Data were analyzed by ANOVA in SAS 9.3 (SAS Institute, Inc.) as a randomized complete block design with pen as the experimental unit (n = 7/treatment). The model included the fixed effect of treatment and random effect of block. Final ultrasound data were analyzed using the initial scan measurements as a covariate. Performance and carcass characteristic data were analyzed using PROC Mixed while YG and QG distribution data were analyzed using PROC Glimmix of SAS. Three *a priori* single df contrast statements were constructed: 1) CON vs. TRAD, 2) TRAD vs. CEL, and 3) CEL vs. CEL+CCDS.

For both experiments, outliers were determined using Cook’s D statistics, and if Cook’s D values were greater than 0.5, outliers would have been removed; however, no outliers were identified. Significance was declared at P ≤ 0.05 and tendencies were
declared from $P = 0.06$ to 0.10. Means reported are least square means (LSMEANS) ± SEM.

**Results**

**Experiment 1.** Dry matter intake, diet digestibility, and fecal and urine output are presented in Table 4. While DMI and OMI were not different ($P \geq 0.11$) between CORN, 30% T-WDG, 45% T-WDG, or 45% C-WDG, lambs fed 30% C-WDG had decreased ($P \leq 0.05$) DMI and OMI compared to the other treatments. Dry matter digestibility was affected ($P \leq 0.01$) by treatment. Compared to lambs fed CORN or 30% T-WDG, DM digestibility of lambs fed 45% T-WDG or 30% C-WDG was lesser ($P < 0.05$), while lambs fed 45% C-WDG had lesser ($P \leq 0.05$) DM digestibility than all other treatments. Daily fecal output was less ($P \leq 0.01$) for lambs fed the lesser inclusions of WDG (CORN, 30% T-WDG, and 30% C-WDG) compared to those fed 45% WDG, regardless of WDG source. Urine output was also influenced by treatment ($P = 0.02$) with lambs fed CORN having lesser ($P \leq 0.05$) urine output than all other treatments.

As expected, increasing concentrations of T-WDG or C-WDG increased NDF and ADF concentrations in the diets ($P \leq 0.01$; Table 5). At the 30% inclusion, dietary concentrations of NDF were greater ($P \leq 0.05$) in C-WDG compared to T-WDG and dietary concentrations of ADF were not different ($P = 0.63$) between the two WDG sources. Digestibility of NDF was not different ($P = 0.13$) due to treatment. Digestibility of ADF by lambs fed 30% T-WDG, 30% C-WDG, or 45% C-WDG were not different ($P \geq 0.21$) compared to CORN, but tended to differ ($P = 0.06$) between 30% T-WDG and 45%
C-WDG, and was greater \( P \leq 0.05 \) in lambs fed 45% T-WDG compared to CORN, 30% T-WDG, 30% C-WDG, or 45% C-WDG.

Ether extract concentrations of the diet were not affected by source of WDG but increased as inclusions of WDG increased in the diet \( (P < 0.01; \text{Table 5}) \). While EE digestibility was not different \( (P = 0.54) \) between the two sources of WDG at 30% inclusion, at the 45% inclusion, EE digestibility was greater \( (P < 0.05) \) for C-WDG compared to T-WDG.

Dietary N concentrations increased \( (P \leq 0.01) \) as inclusion of WDG increased in the diets, and concentrations were greater \( (P \leq 0.05) \) for C-WDG compared to T-WDG at both 30% and 45% inclusions of WDG. Sulfur concentrations in the diets increased \( (P \leq 0.01) \) as inclusion of WDG increased, but were not different due to source of WDG. Digestibility of N was lesser for CORN and greater for 45% C-WDG compared to all other treatments \( (P \leq 0.05) \), while N digestibility was similar across 30% and 45% T-WDG and 30% C-WDG \( (P \geq 0.12) \). Similarly, PUN concentrations were different due to treatment \( (P = 0.01; \text{Table 5}) \). Compared to the CORN–fed lambs, PUN concentration was greater \( (P \leq 0.05) \) at 30% WDG inclusion regardless of source, followed by 45% T-WDG fed lambs \( (P \leq 0.05) \), and greatest \( (P \leq 0.05) \) in lambs fed 45% C-WDG. Nitrogen balance was not affected \( (P = 0.27) \) by addition of WDG, regardless of source.

**Experiment 2.** Live animal performance and carcass data are presented in Table 6. While DMI did not differ \( (P = 0.31) \) between CON or TRAD, TRAD–fed steers had improved ADG \( (P < 0.01) \) and thus, improved G:F \( (P < 0.01) \) compared to steers fed CON. Likewise, energy values (ME and NEg) calculated from steer performance were greater \( (P \)
< 0.01) for steers finished on TRAD compared to those finished on CON. Steers finished on TRAD had heavier FBW and HCW \((P = 0.01)\) compared to CON–fed steers. Marbling score, BF, and YG did not differ \((P \geq 0.52)\) between CON and TRAD; however, steers finished on TRAD tended \((P = 0.07)\) to have a larger LM area compared to steers fed CON.

No differences \((P \geq 0.12; \text{Table 6})\) were observed among steers fed CEL or TRAD for ADG, FBW, HCW, LM area, or marbling score. However, steers fed CEL had decreased G:F, ME, and NEg \((P \leq 0.01)\) and increased DMI \((P = 0.02)\) compared to TRAD–fed steers. Steers fed CEL had leaner carcasses as indicated by lesser USDA YG \((P = 0.03)\) and decreased BF \((P = 0.04)\) compared to steers fed TRAD. Among steers fed CEL and CEL+CCDS, G:F was not different \((P = 0.50)\). However, steers fed CEL+CCDS had lesser \((P \leq 0.04)\) DMI and ADG compared to steers finished on CEL. This resulted in a tendency \((P = 0.09)\) for steers fed CEL+CCDS to have lesser FBW and HCW compared to CEL steers. Based on steer performance, the CEL+CCDS diet tended to have greater \((P \leq 0.06)\) calculated ME and NEg values compared to CEL. Marbling score, BF, LM area, and YG did not differ \((P \geq 0.15)\) between steers fed CEL and CEL+CCDS.

Distributions of YG were not affected \((P \geq 0.15; \text{data not shown})\) by treatment and averaged 3.6, 45.6, 44.6, and 4.8%, SEM of 7.35, for YG 1, 2, 3, and 4, respectively. Likewise, QG distributions did not differ \((P \geq 0.12; \text{data not shown})\) due to treatment and averaged 18.8, 65.7, and 13.2%, SEM of 6.26, for average choice or higher, low choice, and select, respectively.

Real time ultrasound measurements are presented in Table 7. Final ultrasound measurements showed that steers fed CEL had decreased BF \((P = 0.03)\) compared to steers fed TRAD, but LM area and IMF did not differ \((P \geq 0.27)\) between treatments. Steers
finished on CEL had a decreased rate of external fat deposition \( (P = 0.04) \) without negatively affecting marbling score \( (P = 0.59) \) compared to TRAD–fed steers.

**Discussion**

While corn oil extraction has become standard in the ethanol industry, generation of cellulosic ethanol via corn fiber fermentation has only recently become possible due to technological advancements. This research was conducted to better understand how a co-product of a cellulosic ethanol process from corn fiber (C-WDG) may influence nutrient digestibility and cattle performance compared to traditional WDG (T-WDG) in finishing diets. To the authors’ knowledge, this is the first report on the influence of co-product produced from corn kernel fiber derived cellulosic ethanol production on ruminant digestibility or performance. The ethanol plant responsible for C-WDG technology has commercially been producing C-WDG since July 2014, and to date, the nutrient composition has been similar to the C-WDG produced in the test-run for use of this research.

In the lamb study, NDF digestibility was not different between treatments and ADF digestibility was similar between sources of WDG at 30% inclusion. However, at the 45% inclusion of WDG, ADF digestibility was greater for lambs fed 45% T-WDG compared to those fed 45% C-WDG, suggesting that the secondary fermentation process may have hindered the bioavailability of some portion of the remaining fiber in the C-WDG. Previous *in vitro* research with a pretreatment of corn fiber utilizing cellulase and additional heat resulted in almost 80% of the kernel fiber being dissolved during the first 24 h of the pretreatment process (Mosier et al., 2005), suggesting that after pretreatment processing of
the corn kernel, only the less soluble fiber remains. It appears that the secondary fermentation process may impact digestion of the residual fiber; however, additional research is needed to further clarify this finding.

At the 30% inclusions, T-WDG and C-WDG resulted in similar digestibility for NDF, EE, and N in lambs. However, DM and ADF digestibility was decreased in 30% C-WDG-fed lambs compared to 30% T-WDG. While growth did not differ between CEL and TRAD-fed cattle, G:F was less efficient in CEL-fed steers which may be attributed to the reduction in DM digestibility of C-WDG. The increase in EE digestibility of C-WDG at the 45% inclusion compared to 45% T-WDG suggests that although slightly more oil was removed from DG following the secondary fermentation process, the remaining oil was more available to the animal for utilization compared to the T-WDG. Previous research providing equivalent dietary EE from corn oil or WDG plus solubles (WDGS) indicated that cattle fed WDGS had improved performance and thus, the authors concluded that oil in DG is more digestible than free corn oil (Vander Pol et al., 2009). However, free corn oil has also been attributed to interfering with fiber digestion (Jenkins and Fotouhi, 1990), which could explain why ADF and DM digestion were lesser in C-WDG-fed lambs compared with T-WDG fed lambs in Exp. 1.

While this is the first research to be conducted with WDG from a secondary fermentation process and no data are available for direct comparison, previous research has compared de-oiled and low-fat DG to traditional DG. Gigax et al. (2011) found that steers fed 35% traditional-fat WDGS (12.9% fat; 6.91% total dietary fat) had improved feed conversion and heavier FBW and HCW compared to steers fed 35% low-fat WDGS (6.7% fat; 4.72% total dietary fat). However, similar EE concentrations among the two WDG
sources used in the present experiment (7.7% and 7.3% EE for T-WDG and C-WDG, respectively) may partially explain why steer growth was not different between cattle fed 30% WDG of either source. Similar to results in Exp. 2, Ceconi et al. (2013) fed diets containing 35% traditional-fat dried DG plus solubles (DDGS; 6.7% total dietary fat) or 35% low-fat DDGS (4.5% total dietary fat) to steers and observed no difference in DMI. However, OM digestibility also did not differ (Ceconi et al., 2013), whereas in Exp. 1, DM and OM digestibilities of lambs fed diets containing T-WDG were greater than those fed C-WDG.

Much of the digestibility differences in the lamb trial (Exp. 1) were driven by the 45% inclusions of WDG, which were not evaluated in the steer study (Exp. 2). One difference between C-WDG and T-WDG that was not directly measured in Exp. 1 is digestibility of starch, which may have potentially impacted results of Exp. 2 as there was less starch in C-WDG (1.6%) compared to T-WDG (5.1%). Although starch concentrations are decreased in DG (Klopfenstein et al., 2008), starch is a rapidly-fermentable carbohydrate which supplies energy and supports performance of the ruminant (Huntington, 1997). While starch remained a small component of the final diets, removal of residual starch during the C-WDG process may have contributed to the decreased feed efficiency of steers fed C-WDG compared to steers fed T-WDG.

Compared to CORN, increasing inclusions of C-WDG and T-WDG in the diets of Exp. 1 increased N digestibility. Urine output was increased as WDG increased in the diet, regardless of source, and may in part be due to increased S concentrations of the diets. This is consistent with previous studies where urine output increased linearly in lambs fed up to 60% DDGS as dietary S concentrations increased from 0.22 to 0.84% (Neville et al., 2011)
or 0.12 to 0.47% (Felix et al., 2012). As inclusions of WDG increased in the diets regardless of source, lamb PUN concentrations also increased, which was reflective of the increase of N dietary concentrations and N digestibility of diets. Plasma urea concentrations reported in other feedlot lamb trials were lesser than results from Exp. 1, but the N content of the diets fed in previous trials were also lesser than the present study (Bohnert et al., 2002; Sunny et al., 2007). However, Radunz et al. (2011) fed gestating ewes diets containing similar dietary concentrations of N to those fed in Exp. 1 and noted PUN concentrations similar to those observed in the present study. In the current study, the increase in PUN concentrations as WDG increased, regardless of source, along with the positive N balance, suggest that diets exceeded the lamb protein requirements (NRC, 2007) to support maintenance and growth. The lack of N balance differences between treatments could be explained by the large variation between lambs; however, the focus of Exp. 1 was on nutrient digestibility rather than N retention.

In a study by Pritchard et al. (2012), feeding 40% WDGS (12.2% fat; 6.58% total dietary fat) to steers increased DMI, ADG, and improved feed conversion compared to feeding 40% WDG (8.9% fat; 5.34% total dietary fat). However, in Exp. 2 of the present report, the addition of CCDS to the C-WDG (CEL+CCDS diet) appeared to hinder DMI and ADG compared to steers fed CEL. The decreased performance of steers finished on CEL+CCDS is most likely attributed to the S content of the CCDS which were analyzed to be 2.10% S (Dairyland Laboratories Inc., Acardia WI), corresponding to 0.47% dietary S for CEL+CCDS compared to 0.34% S for CEL diet. Diets containing greater than 0.40% S have been shown to decrease DMI and growth performance in cattle in numerous studies (DiCostanzo and Crawford, 2013; Pogge and Hansen, 2013; Drewnoski et al., 2014). In
this study, CCDS were included at 12% of the diet (DM basis); therefore, more moderate inclusions of CCDS to C-WDG may be feasible without decreasing DMI and hindering ADG as observed in Exp. 2.

Results from the present studies are consistent with previous research reiterating that traditional WDG are superior to corn in energy value in finishing cattle diets (Gigax et al., 2011; Pritchard et al., 2012; Jolly et al., 2013; Watson et al., 2014). Although diets were formulated to meet or exceed NRC (2000) requirements, DIP may have limited cattle performance in the CON diet, contributing to performance differences between CON and TRAD–fed steers. Based on the dietary ME and NEg values calculated from cattle performance in Exp. 2, the energy value of T-WDG was calculated to be 25% greater than C-WDG. While not statistically compared, dietary energy content was similar between CON and CEL based on cattle growth and DMI.

In summary, feeding 30% T-WDG in the present experiments resulted in similar digestibility and improved performance compared to feeding corn-based control diets. Wet DG from a novel, secondary fermentation process to produce cellulosic ethanol from corn kernel fiber (C-WDG) resulted in similar fiber, EE, and N digestibilities at 30% of the diet compared to 30% T-WDG. Although DM digestibility was slightly decreased in C-WDG compared to T-WDG at 30% inclusion in the lamb digestibility study, growth and carcass performance of steers fed 30% C-WDG was similar to those fed 30% T-WDG while feed efficiency was decreased. Therefore, incorporation of a co-product from a novel, secondary fermentation process for conversion of corn kernel fiber into cellulosic ethanol maintained growth performance of cattle when replacing corn in feedlot diets.
Literate Cited


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


Table 1. Nutrient composition of co-products (% DM basis).

<table>
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<th>T-WDG(^1)</th>
<th>C-WDG(^2)</th>
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<td>10.3</td>
</tr>
<tr>
<td>Starch</td>
<td>5.1</td>
<td>1.6</td>
<td>–</td>
</tr>
<tr>
<td>Lignin</td>
<td>1.0</td>
<td>1.4</td>
<td>–</td>
</tr>
<tr>
<td>S</td>
<td>0.74</td>
<td>0.72</td>
<td>2.10</td>
</tr>
</tbody>
</table>

\(^1\)Traditional wet distillers grains.

\(^2\)Cellulosic wet distillers grains derived from secondary fermentation of corn kernel fiber.

\(^3\)Corn condensed distillers solubles.
## Table 2. Ingredient composition of diets fed to lambs in Exp. 1 (% DM basis).

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>CORN(^1)</th>
<th>T-WDG(^2)</th>
<th>C-WDG(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry rolled corn</td>
<td>65</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>Chopped bromegrass hay</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Traditional wet distillers grains</td>
<td>7.5</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>CEL wet distillers grains(^3)</td>
<td>7.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Finely ground corn(^4)</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
</tr>
<tr>
<td>Limestone</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Ammonium chloride</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Salt</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>Vitamin A, D and E premix(^5)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Trace mineral premix(^6)</td>
<td>0.027</td>
<td>0.027</td>
<td>0.027</td>
</tr>
<tr>
<td>Bovatec(^7)</td>
<td>0.0125</td>
<td>0.0125</td>
<td>0.0125</td>
</tr>
</tbody>
</table>

\(^1\)CORN: corn-based control diet with 7.5% traditional wet distillers grains and 7.5% cellulosic wet distillers grains (DM basis).

\(^2\)Traditional wet distillers grains included at 30% and 45% of the diet (DM basis).

\(^3\)Cellulosic wet distillers grains derived from secondary fermentation of corn kernel fiber included at 30% and 45% of the diet (DM basis).

\(^4\)Carrier for micro-ingredients.

\(^5\)Vitamin A, D and E premix contained 4,410,000 IU/kg\(^1\) of Vitamin A, 1,100,000 IU/kg\(^1\) of Vitamin D, and 900 IU/kg\(^1\) of Vitamin E.

\(^6\)Provided per kg of diet DM: 30 mg of Zn (zinc sulfate), 25 mg of Mn (manganese sulfate), 0.6 mg of I (calcium iodate), 0.22 mg Se (sodium selenite), and 0.2 mg of Co (cobalt carbonate).

\(^7\)Provided lasalocid at 25g/t of diet (Zoetis, New York, NY).
### Table 3. Ingredient and nutrient composition of diets fed to steers in Exp. 2 (% DM basis).

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>CON(^1)</th>
<th>TRAD(^1)</th>
<th>CEL(^1)</th>
<th>CEL+CCDS(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry rolled corn</td>
<td>70</td>
<td>53</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Chopped bromegrass hay</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Traditional wet distillers grains</td>
<td>13</td>
<td>30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CEL wet distillers grains(^2)</td>
<td>-</td>
<td>-</td>
<td>30</td>
<td>18</td>
</tr>
<tr>
<td>Corn condensed distillers solubles</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>Dried distillers grains plus solubles(^3)</td>
<td>3.13</td>
<td>3.13</td>
<td>3.13</td>
<td>3.13</td>
</tr>
<tr>
<td>Limestone</td>
<td>1.41</td>
<td>1.41</td>
<td>1.41</td>
<td>1.41</td>
</tr>
<tr>
<td>Salt</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>Vitamin A premix(^4)</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Trace mineral premix(^5)</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
</tr>
<tr>
<td>Rumensin90(^6)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

**Analyzed composition**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>CON(^1)</th>
<th>TRAD(^1)</th>
<th>CEL(^1)</th>
<th>CEL+CCDS(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP</td>
<td>12.29</td>
<td>16.63</td>
<td>18.12</td>
<td>16.08</td>
</tr>
<tr>
<td>NDF</td>
<td>23.85</td>
<td>26.48</td>
<td>25.89</td>
<td>22.46</td>
</tr>
<tr>
<td>ADF</td>
<td>11.90</td>
<td>12.72</td>
<td>13.27</td>
<td>11.00</td>
</tr>
<tr>
<td>Starch</td>
<td>48.91</td>
<td>37.98</td>
<td>39.92</td>
<td>39.03</td>
</tr>
<tr>
<td>Ether extract</td>
<td>4.97</td>
<td>6.13</td>
<td>6.29</td>
<td>7.35</td>
</tr>
<tr>
<td>S</td>
<td>0.21</td>
<td>0.36</td>
<td>0.34</td>
<td>0.47</td>
</tr>
</tbody>
</table>

\(^1\)Treatments: CON: control; TRAD: 30% traditional wet distillers grains; CEL: 30% cellulosic wet distillers grains; CEL+CCDS: 18% cellulosic wet distillers grains and 12% corn condensed distillers solubles.

\(^2\)Cellulosic wet distillers grains derived from secondary fermentation of corn kernel fiber.

\(^3\)Carrier for micro-ingredients.

\(^4\)Vitamin A premix contained 4,400,000 IU/kg\(^1\).

\(^5\)Provided per kg of diet DM: 30 mg Zn (zinc sulfate), 20 mg Mn (manganese sulfate), 10 mg Cu (copper sulfate), 0.5 mg I (calcium iodate), 0.1 mg Se (sodium selenite), and 0.1 mg Co (cobalt carbonate).

\(^6\)Provided monensin at 27g/t of diet (Elanco Animal Health, Greenfield, IN).
Table 4. Influence of traditional and cellulosic\(^1\) wet distillers grains on lamb daily dry matter intake, diet digestibility, and fecal and urine output (Exp. 1).

<table>
<thead>
<tr>
<th></th>
<th>T-WDG(^3)</th>
<th>C-WDG(^4)</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30%</td>
<td>45%</td>
<td>30%</td>
<td>45%</td>
</tr>
<tr>
<td>Lambs (n)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>DM intake, kg/d</td>
<td>1.18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.23&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.08&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>OM intake, kg/d</td>
<td>1.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.04&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>DM digestibility, %</td>
<td>80.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>78.3&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>OM digestibility, %</td>
<td>81.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>81.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>78.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>79.4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Daily output</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fecal, kg DM/d</td>
<td>0.23&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.23&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.24&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Urine, L/d</td>
<td>1.76&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.41&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

\(^1\)Cellulosic wet distillers grains derived from secondary fermentation of corn kernel fiber.
\(^2\)CORN: corn-based control diet with 7.5% traditional wet distillers grains and 7.5% cellulosic wet distillers grains (DM basis).
\(^3\)Traditional wet distillers grains included at 30% and 45% of the diet (DM basis).
\(^4\)Cellulosic wet distillers grains included at 30% and 45% of the diet (DM basis).
\(\text{abc}\)Means within a row without a common superscript differ \((P \leq 0.05)\).
Table 5. Influence of traditional and cellulosic\textsuperscript{1} wet distillers grains on dietary concentrations and digestibility of nutrients by lambs (Exp. 1).

<table>
<thead>
<tr>
<th></th>
<th>T-WDG\textsuperscript{3}</th>
<th>C-WDG\textsuperscript{4}</th>
<th>SEM</th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diet concentrations, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>24.6\textsuperscript{d}</td>
<td>26.9\textsuperscript{c}</td>
<td>32.2\textsuperscript{ab}</td>
<td>31.0\textsuperscript{b}</td>
</tr>
<tr>
<td>ADF</td>
<td>8.8\textsuperscript{c}</td>
<td>9.7\textsuperscript{bc}</td>
<td>11.4\textsuperscript{a}</td>
<td>10.4\textsuperscript{ab}</td>
</tr>
<tr>
<td>Ether extract</td>
<td>2.7\textsuperscript{c}</td>
<td>3.5\textsuperscript{b}</td>
<td>4.1\textsuperscript{a}</td>
<td>3.6\textsuperscript{b}</td>
</tr>
<tr>
<td>N</td>
<td>2.1\textsuperscript{c}</td>
<td>2.6\textsuperscript{d}</td>
<td>3.2\textsuperscript{b}</td>
<td>2.9\textsuperscript{c}</td>
</tr>
<tr>
<td>S</td>
<td>0.21\textsuperscript{c}</td>
<td>0.32\textsuperscript{b}</td>
<td>0.41\textsuperscript{a}</td>
<td>0.33\textsuperscript{b}</td>
</tr>
<tr>
<td>Digestibility, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>50.8</td>
<td>51.8</td>
<td>55.1</td>
<td>53.0</td>
</tr>
<tr>
<td>ADF</td>
<td>50.2\textsuperscript{b}</td>
<td>51.8\textsuperscript{b}</td>
<td>57.2\textsuperscript{a}</td>
<td>50.6\textsuperscript{b}</td>
</tr>
<tr>
<td>Ether extract</td>
<td>81.5\textsuperscript{c}</td>
<td>84.1\textsuperscript{abc}</td>
<td>82.8\textsuperscript{bc}</td>
<td>85.1\textsuperscript{ab}</td>
</tr>
<tr>
<td>N</td>
<td>73.9\textsuperscript{e}</td>
<td>79.5\textsuperscript{b}</td>
<td>80.8\textsuperscript{b}</td>
<td>80.8\textsuperscript{b}</td>
</tr>
<tr>
<td>N balance, g/d</td>
<td>6.4</td>
<td>6.3</td>
<td>7.6</td>
<td>5.9</td>
</tr>
<tr>
<td>PUN\textsuperscript{5}</td>
<td>12.3\textsuperscript{d}</td>
<td>17.2\textsuperscript{c}</td>
<td>20.6\textsuperscript{b}</td>
<td>18.0\textsuperscript{c}</td>
</tr>
</tbody>
</table>

\textsuperscript{1}Cellulosic wet distillers grains derived from secondary fermentation of corn kernel fiber.

\textsuperscript{2}CORN: corn-based control diet with 7.5% traditional wet distillers grains and 7.5% cellulosic wet distillers grains (DM basis).

\textsuperscript{3}Traditional wet distillers grains included at 30% and 45% of the diet (DM basis).

\textsuperscript{4}Cellulosic wet distillers grains included at 30% and 45% of the diet (DM basis).

\textsuperscript{5}Plasma urea nitrogen concentration.

\textsuperscript{abcde}Means within a row without a common superscript differ \((P \leq 0.05)\).
Table 6. Influence of traditional and cellulosic\textsuperscript{1} wet distillers grains on steer performance and carcass characteristics (Exp. 2).

<table>
<thead>
<tr>
<th>Performance</th>
<th>CON\textsuperscript{2}</th>
<th>TRAD\textsuperscript{2}</th>
<th>CEL\textsuperscript{2}</th>
<th>CEL+CCDS\textsuperscript{2}</th>
<th>SEM</th>
<th>CON vs TRAD\textsuperscript{3}</th>
<th>TRAD vs CEL\textsuperscript{4}</th>
<th>CEL vs CEL+CCDS\textsuperscript{5}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial BW\textsuperscript{6}, kg</td>
<td>422</td>
<td>421</td>
<td>420</td>
<td>421</td>
<td>9.6</td>
<td>0.17</td>
<td>0.24</td>
<td>0.14</td>
</tr>
<tr>
<td>Final BW\textsuperscript{7}, kg</td>
<td>572</td>
<td>586</td>
<td>578</td>
<td>570</td>
<td>11.1</td>
<td>0.01</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>10.7</td>
<td>10.5</td>
<td>10.9</td>
<td>10.0</td>
<td>0.24</td>
<td>0.31</td>
<td>0.02</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>1.59</td>
<td>1.75</td>
<td>1.68</td>
<td>1.58</td>
<td>0.04</td>
<td>&lt;0.01</td>
<td>0.17</td>
<td>0.04</td>
</tr>
<tr>
<td>Gain:feed</td>
<td>0.149</td>
<td>0.166</td>
<td>0.154</td>
<td>0.157</td>
<td>0.004</td>
<td>&lt;0.01</td>
<td>0.01</td>
<td>0.50</td>
</tr>
<tr>
<td>ME\textsuperscript{8}, Mcal/kg</td>
<td>2.84</td>
<td>2.96</td>
<td>2.84</td>
<td>2.92</td>
<td>0.03</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>NE\textsuperscript{8}, Mcal/kg</td>
<td>1.26</td>
<td>1.35</td>
<td>1.26</td>
<td>1.32</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Carcass characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCW, kg</td>
<td>364</td>
<td>372</td>
<td>368</td>
<td>362</td>
<td>7.1</td>
<td>0.01</td>
<td>0.16</td>
<td>0.07</td>
</tr>
<tr>
<td>Backfat thickness, cm</td>
<td>1.21</td>
<td>1.24</td>
<td>1.13</td>
<td>1.21</td>
<td>0.05</td>
<td>0.52</td>
<td>0.04</td>
<td>0.15</td>
</tr>
<tr>
<td>LM area, cm\textsuperscript{2}</td>
<td>82.54</td>
<td>85.41</td>
<td>85.71</td>
<td>84.67</td>
<td>1.54</td>
<td>0.07</td>
<td>0.84</td>
<td>0.50</td>
</tr>
<tr>
<td>Marbling score\textsuperscript{9}</td>
<td>455</td>
<td>450</td>
<td>450</td>
<td>441</td>
<td>10.20</td>
<td>0.75</td>
<td>0.98</td>
<td>0.56</td>
</tr>
<tr>
<td>Yield Grade</td>
<td>3.1</td>
<td>3.1</td>
<td>2.8</td>
<td>3.0</td>
<td>0.08</td>
<td>0.75</td>
<td>0.03</td>
<td>0.16</td>
</tr>
</tbody>
</table>

\textsuperscript{1}Cellulosic wet distillers grains derived from secondary fermentation of corn kernel fiber.

\textsuperscript{2}Treatments: CON: corn-based control with 13% traditional wet distillers grains; TRAD: 30% traditional wet distillers grains; CEL: 30% cellulosic wet distillers grains; CEL+CCDS: 18% cellulosic wet distillers grains and 12% corn condensed distillers solubles.

\textsuperscript{3}Contrast comparing CON and TRAD.

\textsuperscript{4}Contrast comparing TRAD and CEL.

\textsuperscript{5}Contrast comparing CEL and CEL+CCDS.

\textsuperscript{6}A 4% pencil shrink was applied to all live weights.

\textsuperscript{7}Final body weights were calculated from HCW using a common dressing percentage of 63.55%.

\textsuperscript{8}Energy values calculated based on cattle performance using equation by Plascenia et al. (1999).

\textsuperscript{9}Marbling score: 300=slight, 400=small, and 500=modest.
Table 7. Influence of traditional and cellulosic\(^1\) wet distillers grains on real time ultrasound measurements of steers (Exp. 2).

<table>
<thead>
<tr>
<th></th>
<th>CON(^2)</th>
<th>TRAD(^2)</th>
<th>CEL(^2)</th>
<th>CEL+CCDS(^2)</th>
<th>SEM</th>
<th>CON vs TRAD(^3)</th>
<th>TRAD vs CEL(^4)</th>
<th>CEL vs CEL+CCDS(^5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial (d 0)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backfat, cm</td>
<td>0.70</td>
<td>0.73</td>
<td>0.72</td>
<td>0.68</td>
<td>0.03</td>
<td>0.53</td>
<td>0.83</td>
<td>0.30</td>
</tr>
<tr>
<td>LM area, cm(^2)</td>
<td>71.28</td>
<td>72.63</td>
<td>72.02</td>
<td>71.33</td>
<td>1.07</td>
<td>0.39</td>
<td>0.69</td>
<td>0.65</td>
</tr>
<tr>
<td>IMF(^6), %</td>
<td>3.72</td>
<td>3.50</td>
<td>3.48</td>
<td>3.57</td>
<td>0.17</td>
<td>0.36</td>
<td>0.95</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Final (d 94)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backfat, cm</td>
<td>1.17</td>
<td>1.17</td>
<td>1.09</td>
<td>1.07</td>
<td>0.03</td>
<td>0.80</td>
<td>0.03</td>
<td>0.74</td>
</tr>
<tr>
<td>LM area, cm(^2)</td>
<td>90.81</td>
<td>91.76</td>
<td>92.72</td>
<td>91.25</td>
<td>1.00</td>
<td>0.49</td>
<td>0.49</td>
<td>0.29</td>
</tr>
<tr>
<td>IMF, %</td>
<td>3.84</td>
<td>3.83</td>
<td>3.96</td>
<td>3.76</td>
<td>0.08</td>
<td>0.92</td>
<td>0.27</td>
<td>0.11</td>
</tr>
</tbody>
</table>

\(^1\)Cellulosic wet distillers grains derived from secondary fermentation of corn kernel fiber.

\(^2\)Treatments: CON: control; TRAD: 30% traditional wet distillers grains; CEL: 30% cellulosic wet distillers grains; CEL+CCDS: 18% cellulosic wet distillers grains and 12% corn condensed distillers solubles.

\(^3\)Contrast comparing CON and TRAD.

\(^4\)Contrast comparing TRAD and CEL.

\(^5\)Contrast comparing CEL and CEL+CCDS.

\(^6\)Percent intramuscular fat of the LM area.

\(^7\)Analyzed using the initial scan measurements as a covariate.
CHAPTER 5.

GENERAL CONCLUSION

Changes in the ethanol production process alter the nutrient profile of distillers grains (DG) produced. For example, removal of corn oil during ethanol production results in a decreased oil or fat content of DG. Because of these changes in the ethanol production process, the value and management of new generation DG in finishing diets could be altered compared to traditional process DG in order to maximize performance of cattle. In an era of increasingly volatile feed prices, cattle feeders may vary inclusion of corn co-products and test the upper limits at which they can safely feed co-products. Even with typical inclusions, less grain is now being fed, and producer management, such as corn processing, may be changed. Therefore, the research included in this thesis was designed to determine the influence of corn processing methods in diets of moderate inclusions of wet DG plus solubles (WDGS) as well as wet DG (WDG) produced from a novel cellulosic ethanol process (C-WDG) on nutrient digestibility of lambs and feedlot performance of cattle.

The first experiment was designed to answer a practical producer question of whether feeding moderate inclusions of WDGS would help moderate the acidosis risk when feeding finely ground corn (FGC). The hypothesis was that decreasing corn particle size would allow for improved starch utilization and thus, cattle performance when fed in conjunction with 35% WDGS which would moderate the rumen pH to aid in avoiding acidosis. While steers fed FGC did have an 11% advantage in starch utilization over steers fed dry-rolled corn (DRC), ADG and DMI were decreased by 8% and 6%,
respectively, for FCG-fed steers. The FGC used in this study was less than half the density of the industry standard for DRC (Schwandt et al., 2014); therefore, a more moderate grind may result in similar starch digestibility, but improve cattle performance. Likewise, adjusting the inclusion of WDGS in the diet may have a more beneficial impact on performance. Additional research is needed to determine the optimal inclusion of WDGS and corn processing method to maximize cattle performance.

Logically, it would appear that acidosis was a problem for steers fed FGC because DMI and ADG were decreased; however, incidence of liver abscesses, which commonly follow rumen acidosis (Jensen et al., 1954; Kleen et al., 2003), were not different between treatments. Interestingly, during the first 72 days on feed, terminal liver abscess score (LAS) did not affect ADG; however, during the last 55 days on trial, steers identified at slaughter to have a severe LAS gained approximately 0.4 kg less than steers with no liver abscesses or a mild LAS. While previous research by Nagaraja and Lechtenberg (2007) also noted that liver abscesses appear to develop during the last 60 days on feed, limited up-to-date research pertaining to liver abscesses exists. Thus, additional research on liver abscess development and effects on cattle performance is warranted.

The ethanol industry has begun exploiting fiber extraction as another method to add value to the corn kernel. Because no previous research with WDG derived from a secondary fermentation process for conversion of corn kernel fiber exists, two research trials to determine the impact of C-WDG on nutrient digestibility of lambs and growth performance of steers in the feedlot were conducted. The hypothesis was that although slightly more oil and fiber were removed from DG during the production process, C-
WDG would have minimal impact on nutrient digestibility and overall growth performance of ruminants compared to traditional WDG (T-WDG). While steers fed C-WDG maintained similar ADG and final BW compared to T-WDG, steers fed C-WDG were less efficient. This performance difference is reflective of the decreased in DM digestibility of lambs fed 30% C-WDG compared to lambs fed 30% T-WDG. While the digestibility of diets which included addition of corn condensed distillers solubles (CCDS) to the C-WDG was not measured, DMI, ADG, and final BW were lesser compared to C-WDG which could be attributed to the S content of the CCDS. Because CCDS are a high energy feedstuff (Klopfenstein et al., 2008), the addition of CCDS to the diet resulted in an increased NEg calculated based on improved feed efficiency of cattle compared to C-WDG despite the reduction in growth. In this study, the addition of CCDS added 32% value to C-WDG (Appendix A). Because the ratio of CCDS added back to DG alters the nutrient profile (Berger and Singh, 2010), additional research should be conducted to determine the optimal ratio to avoid the negative performance effects of high S while still taking advantage of the energy value.

In this experiment, while the energy value of C-WDG was decreased by 25% compared to T-WDG, performance was similar between the two treatment groups. Based on an economical simulation, using cattle performance from this study resulted in a similar break-even price of C-WDG compared to the historical value of T-WDG (Appendix A). Although not statistically compared in this study, the NEg of C-WDG was consistent with the corn-based control, although cattle fed C-WDG had heavier final BW and increased ADG. Therefore, incorporation of WDG produced from a secondary
fermentation process for conversion of corn kernel fiber into cellulosic ethanol maintains an advantage over corn in feedlot finishing diets.

These series of studies were designed to determine the effects of new generation DG and corn particle size on starch digestibility and cattle performance as well as the influence of DG produced from a novel cellulosic process on nutrient digestibility and feedlot performance compared to traditional DG. As the ethanol industry continues to make advancements in ethanol production, the nutrient profile of DG will continue to change. Compared to traditional DG, new generation DG have altered cattle performance creating implications for cattle feeders; however, changes in management techniques can help offset these challenges. For example, the variation in nutrient composition of DG, especially S and fat content, can significantly impact cattle performance. More specifically, sudden spikes in S intake can cause S toxicity and if severe enough, lead to death. With proper routine analysis of DG and providing sufficient roughage in the diets to manage rumen pH, these risks can be reduced.

To date, previous research with new generation DG has shown a decreased energy value compared to traditional DG but still has an advantage over corn-based finishing diets (Depenbusch et al., 2008; Jolly et al., 2013; Bremer, 2014; Jolly et al., 2014). This research is the first to evaluate cattle performance when fed DG produced from a novel cellulosic ethanol process from corn grain fiber and shows promise that new generation DG are an advantageous feedstuff in finishing diets. However, as the ethanol industry continues to look for ways to extract more value and becomes more efficient in cellulosic ethanol production derived from fiber in the corn kernel, additional information will be warranted to determine how these new generation DG are best utilized in finishing diets.
APPENDIX A.

ECONOMICS OF CELLERATE™

Because Cellerate™ (CEL) wet distillers grain (WDG), a product of a secondary fermentation process for conversion of the corn kernel fiber into cellulosic ethanol, is new to the market, the economic value of the product in finishing diets is unknown. Therefore, performance data from Lundy et al. (2015) were analyzed in a decision tool spreadsheet available on the Kansas State University Ag Manager website (Pricing DDGS in Feedlot Rations by Dr. Glynn Tonsor) to predict the break-even price of CEL in the finishing diet at 30% inclusion (DM basis) when compared to a traditional corn-based diet (Table 1). This spreadsheet (http://www.agmanager.info/Tools/default.asp) is designed to solve for the break-even feed price where costs of gain are equal between the two diets differing only in the inclusion of the feed in question. Comparisons between CEL and CEL plus corn condensed distillers solubles (CEL+CCDS) were also made to determine the value of CCDS.

Table 1. Break-even price ($/ton, as-fed basis) of Cellerate™\(^1\) based on feedlot performance\(^2\) at varying corn prices

<table>
<thead>
<tr>
<th>Corn ($/bu)</th>
<th>$4.00</th>
<th>$5.00</th>
<th>$6.00</th>
<th>$7.00</th>
<th>$8.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEL</td>
<td>45.16</td>
<td>56.49</td>
<td>67.81</td>
<td>79.13</td>
<td>90.45</td>
</tr>
<tr>
<td>CEL+CCDS</td>
<td>60.04</td>
<td>74.93</td>
<td>89.81</td>
<td>104.69</td>
<td>119.57</td>
</tr>
<tr>
<td>CCDS</td>
<td>62.20</td>
<td>77.51</td>
<td>92.82</td>
<td>108.13</td>
<td>123.44</td>
</tr>
</tbody>
</table>

\(^1\)Cellulosic ethanol wet distillers grains derived from secondary fermentation of corn kernel fiber.  
\(^2\)Lundy et al. (2015).  
\(^3\)CEL: 30% cellulosic ethanol wet distillers grains; CEL+CCDS: 18% cellulosic ethanol wet distillers grains plus 12% corn condensed distillers solubles; CCDS: corn condensed distillers solubles.
For all diet comparisons, initial BW used was 422 kg and final BW was 590 kg. The following inputs were entered for the traditional corn-based diet based on feed ingredients used in the study and performance of cattle on test and were not changed for each corn price simulation: 6.75 feed:gain ratio, 1.59 kg ADG, 70% corn, 12% hay, 1.41% limestone, 0.31% salt, 0.12% vitamin-premix, and 0.01% ionophore mix. Two additional rows were added in the ration section for the traditional corn-based diet which included 13% WDG and 3% dried distillers grains plus solubles (DDGS), and the feed nutrient composition given in the spreadsheet was used for the nutrient values of WDG and DDGS used in the control diet. The following inputs were used for CEL diets and were held constant across comparisons: 6.50 feed:gain ratio, 1.68 kg ADG, 30% WDG (price solving for), 3% DDGS, 12% hay, 1.41% limestone, 0.31% salt, 0.12% vitamin-premix, and 0.01% ionophore mix. For the CEL+CCDS diet, the following inputs were used: 6.40 feed:gain, 3.50 kg ADG, 53% corn, 30% WDG (price solving for), 3% DDGS, 12% hay, 1.41% limestone, 0.31% salt, 0.12% vitamin-premix, and 0.01% ionophore mix. The addition of 3% DDGS included in all diets was used to account for the micro-ingredient carrier within the diets. The price of corn was adjusted by $1 increments ranging from $4.00/bu to $8.00/bu, which covers the range of monthly average corn price in Iowa over the past 10 years. As corn price was increased, the price of WDG used in the control diet, DDGS, was adjusted according to Table 2.

**Table 2.** Historical 10-year average price relationship between common ingredients in finishing diets compared to corn (as-fed basis)

<table>
<thead>
<tr>
<th>Corn ($/bu)</th>
<th>Hay</th>
<th>WDGS</th>
<th>DDGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.00</td>
<td>102.62</td>
<td>44.93</td>
<td>138.12</td>
</tr>
<tr>
<td>5.00</td>
<td>128.28</td>
<td>56.17</td>
<td>172.64</td>
</tr>
<tr>
<td>6.00</td>
<td>153.93</td>
<td>67.40</td>
<td>207.17</td>
</tr>
<tr>
<td>7.00</td>
<td>179.59</td>
<td>78.63</td>
<td>241.70</td>
</tr>
<tr>
<td>8.00</td>
<td>205.24</td>
<td>89.87</td>
<td>276.23</td>
</tr>
</tbody>
</table>
and hay were adjusted to reflect the price relationship to corn based on a 10-year average price of each ingredient (Table 2).

The values listed in Table 1 are the break-even price/ton (as-fed basis) delivered to the farm for the given co-product based on performance data at 30% inclusion and a given corn price. Thus, at $5.00/bu corn, the break-even price for CEL delivered is $56.49/ton (as-fed) based on this comparison. While the break-even price of CEL is similar to the historical prices of traditional WDG, the break-even price may be confounded because the corn-based control diet did contain 13% WDG. The similarity in prices of CEL and traditional WDG suggests that although more nutrients are being removed from CEL during the secondary fermentation process, CEL still adds value over control, corn-based feeding programs.

Based on this simulation, corn condensed distillers solubles (CCDS) adds 32% value to CEL. Because CCDS have a greater energy content compared to distillers grains plus solubles, the addition of CCDS to CEL resulted in a decreased feed to gain (improved feed efficiency) compared to CEL-fed cattle. Therefore, the economic value of CEL+CCDS is greater than CEL, although ADG and DMI of cattle fed CEL+CCDS were lesser than cattle fed CEL because feed efficiency is a larger driver in the cost of production. The break-even price of CCDS was also solved for in a third comparison based on cattle performance and 12% inclusion. When corn is $5.00/bu and WDG, DDGS, and hay are priced at the 10-year relative price levels, the break-even price of CCDS is $77.51/ton (as-fed). While this simulation takes into account the economic advantage of feeding CCDS due to its high energy value, the additional cost of storing and handling a liquid feedstuff (30% DM) was not taken into account. The added costs
of storing and handling CCDS often is the limiting factor of producers taking advantage of this high energy feedstuff. For more information on storing and handling CCDS, the reader is referred to Geppert et al. (2014). While this chart aids in value determination of the addition of CEL, CEL+CCDS, and CCDS in finishing diets, assumptions were made on limited performance data, and other factors affecting costs associated with utilization should be considered.