UTILIZING REDUCED-OIL CORN DISTILLERS GRAINS WITH SOLUBLES IN FINISHING BEEF CATTLE DIETS

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ABSTRACT

As ethanol producers continue to seek greater value from a grain, adoption of oil extraction via front-end fractionation of the whole kernel prior to fermentation or through back-end centrifugation of the thin stillage stream contributes to varying nutrient composition and feeding value of distillers grains with solubles (DGS). The impact of oil extraction on finishing feedlot cattle performance and resulting energy values is an item of interest to cattle feeders and nutritionists. Thus, two studies were conducted: a 181-d finishing feedlot experiment and a meta-analysis of published data, to determine effects of oil extraction on finishing cattle performance and resulting energy values. Effects of feeding reduced-fat (RF) modified wet distillers grains with solubles (MDGS) on finishing cattle performance, carcass characteristics, and resulting energy values were evaluated in Study 1. Linear contrasts in experiment 1 demonstrated that feeding RF MDGS at 30 and 45% inclusion (high inclusion) led to cattle consuming more DM than feeding full-fat (FF) or RF MDGS at 15% inclusion. There were no significant differences in all other performance variables, carcass characteristics or resulting energy values. Study 2 was conducted utilizing a meta-analysis approach to determine the energy value of oil extracted corn distillers grains with solubles (DGS) in finishing feedlot cattle diets. Results from Study 2 revealed that feeding FF DGS resulted in greater ADG compared to feeding RF DGS or control diets, and feeding RF DGS resulted in greater ADG compared to feeding control diets. At increasing DGS inclusion, feeding FF DGS led to lower DMI than feeding RF DGS. Feeding DGS at moderate or high inclusion, regardless of fat content, resulted in greater feed conversion efficiency compared to feeding control diets. At high inclusion, feeding FF DGS led to greater feed conversion

efficiency than feeding RF DGS. Feeding FF DGS at moderate or high inclusion or RF DGS at moderate inclusion resulted in greater observed ME concentration compared to feeding control diets. One unit of ether extract (EE) from DGS contributed 0.06 Mcal ME/kg DM to dietary ME. Results of the meta-analysis demonstrated that reducing oil content of corn DGS reduced energy value of the DGS, thus corrections to energy content of currently available DGS are required. A third experiment was conducted to characterize the nutrient content of corn plant components at various corn crop harvest endpoints. Through reproductive stages of development, corn plant DM increased until dry corn grain harvest. Concurrently; NDF, ADF, and CP concentrations decrease as the plant matures while ether extract (EE) increases once the plant reaches physiological maturity. When concluding the results of this experiment in terms of a producer growing corn as a feed resource for cattle, it is recommended that scouting of corn fields begins once pollination occurs. By beginning to scout fields at the beginning of reproduction, producers can then closely monitor plant DM in order to harvest various corn crop endpoints at their ideal time.

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Chapter I

REVIEW OF LITERATURE

Introduction

Ethanol use to power engines in the United States dates back to the 1800's. During the mid-1800's, ethanol was not a popular fuel source as it was taxed as a liquor to help pay for the civil war. Then in the 1970's, petroleum-based fuel became expensive due to events like the Arab Oil Embargo of 1973. Several Arab nations were angered at the United States over their support of Israel in the 1973 Arab-Israeli War. This ultimately resulted in the institution of an oil embargo against the United States. Furthermore, the Iranian Revolution in 1978 led to a drop in production of nearly 3.9 million barrels of crude oil per day from Iran resulting in tight world supplies (EIA, 2002). The aftermath of the increase in price of petroleum-based fuel along with increased environmental concerns involving lead-based gasoline in the 1970's sparked a significant increase in ethanol production. Since that time, ethanol production in the United States increased steadily; production of ethanol in 1980 was about 175 million gallons and rose to about 5.0 billion gallons in 2006 (Rendleman and Shapouri, 2007).

The process of making ethanol in the United States starts with cereal grains, where corn is the predominant source of grain utilized while other grains like wheat, sorghum and barley may be used as well. Comparing ethanol production from various sources; corn grain, with the exception of sugar cane, provides the highest ethanol yields compared to any other feedstock being used (U.S. Grains Council, 2012). Ethanol is produced from the fermentation of starch (glucose) in cereal grains by two primary

milling procedures; wet milling or dry milling. Because starch is the major carbohydrate storage product in corn kernels; comprising 70 to 72% of the kernel weight on a dry matter basis, corn is the most important and economical source of starch in the United States (Bothast and Schlicher, 2005). Due to the fact that corn is the predominant source of starch provided for fermentation of ethanol; ethanol production has added value to corn farmers across the country. In 2011, Minnesota ethanol production added $912 million to the value of corn, where for every bushel of corn processed into ethanol, $2.07 was generated in additional revenue. Furthermore, the ethanol industry's return on investment in Minnesota from 1990 to 2011 was 813%, where for every dollar invested into building ethanol plants, more than $8 were generated for the state economy (Ye, 2012).

Wet milling and dry milling are the two primary fermentation processes to convert starch into ethanol. Out of roughly 200 operating ethanol plants in the United States, approximately 90% utilize dry milling processes, while the remaining 10% utilize wet milling processes (RFA, 2015a). Comparing the two milling processes, dry milling produces roughly 2.8 gallons of ethanol per bushel of corn utilized while wet milling produces roughly 2.5 gallons of ethanol per bushel of corn utilized (Bothast and Schlicher, 2005). Co-products of wet and dry milling ethanol production results in high quality livestock feed resources of which the primary co-products are distillers grains (DG) and distillers grains with solubles (DGS) produced from dry milling processes and corn gluten meal and corn gluten feed from wet milling processes, respectively. These resulting co-products are produced at a rate of roughly 17 to 18 pounds of DGS per bushel of corn utilized from dry milling and 2.6 pounds of corn gluten meal and 13.5

pounds of corn gluten feed per bushel of corn utilized from wet milling production (Bothast and Schlicher, 2005).

Distillers Grains Production

Introduction

The larger proportion of ethanol plants predominately utilize dry milling processes because of lower capital costs per gallon of ethanol produced as well as the incentive for farmer-owned co-operatives (Shapouri et al., 1996; Wang et al., 1997). Through dry milling production, the entire corn kernel is utilized where the process was established to ferment as much of the starch component that gets converted into ethanol. The co-products produced from dry milling production consist of dry, modified-wet, or wet distillers grains with and without solubles and also condensed distillers solubles (CDS), all of which are high-quality livestock feeds.

Dry-Grind Process with Corn

The ethanol process begins by receiving corn at the ethanol facility where it is stored and any broken corn, any type of foreign objects, or finer materials are removed using a blower and screen. The clean corn is then ground through a hammer mill with screens ranging in size from 3 to 5 mm in diameter to reduce the particle size of the grain to a coarse flour to allow better contact between water and enzymes with the starch component. Reducing the particle size has shown to increase the production of ethanol by increasing fermentation capacity through finer particle size (U.S. Grains Council, 2012). The fine ground corn is then mixed with fresh water and recycled water from the end of production to form a slurry or mash. The pH of the slurry is adjusted to 6.5 by the

addition of ammonia and lime; ammonia contains nitrogen to serve as a nutrient for yeast during fermentation. Also, heat stable α-amylase enzyme is added to hydrolyze starch fraction. Once the slurry is prepared, the mixture undergoes liquefaction, where starch is gelatinized using a steam injection heater. During this process, starch is hydrolyzed/broken down by the heat stable α-amylase into oligosaccharides also known as dextrins (Kwiatkowski et al., 2006). This primary liquefaction phase is initially held at 88 ˚C for 60 min. After 60 min, backset, a recycled stream obtained from the liquid portion of whole stillage separated by centrifugation, is added to the output of the initial liquefaction step. Addition of backset provides critical nutrients for yeast later during fermentation (Kwiatkowski et al., 2006). The output from the initial liquefaction step and the backset are cooked at 110 ˚C for 15 minutes, after which the combined streams are transferred to the saccharification tank. During the saccharification step, sulfuric acid is added to lower the pH in the tank to 4.5 and glucoamylase, another enzyme, is added to convert oligosaccharides to glucose through stepwise hydrolysis of glucose from the end of the molecules. The slurry is then held stable under these conditions for 5 h at 61 ˚C, where nearly all of the dextrins are hydrolyzed into fermentable glucose (Kwiatkowski et al., 2006). Following saccharification, the slurry in then transferred to the fermentation vessels where yeast is added to convert the sugars into ethanol and carbon dioxide. The mash ferments for approximately 50 to 60 h, after which the products yielded contain a mixture of about 15% ethanol and solids along with the added yeast (ICM, 2012). The fermented mash is then pumped into a continuous flow distillation system where ethanol is removed from solids and water. The process of removing ethanol is through the top of the distillation columns, where the liquid stream contains about 95% ethanol by volume

(190 proof). Through the bottom of the distillation columns is where whole stillage (solids and water) is recovered. This contains nutrients from the remaining one-third of the corn kernel (ICM, 2012). These unfermented portions (protein, fat, fiber, ash, and phosphorus) are pumped out of the bottom of the distillation columns and centrifuged to separate the wet cake/solids from the thin stillage. The wet cake can then be sold as wet distillers grains (WDG) or dried down and sold as modified wet or even further dried to dried distillers grains. Roughly 15% or more of the thin stillage is recycled and used as backset for the second step of the liquefaction process (ICM, 2012). The remaining thin stillage is then concentrated through an evaporation system, resulting in condensed distillers solubles (CDS) or syrup that is then added to WDG to produce wet distillers grains plus solubles (WDGS; Liu, 2011). The WDGS can be dried to produce modified wet distillers grains plus solubles (MDGS) or further dried to produce dried distillers grains plus solubles (DDGS).

Nutrient Composition

Starch is the primary component needed in the production of ethanol. Because corn grain contains approximately two-thirds starch that is removed during the conversion to ethanol, the concentration of the remaining nutrients (protein, fat, fiber, ash, and phosphorus) increases anywhere from 2 to 3 times greater than the concentration found in dry corn grain (Lim and Yildirim-Aksoy, 2008). Corn grain contains roughly 10% CP, 4% crude fat (EE), 12% NDF, and about 0.3% phosphorus P. Following removal of the starch component through conversion to ethanol, the nutrient concentration in DGS contains roughly 30% CP, 12% EE, 36% NDF and 0.9% P respectively (Klopfenstein et al., 2008). Although the nutrients that remain after the

removal of starch are concentrated 2 to 3 fold greater than traditional dry corn, the nutrient composition of DGS can vary between ethanol plants and also within ethanol plants. This variation can be attributed to processing procedures and techniques, the amount of CDS added to WDG, and also the effectiveness of the yeast in converting glucose into ethanol during the fermentation process. The composition of DGS can vary substantially (Belyea et al., 1989); thus effecting the quality of DGS vary and could potentially negatively impact its market value. Furthermore, factors that affect the quality of DGS directly impact the economics of ethanol production (Singh et al., 2001); as well as the economic feeding value of DGS when fed to livestock.

Variable nutrient concentrations in DGS may lead livestock feeders to under- or overfeed livestock. Protein is one of the most expensive nutrients in an animal's diet; and the variation in the proportion of protein in feeds can cause rations to not be properly formulated thus effecting the productivity of the animal (Belyea et al., 2004). The wide range of variation (27% to 35%) in CP concentration of DGS make it imperative for livestock feeders to formulate rations accordingly to meet the requirements of the animal. In the case of feedlot cattle, protein costs can represent up to 15% of total feed costs for feedlots (DiCostanzo, 1996). Overall, the nutrient composition of DGS can and will vary from ethanol plant to ethanol plant as well as vary within an ethanol plant, therefore livestock feeders utilizing DGS as a feedstuff when formulating rations need to be meticulous in regards to the nutrient composition of DGS and adjust rations accordingly.

Distillers Grains Oil Extraction

As indicated, factors contributing to variation in nutrient content of DGS include production processes, inclusion of CDS in distillers grains (DG) and impact of yeast on

transformation of glucose to ethanol. As ethanol producers seek greater economic value from corn grain by extracting oil (CDO) during the ethanol production process; oil extraction process or lack thereof is an additional factor affecting nutrient concentration of modern DGS. Corn oil is currently sold as a feed ingredient fed to livestock or as feedstock for the biodiesel industry.

In the past decade, the ethanol industry has become a large producer of CDO. In 2014, approximately 85% of dry milling plants were extracting oil; it was estimated that 2.5 billion pounds of CDO were produced (RFA, 2015b). There are two main methods of extracting CDO; and those are through front-end fractionation or back-end centrifugation; of these, back-end centrifugation is the most common practice.

Back-End Oil Centrifugation

Following centrifugation of whole stillage, which separates wet cake from thin stillage, back-end oil centrifugation involves a second centrifuge in which thin stillage is further centrifuged to separate oil from CDS. In October of 2009, Greenshift (Greenshift Corp., Alpharetta, GA) received a patent on its first corn oil extraction system from the U.S. Patent and Trademark Office. Corn Oil Extraction system 1, developed by Greenshift, consists of a second centrifuge that can be added to an existing dry-mill ethanol plant. Because concentrated thin stillage contains approximately 30% of the oil available in corn, Corn Oil Extraction system 1 function is to extract the majority of the oil from the thin stillage by separation in a second centrifuge. Heat exchangers use steam to raise the temperature of thin stillage to facilitate extraction, so that after the corn oil is extracted, thermal energy from the stillage is recovered in heat exchangers to heat incoming stillage and thus continue to facilitate oil extraction (CEPA, 2011). Traditional

WDGS has an ether extract (fat) content around 10 to 12%, but following the second centrifugation to remove oil from CDS, WDGS produced after back-end centrifugation contains EE in the range of 7 to 9%.

Greenshift also developed another corn oil extraction system, Corn Oil Extraction system 2, which is an additional extraction system that can aid in the extraction of an additional 30 to 40% of the corn oil by adding a surfactant prior to the second centrifugation of the whole stillage (CEPA, 2011). Because around 40% or more of the total oil within whole stillage is bound within wet cake, Greenshift system 2 was developed to wash the wet cake with surfactant prior to centrifugation of whole stillage in order to free additional oil from wet cake (CEPA, 2011). Pre-extraction using Greenshift system 2 generally releases sufficient oil to double corn oil yield. Therefore, when these two systems are applied together, 60 to 70% of the corn oil passing through a dry grind plant can be extracted which yields 6 to 7 gallons of corn oil per 100 gallons of ethanol produced (CEPA, 2011). Extraction of oil through the use of Greenshift System 1 and 2 oil extraction systems results in DGS with EE concentrations ranging from 4 to 9%.

Front-End Fractionation

The corn kernel is made up of four main parts which include the tip cap and pericarp (bran), endosperm, and germ. Front-end fractionation is a technology that involves separating the endosperm, germ, and bran fractions of the corn kernel prior to fermentation. The endosperm represents about 83% of the corn kernel and is primarily composed of starch, whereas the germ (about 12% of the kernel) is high in oil, protein, ash and non-fermentable carbohydrates; the remaining bran portion is almost exclusively composed of fiber (non-fermentable carbohydrates; Shurson and Alghamdi, 2008).

Generally, front-end fractionation is a technology that is adapted in wet-milling ethanol plants. Corn oil recovery occurs after fractionation separates the endosperm, germ, and bran fractions of the corn kernel. The germ component, which contains roughly 85% of the corn kernels oil, is pumped onto screens and washed to remove any starch left in the mixture to result in the recovery of high quality corn oil (CRA, 2015). Although front-end fractionation was developed for use in wet-milling ethanol facilities, adopting the technology of front-end fractionation to dry-milling ethanol plants has been thought of as a new possible strategy for recovering oil from the whole germ prior to fermentation (Wang et al., 2010). Front-end fractionation in dry-milling ethanol facilities contains two methods of this technology. One of which is a modified wet milling process that recovers the germ using the wet-degermination facility of the wet-milling plants, and the other is simply a dry-degermination process (Wang et al., 2010).

Modified wet fractionation in dry-milling facilities is further divided into two methods in itself. The first method, developed by Singh and Eckhoff (1996) and named the Quick Germ process, is a modification of dry-grind ethanol production where whole corn is soaked in water for 12 h at 60 ˚C before degermination occurs. The germ is then recovered by Germ Hydrocyclones (Fluid-Quip, Inc., Springfield, OH), while the rest of the corn kernel is further processed to produce ethanol. The second method of wet fractionation is through the same method as the Quick Germ process, which is known as Quick Fiber. Through the Quick Fiber method, the fiber portion can be recovered using hydrocyclones and can be either done after the Quick Germ process or both the germ and the fiber can be recovered at the same time, then dried and separated using an aspirator (Singh et al., 1999). The result of the Quick Germ and Quick Fiber fractionation methods

is the removal of the germ which can then be further processed to remove the high-value corn oil as well as a high fiber animal feed products that can be combined with the evaporated, concentrated and dried steep liquor and other co-product streams to produce Corn Gluten Feed (AMG, 2013). By removing the germ and the bran prior to the fermentation process, the starch component can be further concentrated thus increasing the fermentation capacity resulting in quicker conversion of starch to ethanol and reduces the amount of enzymes used in the process.

During front-end dry fractionation process, grain is tempered for a short period of time, degermed, then passed through a roller mill to reduce the particle size (Murthy et al., 2009). Following grinding in the roller mill, corn is separated into the germ, bran, and endosperm components by particle size or density through a sieve. Designed for ethanol production, the dry fractionation process maintains the cleanliness of the germ and pericarp fractions and minimizes the loss of starch through fractionation processes (Lin et al., 2011); thus contributing to greater ethanol production. While both wet and dry front-end fractionation processes are effective, modified wet front-end fractionation recovers greater amounts of oil present within the germ. Approximately 40% of the germ oil was recovered through a modified wet process while only 20% of the germ oil was recovered during dry front-end fractionation (Weller et al., 1989a; Johnston et al., 2005). This was because in the dry fractionation process, the separation of the germ and other components was incomplete; Murthy et al. (2009) reported that less than 50% of germ was recovered through dry fractionation.

Variation in Distillers Grains with Solubles from various Dry-Grind Ethanol Processes

Corn oil extraction, through back-end centrifugation or front-end fractionation, increases value of co-product streams that ethanol producers can derive from each bushel of corn. More and greater quality corn oil can be recovered through front-end fractionation, but investment capital needed, which is 4 to 5 times greater than that needed to install back-end centrifugation (AURI, 2009). Corn oil obtained from front-end fractionation can become food-grade oil (Winkler-Moser and Breyer, 2011), which is sold at a greater price than corn oil for livestock use or biodiesel feedstock.

Traditionally derived DGS contains the residual components (i.e., bran, protein, germ, and minerals) of the grain after the majority of the starch has been fermented (NRC, 2000); yet, as a result of oil extraction through back-end centrifugation, EE concentrations in WDGS, MDGS, or DDGS range from 6 to 9%. The future of corn-based ethanol production may be heading towards a shift in applying fractionation processes to dry-milling facilities because fractionation of the grain increases fermentation efficiency of starch and increases value and type of co-product streams (Rajagopalan et al., 2005; Rausch and Belyea, 2006). Distillers grains with solubles derived from front-end fractionation through dry-milling ethanol production contain less fat (3 to 5%) and phosphorus; however, have greater concentrations of protein Rausch and Belyea (2006) compared to the CP concentration of traditional DGS and DGS produced following back-end centrifugation of thin stillage. Furthermore, processing corn grain for ethanol production through front-end modified dry-grind fractionation (Quick Germ and Quick Fiber) or partial fractionation will reduce EE and fiber concentrations of resulting DGS. Lower fiber concentrations in resulting DGS increase potential use by

nonruminant animals (Singh et al., 2005). Dry matter and nutrient composition of various DGS sources resulting from the aforementioned ethanol production processes and oil extraction method are listed in Table 1.

Feeding Dried Distillers Grains with Solubles to Monogastric Species

Research with feeding ethanol co-products to swine has been conducted for more than half a century, where early work focused on evaluating the feeding value of dried distillers solubles, dried distillers grains (DDG), and DDGS fed to growing pigs (Fairbanks et al., 1944; Fairbanks et al., 1945; Livingstone and Livingston, 1969). During the last decade, with the boom in production of ethanol contributing to significant increases in the availability of DDGS, increased interest led to research studies to evaluate the impact of nutrient concentration and DDGS inclusion on nutrient digestibility and feeding value of DDGS to pigs. Dried distillers grains with solubles typically contained 10 to 11% EE with an ME content similar to that of corn (Stein and Shurson, 2009). However, recent efforts to increase oil extraction by the ethanol industry have led to production of corn-DDGS with a fat concentration ranging from 3 to 12%. Theoretically, because oil contains 2.25 times more energy than carbohydrates, removal of oil was likely expected to reduce the ME content in corn-DDGS. This reduction in energy can affect its economic value and impact the rate at which it is included in swine diets (Kerr et al., 2013). One of the biggest concerns is the lack of constant nutrient composition or lack thereof a standardized test for nutrient content analysis. Greg Sample (as quoted by Bernick, 2007), director of nutrition and information at Next Generation Pork (NGP, LeRoy, MN), indicated feeding DDGS in swine rations is a hot topic and

there are a lot of opinions regarding its feeding value and the rate at which it should be included in rations.

Inclusion and Performance

Traditionally, corn DDGS with 10% EE contained similar ME content as that of corn grain (Stein, 2007). Early research evaluating the addition of traditional corn DDGS to diets fed to grower and finishing pigs showed that growth performance could be maintained when feeding up to 20% DDGS; using traditional DDGS reduced performance when fed at 40% of diet (Cromwell et al., 1983).

Recently, Stein and Shurson (2009) concluded, in a review of 25 scientific manuscripts, that pigs fed up to 30% full-fat DDGS in the diet experienced no negative impacts on growth performance. Authors indicated that this is due to DDGS having similar energy value as that of corn. However, carcass fat from pigs fed diets containing 30% FF DDGS had greater iodine values (IV) than that from pigs not fed DDGS, due to high fiber and unsaturated fatty acid content of DDGS respectively (Stein and Shurson, 2009).

One concern with feeding DDGS produced today is that lower EE content of DDGS might negatively affect pig growth performance, due to lower energy values. This was the observed by Graham et al. (2014b), where pigs fed a corn-soybean meal control diet or the control diet with 15, 30, or 45% medium-oil DDGS (7.6% oil) experienced linear decreases in ADG and G:F with increasing levels of medium-oil DDGS. For every 15% of added medium-oil DDGS, ADG and G:F were decreased 2.2 and 1.3%, respectively. This is contrary to what Stein and Shurson (2009) concluded. This

contrasting observation may be reconciled by the fact that DDGS sources examined by Stein and Shurson (2009) contained EE concentrations that were 10% or greater while those of DDGS fed by Graham et al. (2014b) contained 7.6%.

Pigs fed concentrations of conventional DDGS (12.1% EE) up to 40% of the diet had ADG similar to those fed a control diet (Graham et al., 2014a). Yet, pigs fed reduced-fat DDGS (9.6% EE) gained at similar rates as control-fed pigs at up to 20% inclusion; at 40% DDGS inclusion, ADG of pigs fed 9.6% EE DDGS declined (Graham et al., 2014a). There was no difference in ADFI or G:F when pigs were fed increasing amounts of DDGS containing 9.6% EE compared to pigs fed traditional DDGS (Graham et al., 2014a). In another experiment, inclusion of 40% DDGS containing 5.4% EE resulted in increased ADFI and decreased G:F compared to inclusion of 20% DDGS (Graham et al., 2014a).

Carcass Characteristics

While increasing DDGS up to 30% inclusion had no adverse effects on growth performance of pigs, increasing DDGS levels regardless of source or fat concentration decreased carcass yield (Graham et al., 2014a). Graham et al. (2014b) found that increasing the inclusion of medium-oil DDGS (7.6 % EE) resulted in decreased final BW, carcass yield, HCW, backfat, and loin-eye depth compared to the control (corn-soybean meal) fed group These findings were in agreement with those reported with increasing full-fat (> 10% EE) DDGS inclusions (Whitney et al., 2006; Linneen et al., 2008). The observed decrease in carcass yield resulted from increases in intestinal and organ weights in response to greater fiber inclusion (from DDGS), and the duration of feeding DDGS (Agyekum et al., 2012).

Iodine values (IV) of a fat source, an estimate of the degree of unsaturation present in carcass fat fatty acids, can be used as an indicator of overall fat firmness (Benz et al., 2011). Iodine values are based using iodine to qualitatively measuring the number of double bonds (degree of unsaturation) in fats and oils (U.S. Grains Council, 2012). Fats with no double bonds (saturated fatty acids) are solid at room temperature and have a relatively low IV while fats with increasing number of double bonds, as the degree of unsaturation in fatty acids increases, result in increased IV. In pork fat, IV and resulting fat firmness are heavily influenced by the ratio of linoleic to stearic acid (Wood et al., 2004), where overall acceptable firmness is achieved when it contains 12 to 15% linoleic acid and more than 41% saturated fatty acids (Hugo and Roodt, 2007). Because dietary fatty acids can affect the quality of fat present in a pork carcass, carcass fat IV is an indirect indicator of the percentage of unsaturated fatty acids, softness of fat, or potential rancidity of carcass fat (Hugo and Roodt, 2007). Due to softness of the fat, pork with high IV values is difficult to fabricate at high speeds. Dietary linoleic acid is as a good indicator of carcass IV because its high double bond content, while overall, jowl fat predicts IV in the entire carcass; yet it may overestimate backfat IV (Benz et al., 2011).

Adding DDGS to grower-finisher diets did not affect pork muscle quality, but it negatively affected pork fat quality, especially at dietary inclusion rates greater than 20% (Xu et al., 2010). At dietary inclusions greater than 20%, DDGS decreased fat firmness and increased softness of pork bellies (Stein and Shurson, 2009), which was the result of high concentrations (58%) of linoleic acid present in the oil within DDGS. As concentrations of DDGS fed to finishing pigs increased, dietary unsaturated fatty acid concentration, in particular linoleic acid, increased which caused carcass fat IV to

increase; thus, carcass fat quality decreased because fat composition is affected by dietary fatty acids (Gatlin et al., 2002). Traditional full-fat DDGS with EE concentrations greater than 10% contain more linoleic acid compared to DDGS with EE concentrations less than 10%; thus, greater linoleic acid concentrations in traditional DDGS would affect a greater impact on IV for pigs fed traditional DDGS. Graham et al. (2014a) found a source by level interaction on jowl, backfat, and belly fat IV. Iodine values in these fat depots increased as DDGS concentration increased, but to a greater extent in pigs that were fed DDGS with greater EE concentrations. In these 2 experiments, Graham et al. (2014a) fed two different sources of DDGS per experiment where EE concentrations of the DDGS were 5.4 and 9.6% in experiment 1 and 9.4 and 12.1% in experiment 2 with linoleic concentrations of 50.43, 52.47, 53.85, and 54.96%, respectively as well as IV of 114.4, 118.5, 120.1, and 121.3%, respectively. Overall, feeding DDGS reduced pork fat quality but to a greater extent with full-fat than reduced- or low-fat DDGS.

Removing or significantly reducing dietary DDGS concentration during the late finishing phase can minimize negative effects of feeding greater concentrations of DDGS on pork fat quality. Fat in pigs is continually being deposited and mobilized; therefore, reduction or elimination of DDGS from the diet results in a rapid response in fatty acid composition that improves pork fat quality. Abruptly withdrawing DDGS from the diet prior to harvest was expected to have negative effects on performance; however, Hilbrands et al. (2013) found that a sudden change in DDGS concentration in diets had no effect pig performance. Pigs fed diets containing 30% DDGS had DDGS removed from the diet 3 wk prior to harvest that resulted in IV of belly fat being reduced to 68.2, which meets the National Pork Producers Council (2000) standards for pork fat quality

(Xu et al. 2010). These standards for pork fat quality or IV will also vary from processor to processor. The majority of fatty acid composition change of adipose tissue occurs within 25 days of a dietary change (Wood et al., 1994); therefore, withdrawing DDGS from the diet 3 wks or longer prior to harvest should improve pork fat quality and reduce IV.

Importance and Economic Significance of Energy (fat) in Swine Diets

Carbohydrates and fats from cereal grains in the diet supply most of the pig's caloric needs; energy content of feeds is a major determinant of pig performance. Consequently, energy is the single most important and expensive component of swine diets. Therefore, from a financial point of view, it is important to accurately determine the energy value of feed ingredients. The most significant economic value for a pigs ration is the total energy level of the complete diet and expected intake (Usry et al., 2012). In addition to cereal grains in pig rations, supplemental fats are used to increase the energy density of swine diets. The response exerted in pigs to the inclusion of dietary fat depends on the animal's feed intake, digestibility of the fat source, and the efficiency of utilization of fat for body maintenance and tissue growth (Stahly, 1996). The ability of the pig to digest a fat source is dependent on the ratio of total unsaturated to saturated dietary fatty acids. If this ratio exceeds 1.5 to 1, the digestibility of fat is high. In the instance of a corn-based diet, this ratio will normally be around 1.5 to 1 or greater regardless of the supplemental fat source because the oil in the corn kernel (4%) is so unsaturated (Stahly, 1996).

Dietary fat provides many nutritional benefits to pigs, but another key component in deciding whether or not to include supplemental fat in swine diets is largely driven by

economics and specifically costs per unit of energy provided to the pig. The economic value of dietary fat can be estimated from the impact of dietary fat additions on days required to reach market weight, pounds of feed required per pig, and carcass composition (Stahly, 1996). For diets that contained anywhere from 3 to 12% total fat, the response to added fat was linear: days to market were fewer, pounds of feed fed per pig were less and carcass backfat thickness increased for pigs regardless of thermal environment (Stahly, 1996).

The increase in dietary energy varies depending on source of fat. Barrows fed diets containing 10% corn oil for 6 weeks, in environmental temperatures ranging from 25 to 30 ˚C, had significantly greater weight gains than those fed diets containing 10% beef tallow or no added fat (MacGrath et al. 1968). Also, barrows fed 10% beef tallow had significantly greater weight gains than those fed diets containing no added fat. The digestibility of dietary fat, quantity of ME and fat consumed, and the environmental temperature in which pigs are housed influenced the nutritional value of fat (Stahly, 1984). Generally, when pigs were maintained in a thermoneutral environment, substituting carbohydrate energy with fat increased growth rate and decreased ME required per unit of body weight gain. Additionally, pigs housed in a warm environment responded to dietary fat inclusion with increasing voluntary ME intake by 0.2 to 0.6% for each additional 1% of fat added to the diet (NRC, 2012). This increase in ME intake is because the heat increment of fat is less than that of carbohydrate (Stahly, 1984).

Thermoneutral environmental conditions that maximize feed (energy) intake and minimize nutrient needs for body maintenance will allow the greatest opportunity for efficient utilization of dietary fat (Stahly, 1996). Similarly, correcting the effect of warm

environmental conditions on intake by including dietary fat permits utilization of fat inclusion under these conditions (Stahly, 1996). Yet, cold environmental conditions require more feed for body maintenance and greater proportions of dietary fat must undergo metabolic transformations decreasing body fat deposition and utilization of dietary fat (Stahly, 1996).

Inclusion of dietary fat in swine diets provides a dense source of energy, essential fatty acids, leads to low heat increment, facilitates absorption of fat-soluble vitamins, lubricates equipment during pelleting, reduces feed dust, and aids in lubrication during mastication and swallowing (NRC, 2012). With the boom in ethanol production in the past few decades, DDGS has been an attractive and available feed ingredient in swine diets; however, new technologies developed to remove fat have led to DDGS with lower energy value (Curry et al., 2014). Although reducing fat content in DDGS can contribute to the energy value of the feedstuff, fiber represents a greater proportion (30 to 40%) of DDGS compared to the oil content (5 to 13%). The total tract digestibility of fiber can range from 23 to 55% thus can contribute a significant proportion of energy (Shurson and Kerr, 2013).

Dried Distillers Grains with Solubles Fiber Digestibility

Distillers dried gains with solubles is a moderately high fiber feedstuff that is generally a widely used product in cattle diets, but historically has had limited inclusion in swine diets because of the limited capacity for fiber utilization in pigs (Stein and Shurson, 2009). The efficiency of energy utilization with fibrous feedstuffs in swine diets and in the case of DDGS, is effected by the digestibility of dietary fiber and production of VFA (Bindelle et al., 2008). Since pigs have limited capacity to utilize fiber in their diets

and since DDGS is a moderately high fiber feedstuff, the apparent ileal digestibility (AID) and the apparent total tract digestibility (ATTD) of total dietary fiber (TDF) of DDGS are utilized to assess the digestibility of TDF and the feeding value of DDGS in swine diets. The ATTD of TDF in DDGS was determined to be greater relative to that of corn, which is related to the processing of corn during ethanol production (Urriola et al. 2010); thus, making DDGS fiber more digestible due to modifying the structure of the dietary fiber (Le Gall et al., 2009). However, high inclusion of DDGS reduces total tract digestibility due to the fact that DDGS contains roughly 3 times more dietary fiber than corn resulting in less energy available to the pig because the fiber was not fermented and metabolized into VFA (Zijlstra and Beltranena, 2014) such as acetate, propionate, and butyrate. These VFA are rapidly absorbed and have been shown to supply between 5 and 28% of maintenance energy requirements to pigs (Kerr and Shurson, 2013). Because dietary fiber represents a greater proportion than oil in DDGS, dietary fiber, namely ADF or TDF, may be the most important variable in determining the DE or ME content of DDGS with variable EE content. (Kerr et al., 2013), while EE concentration may also be a contributing factor in determining the energy value of corn DDGS since fat contains 2.25 times more energy than carbohydrates.

Energy Content of Distillers Dried Grains with Solubles

Since feed costs comprise about 60 to 70% of the total cost of production, efforts to reduce feed costs will pay big dividends to swine producers and when breaking down the total costs of feed, where dietary energy is the most expensive nutritional component. Due to the ethanol industry adapting oil extraction methods, the 2012 NRC has 3 classifications of DDGS; traditional-, medium-, and low-oil with EE concentrations of >

10%, > 6 and < 9%, and < 4%, respectively (NRC, 2012). Under each of these categories, DDGS have been assigned energy values as guidelines. In the study by Graham et al. (2014b) medium-oil DDGS (7.63% EE) had a GE value of 4,585 (kcal/kg) which was 97% the GE value listed by the NRC (4,710 kcal/kg; NRC, 2012). Graham et al. (2014a) reported an average GE of 4,656 (kcal/kg) for DDGS with EE concentrations ranging from 5.4 to 12.1% EE while corn utilized in the study contained a GE value of 3,871 (kcal/kg). The average GE concentration for DDGS is greater than that of corn but the digestibility of energy is less in DDGS than that in corn.

Energy (GE) values of DDGS with varying fat concentrations were 5,098, 4,710, and 4,849 kcal/kg (as-fed basis), respectively, for DDGS containing low-, medium-, or high-fat concentrations (NRC, 2012). However, Kerr et al. (2013) found GE for DDGS (DM basis) containing low EE concentrations had the lowest GE value; GE concentration increased as fat concentration increased. Gross energy digestibility coefficient listed in the NRC (2012) was lowest for DDGS containing the lowest EE concentrations, while medium-oil DDGS had a greater digestibility coefficient of GE compared to DDGS sources containing greater than 10% EE. However, these observations disagree with data from Graham et al. (2014a). Dry distillers grains with solubles containing 12.1% EE had the lowest digestibility coefficient of GE when compared to both low EE and medium EE DDGS sources. As the concentration of oil in DDGS decreased, the fiber concentration decreased as well. Removing oil from DDGS reduced GE values of DDGS because fat is energy dense, but it also reduced fiber content in DDGS. Lower DE in traditional DDGS may be related to greater fiber content. Since pigs have limited ability to utilize dietary fiber, where roughly only 23 to 55% of total dietary fiber from DDGS is digested

(Shurson and Kerr, 2013), increasing levels of dietary fiber will reduce total tract digestibility.

When nutritionists are working with feedstuffs that may vary drastically from one source to the next, it is imperative to adjust rations according to nutrient compositions of feedstuffs. Although fat contains 2.25 times more energy than carbohydrates and is a very important component of swine diets, Kerr et al. (2013) found that fiber is a central component in regression equations to predict DE and ME. Of the variables selected for predicting DE and ME of DDGS, fiber is the primary component affecting energy content. When calculating both DE and ME, total dietary fiber (TDF) is a good predictor of a more complete estimate of fiber in DDGS as it includes the value of β-glucans (Kerr et al., 2013). However TDF analysis is expensive therefore it is not included in the equation to predict DE where it is replaced by NDF (Anderson et al., 2012) or ADF (Kerr et al., 2013). The best fit equation for predicting ME of DDGS included TDF in the prediction equation based on previous work (Anderson et al., 2012) and because fermented co-products contain significant amounts of β-glucans (Liu, 2011).

In other prediction equations utilizing regression procedures, EE appeared to be the component that was best suited for predicting the energy values of DDGS sources (Graham et al., 2014a). Where when generating DE and NE as a function of oil content, a change of 1% in the EE content of DDGS resulted in a DE difference of 62 kcal/kg and an NE difference of 115 kcal/kg on an as-fed basis. Furthermore, Kerr et al. (2013) utilized EE in predicting GE from nutrient composition of DDGS and then calculated ME as a percentage of GE. The fact that lipids contain roughly 2.25 times the energy than that of carbohydrates, make it logical to conclude that EE by itself would be the most

important component in estimating DE and ME content of DDGS, but Kerr et al. (2013) did not utilize EE in DE prediction equations and was only used as a secondary variable in ME prediction equations. This was also determined by others, (Pedersen et al., 2007; Anderson et al., 2012) who went on to report that EE was not the most important component in energy prediction equations, rather that fiber measurements (TDF, NDF, ADF) were variables that were found to be more important thus included before EE. The fiber component of DDGS constitutes are greater proportion (3 to 4 times greater) when compared to the concentration of EE. Because fiber makes up a greater proportion of DDGS and that fiber has a large impact on energy digestibility (Fernández and Jørgensen, 1986; Chabeauti et al., 1991), as well as a large impact on the digestibility of lipids (Dégen et al., 2007), fiber content is of greater concern when predicting the energy value of DDGS.

Objectives

Distillers grains with solubles are an important energy and protein source for beef cattle, yet as ethanol producers continue to seek greater value from corn grain by removing oil, the feeding value of reduced-oil DGS is of great interest to cattle feeders. Given recent reductions in the U.S. beef cow herd, there has been increasing interest in crossbreeding dairy cows with beef bulls; therefore, an objective of this dissertation was to determine effects of feeding reduced-fat distillers grains with solubles (RFDGS) on finishing cattle performance and energy values when fed to dairy/beef crossbred feedlot cattle. Also, although there are studies that have shown minimal effects on feedlot cattle performance when fed reduced-oil DGS, a second objective of this dissertation was to utilize a meta-analysis approach to determine the impact of oil extraction from DGS on

finishing cattle performance and resulting energy values. Lastly, as corn grain varieties have been improved for grain yield and fast kernel drying under field conditions, cattle feeders are challenged to time kernel moisture with appropriate stalk and leaf moisture concentration for a given corn crop endpoint; corn silage, earlage or high-moisutre corn. Thus, a third objective of this dissertation was to study nutrient concentration changes in corn plant components in response to a single growing season in various fields on sandy soils.

Table 1. Nutrient analysis of distillers grains with solubles from dry-grind traditional, partial fractionation, quick germ, and quick germ and quick fiber ethanol production processes

Item	Conventional Process[1]	Quick Germ Process[1]	Quick Germ and Quick Fiber Process[1]	Traditional[2]	Partial Fractionation[2]	Traditional[3]	Back-end Oil Extraction[3]
Nutrient, %							
DM	N/A	N/A	N/A	87 (1.6)[4]	91 (0.8)	93.20	91.97
CP	28.50[c]	35.91[b]	49.31[a]	26 (0.9)	43 (0.2)	28.53	29.63
Crude Fat	12.70[a]	4.83[b]	3.85[b]	12 (0.6)	4 (0.2)	12.13	9.58
NDF	N/A	N/A	N/A	26 (2.2)	23 (2.4)	31.38	28.58
ADF	10.80[a]	8.22[b]	6.80[c]	N/A	N/A	17.57	15.25

[abc] Means within a row with different superscripts differ ($P < 0.01$).
[1] Adapted from (Singh et al., 2005).
[2] Adapted from (Depenbusch et al., 2008).
[3] Adapted from (Graham et al., 2014a).
[4] Standard deviation for nutrient analysis presented in parenthesis.

Chapter II

EFFECTS OF FEEDING REDUCED-FAT MODIFIED DISTILLERS GRAINS WITH SOLUBLES ON FINISHING CATTLE PERFORMANCE, CARCASS CHARACTERISTICS AND RESULTING DIETARY ENERGY VALUES

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SUMMARY

A 181-d feedlot study was conducted to determine effects of feeding reduced-fat modified distillers grains with solubles (RF MDGS) on finishing cattle performance, carcass characteristics and resulting dietary energy values. Fifty crossbred steers (initial BW 379 ± 32 kg) were fed individually utilizing a Calan gate system in which they were randomly assigned to 1 of 4 dietary treatments. Dietary treatments utilized in this study consisted of full-fat modified wet distillers grains with solubles (FF MDGS) at 15% of dietary DM (FF 15), RF MDGS at 15% of dietary DM (RF 15), RF MDGS at 30% of dietary DM (RF 30), and RF MDGS at 45% of dietary DM (RF 45). All dietary treatments consisted of the same source of RF MDGS containing 8.80% ether extract (EE). In order to reconstitute the FF MDGS (12.81% EE) source in treatment 1; supplemental corn oil was added to 14.30% RF MDGS at a rate of 0.70% of dietary DM to establish 15% FF MDGS (DM basis). Steers were implanted with Revalor-IS on d 28 and were re-implanted with Synovex Choice on d 142. On d 181, final BW was recorded after withholding feed and water for 16-h. Steers were then housed and fed a common diet for an additional 4 d before being shipped to a commercial abattoir where they were harvested the following morning. Over the entire cumulative feeding period of 181 d, steers consuming low inclusion of MDGS, regardless of EE content, had lower DMI (P = 0.02). No other performance variables as well as no carcass characteristics were affected ($P > 0.21$) by dietary treatment over 181 d on feed. No treatment effects were observed on observed ME concentration ($P > 0.54$). Overall, results from this experiment indicate that oil extraction through back-end oil extraction of MDGS does not impact animal growth performance, carcass characteristics, or resulting energy values.

Keywords: distillers grains, finishing cattle, ether extract, energy value

INTRODUCTION

Distillers grains with solubles (DGS) are a co-product of dry-grind fuel ethanol production and have a long history of being fed to livestock; the first study about feeding distillers grains to cattle in the United States was published in 1907 (Weiss et al., 2007). Substantial growth in fuel ethanol production increased the supply of DGS in recent years. In 1998, production of DGS (on a dry matter basis) was about 1 million metric tons. By 2014, the dry milling industry used 4.6 billion bushels of corn (33% of the U.S. corn supply) to produce 50.35 billion liters of ethanol and 39 million metric tons of distillers grains (RFA, 2015a); nearly half of which was fed to beef cattle. Traditionally feedlots that utilize DGS at concentrations lower than 15 to 20% of diet DM were feeding it as a protein source; conversely, DGS added above these concentrations is utilized as an energy source (Erickson et al., 2007).

The predominant grain utilized in ethanol production in the United States is corn, where during the dry-grind ethanol production process, whole corn kernels are fermented with yeast and water to produce ethanol. The corn kernel is made up of two-thirds starch, which is fermented into ethanol. The remaining unfermented portions are removed from the bottom of the distillation columns as whole stillage (wet cake). Concentration of unfermented portions (protein, oil, fiber, ash, and phosphorus) in whole stillage are increased 3-fold in DGS when compared to whole corn (Lim and Yildirim-Aksoy, 2008). Whole stillage then is centrifuged to separate solids from liquid portions to form distillers grains (DG) and thin stillage. Typically water is evaporated from thin stillage to produce condensed distillers solubles (CDS) which is then added back to DG to form DGS. Traditionally, DGS contained ether extract (EE) concentrations that ranged between 10 to

13% (Buckner et al., 2011). When DGS with EE concentrations ranging from 10 to 13% were included in cattle diets, the energy value of DGS was determined to be from 102 to 150% the energy value of corn (Erickson et al., 2005). However, the energy values are dependent on the method used to process the grain; whether the DGS were wet or dry, and the integrity of the fiber and protein after the grains underwent heating and fermentation process (Klopfenstein et al., 2008).

It has been determined that the production process to convert corn into ethanol contributes to a wide variation in the overall nutrient composition of DGS (Singh et al., 2005). Furthermore, as ethanol producers continue to seek greater value from corn grain being processed, oil extraction from DGS has become a method to increase their revenue stream. Approximately 85% of ethanol plants had the capability to extract oil in 2014 (RFA, 2015b); as a result, DGS commonly found today contain lower EE concentrations. In the dry-milling ethanol production process, oil can be removed via front-end fractionation or through back-end oil extraction. As a result of oil removal, EE concentrations of DGS can vary anywhere from 4 to 13%.

Results from previous research indicated no significant difference in DMI when various concentrations of full-fat (FF) DGS replaced basal corn or barley grain in diets (Buckner et al., 2008; Depenbusch et al., 2009a; Anderson et al., 2011). Conversely, when DGS replaced steam-flaked corn (SFC), dry-rolled corn (DRC), or high-moisture corn (HMC)-based diets up to 40% of diet DM, DMI increased in feedlot cattle diets (Vander Pol et al., 2006; Depenbusch et al., 2009b; Luebbe et al., 2012); however, as inclusion of DGS was increased above 40%, DMI decreased. In other experiments, cattle fed 10 to 30% DGS performed better than those fed greater concentrations of DGS

(Buckner et al., 2008). Furthermore, Vander Pol et al. (2006) fed cattle WDGS at increasing concentrations that resulted in a quadratic response by G:F as inclusion of WDGS increased with optimum inclusion between 30 to 40%. Traditional WDGS was reported to have 120 to 150% the energy value of corn in beef finishing diets. High energy values discovered for WDGS may be attributed to the energy contribution of EE as well as acidosis control, making this a primary advantage of utilizing DGS in finishing cattle diets (Erickson et al., 2005).

As oil extraction through either front-end fractionation or back-end centrifugation continues to be adopted in ethanol production, there has been limited research conducted on the effects of feeding RF DGS to finishing feedlot cattle. Therefore it is the objective of this experiment to determine the effects of feeding reduced-fat modified distillers grains with solubles on finishing cattle performance, carcass characteristics and resulting dietary energy values.

MATERIALS AND METHODS

All animal use procedures were reviewed and approved by the University of Minnesota Institutional Animal Care and Use Committee. Steers in this experiment were housed at the University of Minnesota's Beef Research and Education Complex located at UMore Park (Rosemount Research and Outreach Center) in Rosemount, MN.

Cattle

Fifty crossbred steers (initial BW 379 ± 32 kg) were utilized in a 181-d finishing experiment arranged in a completely randomized design. Upon arrival at the feedlot, steers were vaccinated with a modified-live viral vaccine (Pyramid 5 + Presponse SQ,

Boehringer Ingelheim, Inc., Ridgefield, CT), an intranasal vaccine (Inforce 3, Zoetis, Florham Park, NJ), and rectal temperatures were recorded; cattle with temperatures above 39.7˚ C were treated with an antibiotic (Resflor Gold, Merck Animal Health, Madison, NJ). Initial BW was recorded after a 16-h period during which steers had no access to feed or water.

Treatments and Design

Steers were randomly assigned to 1 of 4 dietary treatments and were individually fed in a Calan gate system (American Calan, Inc., Northwood, NH). Dietary treatment 1 was formulated to contain 14.3% RF MDGS along with 0.7% supplemental corn-oil to construe FF MDGS at 15% (FF 15) of diet DM. The remaining dietary treatments were formulated to contain RF MDGS at inclusions of 15, 30, or 45% (RF 15, RF 30, or RF 45) of diet DM. Nutrient composition and DM for each feedstuff utilized throughout this experiment (weighted composite) are listed in Table 1. Additionally, dietary feedstuff inclusion achieved after weighing contribution of each load mixed throughout the study and respective dietary nutrient compositions consumed (corrected for weighted nutrient composition of feed offered and refused) are listed in Table 2. There was a single source of RF MDGS utilized (Big River Resources, LLC, Boyceville, WI). The RF MDGS used in this experiment were processed by a dry-milling process with back-end centrifugation of thin stillage and contained 8.81% EE. When corn oil was added to RF MDGS in treatment 1, the MDGS represented FF MDGS containing 13.09% EE. A supplement was added to each diet to provide steers with 287 mg monensin/steer/d (Rumensin, Elanco Animal Health, Greenfield, IN).

As this study utilized a Calan gate system and cattle were fed individually by hand, total mixed rations were mixed once per week and stored on a feed pad in close proximity to the bunk line. Because rations were mixed and stored for one week at a time, a preservative (MYCO CURB, Kemin, Des Moines, IA) was added to total mixed rations. This product is a blend of organic acids formulated to inhibit mold growth in total mixed rations.

Steers were fed dietary treatments once daily at 0700 h. Intakes were adjusted according to amount of feed refused from previous days feeding and recorded to determine daily DMI. Along with collection of daily feed refusals, dietary feedstuff samples were collected weekly. All dietary feedstuff samples and feed refusal samples were stored at -20˚ C until laboratory analysis.

Sample Analysis

Prior to laboratory analysis, feedstuffs and feed refusal samples were dried in a drying oven (Blue M Electric, Thermal Product Solutions, New Columbia, PA) at 60˚ C for 48 h. All samples were then ground to pass through a 2-mm screen using a Thomas Model 4 Wiley Mill (Thomas Scientific, Swedesboro, NJ). The total weight of all feed refusals per steer were determined then each individual feed refusal was composited based on individual percentage of the total feed refused in order to obtain a single composite for each steer. Feed refusal composite samples and feedstuffs samples obtained each time diets were mixed were then prepared and nutrient compositions were analyzed. Individual samples were analyzed for CP (Method 992.15; AOAC, 1995), NDF (Van Soest et al., 1991), ADF (Method 973.18; AOAC, 2000), and EE (Method 920.39, AOAC, 2000). For CP analysis, all samples were prepared and shipped to an outside lab

(University of Florida – North Florida Research and Education Center, Marianna, FL) to be analyzed following the procedure of Ciriaco et al. (2015). All other analysis was conducted on campus (University of Minnesota – Haecker Hall, St. Paul, MN). Neutral detergent fiber analysis was conducted utilizing an Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY), where samples were extracted for 60 min at 100˚ C in NDF solution with heat-stable α-amylase. Prior to NDF analysis, samples that contained EE concentrations greater than 5% (RF MDGS, DRC, and feed refusals) were pre-extracted following biphasic extraction procedures (Bremer et al., 2010). This procedure was utilized because samples that have EE concentrations greater than 5%, not all of the fat was dissolved during the NDF procedure; thus, decreasing the accuracy of feed sample NDF determination. Following NDF analysis, samples were dried at 100˚ C overnight (Thelco 130DM, Precision Scientific, Chicago, IL) then weighed and NDF percentage was calculated. Acid detergent fiber was then analyzed utilizing the same procedure as NDF; however, ADF solution was utilized and samples were extracted for 60 min at 100˚ C followed by drying overnight, weighing then calculating ADF percentage. Samples were analyzed for EE concentration by the use of an Ankom^{XT10} Extraction System (Ankom Technology, Macedon, NY) for 60 min at 90˚ C with petroleum ether.

Implants and Harvest

Steers were implanted with Revalor-IS (Merck Animal Health, Madison, NJ) on d 28 and were re-implanted with Synovex Choice (Zoetis, Florham Park, NJ) on d 142. On d 181, final BW was recorded after a 16-h period without access to feed and water. Steers were then housed and fed a common diet for an additional 4 d before they were shipped to a commercial abattoir (Tyson Foods, Inc., Dakota City, NE) where they were

harvested the following morning. On the day of harvest; slaughter order, HCW, and KPH measurements were recorded. Additionally, following a 48-h chill, camera measurements recorded LM area, fat depth, and marbling. Individual steer performance and carcass characteristics evaluated included initial and final BW, BW gain, DMI, ADG, G:F, HCW, dressing percent, marbling score, LM area, 12^{th} rib fat thickness, KPH, and USDA Yield and Quality grades. USDA Yield Grade was calculated using the USDA Yield Grade equation: [YG = 2.5 + (0.98425 * 12^{th} rib fat thickness, cm) + (0.20 * KPH%) + (0.00837 * HCW, kg) – (0.0496 * LM area, cm^2)] (Boggs and Merkel, 1993). Carcass adjusted final BW, ADG, and G:F were calculated from HCW using the common dressing percentage of the group (61.70%).

Observed ME

Dietary ME concentration was estimated using iterative procedures (NRC, 2000). Estimation of observed ME was carried out based on average empty BW and empty body ADG to determine daily requirements for NE_m and NE_g using various ME values in iterative attempts to allocate DMI to match net energy required for maintenance and gain. The resulting ME value (observed ME) was then divided by diet formulated ME value (expected value) as an index of the adequacy of ME utilization.

Data Analysis

Data were analyzed using the mixed procedure of SAS 9.3 (SAS Institute Inc., Cary, NC). Experimental unit was the individual steer (FF 15 and RF 15 treatments contained 13 head per treatment and RF 30 and RF 45 treatments contained 12 head per treatment). Preplanned orthogonal contrasts were conducted on performance and carcass

data to determine the effects of feeding FF MDGS compared to feeding RF MDGS (FF 15 versus RF 15, RF 30 and RF 45); effects of feeding low vs high MDGS inclusion regardless of EE content (FF 15 and RF 15 versus RF 30 and RF 45); or to contrast feeding FF MDGS vs RF MDGS at 15% inclusion (FF 15 versus RF 15). Effects were considered significant when a *P* value of less than 0.05 was obtained and were considered a trend when *P* values were between 0.05 and 0.10.

RESULTS AND DISCUSSION

Interim Growth Performance

Cattle fed RF MDGS at 15% inclusion during d 1 to 28 had a tendency for greater ADG and improved G:F ($P = 0.06$) compared to cattle fed FF MDGS (Table 3). Although not statistically significant ($P = 0.34$), DMI was numerically lower for cattle fed FF 15 compared to RF 15 during d 1 to 28 thus potentially contributing to lower gains and decreased G:F. Adaptation to dietary treatments and metabolism of lipids for cattle fed FF 15 during the first 28 d could have impacted gains and feed efficiencies. The MDGS source fed in FF 15 treatment was the same as that of all other treatments but corn oil was added to formulate FF MDGS. It has been suggested that dietary fat added from WDGS is not hydrogenated to the same extent in the rumen as fat provided in the form of supplemental corn oil. Fat added as corn oil was 70% digested in the rumen while fat from WDGS was 81% digested (Vander Pol et al., 2007). Feeding cattle FF MDGS during the initial 28 d led to a tendency for reduced DMI ($P = 0.09$) compared to cattle fed RF MDGS (Table 3). Cattle fed 15% MDGS, regardless of EE content, consumed less DM between d 29 to 56, d 57 to 84, d 85 to 112, and d 141 to 168, respectively, than those fed greater MDGS concentrations ($P < 0.01$; Table 3). Observations gleaned from

past research demonstrated that DMI was greater throughout the feeding period at higher concentrations of RF DGS (Veracini et al., 2013).

During d 29 to 56, cattle fed FF MDGS had lower ADG compared to all RF MDGS treatments ($P = 0.01$; Table 3). Lower ADG for cattle fed FF 15 treatment found during the first 56 d on feed could have been related to decreased digestibility of supplemental corn oil added to the diet (Vander Pol et al., 2007). Furthermore, during d 29 to 56, cattle fed RF MDGS had greater ADG ($P = 0.01$) when compared to cattle fed FF MDGS (Table 3).

Cumulative Performance

Treatment effects on cumulative performance results over 181 d on feed are listed in Table 4. Cattle fed MDGS at 15% inclusion, regardless of EE content, consumed less DM ($P = 0.01$) over the 181 d feeding period. These results are consistent with one of the experiments by Veracini et al. (2013); where feeding increasing concentrations of RF MDGS from 0 to 70% resulted in increased DMI as inclusion increased. Similarly, feeding FF DDGS, FF MDGS, and FF WDGS at increasing concentration resulted in quadratic DMI increases (Bremer et al. 2011). In this review, Bremer et al. (2011) found that as DGS inclusion reached 40%, DMI began to decline. From d 1 to 56, cattle fed FF 15 treatment tended to have lower ADG ($P = 0.08$) compared to cattle fed RF 15 treatment. Cattle fed either FF or RF MDGS at 15% inclusion tended to have lower ADG from d 1 to 56 ($P = 0.09$); as well as lower ADG for cattle fed FF 15 compared to all other treatments from d 1 to 56 ($P = 0.02$) and d 1 to 84 ($P = 0.05$). Due to lower ADG observed in cattle fed 15% FF MDGS during d 1 to 56, G:F also tended to be lower ($P = 0.08$). It appears that any potential negative impacts that supplemental corn oil had on

cattle fed the FF 15 treatment were resolved following d 84 on feed. Following d 84, cattle fed 15% MDGS regardless of EE content, had lower DMI ($P < 0.01$); however no other significant observations on growth performance traits were observed over 181 d on feed. These observations are similar to results found by Veracini et al., (2013). Furthermore, Jolly et al. (2014) fed FF or RF WDGS at 35, 50, and 65% of diet DM and observed that cattle fed WDGS at 65% inclusion, regardless of EE content, consumed less DM. However, ADG and G:F were unaffected. These results are similar to the current experiment where there was no difference in ADG or G:F between cattle fed FF MDGS at 15% inclusion or 15, 30, and 45% RF MDGS.

Carcass Adjusted Final Body Weight and Dietary Energy Values

Carcass adjusted final BW and feedlot performances are listed in Table 5. Feeding FF MDGS or increasing concentrations of RF MDGS had no impact on performance. Furthermore, iterated dietary energy values were similar regardless of EE concentration or inclusion of MDGS. Results from previous research led to similar conclusions where either FF or RF MDGS was fed in a finishing experiment (Bremer et al., 2015a).

Carcass Characteristics

Hot carcass weight, DP, LM area, 12th rib fat depth, marbling score, KPH, USDA Yield Grade and USDA Quality Grades were all unaffected ($P > 0.29$) by dietary treatments (Table 6). Finding no significant differences between treatment groups for carcass characteristics could be a result of no significant differences in dietary ME intake observed for cattle in all treatment groups. Similar results were found when replacing

corn-based diets with diets containing increasing concentrations of either FF or RF DGS where there were no significant differences in HCW, LM area, 12th rib fat depth, marbling score, and USDA Yield Grades (Buckner et al., 2008; Jolly et al., 2014). Furthermore, similar effects of feeding increasing concentrations of DGS sources were found when assessing carcass characteristics, as HCW was the only carcass characteristic that differed with increasing concentrations of DGS (Vander Pol et al., 2006b; Veracini et al., 2013). Conversely, Larson et al. (1993) and Anderson et al. (2011) reported that replacing either corn or barely-based diets with DGS resulted in increased HCW and marbling score and increased HCW, dressing percent, LM area, 12th rib fat depth, yield grade, and KPH, respectively.

Conclusion

This experiment revealed that feeding FF MDGS at 15% inclusion or feeding RF MDGS at 15, 30, and 45% inclusion had no impact on cattle growth performance, carcass characteristics, and resulting dietary energy values. However, cattle fed low inclusion of MDGS, regardless of EE concentration, had lower DMI compared to cattle fed 30 and 45% RF MDGS. It has been suggested that optimum dietary inclusion of DGS range between 30 to 40% (Klopfenstein et al., 2008), and this study suggests that oil removal via back-end centrifugation of thin stillage had minimal effects on the feeding value of RF MDGS.

Table 1. Nutrient composition of feedstuffs

Nutrient, (DM basis)	Straw	RF MDGS[1]	DRC[2]	Corn Oil	Supplement[3,4]
DM, %	73.73	47.46	83.63	98.00	70.02
CP, %	5.24	29.95	7.77	-	29.31
NDF, %	73.90	39.20	11.25	-	-
ADF, %	45.61	9.06	2.21	-	-
Ether extract, %	1.23	8.81	3.50	99.15	-

[1] RF MDGS = Reduced-fat modified wet distillers grains with solubles (Big River Resources, LLC, Boyceville, WI).
[2] DRC = Dry rolled corn.
[3] Supplement formulated to provide 287 mg monensin/hd/d (Rumensin, Elanco Animal Health, Greenfield, IN).
[4] MYCO CURB (Kemin, Des Moines, IA) added to supplement to reduce mold contamination.

Table 2. Dietary inclusion and composition (DM; after correcting for composition of feed offered and refused) of DRC[1]-based finishing diets containing FF MDGS[1] or various concentrations of RF MDGS[1]

	Treatment[2]			
Item	FF 15	RF 15	RF 30	RF 45
Ingredient				
Straw, %	9.00	9.01	9.01	8.89
RF MDGS[3], %	14.93	15.60	30.84	46.27
DRC, %	72.01	72.06	56.84	41.55
Corn oil, %	0.74	-	-	-
Supplement[4,5], %	3.31	3.33	3.31	3.28
Composition				
DM, %	74.03	73.62	66.83	61.20
CP, %	11.23	11.47	14.80	18.20
NDF, %	20.21	20.52	24.85	28.87
ADF, %	6.93	7.00	8.04	9.03
Ether extract, %	4.58	3.92	4.79	5.52

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RF MDGS = reduced-fat MDGS (RF MDGS).
[2] Treatments included: FF 15 = 15% RF MDGS inclusion with 0.7% added corn oil to constitute FF MDGS, RF 15 = 15% RF MDGS inclusion, RF 30 = 30% RF MDGS inclusion, RF 45 = 45% RF MDGS inclusion.
[3] RF MDGS = reduced-fat modified wet distillers grains with solubles (Big River Resources, LLC, Boyceville, WI).
[4] Supplement formulated to provide 287 mg monensin/hd/d (Rumensin, Elanco Animal Health, Greenfield, IN).
[5] MYCO CURB (Kemin, Des Moines, IA) added to supplement to reduce mold contamination.

Table 3. Interim animal growth performance of finishing steers fed DRC[1]-based diets containing FF MDGS[1] or various concentrations of RF MDGS[1]

	Treatment[2]					Contrast[3]		
Item	FF 15	RF 15	RF 30	RF 45	SEM	1	2	3
Initial BW, kg	385	377	385	370	9.25	0.47	0.72	0.53
d1 to 28								
BW, kg	413	413	419	401	10.63	0.90	0.78	0.97
DMI, kg/d	6.32	6.55	6.94	6.49	0.17	0.09	0.11	0.34
ADG, kg	1.00	1.31	1.21	1.13	0.12	0.11	0.91	0.06
Gain:Feed	0.154	0.201	0.173	0.175	0.017	0.15	0.84	0.06
d29 to 56								
BW, kg	450	453	468	446	11.02	0.64	0.64	0.81
DMI, kg/d	8.58	8.19	9.56	9.28	0.44	0.39	0.02	0.52
ADG, kg	1.33	1.43	1.76	1.58	0.09	0.01	< 0.01	0.39
Gain:Feed	0.160	0.183	0.187	0.178	0.02	0.21	0.48	0.29
d57 to 84								
BW, kg	484	488	503	484	12.07	0.61	0.55	0.84
DMI, kg/d	9.45	7.83	10.58	10.39	0.62	0.83	< 0.01	0.06
ADG, kg	1.24	1.22	1.24	1.37	0.12	0.77	0.55	0.94
Gain:Feed	0.139	0.171	0.137	0.144	0.020	0.59	0.47	0.23
d85 to 112								
BW, kg	528	530	541	522	13.46	0.84	0.84	0.91
DMI, kg/d	9.86	8.15	11.64	10.75	0.91	0.76	0.02	0.17
ADG, kg	1.54	1.50	1.37	1.35	0.12	0.32	0.20	0.78
Gain:Feed	0.174	0.203	0.135	0.158	0.026	0.77	0.12	0.42

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RF MDGS = reduced-fat MDGS (RF MDGS).
[2] Treatments included: FF 15 = 15% reduced-fat modified wet distillers grains with solubles (RF MDGS) inclusion with 0.7% added corn oil to constitute full-fat (FF) MDGS, RF 15 = 15% RF MDGS inclusion, RF 30 = 30% RF MDGS inclusion, RF 45 = 45% RF MDGS inclusion.
[3] Preplanned orthogonal contrasts: 1 = FF vs RF (FF 15 vs RF 15, RF 30, and RF 45). 2 = Low inclusion vs. High inclusion (FF 15 and RF 15 vs. RF 30 and RF 45). 3 = 15 vs. 15 (FF 15 vs. RF 15). ($P < 0.05$ considered significant; $P > 0.05$ and ≤ 0.10 considered a trend).

Table 3 (continued). Interim animal growth performance of finishing steers fed DRC[1]-based diets containing FF MDGS[1] or various concentrations of RF MDGS[1]

	Treatment[2]					Contrast[3]		
Item	FF 15	RF 15	RF 30	RF 45	SEM	1	2	3
Initial BW, kg	385	377	385	370	9.25	0.47	0.72	0.53
d113 to 140								
BW, kg	565	567	576	560	14.03	0.89	0.88	0.94
DMI, kg/d	9.14	8.83	11.12	10.22	1.04	0.44	0.11	0.83
ADG, kg	1.35	1.32	1.26	1.37	0.13	0.81	0.86	0.87
Gain:Feed	0.192	0.162	0.126	0.204	0.042	0.55	0.78	0.60
d141 to 168								
BW, kg	603	601	617	593	15.20	0.97	0.86	0.93
DMI, kg/d	9.12	9.50	12.65	10.69	1.11	0.15	0.04	0.80
ADG, kg	1.35	1.23	1.44	1.19	0.11	0.63	0.83	0.45
Gain:Feed	0.193	0.169	0.120	0.135	0.030	0.13	0.08	0.55
d169 to 181								
BW, kg	605	598	615	591	14.70	0.83	0.89	0.71
DMI, kg/d	8.54	8.66	11.98	9.92	1.15	0.21	0.05	0.94
ADG, kg	0.14	-0.28	-0.11	-0.17	0.16	0.07	0.69	0.05
Gain:Feed	0.011	-0.058	-0.009	-0.046	0.023	0.06	0.87	0.03

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RF MDGS = reduced-fat MDGS (RF MDGS).
[2] Treatments included: FF 15 = 15% reduced-fat modified wet distillers grains with solubles (RF MDGS) inclusion with 0.7% added corn oil to constitute full-fat (FF) MDGS, RF 15 = 15% RF MDGS inclusion, RF 30 = 30% RF MDGS inclusion, RF 45 = 45% RF MDGS inclusion.
[3] Preplanned orthogonal contrasts: 1 = FF vs RF (FF 15 vs RF 15, RF 30, and RF 45). 2 = Low inclusion vs. High inclusion (FF 15 and RF 15 vs. RF 30 and RF 45). 3 = 15 vs. 15 (FF 15 vs. RF 15). ($P < 0.05$ considered significant; $P > 0.05$ and ≤ 0.10 considered a trend).

Table 4. Cumulative animal growth performance of finishing steers fed DRC[1]-based diets containing FF MDGS[1] or various concentrations of RF MDGS[1]

	Treatment[2]					Contrast[3]		
Item	FF 15	RF 15	RF 30	RF 45	SEM	1	2	3
Initial BW, kg	385	377	385	370	9.25	0.47	0.72	0.53
d1 to 28								
BW, kg	413	413	419	401	10.63	0.90	0.78	0.97
DMI, kg/d	6.32	6.55	6.94	6.49	0.17	0.09	0.11	0.34
ADG, kg	1.00	1.31	1.21	1.13	0.12	0.11	0.91	0.06
Gain:Feed	0.154	0.201	0.173	0.175	0.017	0.15	0.84	0.06
d1 to 56								
BW, kg	450	453	468	446	11.02	0.64	0.64	0.81
DMI, kg/d	7.43	7.35	8.23	7.87	0.29	0.24	0.03	0.84
ADG, kg	1.16	1.37	1.48	1.36	0.09	0.02	0.09	0.08
Gain:Feed	0.156	0.190	0.182	0.178	0.014	0.08	0.62	0.07
d1 to 84								
BW, kg	484	488	503	484	12.07	0.61	0.55	0.84
DMI, kg/d	8.17	7.56	9.09	8.78	0.38	0.48	0.01	0.24
ADG, kg	1.19	1.32	1.40	1.36	0.08	0.05	0.11	0.21
Gain:Feed	0.148	0.182	0.159	0.164	0.015	0.24	0.81	0.10
d1 to 112								
BW, kg	528	530	541	522	13.46	0.84	0.84	0.91
DMI, kg/d	8.62	7.72	9.76	9.30	0.49	0.58	0.01	0.19
ADG, kg	1.28	1.37	1.39	1.36	0.07	0.25	0.46	0.37
Gain:Feed	0.153	0.186	0.150	0.160	0.016	0.53	0.37	0.15

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RF MDGS = reduced-fat MDGS (RF MDGS).
[2] Treatments included: FF 15 = 15% reduced-fat modified wet distillers grains with solubles (RF MDGS) inclusion with 0.7% added corn oil to constitute full-fat (FF) MDGS, RF 15 = 15% RF MDGS inclusion, RF 30 = 30% RF MDGS inclusion, RF 45 = 45% RF MDGS inclusion.
[3] Preplanned orthogonal contrasts: 1 = FF vs RF (FF 15 vs RF 15, RF 30, and RF 45). 2 = Low inclusion vs. High inclusion (FF 15 and RF 15 vs. RF 30 and RF 45). 3 = 15 vs. 15 (FF 15 vs. RF 15). ($P < 0.05$ considered significant; $P > 0.05$ and ≤ 0.10 considered a trend).

Table 4 (continued). Cumulative animal growth performance of finishing steers fed DRC[1]-based diets containing FF MDGS[1] or various concentrations of RF MDGS[1]

	Treatment[2]					Contrast[3]		
Item	FF 15	RF 15	RF 30	RF 45	SEM	1	2	3
Initial BW, kg	385	377	385	370	9.25	0.47	0.72	0.53
d1 to 140								
BW, kg	565	567	576	560	14.03	0.89	0.88	0.95
DMI, kg/d	8.73	7.95	10.05	9.50	0.58	0.50	0.02	0.32
ADG, kg	1.29	1.36	1.37	1.36	0.07	0.35	0.56	0.46
Gain:Feed	0.158	0.180	0.144	0.162	0.018	0.83	0.36	0.35
d1 to 168								
BW, kg	603	601	617	593	15.20	0.97	0.86	0.93
DMI, kg/d	8.79	8.20	10.48	9.70	0.63	0.35	0.02	0.49
ADG, kg	1.30	1.34	1.38	1.33	0.06	0.49	0.55	0.67
Gain:Feed	0.161	0.174	0.139	0.156	0.018	0.81	0.26	0.59
d1 to 181								
BW, kg	605	598	615	591	14.70	0.83	0.89	0.71
DMI, kg/d	8.78	8.24	10.59	9.72	0.65	0.32	0.01	0.54
ADG, kg	1.22	1.22	1.27	1.22	0.05	0.72	0.59	0.97
Gain:Feed	0.152	0.159	0.127	0.143	0.016	0.63	0.21	0.74

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RF MDGS = reduced-fat MDGS (RF MDGS).
[2] Treatments included: FF 15 = 15% reduced-fat modified wet distillers grains with solubles (RF MDGS) inclusion with 0.7% added corn oil to constitute full-fat (FF) MDGS, RF 15 = 15% RF MDGS inclusion, RF 30 = 30% RF MDGS inclusion, RF 45 = 45% RF MDGS inclusion.
[3] Preplanned orthogonal contrasts: 1 = FF vs RF (FF 15 vs RF 15, RF 30, and RF 45). 2 = Low inclusion vs. High inclusion (FF 15 and RF 15 vs. RF 30 and RF 45). 3 = 15 vs. 15 (FF 15 vs. RF 15). ($P < 0.05$ considered significant; $P > 0.05$ and ≤ 0.10 considered a trend).

Table 5. Cumulative 181 d animal growth performance and energy values for finishing steers fed DRC[1]-based diets containing FF MDGS[1] or various concentrations of RF MDGS[1]

	Treatment[2]					Contrast[3]		
Item	FF 15	RF 15	RF 30	RF 45	SEM	1	2	3
Performance								
Initial BW, kg	385	377	385	370	9.25	0.47	0.72	0.53
Final BW[4], kg	605	600	607	592	18.36	0.78	0.87	0.82
Gain, kg	220	223	222	222	12.82	0.90	0.98	0.89
DMI, kg/d	8.78	8.24	10.59	9.72	0.65	0.32	0.01	0.54
ADG, kg	1.22	1.23	1.23	1.23	0.07	0.89	0.98	0.89
Gain:Feed	0.150	0.161	0.123	0.145	0.017	0.74	0.21	0.61
Energy Values[5]								
Obs ME, Mcal/kg	3.21	3.27	3.01	3.17	0.24	0.82	0.54	0.85
Obs ME/Exp ME	1.04	1.07	0.96	1.00	0.08	0.71	0.32	0.77
Obs NEm, Mcal/kg	2.19	2.23	2.03	2.16	0.19	0.82	0.53	0.85
Obs NEg, Mcal/kg	1.49	1.53	1.36	1.46	0.15	0.81	0.51	0.84

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RF MDGS = reduced-fat MDGS (RF MDGS).
[2] Treatments included: FF 15 = 15% reduced-fat modified wet distillers grains with solubles (RF MDGS) inclusion with 0.7% added corn oil to constitute full-fat (FF) MDGS, RF 15 = 15% RF MDGS inclusion, RF 30 = 30% RF MDGS inclusion, RF 45 = 45% RF MDGS inclusion.
[3] Preplanned orthogonal contrasts: 1 = FF vs RF (FF 15 vs RF 15, RF 30, and RF 45). 2 = Low inclusion vs. High inclusion (FF 15 and RF 15 vs. RF 30 and RF 45). 3 = 15 vs. 15 (FF 15 vs. RF 15). ($P < 0.05$ considered significant; $P > 0.05$ and ≤ 0.10 considered a trend).
[4] Carcass adjusted final BW was calculated from HCW using a common dressing percentage of 61.70%.
[5] Observed ME intake calculated utilizing iterative procedures (NRC, 2000).

Table 6. Carcass characteristics, Yield Grades and Quality Grades for finishing steers fed DRC[1]-based diets containing FF MDGS[1] or various concentrations of RF MDGS[1]

	Treatment[2]					Contrast[3]		
Item	FF 15	RF 15	RF 30	RF 45	SEM	1	2	3
Carcass Characteristics								
HCW, kg	373	370	374	365	11.33	0.78	0.87	0.83
Dressing percentage, %	61.62	61.86	61.54	61.75	0.52	0.87	0.86	0.73
LM area, cm^2	86.40	86.70	83.28	87.47	2.29	0.82	0.61	0.92
12th rib fat depth, cm	1.21	1.20	1.44	1.24	0.15	0.61	0.37	0.97
Marbling score[4]	486	513	475	513	32.78	0.69	0.87	0.54
KPH, %	2.46	2.62	2.41	2.63	0.11	0.47	0.84	0.29
USDA Yield Grade[5]	2.54	2.49	2.97	2.44	0.22	0.70	0.39	0.87
USDA Quality Grade	2.08	2.00	2.00	2.08	0.13	0.74	0.98	0.67

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RF MDGS = reduced-fat MDGS (RF MDGS).
[2] Treatments included: FF 15 = 15% reduced-fat modified wet distillers grains with solubles (RF MDGS) inclusion with 0.7% added corn oil to constitute full-fat (FF) MDGS, RF 15 = 15% RF MDGS inclusion, RF 30 = 30% RF MDGS inclusion, RF 45 = 45% RF MDGS inclusion.
[3] Preplanned orthogonal contrasts: 1 = FF vs RF (FF 15 vs RF 15, RF 30, and RF 45). 2 = Low inclusion vs. High inclusion (FF 15 and RF 15 vs. RF 30 and RF 45). 3 = 15 vs. 15 (FF 15 vs. RF 15). ($P < 0.05$ considered significant; $P > 0.05$ and ≤ 0.10 considered a trend).
[4] Marbling score: 400 = small˚, 500 = modest˚.
[5] Yield grade calculation: [YG = 2.5 + (0.98425 * 12th rib fat thickness, cm) + (0.20 * KPH%) + (0.00837 * HCW, kg) – (0.0496 * LM area, cm^2)] (Boggs and Merkel, 1993).

Chapter III

DETERMINING ENERGY VALUE OF OIL-EXTRACTED CORN DISTILLERS GRAINS WITH SOLUBLES IN FINISHING FEEDLOT DIETS

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SUMMARY

A dataset derived from 14 manuscripts containing 75 means for treatments comparing control grain diets with diets containing various concentrations of low-, reduced-, or full-fat wet, modified wet or dry distillers grains with solubles (DGS) in finishing beef cattle experiments was subject to a meta-analysis to determine the impact of oil extraction from DGS on finishing cattle performance and resulting energy values. In all instances, DGS substituted grain or grain and protein supplement source at a given percentage of diet DM without regard to impact on caloric, lipid, protein or dry matter concentration of dietary treatments. Treatment diets were grouped as low and reduced-fat (RF: 7.75% ether extract) or full-fat (FF: 12.00% ether extract) DGS. Using a mixed model approach independent variables of co-product type (RF or FF) or control, were evaluated through analysis of variance on performance variables: DMI, ADG, feed-to-gain (FTG; analyzed as gain-to-feed GTF), final BW, and observed ME. At increasing DGS inclusion, FF DGS caused a greater ($P < 0.05$) decrease in DMI than RF DGS. Feeding FF DGS resulted in greater ($P < 0.03$) ADG compared to feeding RF DGS or control diets; furthermore, feeding RF DGS resulted in greater ($P = 0.01$) ADG compared to feeding control diets. Feeding DGS at moderate or high inclusion, regardless of type, resulted in greater ($P < 0.05$) feed conversion efficiency compared to feeding control diets. At high inclusion, feeding FF DGS led to greater ($P < 0.05$) feed conversion efficiency than feeding RF DGS. Feeding FF DGS at moderate or high inclusion or RF DGS at moderate inclusion resulted in greater ($P < 0.05$) observed ME intake compared to feeding control diets. Estimated ME values for grain and DGS were similar to previously reported NRC values. Similarly, value of ether extract contribution to dietary

ME (0.06 Mcal/percentage unit EE) from DGS was similar to values observed when adding fat to diets reported by other researchers. At an average of 6.73% ether extract concentration for DGS modeled in this analysis (3.04 Mcal ME/kg DM), the expected ME concentration of FF-, RF-, and LF DGS was 3.35, 3.10, and 2.91 Mcal ME/kg DM, respectively. Equivalent NE_g concentrations for DGS containing 12.00, 7.75 or 4.50% ether extract, corresponding to average ether extract concentrations for full-, reduced- and low-fat DGS, would be 1.62, 1.44, and 1.31 Mcal NE_g/kg DM, respectively. Results of this meta-analysis demonstrated that reducing oil content of corn distillers grains with solubles reduced energy value of the DGS, thus corrections to energy content of currently available DGS are required.

Keywords: distillers grains, meta-analysis, energy value, finishing cattle

INTRODUCTION

Because feed costs account for roughly 60 to 80% of the total cost of production in a feedlot, it is imperative to formulate rations accordingly to match the stage of production, the type of cattle, and the time of year; in order to provide cattle with sufficient nutrients as economically as possible. One way cattle producers achieve these production goals is through the utilization of distillers grains with solubles (DGS). Distillers grains with solubles is a co-product of fuel ethanol production high in energy and protein that has been fed to cattle for many years. Ether extract (EE), generally at concentrations ranging from 10 to 13% in traditional, full-fat DGS (FF DGS) is an excellent source of energy to cattle (Buckner et al., 2011). Conversely, ethanol producers seeking greater value from corn grain processing have made recent adaptions to dry-grind ethanol plants to extract corn oil. This has resulted in production of DGS with variable and lower concentrations of oil.

There are two main methods that have been adapted by dry-grind ethanol plants to capture high value corn oil and those are through front-end fractionation and back-end centrifugation of thin stillage. Front-end fractionation, developed originally for wet-milling ethanol production, has been utilized in dry-grind ethanol production as a modified wet process that typically yields DGS with the lowest EE concentrations of 3 to 5% (Singh et al., 2005). Fractionation of grain increases fermentation efficiency by removing the non-starch components prior to fermentation thus increasing value-added opportunities for various other co-products (Rajagopalan et al., 2005; Rausch and Belyea, 2006). The resulting DGS from modified wet front-end fractionation is generally considered low-fat DGS (LF DGS); however, this is not a common production system

because of high capital investment to implement into an existing ethanol plant. The majority of dry-grind ethanol plants are adapting back-end centrifugation, where the entire corn kernel undergoes fermentation and then a second centrifuge removes oil from the thin stillage stream (CDS) prior to CDS being added back to wet distillers grains (WDG). Typically, DGS generated through this method have EE concentrations ranging between 7 to 9%, and are considered reduced-fat DGS (RF DGS).

As the nutrient composition of DGS continually changes due to oil removal, reducing EE concentration of DGS may have a negative impact on performance of feedlot cattle and finishing pigs. However, there is limited research in the area of feeding RF DGS to cattle. In the swine industry, Stein and Shurson (2009) reported that pigs fed up to 30% DDGS in their ration did not experience any negative impacts in growth performance. However, at 30% inclusion, the carcass fat in pigs had greater iodine values (IV) than carcass fat in pigs not fed DDGS. Graham et al. (2014b) found variable responses in 2 experiments in which pigs fed LF DDGS experienced lower performance; however, they also found no significant differences in one experiment when pigs were fed either RF DDGS or FF DDGS. Cattle fed increasing inclusion of FF DDGS experienced quadratic increases in final BW, DMI, ADG, and G:F (Depenbusch et al., 2009b). Similar observations were found by Klopfenstein et al. (2008). However, Buckner et al. (2007) found no differences in growth performance or carcass characteristics in cattle that were fed FF DGS compared to control. Distillers grains with solubles may be classified into full-fat (≥ 10% EE), reduced-fat (6 to 9% EE), and low-fat (3 to 5% EE).

Because of varying EE concentrations of DGS, impact of oil extraction on the energy value of DGS is an item of interest to cattle feeders and nutritionists. It has been suggested that DGS fat increases cattle performance compared to other sources of fat in high-moisture corn (HMC) and dry-rolled corn (DRC)-based diets (Vander Pol et al., 2009). Thus, due to increasing trends of oil removal from DGS, it is the objective of this research to utilize a meta-analysis approach to summarize results from recent research to determine impact of oil extraction from DGS on finishing cattle performance and resulting dietary energy values.

MATERIALS AND METHODS

Treatments

A dataset derived from 14 manuscripts containing 75 means for treatments comparing control diets with diets containing various concentrations of low-, reduced-, or full-fat wet, modified wet and dry distillers grains with solubles in finishing beef cattle experiments was assembled into a meta-analysis to evaluate response by finishing cattle performance to feeding DGS of various EE concentrations and to derive dietary energy values when fed DGS. The dataset contained 20 control diets that contained whole shelled corn (WSC) or corn processed as DRC, HMC or steam-flaked corn (SFC), and, in some cases, rolled barley. Treatment groups consisted of various dietary concentrations of DGS with varying EE concentrations. Treatments were organized into two different groups according to DGS EE. The RF DGS treatment group contained 36 observations, where EE concentrations of DGS ranged from 4 to 9.2%. This treatment group consisted of both LF DGS and RF DGS sources due to low numbers of observations feeding LF DGS. Treatment group FF DGS contained 19 observations, which consisted of DGS

sources that contained EE concentrations ranging from 10.3 to 13% EE. Within treatment groups, inclusion of DGS varied therefore there were three different classifications of inclusion; low, moderate, or high inclusion where the dietary inclusion of DGS was 1 to 21%, 25 to 35%, or greater than 35%, respectively. In all instances, DGS substituted grain or grain and protein supplement source at a given percentage of diet DM without regard to impact on caloric, lipid, protein or dry matter concentration of dietary treatments. Raw means, weighted by number of observations per treatment, standard deviations, and ranges of variables analyzed for control and treatment groups are listed in Table 1.

Observed Metabolizable Energy (ME)

Dietary ME or observed ME for co-products and control diets fed were estimated using iterative procedures (NRC, 2000). Iteration for dietary or observed ME was carried out by utilizing average empty BW and empty body ADG to determine daily requirements for NE_m and NE_g. Furthermore, various ME values were utilized in iterative attempts to allocate DMI to match net energy required for maintenance and gain. The resulting ME value (observed ME) was then regressed on kilograms of feedstuffs fed in order to determine ME values for each contributing feedstuff as well as to determine impact of co-product EE on ME. The intercept represented the estimate of ME used for maintenance and the regression coefficient represented the NE_g value of each contributing feedstuffs which was then corrected with weighted ADG to determine ME value of each contributing feedstuffs.

Data Analysis

Data were analyzed utilizing the Mixed Procedure of SAS 9.3 (SAS Institute Inc., Cary, NC). The experimental unit depicted in this dataset was either a pen of cattle or an individual animal where the treatment means were then weighted by the experimental unit/mean in order to account for varying number of cattle per pen or individuals per treatment. In the analysis, co-product type (whether RF DGS or FF DGS) or control and the inclusion of co-products were assigned as discrete independent variables. Dependent variables in this analysis were feedlot performance variables (DMI, ADG, G:F, and final BW). Also, the effect of co-product type or control and inclusion was utilized to determine the effect on dietary observed ME values. The random effect of manuscript by study was utilized as data were derived from multiple sources; initial BW was retained as a covariate in the analysis when observed to be significant ($P < 0.05$). In the instance of evaluating DMI, F:G, and observed ME, impact of both type of co-product and its respective dietary inclusion concentration were modeled using a regression for co-product percent inclusion and type to assess what affects this interaction had on performance variables and observed ME. Effects were considered significant when a P value of less than 0.05 was obtained.

RESULTS AND DISCUSSION

DMI

Figure 1 illustrates the effect of interaction between DGS type and inclusion on DMI. Overall, co-product type or control had no effect ($P > 0.10$) on DMI. These results are consistent with results from past research (Anderson et al., 2011). In growing-

finishing pigs that were fed 0% RF DDGS or increasing inclusion of RF DDGS, ADFI was similar across dietary treatments (Graham et al., 2014a). Depenbusch et al. (2009b) found a linear decrease in DMI in yearling heifers that were fed increasing concentrations of FF DDGS in SFC-based diets. The interaction of DGS type by inclusion in this analysis revealed that as DGS inclusion increased, cattle fed FF DGS had lower DMI ($P < 0.05$; Figure 1). Observations collected from finishing pigs that were fed LF DDGS (5.4% EE) or RF DDGS (9.6% EE) demonstrated that at 40% inclusion, pigs fed RF DDGS source had lower ADFI (Graham et al., 2014b). Bremer et al. (2011) found that cattle fed increasing inclusions of MDGS and WDGS had quadratic increases in DMI; at 40% inclusion DMI was reduced. The decrease in DMI as inclusion of DGS increases may be a function of increased dietary fat concentrations (Depenbusch et al., 2009b; Luebbe et al., 2012).

ADG

Effects on ADG are listed in Table 2. Feeding FF DGS resulted in greater ($P < 0.03$) ADG compared to feeding RF DGS or control diets. Furthermore, feeding RF DGS resulted in greater ($P = 0.01$) ADG compared to feeding control diets (Table 2). Observations from previous research revealed similar results when cattle were fed FF DGS. Vander Pol et al. (2006a) and Buckner et al. (2008) found that ADG was greater for finishing steers that were fed were fed 20 to 30% FF DGS compared to control diets; however, as DGS inclusion increased above these concentrations, ADG was lower. When de-oiled DDGS was fed to growing-finishing pigs at increasing inclusion, it resulted in a linear decrease in ADG as inclusion increased (Jacela et al., 2011). However, contrary to

increased ADG found in this analysis, Buckner et al. (2007) found no difference in ADG compared to control cattle and no difference with increasing DGS inclusion.

Feed Conversion Efficiency (G:F)

Effect of control diets and effects of DGS type and its respective inclusion on G:F are presented in Figure 2. Cattle fed FF DGS at moderate or high inclusion resulted in improved ($P < 0.05$) G:F when compared to feeding FF and RF DGS at low inclusion. Furthermore, feeding DGS at moderate or high inclusions to cattle regardless of EE concentration resulted in improved ($P < 0.05$) G:F when compared to feeding control (grain) diets. In a review of the use of distillers by-products in the beef cattle industry, Klopfenstein et al. (2008) reported that increasing DDGS inclusion in finishing diets resulted in a quadratic improvement in G:F, where at 40% inclusion, G:F decreased. Although not statistically significant, similar effects were observed in this analysis. At high inclusion of RF DGS, G:F is slightly reduced. Furthermore, Stein and Shurson (2009) reported variable responses to G:F in several studies in which DDGS were included in growing-finishing swine diets. These effects on G:F could potentially be a function of not only EE concentration of DGS being fed but also the entire dietary EE concentration. Feeding increasing concentrations of FF DGS compared to feeding grain diets will reduce the amount of feed required for 1 pound of gain (Vander Pol et al., 2006b); because the amount of energy that cattle are consuming is greater than that of what they are consuming from grain diets. This analysis also revealed that when DGS are fed at high inclusion rates, FF DGS affected a greater improvement in G:F ($P < 0.05$) when compared to feeding high levels of RF DGS (Figure 2). Similar observations were

observed in finishing pigs that were fed 40% LF DDGS compared to pigs fed 40% RF DDGS (Graham et al., 2014b).

Observed Metabolizable Energy

The effects of grain-fed diets and co-product type on observed ME intake values are presented in Figure 3. Feeding FF DGS at moderate or high inclusion rates and feeding RF DGS at high inclusion resulted in a greater ($P < 0.05$) observed ME intake compared to feeding control grain diets. In addition, feeding FF DGS at high inclusion rates led to greater ($P < 0.05$) observed ME intake than feeding RF DGS at high or low inclusion. Fat is an important source of energy for cattle.

High concentrations of dietary fat can have detrimental impacts on feedlot performance. Limiting total dietary fat to less than 5% of the total ration it optimal to prevent rumen fermentation problems (Church, 1988). Specifically, high concentrations of dietary fat inhibit fiber digestion. One of the main mechanisms through which high concentrations of fat inhibit fiber digestion is through coating of fiber in the rumen. Therefore when fat coats fiber particles, rumen microbes are inhibited from breaking down particles thus reducing fiber digestion that will ultimately reduce cattle performance (Church, 1988).

Regardless of type, increasing inclusion of DGS in the ration increased the amount of dietary fat being fed to cattle; therefore, energy intakes should increase. As demonstrated in Figure 3, feeding FF DGS at high inclusion significantly increased observed ME values compared to feeding high inclusions of RF DGS. The net energy value of fat is a predictable function of concentration of fat intake and intestinal

digestibility (Zinn et al., 2000). When cattle are fed higher concentrations of dietary fat, digestion of fat in the intestines decreased (Plascencia et al., 2003). The greater dietary observed ME intakes observed in this analysis when feeding high inclusions of FF DGS compared to feeding high inclusions of RF DGS may be related to substantial increases in dietary fat concentrations. Similar to what Vander Pol et al. (2009) suggested, fat in DGS may be partially protected from biohydrogenation in the rumen. This may explain the increase in observed ME as there is abundance of fat when FF DGS is fed at high inclusions, but not enough fat when RF DGS is fed to overcome the reduction in rumen function. These values illustrating significant increased dietary observed ME intake are reflective of the effect that increasing dietary concentrations of FF DGS also significantly improves G:F while significantly reducing DMI.

Energy Value of Feedstuffs

Results from regression of observed ME intake on amounts of each dietary ingredient are presented in Table 3. The resulting intercept from the regression analysis represented ME used for maintenance while the regression coefficient represented the NE_g value of each contributing feedstuffs. The NE_g value of each contributing feedstuff was then adjusted with weighted ADG and then resulting ME values of each contributing feedstuff were reported (Table 3). Estimated ME values for grain utilized in this analysis were similar to that reported by NRC (2000) for cracked corn; however, variability in this analysis is due to various types of grain fed in control diets. Furthermore, ME value for DGS containing average EE concentration in this analysis was also similar to reported values by NRC, however it was slightly lower due to the average reported EE concentration of DGS in this analysis being 6.73% while the EE concentration listed by

NRC for DGS is 10.30% (NRC, 2000). One unit of DGS EE impacted 0.06 Mcal ME/kg DM which was similar to values observed when yellow grease was supplemented (0.05 Mcal/kg DM) in finishing feedlot diets (Zinn, 1988). It appears that DGS oil may be partially protected from rumen hydrolysis because it is bound to DGS while supplemental fat is not as protected because it is not bound with any feedstuffs; therefore, it will bind to fiber particles to a greater extent and affect cattle performance.

Metabolizable energy values for LF-, RF-, or FF DGS were calculated and are presented in Table 4. As expected, the energy value of DGS source is decreased as the amount of oil extracted increases. Compared to grains utilized in this analysis, FF DGS contained 9% more energy; while RF DGS contained similar energy values. Vander Pol et al. (2009) found that greater energy values in DGS may be due to greater propionate production in the rumen, increased fat digestibility and increased amounts of unsaturated fatty acids that reach the hind gut; thus increasing the utilization of energy from the diet.

Conclusion

Due to the nature of a meta-analysis, which analyzes results from several studies, the sample size was increased and thus the power to study effects of performance and energy values were increased. As some manuscripts reported significant differences in various performance values and or there was a trend for these performance variables to be significantly different when comparing effects of DGS type and inclusion, other manuscripts reported no significant difference in performance or energy values when cattle were fed RF DGS. With the use of a meta-analysis approach, it is often possible to identify those factors that are influencing performance results which might help to better manage nutrient compositions of feedstuffs (Sauvant et al., 2008). When data from all

studies were combined, the results of performance data indicated significant differences across performance variables and energy values of reduced-oil DGS. Cattle feeders and nutritionists are constantly evaluating nutrient compositions of feedstuffs to properly formulate rations to feed to cattle, thus a quantitative summary of past research is ideal to expand the results from individual studies.

When compared to feeding FF DGS, feeding RF DGS or basal grain diets resulted in reduced ADG. Also, feeding basal grain resulted in slower ADG compared to feeding RF DGS. At high inclusion, feeding FF DGS resulted in greater observed ME intake compared to basal grain diets or RF DGS diets at high inclusion rates. Relative to grains that were fed in this analysis, FF DGS contained 9% more energy, RF DGS contained similar energy values, and LF DGS contained 95% the energy value of corn. Based on energy value of 1 unit of EE in DGS, the values modeled represented 0.04 Mcal NE_g/kg for every percentage unit change in DGS EE concentration. Due to energy values calculated for various types and sources of DGS, corrections to energy content of currently available DGS are required in order for cattle feeders and nutritionists to properly formulate rations.

Table 1. Mean values of the variables analyzed for control (grain), full-fat and reduced-fat distillers grain with solubles treatments

Item	n	Average	SD	Minimum	Maximum
			Control[1]		
In BW, kg	20	378	149	291	477
DMI, kg/d	20	10.43	3.52	7.77	13.83
ADG, kg	20	1.52	0.93	0.81	2.12
F:G	20	7.07	3.04	5.27	10.00
Observed ME, Mcal/kg DM	20	2.84	0.54	2.31	3.24
			FF DGS[2]		
In BW, kg	19	360	146	300	490
DMI, kg/d	19	10.46	2.87	8.82	14.19
ADG, kg	19	1.67	0.71	1.14	2.16
F:G	19	6.41	2.43	5.13	8.40
Observed ME, Mcal/kg DM	19	2.98	0.31	2.76	3.16
			RF DGS[3]		
In BW, kg	36	386	146	289	507
DMI, kg/d	36	10.63	3.20	8.53	13.64
ADG, kg	36	1.62	0.83	1.06	2.09
F:G	36	6.77	3.16	4.55	10.00
Observed ME, Mcal/kg DM	36	2.95	0.73	2.48	3.87

[1] Control = diets containing whole shelled corn, dry-rolled corn, high-moisture corn, steam-flaked corn, or rolled barley.
[2] FF DGS = diets containing full-fat distillers grains with solubles with ether extract concentrations of 10.3 to 13.0%.
[3] RF DGS = diets containing low-fat and reduced-fat distillers grains with solubles with ether extract concentrations of 4.0 to 9.2%.

Table 2. Mean dietary nutrient composition for control (grain), full-fat and reduced-fat distillers grain with solubles treatments

Item	n	Average	SD	Minimum	Maximum
			Control[1]		
DM, %	20	78.64	6.85	74.93	86.50
CP, %	20	13.14	2.73	11.49	15.89
NDF, %	20	15.59	10.85	11.42	27.68
Sulfur, %	20	0.15	0.08	0.09	0.22
Ether Extract, %	20	3.58	1.48	2.36	5.65
			FF DGS[2]		
DM, %	19	67.32	26.49	46.03	86.58
CP, %	19	17.70	7.40	12.12	22.06
NDF, %	19	23.71	14.94	13.35	40.30
Sulfur, %	19	0.33	0.22	0.19	0.52
Ether Extract, %	19	6.11	3.15	4.50	9.31
			RF DGS[3]		
DM, %	36	68.01	24.49	46.03	86.51
CP, %	36	17.96	9.10	12.70	28.42
NDF, %	36	24.14	13.40	13.01	38.02
Sulfur, %	36	0.32	0.23	0.08	0.54
Ether Extract, %	36	4.88	2.34	3.47	6.46

[1] Control = diets containing whole shelled corn, dry-rolled corn, high-moisture corn, steam-flaked corn, or rolled barley.
[2] FF DGS = diets containing full-fat distillers grains with solubles with ether extract concentrations of 10.3 to 13.0%.
[3] RF DGS = diets containing low-fat and reduced-fat distillers grains with solubles with ether extract concentrations of 4.0 to 9.2%.

Table 3. Effects of substituting basal grain (control) with either full-fat or reduced-fat distillers grains with solubles on final body weight and average daily gain

	Treatment[1]			
Item	Control	FF	RF	SE
Final BW, kg	589[b]	606[a]	599[a]	12.34
ADG, kg	1.58[c]	1.70[a]	1.64[b]	0.09

[1] Treatments included control diet (control); diets containing whole shelled corn, dry-rolled corn, high-moisture corn, steam-flaked corn, or rolled barley, diets containing full-fat distillers grains with solubles (FF) with ether extract concentrations of 10.3 to 13.0%, and diets containing low-fat and reduced-fat distillers grains with solubles (RF) with ether extract concentrations of 4.0 to 9.2%.
[abc] Means within rows with different superscript differ ($P < 0.05$).

Table 4. Estimation of ME per feedstuff (Mcal/kg DM)

Feedstuff	Mcal/kg DM	Book Value[1]	Standard Error	*P*-Value
Grain	3.07	3.25[2]	0.43	<0.01
Roughage	2.57	2.60[2]	1.97	0.40
DGS (6.73%)	3.04	3.18[2]	0.46	<0.01
1 Unit EE	0.06	0.05[3]	0.04	0.02

[1] Reported ME book values for various feedstuffs analyzed.
[2] (NRC, 2000).
[3] (Zinn, 1988).

Table 5. Effect of ether extract (EE) content on energy value of distillers grains with solubles

DGS Type	EE, %[1]	ME, Mcal/kg	NE_g, Mcal/kg
Full-fat	12.00	3.35	1.62
Reduced-fat	7.75	3.10	1.44
Low-fat	4.50	2.91	1.31

[1] Average ether extract concentration of distillers grains with solubles depicted as full-, reduced-, and low-fat respectively.

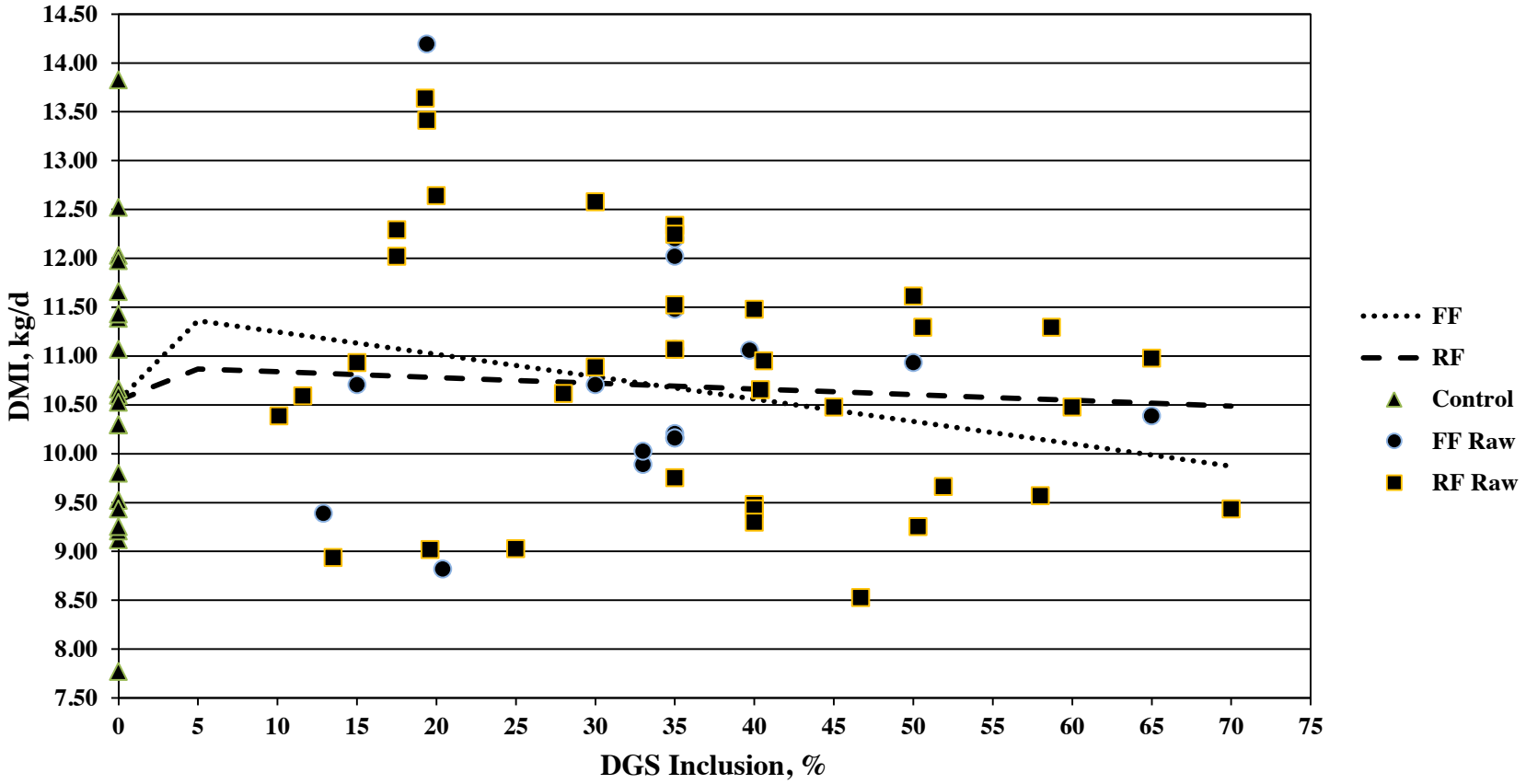

Figure 1. Effect of distillers grains with solubles type and inclusion on DMI ($P < 0.05$).

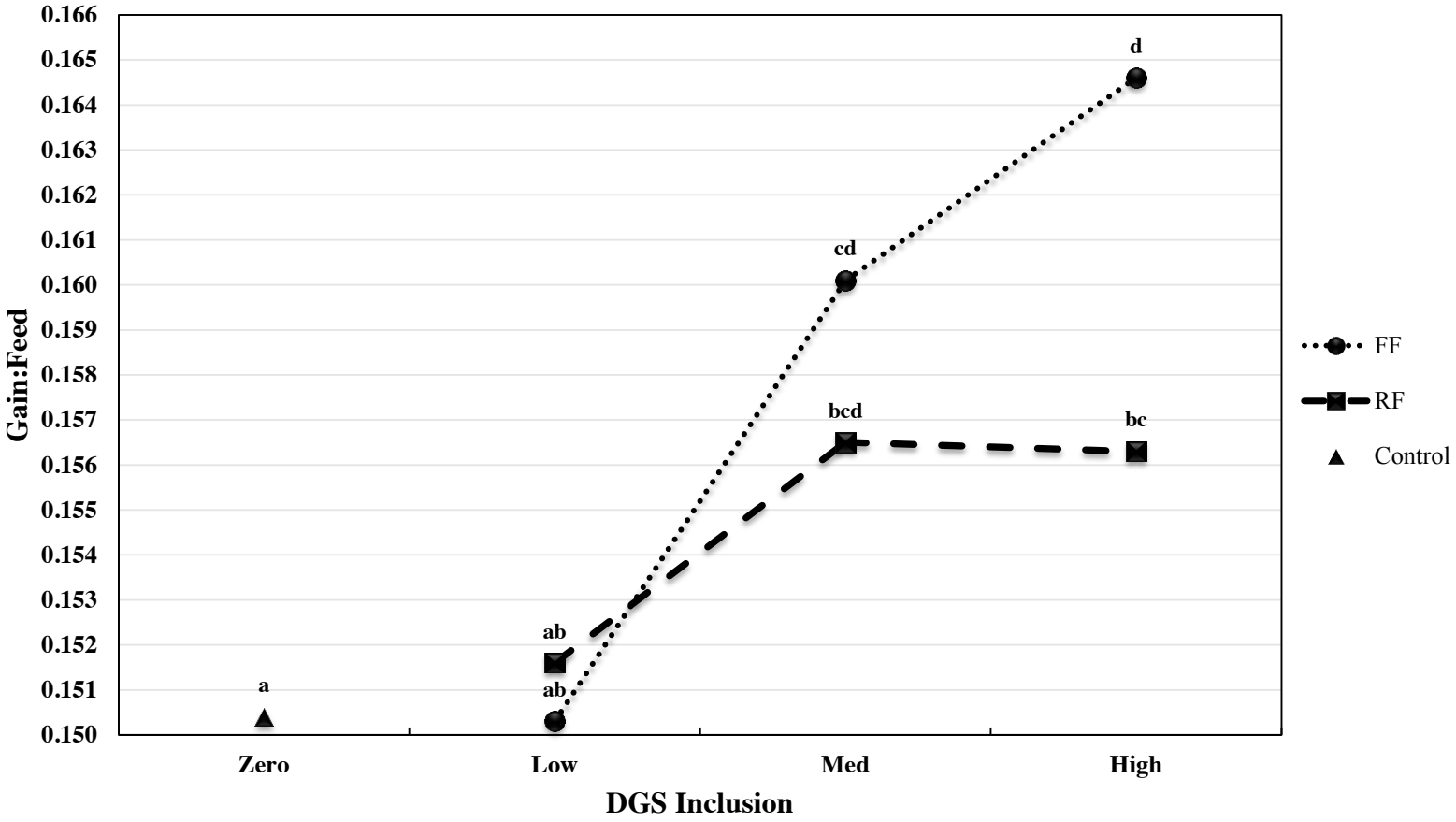

Figure 2. Effect of distillers grains with solubles type and inclusion on feed conversion efficiency, gain to feed (G:F).
[abcd] Means with different superscript differ ($P < 0.05$).

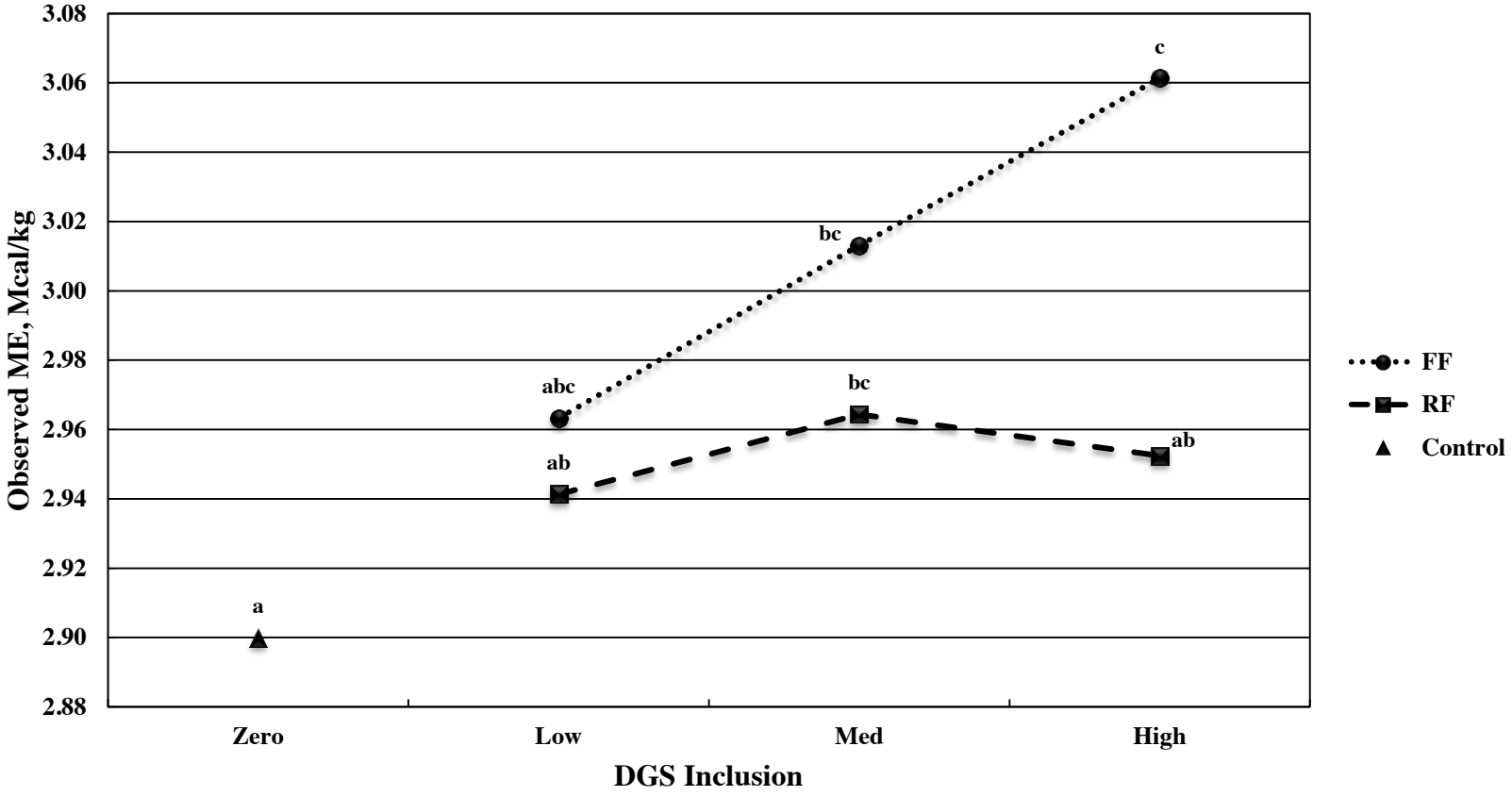

Figure 3. Effect of distillers grains with solubles type and inclusion on observed ME (Mcal/kg DM).
[abc] Means with different superscript differ ($P < 0.05$).

Chapter IV

CHARACTERIZING NUTRIENT CONTENT OF CORN PLANT COMPONENTS AT VARIOUS CORN CROP HARVEST ENDPOINTS

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SUMMARY

Seed corn of 3 yellow dent varieties was planted in 11 fields in 2014 at the Rosemount Research and Outreach Center (UMore Park) in Rosemount, MN. The 3 varieties were utilized to characterize nutrient content of corn plant components at various corn growth stages starting at the reproductive stages of development. Field planting occurred between May 15, 2014 and May 17, 2014. All fields were planted utilizing a John Deere seed corn planter with 76.2 cm row spacing's. Seed corn varieties were distributed between fields accordingly: 4 fields were planted to Mycogen 2A557, 4 planted to Dekalb DKC 49-29 RIB Brand Blend, and 3 planted to Dekalb DKC 53-56 RIB Brand Blend. Maps generated using Google Earth (Google Inc., Mountain View, CA) were utilized to allocate latitude and longitude locations of fields utilized in this experiment. From latitude and longitude coordinates, a random number generator was utilized to identify 6 randomly selected experimental plots based on random latitude and longitude coordinates constrained by field coordinates. The 6 random plots represented 6 sample collection periods where samples were collected from a plot each at R1 (silking), R3 (milk), R4 (dough), R5 (dent), R6 (physiological maturity), and at dry corn harvest. Sample collection began at silking (R1) 73 d after planting, then stages R3, R4, R5, R6 and harvest occurred on d 15, 22, 39, 56, and 86 following the onset of silking. Within each sampling plot, a total of 4 corn plants were harvested by cutting the stalk 15.24 cm from the ground. Samples were then collected and taken to the lab on the University of Minnesota campus where the entire plant was dissected into stalks, leaves, tassels, ears, silks, and ear husks. For collection periods 1 through 3, plant components were separated into 3 composites; 1: stems, leaves, 2: tassel, silk, husk, and 3: cobs. Starting at collection

period 4 through collection period 6, when whole corn kernels were dissected, components were composited as; 1: stems, leaves, tassels, 2: silk, cob, husk, and 3: whole shelled corn. Once the plant reached reproduction and pollination occurred (R1), DM of plant component composites significantly increased at each reproductive stage through dry corn harvest ($P < 0.01$) which also reflected a significant increase in whole plant DM ($P < 0.01$). Neutral detergent fiber and ADF concentrations of whole plants significantly decreased from R1 through physiological maturity ($P < 0.01$) then remained steady until dry corn harvest ($P = 0.82$; $P = 0.68$, respectively). Components that were harvested as earlage (kernel, cob, silk, and husk) decreased in NDF and ADF concentrations from R3 until physiological maturity ($P < 0.01$), then remained steady until dry corn harvest. Crude protein of earlage components decreased significantly from R1 to R3 ($P < 0.01$) then slowly decreased up to earlage harvest (R6) ($P < 0.05$), and increased slightly at dry corn harvest. Neutral detergent fiber concentration of whole shelled corn (WSC) tended to decrease from R5 to R6 ($P = 0.06$), then remained steady until dry corn harvest. Crude protein ($P = 0.53$) and ADF ($P = 0.11$) concentrations of WSC remained steady from R5 through dry corn harvest. Corn silage was harvested 39 d after silking at 37.34% DM with CP, NDF, ADF, and EE concentrations of 6.46, 43.18, 21.56, and 2.25%, respectively. Earlage was harvested 56 d after silking at a DM of 60.53% with CP, NDF, ADF, and EE concentrations of 6.79, 23.58, 8.58, and 2.76%, respectively. High-moisture corn was harvested 70 d after silking at a DM of 72.40% with CP, NDF, ADF, and EE concentrations of 7.59, 10.78, 1.80, and 3.29%, respectively. Dry corn was harvested 86 d following silking where kernel DM was 78.96% with CP, NDF, ADF, and EE concentrations of 7.79, 10.89, 1.92, and 3.29%, respectively. Overall, results from this

experiment indicate that when producers are growing corn as a feed resource for cattle, and in particular silage, earlage, and high-moisture corn, it is recommended that field scouting begins at the onset of reproduction to capture ideal DM and nutrient composition of each feedstuffs. Corn silage should be harvested at R5 when kernel milk line is at 2/3 and whole plant DM is 30 to 40%. Earlage at physiological maturity (R6) when kernels, cob, silk, and husk have a DM of 60 to 75%, high-moisture corn when kernel DM is 68 to 74% DM, and WSC when kernel DM is > 77%.

Keywords: Corn reproductive stages, maturity, silage, earlage, high-mositure corn, dry rolled corn

INTRODUCTION

The timely completion of corn planting is critical to the productivity and profitability of crop farms which in turn can affect the amount of feed available for use as livestock feed resources. Depending on the variety of corn being planted and the days it takes to reach relative maturity, optimum planting dates in Minnesota range from mid-April to mid-May in order to achieve maximum yield potential (Buaha et al., 1995). Timeliness in planting is especially important in corn production because yields fall steadily with each day of delay in planting. Optimizing planting date is crucial for corn growers in Minnesota and it is imperative for producers to follow these guidelines as there are only so many days during this time of year to get field work done due the ground being saturated (Buaha et al., 1995). The rate of corn growth between plant emergence and tassel emergence will have the greatest and most significant impact on the total time required for plant maturity to be reached thus establishing an estimate of when the crop will be ready for harvest (Ashley, 2001).

Reproductive corn growth stages, where actual kernel number and kernel size may be determined, occurs roughly 69 to 75 d after plant emergence (Darby and Lauer, 2015). This stage, noted as the R1 stage of reproductive development, begins when the silk is visible outside of the husk. After the silk becomes visible, pollination occurs where the moist silks catch falling pollen grains; thereafter, from the time it starts to the time that pollination ceases is generally 5 to 8 d (Darby and Lauer, 2015). Pollen then travels for 24 h down the silk to the ovule where fertilization occurs (Abendroth, 2005). Çakir (2004) found that the effect of drought was much more severe during tasseling and ear formation that resulted in decreased yields. Hot and dry conditions resulted in poor

pollination and seed set because the silk became dehydrated which hastened pollen shed causing plants to miss the pollination window; thus decreasing yield 7% per day (Darby and Lauer, 2015). Sufficient moisture during R1 is critical for the integrity of the corn plant as it develops an ear.

Stage 2 of reproduction (R2) occurs 10 to 14 d following silking where the kernels are white on the outside and resemble a blister (Abendroth, 2005). During this stage, the endosperm becomes evident with clear inner fluid from starch accumulation, and the kernel has accumulated about 15% DM (Abendroth et al., 2011).

Eighteen to twenty two days after silking, R3 (milk) occurs. Kernels have a milky interior due to increased accumulation of starch; thus resulting in increased kernel DM around 20% (Abendroth et al., 2011). Within 28 d following pollination, cell division of the endosperm is essentially complete (Ingle et al., 1965), and kernel growth that occurs results from expansion of cells and accumulation of starch within the kernel (Abendroth, 2005).

Approximately 24 to 28 d after silking, R4 (dough) occurs where continued starch accumulation causes milky inner fluid to thicken. Generally 4 embryonic leaves have formed and the embryo has grown drastically. Toward the middle of R4, the embryo will stretch across more than half of the width of the kernel side (Pioneer, 2012). Kernels have accumulated roughly half of their mature dry weight and have a DM of roughly 30%.

Following R4, producers growing corn for silage as a feed resource for cattle need to be alert that harvest time is approaching very fast. When harvesting corn for silage, whole plant moisture content is crucial for optimal storage. Depending on storage system

being utilized, ideal whole plant DM for proper ensiling should range from 30 to 40% (Mueller et al., 1991). Dry matter concentration at harvest is important to ensure maximum packing density; subsequently reducing losses from spoilage or runoff to maintain maximum feeding value.

Upon the reproductive stage of R5 (dent), 25% or more of the kernels have dented where the kernels have a DM content of about 45%; which occurs roughly 35 to 42 d following silking (Hanway, 1963). Once R5 has been reached, silage harvest should then occur. Harvesting corn silage at moisture concentration above 70% (below 30% DM) will result in reduced yields. Additionally, low harvest DM has caused increased seepage and undesirable clostridia fermentation that resulted in increased concentrations of foul-smelling butyric acid, increased pH and greater DM losses, reflecting decreased quality and palatability of the corn silage (Ramsey, 2014). Once corn reaches R5, kernel dry down rate has been found to be 0.77% per day from ½ milk line to no milk line (Wiersma et al., 1993), and can range anywhere from 0.4 to 0.8% moisture loss per day depending on weather (Elmore and Abendroth, 2007). Corn silage containing higher DM will result in poor storage packing densities thus allowing growth of aerobic micro-organisms because of the presence of oxygen which can be detrimental during the ensiling process (Ramsey, 2014).

Physiological maturity of corn occurs roughly 55 to 65 d following silk elongation, where the hard starch layer has advanced completely to the cob. At this time, the kernel DM is roughly 65 to 70% (Abendroth et al., 2011); additionally, husk and leave components are turning brown as they dry down. Optimal DM concentration of components harvested as earlage (kernel, cob, silk, and husk) has been reached during the

onset of physiological maturity. Earlage is a valuable feedstuff that provides cattle with a high quality roughage and concentrate source. Similar to corn silage, proper harvest moisture is pertinent for ideal packing densities. Nevertheless, it is important to eliminate trapped oxygen along with oxygen that penetrates the surface of the earlage pile, thus maximizing feeding quality (Lardy and Anderson, 2010). This can be achieved by harvesting earlage at a DM of 60 to 75%.

Following physiological maturity, an abscission layer forms at the base of the kernel that is referred to as the black layer (Abendroth et al., 2011). Around the time of black layer formation, high-moisture corn (HMC) is harvested when kernel DM concentrations around 68 to 75%. Harvesting HMC as shelled corn as compared to earlage may reduce the risk of mycotoxins and generally has similar feeding values to that of dry rolled corn (DRC; Rankin, 2009). Following harvest, HMC is either rolled or ground then is immediately ensiled (Goodrich et al., 1975). Once kernels have dried to 83 to 86% DM, dry corn harvest is recommended. Planting date, relative days to maturity, and amount of moisture throughout the growing season all will have an impact on harvest yields (Buaha et al., 1995).

Planting date and weather conditions have a large impact on the time it takes for corn to reach reproductive stages of development; thus affecting harvest dates for various corn crop endpoints. Around mid-July in Minnesota, reproductive corn growth stages begin as the silk becomes visible outside of the husk. The length of time between each reproductive stage and their respective identifying characteristics may differ for different corn hybrids and for different environmental conditions (Hanway, 1963). Thus it is the objective of this experiment to evaluate the nutrient content of corn plant components at

various corn crop harvest endpoints through the reproductive stages of development and to examine the effects that various varieties have on nutrient compositions at each reproductive stage.

MATERIALS AND METHODS

Fields and Corn Varieties

Seed corn of 3 yellow dent varieties was planted in 11 fields in 2014 at the Rosemount Research and Outreach Center (UMore Park) in Rosemount, MN to characterize nutrient content of corn plant components at various corn growth stages starting at the reproductive stages of development (R1). Field planting occurred between May 15, 2014 and May 17, 2014. All fields were planted utilizing a John Deere (John Deere Inc., Moline, IL) seed corn planter with 76.2 cm row spacing's. Seed corn varieties were distributed between fields accordingly: 4 fields were planted to Mycogen 2A557 (Mycogen Seeds, a product of Dow AgroSciences LLC, Indianapolis, IN), 4 fields were planted to Dekalb DKC 49-29 RIB Brand Blend (49-29; Dekalb Genetics Corp., a product of Monsanto Company, St. Louis, MO), and 3 fields were planted to Dekalb DKC 53-56 RIB Brand Blend (53-56; Dekalb Genetics Corp., a product of Monsanto Company, St. Louis, MO). Total ha planted for Mycogen 2A557, Dekalb 49-29, and Dekalb 53-56 was 24.69, 27.52, and 38.45 ha, respectively. The two Dekalb varieties were designated as dual purpose hybrids, as they can be grown for grain harvest or as silage for cattle, while the Mycogen variety was designated as a corn grain hybrid solely. Listed in Table 1 are agronomic field and variety information.

Random Sampling Plot Allocations

Prior to scouting and sample collection, Google Earth (Google Inc., Mountain View, CA) was utilized to allocate latitude and longitude locations for 11 corn fields utilized in this study. From latitude and longitude coordinates, a random number generator was utilized to identify 6 experimental plots based on random latitude and longitude coordinates constrained by field coordinates; thus a total of 66 random plots were allocated. The 6 random latitude and longitude coordinates generated for each field represented the south east corner of a sample collection plot that spanned 4 corn rows (3.05 m) which then was extended 1.22 m in length. The 1.22 m length measurement was made utilizing a tape measure starting at the south east corner; then all four corners were marked with flags to depict the sampling area of each plot location. An example of randomly selected plots within a field is shown in Figure 1.

Scouting and Sampling Times

All sampling periods were followed by the guidelines of Hanway (1963) and Pioneer (2012) for tips on reproductive growth stages of corn and scouting tips. Fields were scouted weekly beginning around stage 4 of development (Hanway, 1963) to ensure that samples would be collected starting at R1 (silking). Table 2 illustrates sample collection dates. At 73 d following planting, fields reached stage 5 (R1 silking). The second sample collection period was executed 15 d after silking at stage 6.5 or the R3 milk stage. Collection period 3 was carried out at stage 7 or the R4 dough stage, 22 d following silking. Sampling 4 occurred 39 d following silking at stage 8 (R5 of dent). Following guidelines by Mueller et al. (1991) for optimal DM at silage harvest; corn silage (shredlage) was harvested when whole plant DM reached optimum concentration.

Fifty-six days following silking, collection period 5 occurred as plants reached physiological plant maturity (stage 10; R6). During this sample collection period, earlage harvest occurred as components harvested as earlage accumulated ideal DM (Lardy and Anderson, 2010). In between collection periods 5 and 6, 70 d following silking, HMC was harvested at previously reported harvest DM (Lardy and Anderson, 2010). The final sample collection period was 86 d following silking at the time when dry corn harvest occurred. Throughout the 6 collection periods, 6 individual samples were collected from each of the 11 fields. However, 2 fields were deducted from sample collection period 6 due to harvest being completed; thus the total number of samples collected throughout 6 collection periods totaled 64.

Plant Count and Identification

In order to locate latitude and longitude coordinates of each random sampling plot in each respective field, the phone application, AGRIplot (Sharpe Technology Consulting, Elizabethtown, KY) was utilized. This application used GPS coordinates, and was utilized to precisely locate each random plot within each field. Once latitude and longitude coordinates were located for each sampling plot, the 3.72 m^2 area was measured and flagged off where the latitude and longitude coordinates represented the south east corner of the sampling plot. Before any sample collections were made, observation of 10 plants, within a single row, were made to determine stage of development. Each reproductive stage is denoted by a significant developmental characteristic. Hence, at R1, R3, R4, R5, R6, and dry corn harvest the percentage of plants silking, blistery/milky kernels, kernels exemplifying dough consistency, dented kernels, and formed kernel black layers, respectively, were determined. Furthermore,

plant population was also determined by counting the number of plants within each 3.72 m^2 sampling plot area. Developmental characteristics, plant count, and plant population throughout 6 sample collection periods are presented in Table 2.

Sample Collection

Within each experimental plot, a total of 4 corn plants were harvested by cutting the stalk 15.24 cm from the ground. Samples were then collected and taken to the lab on the University of Minnesota campus where the entire plant was dissected into stalks, leaves, tassels, ears, silks, and ear husks. For collection periods 1 through 3, plant components were separated into 3 composites; 1: stems, leaves, 2: tassel, silk, husk, and 3: cobs. Then starting at collection period 4 through collection 6, where whole corn kernels were dissected, components were composited as; 1: stems, leaves, tassels, 2: silk, cob, husk, and 3: whole shelled corn. Total biomass and ear weights were calculated from the sum of each component measured. Prior to laboratory analysis, plant components were dried in a drying oven (Blue M Electric, Thermal Product Solutions, New Columbia, PA) at 60˚ C for 48 h. All components were then ground using a Thomas Model 4 Wiley Mill (Thomas Scientific, Swedesboro, NJ) to pass through a 2-mm screen.

Sample Analysis

Corn plant components were analyzed for CP (Method 992.15; AOAC, 1995), NDF (Van Soest et al., 1991), ADF (Method 973.18; AOAC, 2000), and EE (Method 920.39, AOAC, 2000). For CP analysis, all samples were prepared and shipped to an outside lab (University of Florida – North Florida Research and Education Center, Marianna, FL) to be analyzed following the procedure of Ciriaco et al. (2015). All other

analysis was conducted on campus (University of Minnesota – Haecker Hall, St. Paul, MN). Neutral detergent fiber analysis was conducted utilizing an Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY), where samples were extracted for 60 min at 100˚ C in NDF solution with heat-stable α-amylase. Prior to NDF analysis, all whole shelled corn (WSC) samples were pre-extracted following biphasic extraction procedures (Bremer et al., 2010) due to greater EE concentrations. This procedure was utilized because in samples that had EE concentrations of 5% or greater, not all of the fat was dissolved during the NDF procedure; thus, decreasing the accuracy of feed sample NDF determination. Following NDF analysis, samples were dried at 100˚ C overnight (Thelco 130DM, Precision Scientific, Chicago, IL) then weighed and NDF percentage was calculated. Acid detergent fiber was then analyzed utilizing the same procedure as NDF but ADF solution was used and samples were extracted for 60 min at 100˚ C followed by drying overnight and weighing then calculating ADF percentage. Samples were analyzed for EE concentration by the use of an Ankom^{XT10} Extraction System (Ankom Technology, Macedon, NY) for 60 min at 90˚ C with petroleum ether.

Data Analysis

Data were analyzed using the mixed procedure of SAS 9.3 (SAS Institute Inc., Cary, NC) with repeated measures. Repeated measures were utilized to investigate the changes in mean nutrient compositions over time within an individual field. The experimental unit was individual fields. For each sample collection period, sample composite weights for individual fields within corn varieties were utilized to construct weighted nutrient composition means for whole plant components, earlage components, and WSC; thus, creating weighted nutrient composition means for whole plants, earlage

components, and WSC within varieties for each collection period. Statistical analysis was conducted for nutrient composition means of whole plant (silage) and earlage components for all 6 collection periods; however, statistical analysis for WSC was restricted to collection periods 4, 5, and 6. The effects of sample variety and sampling period and their interaction were considered significant when a *P* value of less than or equal to 0.05 was obtained and were considered a trend when *P* values were between 0.05 and 0.10.

RESULTS AND DISCUSSION

Sample Collection

Sample collection began at the onset of stage 5 (R1) which occurred roughly 73 d following planting; where 75% of the plants were silking (Hanway, 1963). At this stage, whole plant DM was 17.82% which was similar to previous observations (Di Marco et al., 2002).

Samples collected at R3 (milk), 15 d following silking, were represented by 100% of the kernels blistered and 75% of kernels were milky due to starch accumulation. Silks at this stage were brown and dry, and kernels were yellow on the outside as observed previously (Abendroth, 2005). Dry matter of the whole plant at R3 was 21.22%, which was slightly lower than previous observations (Di Marco et al., 2002). This reduction in whole plant DM was most likely due to the 15 d interval in between R1 and R3 in this study; previous research would indicate a longer interval between these stages (Hanway, 1963; Abendroth et al., 2011).

Twenty two days following silking, plants reached dough stage, R4. At this stage, the kernel milk line had stretched across more than half the width of the kernel side. Whole plant DM was 26.73%, similar to that in a previous report (Johnson et al., 1999).

At R5, 39 d post-silking, roughly 90% of kernels were denting as the starch in the endosperm began to harden. At this stage, kernels were dissected from the ears and had DM concentrations of 49.83%, similar to values previously recorded (Abendroth, 2005); furthermore, days to R5 from R1 were within previously recorded time interval following silking. Whole plant DM was 37.34%, which is within recommended DM concentrations for silage harvest (Mueller et al., 1991).

Physiological maturity (R6) was obtained 56 d post-silking at which point earlage was harvested. It is common for the interval for days to reach R6 from silking will vary depending on weather conditions; yet, in spite of a dry post-silking growing year, R6 occurred at the expected time interval following silking (Nielsen, 2013). The kernel black layer was formed 70 d following silking at which point 100% of the kernels had formed this layer. Kernels reached maximum accumulation of DM where they represented 50% of the whole plant DM (Abendroth et al., 2011); thus, HMC was then harvested. Eighty-six days following silking, dry corn harvest began as kernel DM reached 78.96%. There are no guidelines to follow to determine when kernels reached harvest DM; however, observations regarding moisture loss were made and indicate moisture loss per day following R6 can be anywhere from 0.4 to 0.8% per day (Elmore and Abendroth, 2007).

Dry Matter

Corn reproduction growth stages (6 stages) represented growth and development of the corn kernel. Table 3 illustrates DM concentration results of whole plant (components harvested as silage) and components harvested as earlage, respectively; at sample collection period 1 (R1) through collection period 6 (dry corn harvest). Furthermore, DM concentration results for WSC from collection period 4 (R5) through collection period 6 (dry corn harvest) are listed in Table 3.

From R1 through dry corn harvest, as kernel development occurred and the whole plant matured through reproductive stages, DM concentration of whole plant (silage) and earlage components increased significantly ($P < 0.05$). From R4 through dry corn harvest, kernel DM increased significantly ($P < 0.05$). Following silking (R1), DM percentage increased in all plant components with advancing maturity (Johnson et al., 1966; Johnson and McClure, 1968; Weaver et al., 1978; Filya, 2004). Rapid growth of the endosperm due to accumulation of starch starting at R3 (Hanway, 1963) began to contribute to increasing kernel DM. Additionally, following R3, kernels began to contribute greater amounts to overall plant DM due to increased starch accumulation (Abendroth et al., 2011); thus adding to increased plant DM. From R5 to physiological maturity, the percentage of moisture lost per day from the kernel was roughly 0.50%; additionally, average moisture lost from R5 to dry corn harvest was 0.65%. These results are in agreement with those of others who determined that when corn kernel reached ½ milk line, kernel DM increased 0.77% per day to no milk line (Wiersma et al., 1993). The percentage at which kernels lose moisture from maturity to harvest will vary from 0.4 to 0.8% per day depending on weather patterns (Elmore and Abendroth, 2007).

Thirty-nine days after silking when kernel dent began at R5, corn silage was harvested. Silage was harvested when whole plant DM was 37.34%, which is considered ideal harvest DM as indicated by Mueller et al. (1991).

Dry matter of components harvested for earlage (kernel, cob, silk, and husk) should range between 60 to 75% DM depending on processing method (Lardy and Anderson, 2010). Typically after pollination, dent corn hybrids grown in United States Corn Belt need roughly 50 to 60 days to reach physiological maturity (Hoeft et al., 2000). Thus, 56 d after pollination, earlage was harvested at physiological maturity (R6) where weighted DM concentration of the kernels, cob, silk, and husk was 60.53% DM.

For proper ensiling and storage of HMC, harvest should occur when kernel DM is between 65 to 75% DM (Mader and Rust, 2006). Elmore and Abendroth (2007) found that 0.4 to 0.8% of kernel moisture can be lost each day following physiological maturity; therefore, 70 d following R1, HMC was harvested at a DM of 72.40%. Air temperatures, heat units, and weather all contribute to grain dry down rates. As the season changes into fall; day length shortens and temperatures drop which causes kernel dry down to slow, and as this occurs, kernel DM stabilized around 80 to 85% (Elmore and Abendroth, 2010). Sixteen d following HMC harvest (86 d post silking), kernel DM reached 78.96%, and dry corn harvest began, however not all fields were harvested on the same day. Dry corn was harvested from all fields within a 10 d period.

Whole Plant

Nutrient composition of the whole plant from R1 to dry corn harvest is presented in Figure 2. Variety had no impact ($P > 0.15$) on the nutrient composition of the whole

plant throughout reproductive stages to dry corn harvest. As corn plants matured and developed kernels throughout their reproductive stages, whole plant nutrient compositions changed. Figure 2 illustrates that as corn plants shifted growth from vegetative developmental stages to reproductive stages (R1) where kernel development was initiated, NDF concentration decreased ($P < 0.05$). However, NDF concentration remained stable from physiological maturity until dry corn harvest ($P > 0.05$). Acid detergent fiber concentration followed similar patterns to NDF concentration, in that as the plants matured, ADF concentration decreased ($P < 0.05$). Additionally, ADF concentration remained steady between physiological maturity and dry corn harvest ($P > 0.05$). Similar results have been found when nutrient composition of the whole corn plant was analyzed at silking, milk stage, and ½ milk line; likewise, NDF and ADF concentrations were both significantly reduced at each reproductive stage (Di Marco et al., 2002). Johnson et al. (1999) and Pereira et al. (2012) found similar effects of maturation on NDF and ADF concentrations. Overall, as plants developed throughout the reproductive stages, the fiber fraction of the stover components increased up to maturity (Pordesimo et al., 2005). Li et al. (2014) evaluated the nutrient composition of corn stover and its components and found that whole stover NDF and ADF were roughly 72 and 41%, respectively, following dry corn harvest.

As the corn plant matured and the kernel accumulated greater amounts of starch, the kernel continued to make up greater proportions of whole plant DM; in fact, at physiological maturity the kernel made up roughly 50% of the whole plant DM (Ensminger et al., 1990). Therefore, because the kernel had low concentrations of NDF and ADF and greater concentration of starch, whole plant NDF and ADF decreased

throughout the reproductive stages. Similarily, as the whole corn plant matured from R3 to black layer formation, NDF and ADF concentrations decreased because kernels contributed greater amounts to whole plant DM; as a result of increased starch accumulation in kernels (Johnson et al., 1999). Because the kernel made up a larger portion of the entire plant DM as the plant matured, nutrient composition of the kernel (starch accumulation) results in a decrease in NDF and ADF concentrations of the entire plant. Di Marco et al. (2002) and Filya (2004) found a dilution effect due to starch accumulation in the kernel that reduced NDF and ADF concentrations of the whole plant as it matured.

As corn plants developed throughout reproductive stages, CP concentration decreased from R1 to physiological maturity; while EE concentration increased. Figure 2 illustrates CP and EE concentrations of whole plants as they developed through reproduction. As whole corn plants matured, there was a decrease in whole plant CP ($P < 0.01$) from R1 to R3. Following R3, CP concentration decreased at a slower rate where it decreased up to physiological maturity ($P < 0.05$) then remained stable ($P > 0.10$) at roughly 6% until dry corn harvest. These results are consistent with previous research that determined when silage was harvested at various stages of reproduction from blister R2 to physiological maturity, CP concentration of the whole plant decreased as the plant matured (Johnson and McClure, 1968; Darby and Lauer, 2002). The same effect that caused whole plant NDF and ADF concentrations to decrease due to increased starch accumulation caused CP concentrations to decrease also; comparatively, increased kernel starch accumulation effected a decrease in CP as the plant matured (Martin et al., 2008).

However, as whole plants matured, EE concentration slowly increased. Between R4 (dough) and R5 (silage harvest), there was an increase in EE concentration ($P < 0.05$). Following R5, EE concentration decreased ($P < 0.05$) at physiological maturity then slightly increased at dry corn harvest to values reported at R5 (Figure 2). Leng (1967) found that kernel oil content reached its maximum 45 to 48 d following pollination. In the current study EE of whole plant reached its maximum 39 d following pollination. Similar results were observed for CP concentration from dough stage (R4) to physiological maturity. During this same time, EE concentration of the whole plant increased (Martínez et al., 2006). In the current experiment, corn silage was harvested when the whole plant DM was 37.34% at stage R5, 39 d following silking. The nutrient composition of the whole plant was 6.49% CP; 43.18% NDF; 21.56% ADF, and 2.25% EE, respectively. The nutrient composition of the whole plant at silage harvest was similar to the low fiber corn silage reported by Martin et al. (2008).

When the corn plant is harvested as silage at R5, the corn kernel contributes a large amount to energy values associated with the feeding value of the corn silage. Starch concentration is a major source of energy in corn silage where it contributes roughly 50 to 70% of the digestible organic matter (Martin et al., 2008). Furthermore, starch digestibility of the corn grain has been determined to affect silage quality; subsequently, it has been found that as DM concentration of the corn kernel increased, starch digestibility also decreased (Johnson et al., 1999).

Earlage Components

Effect of stage of development on nutrient composition of components harvested as earlage (kernel, cob, silk, and husk) is presented in Figure 3 and Figure 4. Neutral

detergent fiber and ADF concentrations decreased ($P < 0.01$; Figure 3) between the milk stage (R3) and physiological maturity (R6). Earlage was harvested at physiological maturity, 56 d following silking at a DM of 60.53%, at which point NDF and ADF concentrations were 24 and 9%, respectively. Concentrations of NDF and ADF were consistent with what was reported in a review of snaplage at a dairy in Iowa by Pioneer (Dupont Pioneer, Johnston, IA) where the NDF and ADF concentrations were 22 and 11%, respectively (Mahanna, 2009).

Similar to what was observed for stover NDF and ADF, as the whole plant matured, NDF and ADF concentration of the cob, husk, and silk increased with maturity (Pereira et al., 2012). Li et al. (2014) determined that the ear husk of whole stover had the highest NDF and ADF concentrations when compared to all other stover components. However, because kernels made up the largest proportion of DM in the components harvested as earlage, NDF and ADF concentrations decreased due to increased starch accumulation in the kernels. This dilution effect was demonstrated in various studies were NDF of the whole plant decreased with maturity due to increased starch accumulation in the kernel (Di Marco et al., 2002; Filya, 2004).

Crude protein of earlage decreased ($P < 0.01$) from 12.43% at R1 to 7.74% at R3 (Figure 3). Following R3, as plants continued to develop through reproduction, CP remained fairly stable, then decreased at earlage harvest ($P < 0.05$). Crude protein increased slightly thereafter at dry corn harvest. Crude protein of earlage at harvest (R6) was 6.8% (Figure 3). Similar results were revealed by (Mahanna, 2009); however, others have harvested earlage with greater CP concentration (Soderlund et al., 2006; Lardy and Anderson, 2010).

Nutrient composition of earlage can be affected by the amount of trash (non-ear plant parts) that is contained in it. Acid detergent fiber content can be used to estimate the amount of trash in earlage (Kezar, 2001). Trash content caused variation in energy content. Furthermore, as the earlage matured, starch accumulation increased in kernels which resulted in lower CP concentration of earlage (Martin et al., 2008); due to kernels representing the greatest amount of whole plant DM at physiological maturity (Weaver et al., 1978). This same effect was found for NDF, ADF, and CP concentrations of earlage harvested at physiological maturity.

Ether extract concentration of earlage increased ($P < 0.01$) between R4 and R5 (Figure 4). Ingle et al. (1965) found that within 28 d following pollination (R4; dough), the embryo stretched across more than half the width of the kernel side, and cell division of the endosperm was complete; thus, growth of the kernel resulted from the accumulation of starch. Furthermore, once plants reached the end of R4 where cell division in the epidermal layer of the endosperm had ceased, there was a rapid increase in the size of the embryo (germ) of the kernels (Hanway, 1963). Approximately 84% of the kernel oil is stored in the germ (Watson, 1984). As a result, the rapid growth of the embryo caused a significant increase in EE concentration of kernels; resulting in significantly greater EE content of earlage. Oil percentage in the whole corn kernel reached its maximum by 45 to 48 d after pollination (Leng, 1967) which is consistent with observations from the current experiment where at R5 (39 d after pollination), EE concentration of earlage components reached its maximum.

Kernel

As corn plants mature through reproductive stages, the corn kernels contribution to whole plant DM significantly increases; at physiological maturity, kernels contributed 50% or more to whole plant DM (Ensminger et al., 1990). Decreasing CP concentration of the whole plant appeared to be a result of continued carbon assimilation following R1 due to nitrogen uptake being complete; thereby diluting plant nitrogen concentration (Wiersma et al., 1993). Ma and Dwyer (2001) found that 23 d following silking, kernel nitrogen concentration significantly decreased while that of carbon significantly increased. As a result of these factors, while kernel starch concentrations increased, CP concentration decreased thus contributing to decreased whole plant CP.

At reproductive stage R5, dent, whole corn kernels were removed from the ear. The nutrient composition of corn kernels from R5 to dry corn harvest is presented in Figure 5 and Figure 6. As kernels dried from R5 through dry corn harvest, CP ($P = 0.53$) and ADF ($P = 0.11$) concentrations remained stable. Between R5 and R6, there was a tendency for NDF concentration to decrease ($P = 0.06$), then remained steady until dry corn harvest.

Ether extract for earlage in this experiment reached its maximum concentration at R5, which is similar to observations made previously (Leng, 1967). It was also determined that from R5 to physiological maturity, oil percentage of kernels decreased; thus, full production of oil by weight was attained dent (2/3 milk line). Results from previous research indicated that as kernels accumulated more DM from R5 to physiological maturity, the weight of the germ decreased; thus germ contribution to kernel weight decreased between R5 and physiological maturity (Weller et al., 1989b).

High-moisture corn and dry corn were harvested 70 d and 86 d following pollination, respectively. Crude protein, NDF, ADF, and EE for dry corn in this experiment were 7.79, 10.89, 1.92, and 3.29%, respectively. However, since no samples were collected on the day of HMC harvest, Figure 5 and Figure 6 illustrate that there was no difference in nutrient composition of kernels from R6 to dry corn harvest; therefore nutrient composition of HMC was likely similar to that of dry corn. These values were similar to that of Dairy One database (Dairy One Corp., Ithaca, NY).

Conclusion

When growing corn as a feed resource for cattle, it is common practice to judge the degree of maturity of a field of corn by evaluating the stage of maturity of the kernels. Thus, it is imperative to utilize scouting tips for reproductive stages and begin scouting at R1. In this experiment corn silage was harvested 39 d following silking when whole plant DM was 37.34%; with 6.46% CP, 43.18% NDF, 21.56% ADF, and 2.25% EE, respectively. Once kernels began to dent, 0.65% of the moisture in the kernels was lost per day up to dry corn harvest. Earlage was harvested 56 d following silking at 60.53% DM with 6.79% CP, 23.58% NDF, 8.58% ADF, and 2.76% EE, respectively. High-moisture corn and dry corn were harvested at 72.40 and 78.96% DM where nutrient compositions were 7.79% CP, 10.89% NDF, 1.92% ADF, and 3.29% EE, respectively. The reproductive corn growth stages and scouting tips by Hanway (1963), Abendroth (2005), and Abendroth et al. (2011) give producers important guidelines that should be followed when determining the maturity of their corn. To capture optimum feed quality, corn silage should be harvested at 2/3 milk line (R5; around 40 d following silking) with whole plant DM around 30 to 40% (Filya, 2004). Earlage should be harvested at

physiological maturity around 56 d following silk with DM concentration of 60 to 75% (Lardy and Anderson, 2010). High moisture corn should then be harvested at 68 to 74% kernel DM and dry corn at greater than 77% DM.

Table 1. Field identification and corn hybrid characteristics utilized in this experiment

Field	Variety[1]	Value-Added Trait[2]	Days to Maturity[3]	Use[4]	Hectares[5]
N04	Mycogen 2A557	RASSLLRR	103	Grain	10.10
N11	Mycogen 2A557	RASSLLRR	103	Grain	4.23
N12	Mycogen 2A557	RASSLLRR	103	Grain	6.05
V01	Mycogen 2A557	RASSLLRR	103	Grain	4.36
E08	Dekalb 49-29 RIB	GENSSRIB	99	Grain/Silage	11.39
E09	Dekalb 49-29 RIB	GENSSRIB	99	Grain/Silage	3.99
V25	Dekalb 49-29 RIB	GENSSRIB	99	Grain/Silage	6.66
V26	Dekalb 49-29 RIB	GENSSRIB	99	Grain/Silage	5.41
E02	Dekalb 53-56 RIB	GENSSRIB	103	Grain/Silage	31.12
E04	Dekalb 53-56 RIB	GENSSRIB	103	Grain/Silage	3.00
N13	Dekalb 53-56 RIB	GENSSRIB	103	Grain/Silage	7.14

[1] (Mycogen Seeds, a product of Dow AgroSciences LLC, Indianapolis, IN); (Dekalb Genetics Corp., a product of Monsanto Company, St. Louis, MO).
[2] RASSLLRR = Refuge Advanced, SmartStax, LibertyLink, Roundup Ready; GENSSRIB = Genuity, SmartStax, RIB Complete.
[3] Days to Maturity = number of days it takes to reach physiological maturity (R6) (kernel moisture roughly 30 to 35%).
[4] Grain = harvest as grain; Silage = harvest whole plant silage.
[5] Total hectares planted in each respective field.

Table 2. Sample collection dates, characteristics associated with stage of production, and populations

Field	Variety[1]	Date[2]	Stage[2]	Characteristic[3]					Plant Count[4]	Population[4]
				Silk	Blister	Milk	Dent	Black Layer		
N11	2A557	7/28/2014	R1	70	0	0	0	0	32	34848
N12	2A557	7/28/2014	R1	70	0	0	0	0	29	31581
V01	2A557	7/28/2014	R1	100	0	0	0	0	31	33759
E08	4929	7/28/2014	R1	90	0	0	0	0	28	30492
E09	4929	7/28/2014	R1	80	0	0	0	0	32	34848
V25	4929	7/28/2014	R1	90	0	0	0	0	32	34848
V26	4929	7/28/2014	R1	90	0	0	0	0	33	35937
E02	5356	7/28/2014	R1	100	0	0	0	0	32	34848
E04	5356	7/28/2014	R1	100	0	0	0	0	34	37026
N13	5356	7/28/2014	R1	80	0	0	0	0	34	37026
N04	2A557	8/12/2014	R3	100	100	85	0	0	35	38115
N11	2A557	8/12/2014	R3	100	100	70	0	0	27	29403
N12	2A557	8/12/2014	R3	100	100	75	0	0	32	34848
V01	2A557	8/12/2014	R3	100	100	85	0	0	33	35937
E08	4929	8/12/2014	R3	100	100	60	0	0	33	35937
E09	4929	8/12/2014	R3	100	100	85	0	0	34	37026
V25	4929	8/12/2014	R3	100	100	85	0	0	34	37026
V26	4929	8/12/2014	R3	100	100	85	0	0	34	37026
E02	5356	8/12/2014	R3	100	100	90	0	0	29	31581
E04	5356	8/12/2014	R3	100	100	70	0	0	34	37026
N13	5356	8/12/2014	R3	100	100	85	0	0	33	35937

[1] Mycogen 2A557 (Mycogen Seeds, a product of Dow AgroSciences LLC, Indianapolis, IN); Dekalb 49-29RIB & 53-56RIB (Dekalb Genetics Corp., a product of Monsanto Company, St. Louis, MO).

[2] Sample collection date and reproductive stage at sampling time.

[3] Silk = % of 10 plants silking, Blister = % of 10 plants with kernels resembling blisters, Milk = % of 10 plants with milky kernels, Dent = % of 10 plants that have kernels dented, Black Layer = % of 10 plants with kernels that have reached maturity.

[4] Plant count = number of plants counted in 40 ft^2 area, Population = planting density in selected plot (plant count*(43560/40)).

Table 2. (continued) Sample collection dates, characteristics associated with stage of production, and populations

				Characteristic[3]						
Field	Variety[1]	Date[2]	Stage[2]	Silk	Blister	Milk	Dent	Black Layer	Plant Count[4]	Population[4]
N04	2A557	8/19/2014	R4	100	100	100	0	0	34	37026
N11	2A557	8/19/2014	R4	100	100	100	0	0	32	34848
N12	2A557	8/19/2014	R4	100	100	100	0	0	32	34848
V01	2A557	8/19/2014	R4	100	100	100	0	0	32	34848
E08	4929	8/19/2014	R4	100	100	90	0	0	32	34848
E09	4929	8/19/2014	R4	100	100	100	0	0	32	34848
V25	4929	8/19/2014	R4	100	100	100	0	0	32	34848
V26	4929	8/19/2014	R4	100	100	100	0	0	33	35937
E02	5356	8/19/2014	R4	100	100	100	0	0	33	35937
E04	5356	8/19/2014	R4	100	100	100	0	0	32	34848
N13	5356	8/19/2014	R4	100	100	95	0	0	31	33759
N04	2A557	9/5/2014	R5	100	100	100	100	0	33	35937
N11	2A557	9/5/2014	R5	100	100	100	70	0	31	33759
N12	2A557	9/5/2014	R5	100	100	100	97	0	35	38115
V01	2A557	9/5/2014	R5	100	100	100	100	0	32	34848
E08	4929	9/5/2014	R5	100	100	100	100	0	34	37026
E09	4929	9/5/2014	R5	100	100	100	95	0	29	31581
V25	4929	9/5/2014	R5	100	100	100	100	0	34	37026
V26	4929	9/5/2014	R5	100	100	100	100	0	32	34848
E02	5356	9/5/2014	R5	100	100	100	100	0	30	32670
E04	5356	9/5/2014	R5	100	100	100	100	0	32	34848
N13	5356	9/5/2014	R5	100	100	100	40	0	31	33759

[1] Mycogen 2A557 (Mycogen Seeds, a product of Dow AgroSciences LLC, Indianapolis, IN); Dekalb 49-29RIB & 53-56RIB (Dekalb Genetics Corp., a product of Monsanto Company, St. Louis, MO).

[2] Sample collection date and reproductive stage at sampling time.

[3] Silk = % of 10 plants silking, Blister = % of 10 plants with kernels resembling blisters, Milk = % of 10 plants with milky kernels, Dent = % of 10 plants that have kernels dented, Black Layer = % of 10 plants with kernels that have reached maturity.

[4] Plant count = number of plants counted in 40 ft^2 area, Population = planting density in selected plot (plant count*(43560/40)).

Table 2. (continued) Sample collection dates, characteristics associated with stage of production, and populations

				Characteristic[3]						
Field	Variety[1]	Date[2]	Stage[2]	Silk	Blister	Milk	Dent	Black Layer	Plant Count[4]	Population[4]
N04	2A557	9/22/2014	R6	100	100	100	100	5	32	34848
N11	2A557	9/22/2014	R6	100	100	100	100	40	29	31581
N12	2A557	9/22/2014	R6	100	100	100	100	40	33	35937
V01	2A557	9/22/2014	R6	100	100	100	100	2	31	33759
E08	4929	9/22/2014	R6	100	100	100	100	0	30	32670
E09	4929	9/22/2014	R6	100	100	100	100	0	34	37026
V25	4929	9/22/2014	R6	100	100	100	100	3	32	34848
V26	4929	9/22/2014	R6	100	100	100	100	3	32	34848
E02	5356	9/22/2014	R6	100	100	100	100	0	31	33759
E04	5356	9/22/2014	R6	100	100	100	100	0	32	34848
N13	5356	9/22/2014	R6	100	100	100	100	5	34	37026
N04	2A557	10/22/2014	Harvest	100	100	100	100	100	33	35937
N11	2A557	10/20/2014	Harvest	100	100	100	100	100	33	35937
V01	2A557	10/22/2014	Harvest	100	100	100	100	100	34	37026
E08	4929	10/20/2014	Harvest	100	100	100	100	100	34	37026
E09	4929	10/22/2014	Harvest	100	100	100	100	100	34	37026
V25	4929	10/22/2014	Harvest	100	100	100	100	100	31	33759
V26	4929	10/22/2014	Harvest	100	100	100	100	100	29	31581
E02	5356	10/22/2014	Harvest	100	100	100	100	100	34	37026
E04	5356	10/22/2014	Harvest	100	100	100	100	100	34	37026

[1] Mycogen 2A557 (Mycogen Seeds, a product of Dow AgroSciences LLC, Indianapolis, IN); Dekalb 49-29RIB & 53-56RIB (Dekalb Genetics Corp., a product of Monsanto Company, St. Louis, MO).

[2] Sample collection date and reproductive stage/harvest at sampling time.

[3] Silk = % of 10 plants silking, Blister = % of 10 plants with kernels resembling blisters, Milk = % of 10 plants with milky kernels, Dent = % of 10 plants that have kernels dented, Black Layer = % of 10 plants with kernels that have reached maturity.

[4] Plant count = number of plants counted in 40 ft^2 area, Population = planting density in selected plot (plant count*(43560/40)).

Table 3. Whole plant and earlage component dry matter through reproductive stages to dry corn harvest, and kernel dry matter from dent to harvest

	Reproductive Stage[2]						
Component[1]	R1	R3	R4	R5	R6	Harvest[3]	SEM
Whole Plant	17.82[a]	21.22[b]	26.73[c]	37.34[d]	53.62[e]	73.41[f]	0.90
Earlage	10.99[a]	20.21[b]	29.36[c]	45.84[d]	60.53[e]	76.39[f]	0.87
Kernel	-	-	-	49.83[a]	63.53[b]	78.96[c]	0.71

[abcdef] Means within a row with different superscripts differ ($P < 0.05$).

[1] Whole plant = entire plant as harvested as silage; Earlage = kernel (when applicable), cob, silk, husk; Kernel = whole shelled corn.

[2] R1 = silking; R3 = milk; R4 = dough; R5 = dent; R6 = physiological maturity.

[3] Harvest = dry corn harvest.

Figure 1. Random sampling plot locations for field N04 at Rosemount Research and Outreach Center, Rosemount, MN with random latitude and longitude locations derived from Microsoft Excel (Microsoft Corp., Redmond, WA) and applied to Google Earth (Google Inc., Mountain View, CA) image where the pin drop indicates the south east corner of a sampling location.

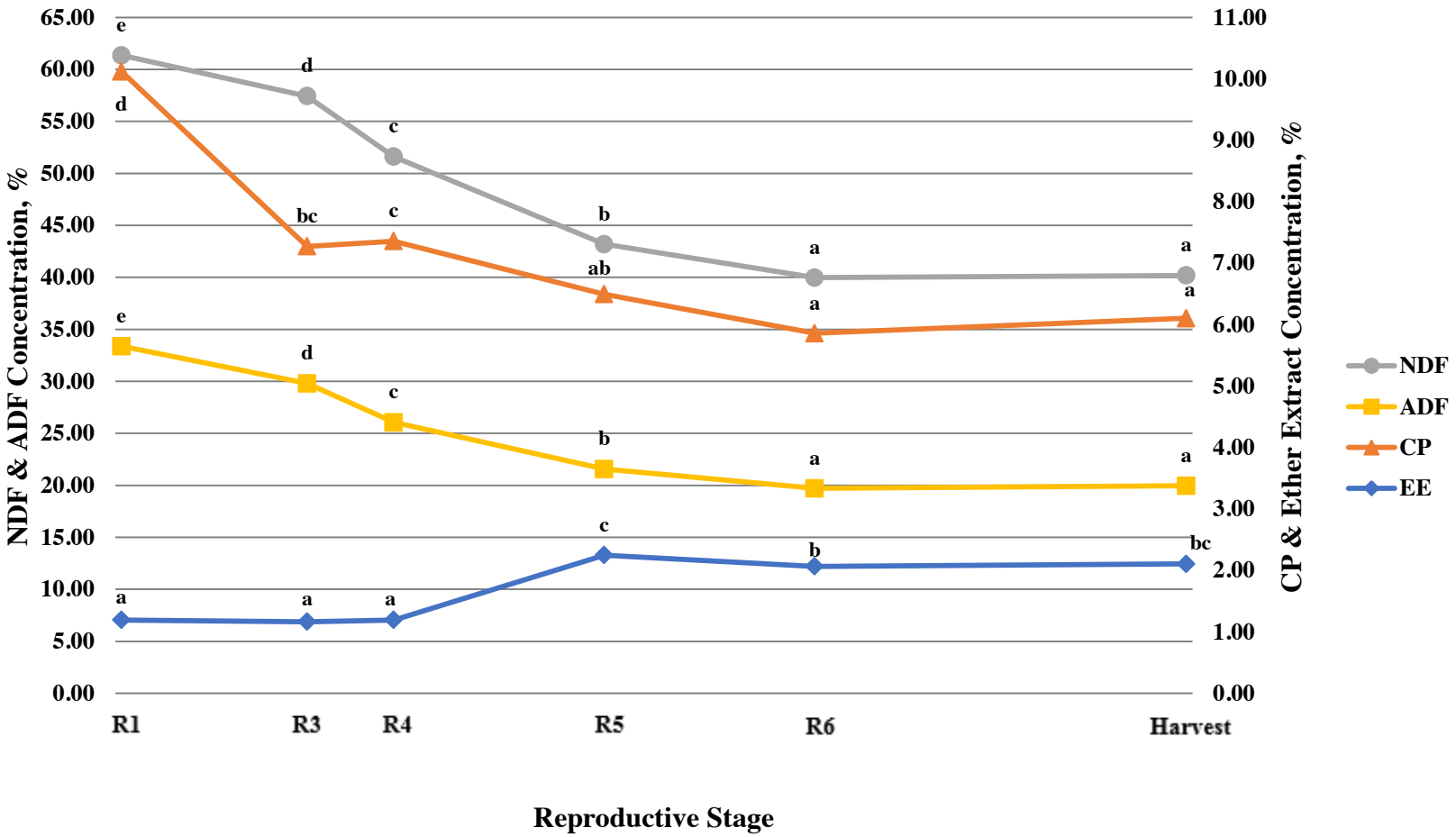

Figure 2. Whole plant nutrient composition from R1 of reproduction through dry corn harvest. Data points for NDF and ADF are run by primary y-axis (left) while data points for CP and ether extract are run by secondary y-axis (right). [abcde] Means within a data series with different superscripts differ ($P < 0.05$).

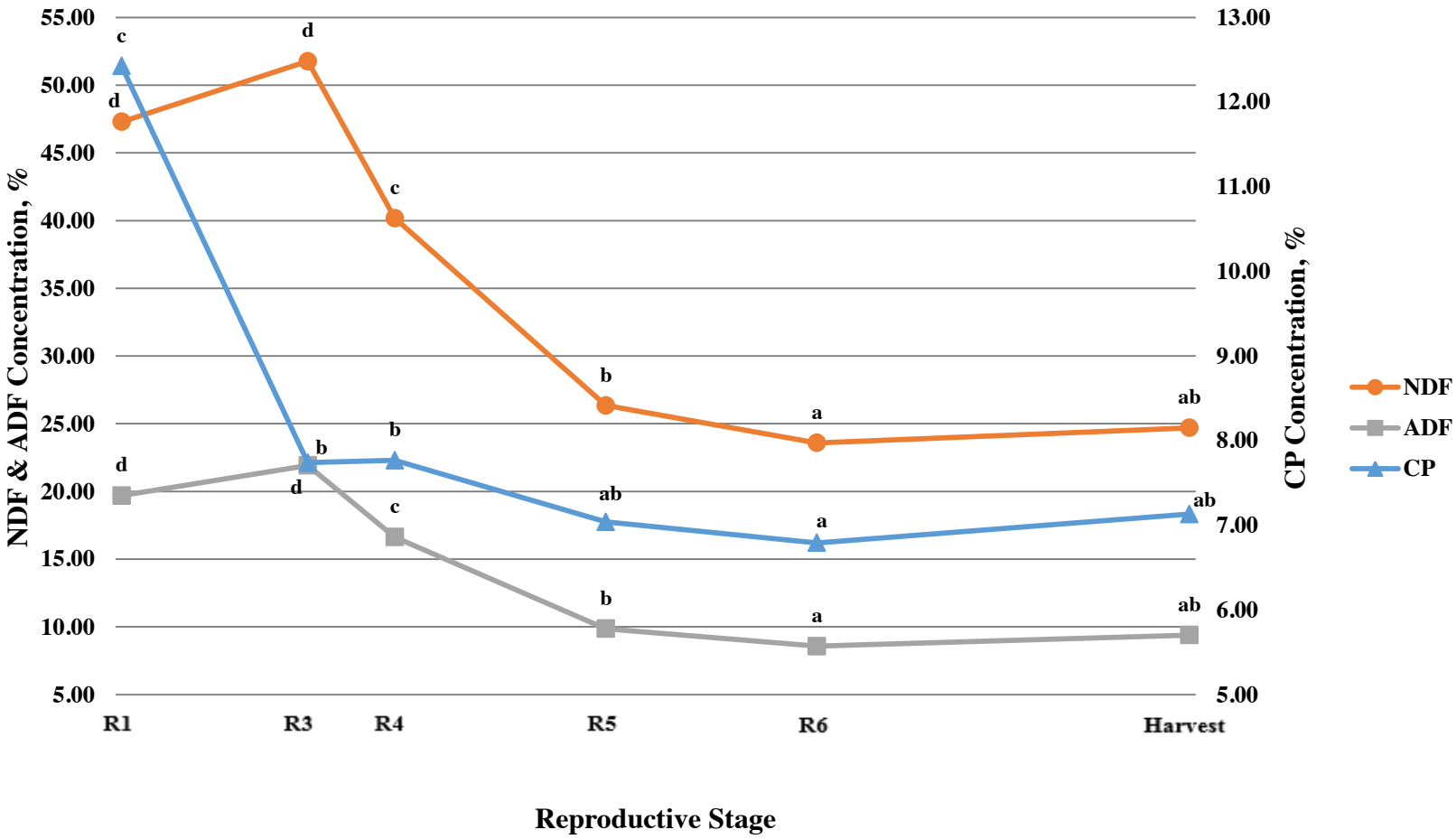

Figure 3. Earlage nutrient composition from R1 of reproduction through dry corn harvest. Data points for NDF and ADF are run by primary y-axis (left) while data points for CP are run by secondary y-axis (right). [abcd] Means within a data series with different superscripts differ ($P < 0.05$).

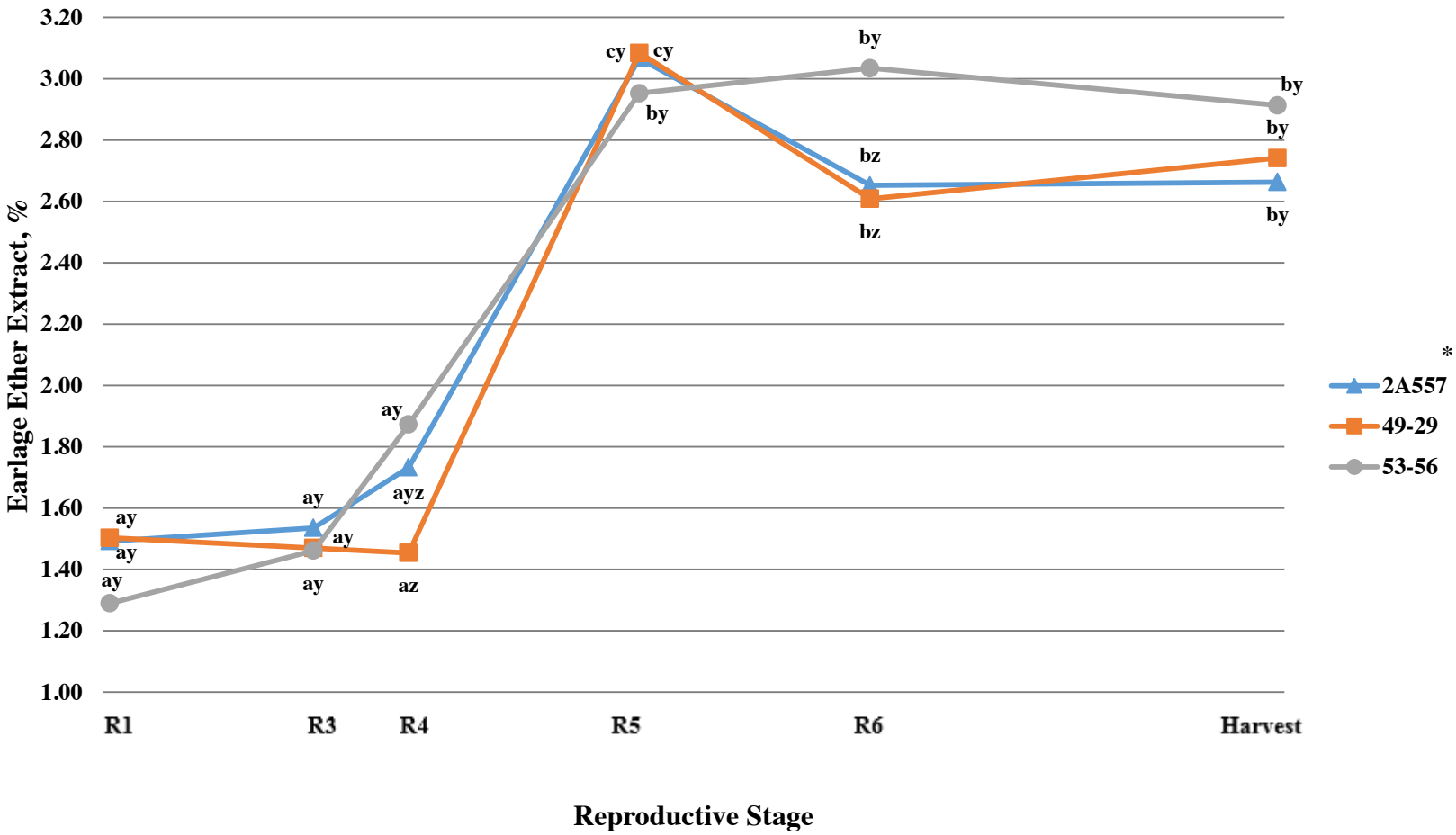

Figure 4. Effects of variety on earlage ether extract concentration from R1 of reproduction through dry corn harvest. [abc] Means within a data series with different superscripts differ ($P < 0.05$). [yz] Variety means within reproductive stage or harvest with different superscripts differ ($P < 0.05$). * Mycogen 2A557 (Mycogen Seeds, a product of Dow AgroSciences LLC, Indianapolis, IN). Dekalb 49-29RIB and Dekalb 53-56RIB (Dekalb Genetics Corp., a product of Monsanto Company, St. Louis, MO).

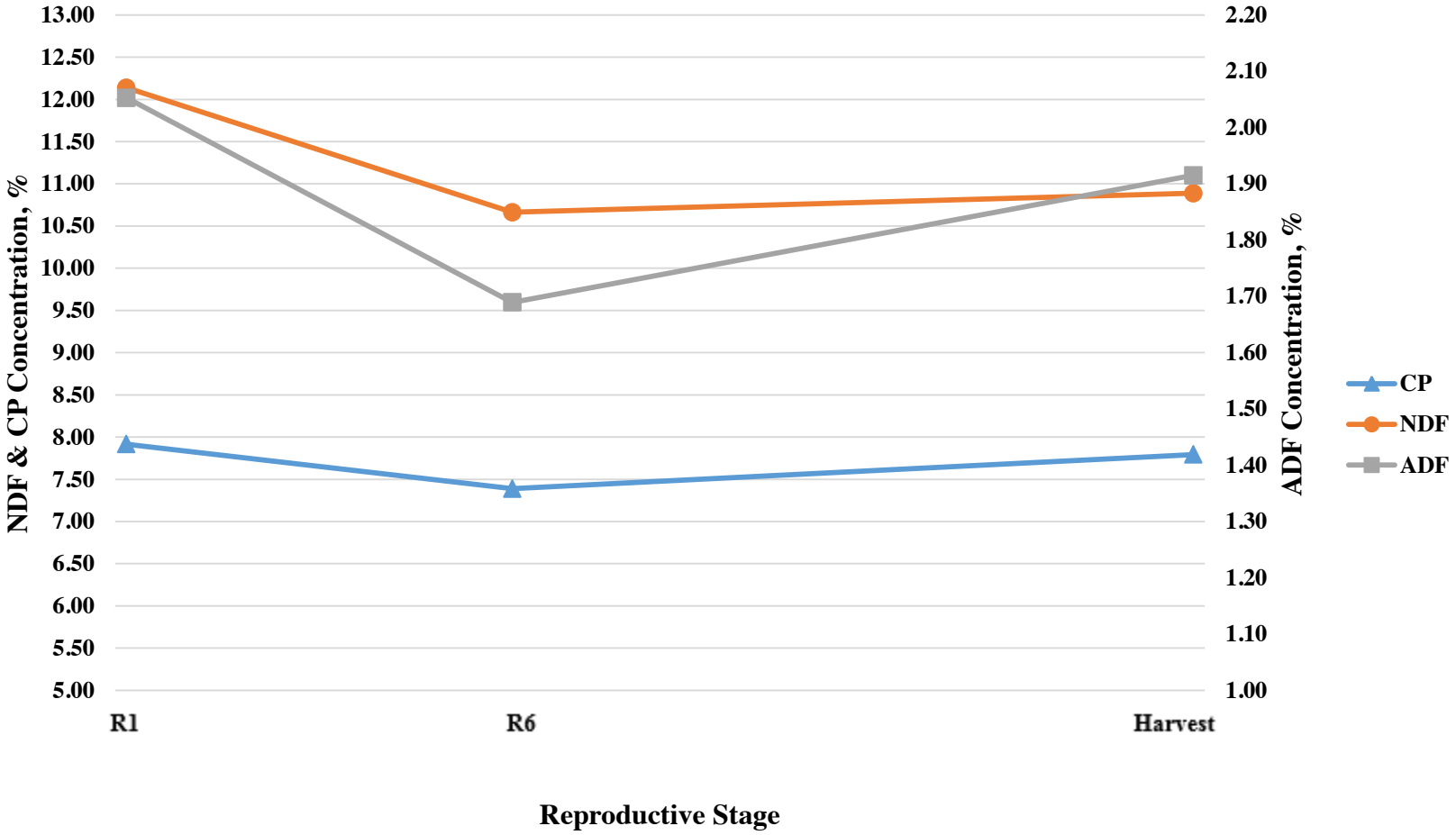

Figure 5. Whole shelled corn nutrient composition from R5 of reproduction through dry corn harvest. Data points for NDF and CP are run by primary y-axis (left) while data points for ADF are run by secondary y-axis (right).

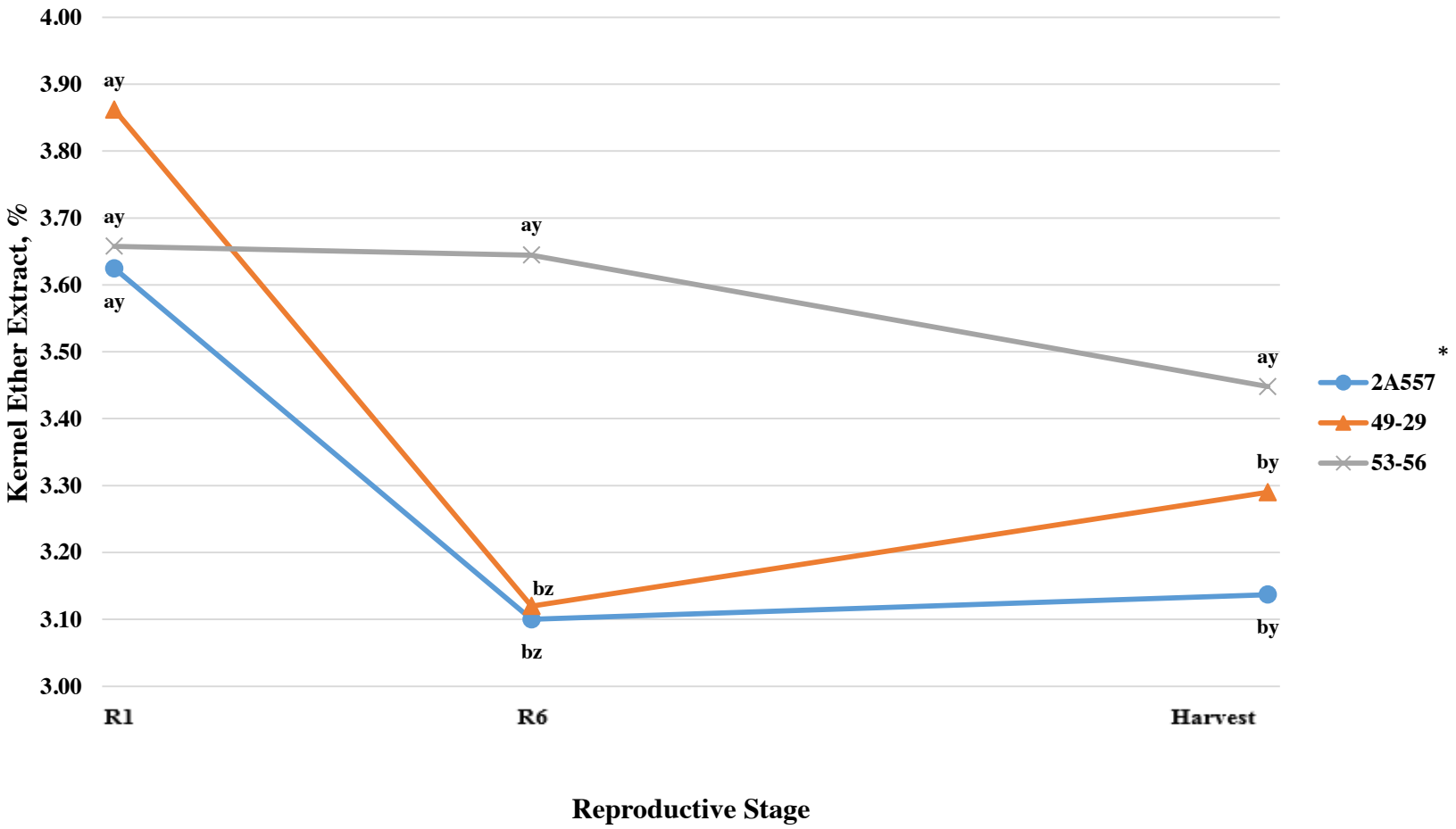

Figure 6. Effects of variety on whole shelled corn ether extract concentration from R5 of reproduction through dry corn harvest. [ab] Means within a data series with different superscripts differ ($P < 0.05$). [yz] Variety means within reproductive stage or harvest with different superscripts differ ($P < 0.05$). * Mycogen 2A557 (Mycogen Seeds, a product of Dow AgroSciences LLC, Indianapolis, IN). Dekalb 49-29RIB and Dekalb 53-56RIB (Dekalb Genetics Corp., a product of Monsanto Company, St. Louis, MO).

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