CHARACTERIZING QUALITY AND COMPOSITION OF BEEF DERIVED FROM CATTLE FED STEAM-FLAKED CORN DIETS WITH COMBINATIONS OF DRY-ROLLED CORN AND DRIED DISTILLER'S GRAINS WITH SOLUBLES

by

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Abstract

A trial was conducted replacing portions of steam-flaked corn with either dry-rolled corn or dried distiller's grains with solubles to evaluate effects on performance, carcass characteristics, carcass composition, meat color stability, and meat sensory attributes. Seven hundred crossbred yearling heifers (302 ± 65 kg initial BW) were used in a randomized complete block experiment with a 2 × 2 factorial arrangement of treatments. All diets contained steam-flaked corn (**SFC**), and factors consisted of the levels of dry-rolled corn (**DRC**; 0 or 25%) and dried corn distiller's grains with solubles (**DDGS**; 0 or 25%). Results revealed no interactions between DRC and DDGS in terms of effects on feedlot performance, and only minor interactive effects were observed for carcass characteristics and meat quality attributes. Feedlot performance and carcass characteristics were not affected by the addition of DRC or DDGS ($P > 0.05$). Carcass composition and meat quality attributes were measured to determine if fat content of carcasses was altered by feeding DDGS. Diet had no significant effects, as carcasses from the four treatments contained similar amounts of separable portions of muscle, adipose, and bone; and similar percentages of protein, moisture, and ether extract. Compositions of both adipose and muscle tissue were evaluated to assess differences in fatty acid profile. Minimal effects were noted on the fatty acid profiles of the muscle and adipose tissue from cattle fed DDGS or DRC. Feeding cattle DDGS decreased alpha tocopherol (vitamin E) content of meat ($P < 0.05$). Meat quality attributes were largely unaffected by addition of DRC or DDGS to the diet, as retail color display life, lipid oxidation, sensory attributes, and heterocyclic amine concentrations were not different among treatments. Overall, DRC or DDGS can replace portions of SFC without negatively altering feedlot performance, carcass characteristics, meat composition, or meat quality attributes.

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CHAPTER 1 - Literature Review

Introduction

Grain processing methods used by feedlots tend to vary by geographical region of the country. Feedlots in the upper Midwest frequently feed dry-rolled corn (DRC) or high-moisture corn (HMC), whereas as most feedlots in the Central and Southern Great Plains use steam-flaked corn (SFC). However, with increasing energy costs and the high price of corn, cattle producers across the U.S. may seek more energy efficient grain processing methods as well as inexpensive by-product feeds. Energy costs have continued to increase over the past few years and are projected to continue to increase in the future. To produce SFC, whole corn is conditioned in a steam chest for 30 to 45 minutes, during which the grain absorbs water and is heated. Natural gas, propane, or coal is expended to fire boilers that generate steam, using large amounts of energy. Producing DRC requires far less energy, and is produced by rolling whole corn through corrugated rollers operating at differential speed, reducing the particle size. A benefit of utilizing processed feeds in finishing diets is the improvement in animal efficiency compared to whole corn. Utilizing combinations of grains produced by different methods often yields benefits for gain and efficiency. Exploiting these positive associative effects provides means of maintaining animal performance while decreasing input costs.

Reduced feed costs also can be achieved by feeding distiller's grains, as they are by-products of ethanol production that often are priced favorably in comparison to corn. Recently, the ethanol industry has expanded extensively and more plants are being built to meet rising demand for fuel ethanol. Accompanying the growth of the ethanol industry is the elevated price of corn. High corn prices are the direct result of increased demand, as more and more corn is being purchased by ethanol producers. One positive offshoot of the ethanol industry is the production of distiller's grains, a by-product of the process. Distiller's grains have become an important feed ingredient for livestock. When compared to corn, distiller's grains are higher in protein, fat, fiber, and phosphorus. In most instances, research has been conducted on the use of distiller's grains in diets with less processed grains such as DRC and HMC, and cattle performance generally has been favorable. Recent research with distiller's grains has revealed that the feeding value of distiller's grains is decreased when fed in combination with SFC. May

et al. (2007) noted that the nutritional value of wet distiller's grains is greater in DRC diets compared to SFC diets. Uwituze (2008a) suggested that differences in feeding value may be due to differences in ruminal pH. Zinn et al. (1995) compared DRC and SFC and noted that ruminal pH was higher for cattle fed DRC compared to SFC. Uwituze (2008a) suggested that low ruminal pH may hinder digestion of distiller's grains fed in SFC diets. Changes in ruminal pH have also been shown when feeding distiller's grains, as May et al. (2007) observed that feeding 25% dried distiller's grains with solubles (DDGS) decreased ruminal pH compared to no DDGS.

Dry-Rolled Corn

Dry-rolling is a fairly simple and energy efficient process. Dry-rolling corn is accomplished by passing whole shelled corn through a roller mill. Roller mills are typically single (one set of rolls) or double (two sets of rolls) in feedlots, however, larger roller mills can be found in commercial feed mills. The roller mill is often designed so that the mill is elevated, which allows corn to drop in a pile after going through the rolls, simplifying the process to allow load out directly from the pile. The use of one or two set of rolls is determined by the quantity needed, as larger feedlot will use more feed daily. Roller mills often are automated and equipped with an alarm system to notify the operator when the supply bin is empty, reducing labor costs. The size of rolls and supply bins are dependent on the size of the feedyard, as larger feedyards use greater quantities of feed at a faster pace. Equipment needed for dry-rolling includes a supply bin, elevated building, roller mill (single or double stack), and bucket elevator. Macken et al. (2006) evaluated costs of producing DRC and SFC. They estimated processing costs for DRC in 5,000- and 20,000-head feedlots at $1.58 and $0.81 per metric ton, respectively. Schake and Bull (1981) and McEllhiney (1986) observed that processing costs for DRC were less expensive in comparison to SFC. Lower inputs costs are due to differences in energy inputs and processing equipment, as dry-rolling requires less equipment and requires no steam. Macken et al. (2006) reported that electricity costs of DRC were $0.04 and $0.03 per metric ton for 5,000 and 20,000 head feedlots, respectively. Dry-rolling is a simple process, with relatively low overall costs.

Steam-Flaked Corn

Steam-flaking is used quite commonly in the Southern and Central Great Plains for processing grains to feed to finishing cattle. Steam-flaking is a process that steams whole grain in

a steam chest for 30-45 min, usually at a temperature of 100°C, before compressing through corrugated rolls rotating at the same speed, and with an appropriate gap width between rolls to produce the desired flaked density. With the addition of steam during the process, costs are increased in comparison to dry-rolling. Macken et al. (2006) estimated processing costs for SFC for 5,000- and 20,000-head feedlots at $9.57 and $6.23 per metric ton, respectively. Macken et al. (2006) reported electricity costs for SFC in 5,000 and 20,000 head feedlots to be $1.61 and $1.09 per metric ton, respectively. They also reported that the natural gas costs for SFC were $2.78 per metric ton for both 5,000 and 20,000 head feedlots. In relation to DRC, energy and natural gas costs are much more expensive. The following specifics on steam-flaking corn were adapted from Zinn et al. (2002). Flaking corn is done primarily to increase the digestibility of starch and increase energy content of the grain. Starch digestibility is limited by the protein matrix that encapsulates starch granules and the compact nature of starch itself. Shear forces on hot grain during flaking can achieve disruption of the protein matrix. Disruption of the protein matrix that surrounds starch granules is considered the first limiting step in optimizing starch digestion.

The quality of steam-flaked corn is important in optimizing starch digestion. Quality is determined by five critical production factors: steam chest temperature, steaming time, roll corrugation, roll gap, and roll tension. Both rolls and grain kernels should be hot when the corn is passed through the rolls to insure optimal shear. To achieve hot kernels, steam chests should be designed to allow a steaming time of at least 30 min at maximum mill production capacity, producing a flake with a density of 310 g/L. Zinn et al. (2002) suggested that the adequate amount of moisture uptake during steaming is 5%. Sindt et al. (2006) evaluated two flake densities (360 and 310 g/L), and observed that decreasing flake density did not improve total tract digestion of OM, starch or N. Conditioning time within the steam chest has little affect on diet digestibility (Zinn, 1990). Grain was retained within the steam chest for 34, 47, or 67 min. They observed that starch leaving the abomasum was the greatest for cattle fed SFC conditioned for 47 min. Total tract digestion of the diet was not affected by steaming time. Fecal excretion of OM increases linearly as conditioning time increased. They concluded that the digestible energy was greatest for cattle fed SFC conditioned for 34 min.

Also critical in the quality of flaked corn is the rate of flaking and distribution of kernels across the rolls. Quality of SFC includes measurements of flake thickness, flake density, starch

solubility, and enzyme reactivity. The most common quality standard is flake density, which is closely associated with starch solubility ($r^2 = 0.87$), and enzyme reactivity ($r^2 = 0.79$), but this only explains 63% of the variability in fecal starch and 52% of the variability in starch digestibility. Evaluating fecal starch directly can explain 91% of the variability in starch digestion. Flaking grains will increase the digestibility of the grain; however, flaking to a density less than 310 g/L, may reduce DMI, increase variability of weight gain between animals within a pen, and predispose cattle to acidosis and bloat without increasing starch digestion. Flaking grains increases energy content, starch digestibility and increases potential for fermentation within the rumen (Zinn et al., 2002).

Grain Processing and Effects on Cattle Performance

Processing of grain originally was done to homogenize particle size, shape, and moisture of grains due to variability of whole grains (Matsushima, 2006). In feedlot diets, the primary purpose of processing grain is to increase energy content of the diet (Owens et al., 1997). Processed grains have higher energy values when compared to whole grains due to increased energy availability that is achieved through disruption of the protein matrix surrounding starch granules. Theurer (1986) noted that improvement in starch utilization is the primary basis for the superior feed conversion of cattle fed diets high in processed grains. Due to these advantages in starch and energy availability, most feedlots feed processed grains. In a survey of consulting nutritionists, Vasconcelos and Galyean (2007) noted that SFC is the most common grain processing method used in feedlots that were serviced by the respondents. Behind SFC, DRC and HMC were the next two most common methods utilized by feedlots. The authors found that almost 90% of respondents used two different processed grains in feedlot diets.

Galyean et al. (1979) and Turgeon et al. (1983) both noted that starch digestion is improved for grinding/cracking corn in comparison to whole corn. Theurer (1986) concluded from a review of the literature that flaking grain increases starch degradation within the rumen by 9 to 18% compared to ground or cracked corn. Owens et al. (1986) also found that when corn is processed more extensively, the proportion of starch digested within the rumen increases. They observed that for SFC, DRC, and HMC, the proportions of ruminal degradation were 82.8, 71.8, and 86%, respectively. Within the small intestine, digestion was 15.6, 16.1, and 5.5% for SFC, DRC, and HMC, respectively. When evaluating the large intestine, digestibilities for SFC,

DRC, and HMC were 1.3, 4.9, and 1.0%, respectively. Total tract digestibilities of SFC, DRC, and HMC were 97.8, 93.2, and 94.6%, respectively. Processing grains extensively increases fermentation within the rumen, decreasing the amount of starch that reaches the small intestine, which, in turn, improves feed efficiency in cattle. Whole grains are digested less in the rumen due to larger particles size, passing more undigested feed to the small intestine. After starch is passed to the large intestine and digested, fecal N loss is increased, and apparent protein digestibility is decreased.

Huntington et al. (1997) observed that total tract organic matter (OM) and starch digestion were greatest for SFC, followed by HMC, then DRC. Cooper et al. (2002) observed when comparing SFC, DRC, and HMC that total tract OM and starch digestion were lowest for cattle fed DRC. Zinn and Owens (1983) conducted a trial where they fed a diet containing DRC at 1.2, 1.5, 1.8, and 2.1% of body weight to evaluate ruminal bypass, and site and extent of digestion. They observed that, as intake increased, flow of N, non ammonia N, microbial N, and feed N to the small intestine were increased linearly. As intake percentage increased, passage rate increased, and ruminal degradation decreased linearly. As intake increased linearly, ruminal degradation of ADF and OM decreased linearly. Ruminal starch digestion increased as intake increased. The authors suggested that increases in starch digestion that occur with increased intake were due to differences in the amount of fermentable material present as intake levels increased. Corona et al. (2005) evaluated finishing diets of SFC, DRC, ground corn (GC), and whole corn (WC) in finishing diets. They observed that starch reactivity (a measure of starch solubility or disruption of the starch granule) was greatest for SFC diets in comparison to DRC, GC, or WC. Total tract digestibilites of DM, OM, starch, and N were increased in animals fed SFC. They also noted that fecal excretions of OM, starch, and N were lower for SFC-fed cattle. The authors suggested that processing grains increases digestion of starch and non-starch OM. Ruminal pH was lowest in SFC-fed cattle compared to DRC, GC, or WC. Total volatile fatty acid (VFA) concentration was not different between SFC and DRC; however, concentrations of acetate and butyrate were decreased, acetate:propionate ratio were decreased, and propionate concentration was increased in the rumen of cattle fed SFC. Processed grains have increased digestibility, increasing energy content and the resulting feeding value, thus improving efficiency.

Associative Effects of Grain Processing Types

Associative effects refer to non-additive differences in digestibility of feedstuffs fed as components of mixed diets fed at high intakes. This is compared to digestibility determined for the same feedstuffs when fed alone (Merchen, 1988). Dry-rolling and steam-flaking grains yield differences in gelatinization of starch due to the addition of heat and moisture in flaking, along with the difference in degree of the disruption of the protein matrix that surrounds starch granules. Greater alteration of the starch granule increases microbial fermentation, resulting in a lower pH when flaked corn is digested in the rumen. The addition of less processed grains, such as DRC, to SFC could potentially modulate this decrease in pH, and achieve positive associative effects.

Grain processing is used to improve animal efficiency, but extensive processing can also predispose cattle to digestive upsets and increase the incidence of acidosis. Extensive processing methods like steam-flaking increase gelatinization and breakdown of the protein matrix that encapsulates starch granules, increasing energy availability. Flake density and thickness also can alter rate of fermentation. Conversely, grains that are processed less have slower rates of fermentation and can the shift the site of digestion from the rumen to the small intestine. Dry-rolled grains are processed less extensively and have a slower fermentation rate, often decreasing digestibility compared to SFC. Feeding mixtures of a fast- and slow-fermenting grain may increase animal performance. Increased animal performance is a direct result of increased digestibility of slow fermenting grains when fed in combination with fast fermenting grains.

Comparisons by researchers (Wagner et al., 1971; Lee et al., 1982; Axe, 1986; Kreikemeier et al., 1987; Stock et al., 1987) were made amoung rapid and slow fermenting grains. Feeding combinations of rapidly digested and slowly digested grains resulted in positive associative effects. Kreikemeier et al. (1987) fed cattle finishing diets of 100% corn or wheat, 67% or 33% DRC with 33% or 67% dry-rolled wheat (DRW). The authors observed that cattle fed grain mixtures of DRC and DRW gained 4% faster and 4.4% more efficiently than the average performance of corn or wheat diets. However, when feeding combinations of rapidly fermenting grains, no positive associative effects were observed. Stock et al. (1990) evaluated DRC and dry-rolled sorghum grain and observed no complementary effects on either ADG or G:F. When evaluating rapidly fermentable grain combinations, such as HMC and dry-rolled wheat, or HMC and dry-rolled barley, there were no complementary effects on ADG or G:F

(Bock et al., 1991; Duncan et al., 1991). This suggests that feeding combinations of rapidly fermenting grains would no be beneficial due to a lack of improvements in cattle performance. However, when Huck et al. (1998) fed combinations of steam-flaked grain sorghum (SFGS), DRC, HMC, and SFC, they noted significant improvements in ADG and G:F with mixtures of SFGS with either DRC or HMC. The authors noted that feeding SFGS in combination with SFC resulted in much smaller effects. Carcass characteristics were not changed by feeding mixtures of processed grains. Benefits of feeding grain mixtures may be due to reducing acidosis or to improvements in starch utilization (Axe, 1986; Stock et al., 1987). Stock et al. (1987) conducted several feeding trials comparing one grain source to mixed grain sources. In their first trial, they fed combinations of HMC and DRC (100:0, 75:25, 50:50, 25:75, and 0:100) and observed that cattle fed mixtures of HMC and DRC were 9.4% more efficient than would be expected from performance of steers fed HMC or DRC alone. In their second trial, they fed diets of 100% HMC, 75% HMC, and 25% dry rolled grain sorghum (DRGS), 50% HMC, and 50% DRC, and 100% DRGS. Cattle fed grain mixtures of HMC and DRGS had a 5.4% positive associate effect for G:F. In the authors' fifth trial, they evaluated grain mixtures of HMC and DRGS on digestion. They observed that feeding grain mixtures improved ruminal starch digestion by 14% and total tract starch digestion by 2% above the expected means. Feeding a highly fermentable grain with slower fermenting grain resulted in the greatest positive associative effects on performance.

Comparison of Dry-Rolled and Steam-Flaked Corn

Feedlots across the Midwest and Great Plains utilize different methods for processing grains, depending on their location. With the widespread use of both dry-rolling and steam-flaking, comparisons of SFC and DRC in finishing diets are common. Steam-flaking is a more extensive process that increases the degradation of starch due to greater disruption of the protein matrix that encapsulates the starch granule. Dry-rolling on the other hand, is a less extensive process that alters starch to a lesser extent.

Feedlot Performance of Cattle fed Dry-Rolled Corn or Steam-Flaked Corn

Differences in feed efficiencies may be due to varying levels of starch degradation. As mentioned earlier, increasing energy (starch digestibility) content is the main objective of processing grains. When evaluating SFC compared to DRC, SFC consistently increased starch

digestibility (Matsushima and Montgomery, 1967; Lee et al., 1982; Zinn et al., 2002), yielding an average of 99% apparent total tract digestion of starch. The rumen is the major site for starch degradation, utilizing microbial activity. Theurer (1986) observed that processing grains increases the microbial degradation of starch and decreases amounts of starch digested post-ruminally. Increasing ruminal starch degradation decreases ruminal pH due to increased VFA production. Starch fermentation and digestion is increased within the rumen when flaking in comparison to rolling grains (Huntington, 1997). Increased amounts of apparent total tract starch digestion increase the amount of energy available to the animal and improve feed efficiencies.

Owens et al. (1997) summarized that processing grain to a greater extent than dry-rolling has been shown to improve cattle performance. Performance of cattle fed DRC is typically lower when compared to SFC-fed cattle due to differences in feeding values. Barajas and Zinn (1998) evaluated feeding values of SFC and DRC in finishing diets. They noted that the reduced starch digestibility of DRC is the primary reason for the lower feeding value of DRC compared to SFC. Ruminal and post-ruminal starch digestion were depressed when feeding DRC compared to SFC. Zinn et al. (1995) observed that differences in post-ruminal starch digestion accounts for most of the variation in total tract starch digestion.

Owens et al. (1997) observed that flaking grain decreases DMI approximately 12% compared to dry-rolling. Intake is primarily controlled by chemostatic regulation that uses blood metabolites (volatile fatty acids) to signal when needs are met. Differences in intake are often the result of differences in energy content of processed grains. A review completed by Zinn et al. (2002) noted that SFC decreases DMI by 6.1% when compared to DRC. Macken et al. (2006) found that SFC decreased DMI in comparison to DRC. Corona et al. (2005) observed that SFC decreased DMI compared to DRC. Owens et al. (1997) stated in a review of grain processing that DMI decreases when the degree of processing increases, concluding that cattle fed SFC were lowest in DMI compared to DRC and HMC. In direct comparison of SFC and DRC, other authors showed that SFC decreased DMI (Zinn, 1987; Barajas and Zinn, 1998). However, conflicting results have also been shown when comparing DMI of DRC and SFC. Huck et al. (1998) noted that DMI was similar across diets of DRC and SFC. Researchers (Zinn, 1987; Owens et al., 1997; Zinn, 1998; Zinn et al., 2002; Corona et al., 2005; Macken et al. 2006) found that extensively processed grains decreased DMI when compared to less extensive grain processing. With more energy available, lower intake is required to meet the needs of the animal.

Uwituze (2008a) observed that total VFA concentration was similar for cattle fed SFC or DRC and suggested that the intake may be responsible for the result. Cattle fed DRC consumed an average of 1.1 kg more DM then cattle fed SFC.

Another important measure of feedlot performance is ADG. A review completed by Zinn et al. (2002) noted that SFC increases ADG by 5.4% when compared to DRC. Corona et al. (2005) evaluated the use of SFC compared to that of DRC in finishing diets and observed that SFC increased. However, conflicting research has been reported by both Zinn (1987) and Barajas and Zinn (1998), as they reported no differences in ADG when feeding SFC or DRC to feedlot cattle. Macken et al. (2006) also found similar ADG when comparing SFC and DRC. Cattle ADG response to grain processing is variable, as some observations show that it is increased while others suggest ADG is similar for SFC and DRC.

Increasing starch availability improves the efficiency of beef cattle production (Theurer, 1986). Research has been conducted to compare different processed grains and their effect on cattle efficiency. Cattle fed steam-flaked (SF) grains were more efficient than those fed dry-rolled (DR) diets (Owens and Gardner, 2000). In comparing SFC and DRC, LaBrune et al. (2008) observed that cattle fed SFC had improved G:F compared to counterparts fed DRC. The same was observed by both Zinn (1987) and Barajas and Zinn (1998), as SFC improved feed efficiency compared to DRC. In a review of grain processing methods Zinn et al. (2002) summarized data indicating that G:F was improved by 12.2% with flaking compared to dry-rolling. Finding slightly lower increases in G:F was Huck et al. (1998), as they observed an 8.6% increase when comparing SFC to DRC. Scott et al. (2003) conducted two trials, measuring improvements in efficiency of 6.6 and a 9.9% for cattle fed SFC compared to DRC for trial 1 and 2, respectively. Barajas and Zinn (1998) found that feeding SFC to finishing cattle improved feed efficiency 16% compared to DRC. The general consensus is that SFC-fed cattle will be more efficient than cattle fed DRC due to the increased energy availability of the diet. Macken et al. (2006) suggested that even with high SFC production costs; a 5,000- or 20,000-head feedlot could justify flaking grain over dry-rolling due to improved cattle performance with flaked grains. The authors also suggested that economic returns are dependent on corn prices, feed efficiency responses, energy costs, and size of feedyards. The authors noted that overall SFC appears to generate the greatest economic return in comparison to DRC, due to sizable differences in feed efficiency. Feedlots are able to get more performance out of their grain

purchase when steam-flaking corn due to the improved feed efficiency. Extensive processing is a means of adding value to grain, creating an opportunity to offset high grain prices.

Carcass Characteristics of Cattle fed Dry-Rolled and Steam-Flaked Corn

To most producers, dressing percentage carries great economic importance as it relates live weight to carcass weight, which is a key determinant of carcass value. Feeding processed grains often increases dressing percent compared to feeding whole grains. Owens and Gardner (2000) noted that cattle fed whole grains had lower dressing percentages when compared to those of cattle fed SF grains. They speculated that differences were due to greater digestive tract fill for those cattle fed whole grain compared to processed grains. When comparing two processing methods, SFC and DRC, Corona et al. (2005) observed that cattle fed SFC had greater dressing percentages. On the other hand, May (2007a) noted no differences in dressing percentage when comparing cattle fed SFC in comparison to those fed DRC.

Hot carcass weight (HCW) is a key determinant of the profitability of finishing cattle. Owens and Gardner (2000) noted that cattle fed SF grains had heavier HCW than those fed DR diets. Huck et al. (1998) and Scott et al. (2003) also observed that cattle fed SFC had heavier HCW when compared to carcasses from cattle fed DRC. In contrast, Macken et al. (2006) and Corona et al. (2005) found HCW to be similar between cattle fed SFC or DRC. Again, researchers have found conflicting results between feeding SFC and DRC; this may be due to differences in physiological end points.

Within the carcass, numerous measurements are collected, such as longissimus muscle (LM) area; kidney, pelvic, and heart fat (KPH); 12th rib fat thickness; marbling score; quality and yield grades; and incidence of liver abscesses. When compared with DR grains, cattle fed SF grains had larger LM areas and greater 12th rib fat thicknesses, but lower marbling scores and quality grades (Owens and Gardner, 2000). The authors also observed that SF increases efficiency of cattle, and when feeding to the same end point, cattle will typically be heavier and fatter. They also observed that feeding cattle SF grain increased fat thickness per unit of LM area and decreased marbling score:12th rib fat thickness ratio. Scott et al. (2003) found conflicting results within two trials that they conducted utilizing different grain processing types fed in conjunction with wet corn gluten feed. In their first trial, they observed no differences in LM area, 12th rib fat thickness, marbling score, quality grade, or yield grade. However, in their

second trial they observed that SFC increased 12th rib fat thickness and yield grade. Cattle in the second trial came into the feedlot heavier and were finished to a heavier weight suggesting that cattle were fatter to start with, creating more opportunity for differences between diets. This may be due to differences of days on feed as cattle in the first trial and second trial cattle were on feed for 170 and 117 d respectively. In a trial completed by LaBrune et al. (2008), they observed no significant differences between SFC and DRC in LM area, 12th rib fat thickness, marbling score, or quality grade, but did observe that SFC increased yield grade and incidence of liver abscesses. Huck et al. (1998) conducted a trial comparing multiple processed grains; they found that cattle fed SFC and DRC were similar in KPH, 12th rib fat thickness, marbling score, % USDA Choice and higher, and liver abscess score.

Meat Attributes of Cattle Fed DRC and SFC

Seldom has previous research evaluated the effects of grain processing, specifically SFC and DRC, on meat attributes. As consumers are the main target of beef producers, their preferences and demands drive the market. When producing beef, feedlot producers should be cognizant for what they are producing. Meat attributes that will affect consumer opinion of meat include color and flavor; however, other attributes of meat such as vitamin E content, formation of heterocyclic amines, and cooking and purge losses also change the quality of meat in ways that consumers can not detect or have little knowledge of.

Visual appearance of meat is a determining factor in how consumers select meat to purchase. Simulated retail display is used to evaluate the change in color of meat over time under conditions simulating a grocery or retail store. Savell et al. (1989) noted that consumers utilize color during their selection process. Color, as described by consumers, denotes freshness and eating potential of a cooked product (Forbes et al., 1974). Furthermore, Jeremiah et al. (1972) observed that consumers preferred beef that was neither too pale nor too dark. Nearly 15% of all retail beef is discounted in price due to surface discoloration, which leads to annual revenue losses of $1 billion (Smith et al., 2000). Color can be measured through multiple means; including computer vision, instrumental color, myoglobin redox forms, and visual color estimates. Each method is used to meet specific needs of researchers. Instrumental color is a common method that is relatively easy to use, and provides quantitative measures of color in meat including lightness, redness, and blueness/yellowness. A handheld Hunter Miniscan

spectrophotometer is commonly used to measure instrumental color. Another method often used by researchers is visual color estimates. Mancini and Hunt (2005) noted that visual determinations are acceptable for estimating consumer preferences. Visual color utilizes trained panelists that score each steak on a scale from 8 (bright cherry red) to 1 (extremely brown or green). Killinger et al. (2004a) polled consumers in Chicago and San Francisco and found that bright cherry red color was preferred by 67.6 and 76.5% of consumers polled, respectively. Carpenter et al. (2001) found a strong relationship between color preference and purchasing intent, with consumers discriminating against beef that is not red (i.e., beef that is purple or brown).

Lipid oxidation can be observed several ways, but most concerning, it can be detected by consumers by the presence of off-flavors in meat. Lipid oxidation is the primary cause of off-flavors in meat and involves the oxidation of unsaturated fatty acids of phospholipids (Tang et al., 2005). Lipid oxidation is often measured by thiobarbituric acid reactive substances (TBARS). Witte et al. (1970) created the procedure for this measurement. Thiobarbituric acid reactive substance is a measurement of the lipid oxidation that occurs within meat over time, causing the meat to change colors and flavors. Oxidation of lipids is one of the primary culprits of quality deterioration in meat (Gray et al., 1996). Another measure that is influenced by lipid oxidation is the amount of alpha-tocopherol (vitamin E). Feeding vitamin E to cattle has decreases the amount of lipid oxidation in meat (Arnold et al., 1993). The authors have also shown that vitamin E prevents discoloration on the surface of steaks.

Flavor is highly correlated with overall consumer acceptability in beef (Neely et al., 1998; Goodson et al., 2002). Sensory attributes can be measured by different methods, depending on what emphasis is wanted or needed. Acree and McLellan (1993) and Meilgaard et al. (1991) noted that the major sensory attributes included appearance, odor, taste, flavor, texture, and noise. The two major types of sensory analyses are: 1) trained sensory panel (flavor, textural or descriptive), and 2) consumer testing. Park (1997) noted that trained sensory panel testing is objective and quantitative, while consumer testing is subjective and qualitative. Differences between these two methods are substantial, and their use depends on the type and need of the experiment. Most commonly, consumer testing is used to collect general perceptions. For more detailed responses on texture and flavor attributes, trained sensory panels are utilized. Trained sensory panels are classified as flavor or textural profile panels or descriptive attribute panels.

Flavor and textural profile panels evaluate specific attributes of flavor and texture, respectively. For example, at Kansas State University, the Department of Human Nutrition panelists evaluate meat for beef flavor identity, bloody/serumy, metallic, and rancid flavors, as well as for initial tenderness, juiciness, chewiness, mealy texture, fiber awareness, and residual connective tissue. On the other hand, descriptive attribute panelists are trained to measure attributes such as myofibrillar tenderness, juiciness, flavor intensity, connective tissue amount, overall tenderness, and off-flavor intensity on an eight-point scale (LaBrune et al., 2008). The authors used the eight-point scale when they analyzed steaks from cattle fed SFC and DRC and observed that all sensory characteristics of tenderness, juiciness, connective tissue amount, and flavor intensity were similar for steaks from cattle fed SFC and DRC.

Heterocyclic amines (HCAs) are carcinogenic chemicals that are formed when meat is cooked at high temperatures. They are formed when amino acids and creatine react at high temperatures. According to the International Agency for Research on Cancer, HCAs are a group 2B carcinogen. Group 2B signifies that the compound is possibly carcinogenic to humans. Skog et al. (1993) noted that the main mutagenic and carcinogenic substances produced in cooked meat are HCAs. The author also noted that there are two forms of HCAs: “thermic” and “pyrolytic”, and they are classified by the temperature at which they are formed (below 300°C and higher than 300°C, respectively). Skog (1993) noted the main difference between thermic and pyrolytic HCAs was the location of the amino ring, as it is attached to the imidazole in thermic HCAs, and to the pyridine ring for pyrolytic HCAs. These carcinogenic compounds are hazardous to human health, as there is a clear correlation between consumption of HCAs and different types of human cancer (Skog, 1993). Heterocyclic amines are the main mutagenic and carcinogenic substances produced in cooked muscle meats, specifically beef, pork, mutton, chicken, and fish (Abdulkarim, 1997). Powrie et al. (1982) and Wie et al. (1981) postulated that the browning reaction (Maillard reaction) plays an important role in the formation of HCAs. Production of HCAs is due to the intermediate products of Maillard reactions reacting with creatine (Abdulkarim, 1997). Skog (1993) suggested that the primary variables that affect the mutagenic activity of cooked meat are cooking temperature, cooking time, and cooking method. Concentrations of HCAs can be reduced if cooking temperature is lower, as less burning or charring occurs (Skog et al., 1995). Heterocyclic amine mutagens often are found in charred portions of beef, possibly leading to health risks for consumers if they over cook meat. Hatch et

al. (1988) noted that surfaces of well-done, charcoal-broiled steaks contained higher levels of HCAs than broiled beef. Tappel (1962) noted that vitamin E acts an anti-oxidant by reacting with free radicals. Chen et al. (1992) and Johansson et al. (1995) found that HCA concentration could be reduced by the anti-oxidant action of vitamin E, as it acts a free radical scavenger, stabilizing the intermediates of the Maillard reaction. Intermediates of Maillard reactions are directly responsible for the formation of HCAs as they react with creatine to form HCAs. High cooking temperatures increase browning of meat, resulting in more Maillard reactions. Aldehydes, which are products of lipid oxidation, also have been shown to reduce the levels of HCA in ground beef (Faulkner, 1994). Unfortunately, research that has been conducted on HCAs has focused on cooking temperatures and little on how nutrition of an animal can influence the formation of HCAs in cooked meat.

Purge or drip loss refers to exudate formed from the meat is packaged to when the consumer removes it from the package. Excessive purge loss would be considered undesirable due to the loss in weight. Cooking loss, a measure of the weight loss during the cooking process, would also lead to negative consumer opinions if the loss was great. A lack of research has been conducted evaluating weight losses during packaging (purge) and cooking on meat resulting from cattle fed SFC or DRC-based diets.

Beyond the above meat attributes, carcass composition and fatty acid composition also affect consumer's opinion of meat, both directly and indirectly. Carcass composition refers to the proportion of the carcass that is muscle, adipose or bone. To consumers, the proportion of muscle and adipose would be the most important; however, most discrepancies can be diminished by trimming the fat on the product before consumers sees the final product with the exception of seam fat (intermuscular fat). Carcass composition can be determined by many methods, but, most are expensive, and tedious. Methods that have been and are currently used to determine carcass composition include total carcass physical separation, partial carcass separation, chemical separation, dual-energy x-ray absorptiometry, retail product equations, video image analysis, computed tomography, dilution techniques, along with several other rarely-used methods. However, some methods, like dual-energy x-ray absorptiometry, video image analysis, and computed tomography, are cost prohibitive. Other methods such as total carcass physical separation and dilution techniques are time consuming, costly, and tedious. Most commonly, researchers will use a partial separation of the carcass. Hankins and Howe (1946) described a

method that removed the 9th-10th-11th rib section from a whole rib with attached plate to measure composition of the rib section, and used this information to predict composition of the entire dressed carcass. The Hankins and Howe (1946) method allows for resale of product, unlike when the whole carcass is ground in total carcass chemical analysis. Although no literature speaks directly on carcass composition from cattle fed different processed grains, SFC may increase fat content in carcasses due to elevated 12th rib fat thicknesses and yield grades.

Fatty acids, especially conjugated linoleic acids (CLA), have been shown to possess anti-carcinogenic, anti-atherosclerotic, and anti-inflammatory effects (Weiss et al., 2004). Conjugated linoleic acids also have been noted to aid in reducing the risk of coronary heart disease by lowering blood cholesterol concentration (Zock and Katan, 1998). McGuire and McGuire (2000) observed that a specific CLA isomer (10t, 12c) decreases lipogenesis, thus impeding obesity. Other fatty acids, such as myristic acid, can be harmful to humans if consumed in excess due to the potential to raise cholesterol levels. Hegsted et al. (1965) noted that myristic acid is suspected to be the fatty acid most associated with elevation of cholesterol. Evaluating fatty acid profiles in meat are important due to the influence of diets on fatty acid composition. Rule et al. (1994) and Mandell et al. (1997) noted that fatty acid composition of bovine tissue can be influenced by dietary regimen. However, due to extensive biohydrogenation by rumen microorganisms, fatty acid composition alteration is difficult by dietary manipulation (Demeyer and Doreau, 1999). LaBrune et al. (2008) evaluated samples from cattle fed SFC and DRC and noted no significant differences in fatty acid profiles. This suggests that processed grains do not create enough difference in fatty acids to maintain that effect when passed through the rumen and acted upon by the rumen microflora.

Overall, most research comparing differing grain processing types, specifically SFC and DRC, has been on the effects on feedlot performance and carcass characteristics, while little has been completed on meat attributes and fatty acid composition.

Ethanol Production

Ethanol production has been around for over a century, as it was first introduced in the United States in the 1900s (Bothast and Schlicher, 2005). It was Henry Ford's idea to produce ethanol from corn to produce a fuel that would be both affordable to the rural population and would boost the rural farm economy (Kovarik, 1998). Ethanol was used as fuel until World War

II, when fuel from petroleum and natural gas became less expensive and more readily available. It was not until additional Federal and State incentives arrived in the 1970's that ethanol made a comeback to aid in the oil supply disruptions in the Middle East (Hunt, 1981). Disruptions in oil supplies have continued in recent years as prices of crude oil in the Middle East have continued to increase, while an emphasis on clean air has also been applied due to the Clean Air Act Amendments by Congress in 1990 (Bothast and Schlicher, 2005). Ethanol production has not only decreased the need for foreign oil, but has increased corn production, and prices in the process. According to the Renewable Fuels Association (2009), ethanol production utilized starch from 81.5 billion kg of corn in 2008 to produce 12.3 million kg of livestock feed and 34.2 billion liters of ethanol. Almost 8 kg of distiller's grains can be produced from 25.5 kg of corn. Production of distiller's grains has increased dramatically over the past decade (Figure 1-1), continually climbing each year.

Ethanol is produced by a dry grind or wet mill process, yielding 10.6 and 9.5 liters of ethanol per 25.5 kg of corn, respectively. In 2005, dry grind accounts for 67% and wet mill for 33% of ethanol production (Bothast and Schlicher, 2005). Distiller's grains are a product of the dry grind process, while corn gluten feed is derived from the wet mill process (Figure 1-2; Bothast and Schlicher, 2005).

Production of Dried Distiller's Grains from Ethanol

The following was adapted from Bothast and Schlicher (2005), who describes the process of dry grind milling to make dried distiller's grains. The corn is first cleaned, then ground, and mixed with water to form a mash. The mash is then cooked and enzymes are added to convert the starch to sugar. To ferment the sugars, yeast is added, and allowed to ferment for 40 to 50 h, producing a mixture containing ethanol and solids, which are then distilled and dehydrated to produce ethanol. Thin stillage is the liquid that is removed from the mash and is also referred to as "sweet water". The resulting thin stillage can be fed directly to livestock or dehydrated to make condensed distiller's solubles (CDS). After distillation, the remaining solids can be left in wet form, as wet distiller's grains (WDG) or dried to produce dried distiller's grains (DDG). Either form can then be sold as animal feed. Additionally, CDS can be mixed with dried or wet distiller's grains to produce dried distiller's grains with solubles (DDGS) and wet distiller's grains with solubles (WDGS), respectively.

Nutrient Content of Dried Distiller's Grains

Recently, DDG have become a popular feed choice due to rising corn prices and increased availability. However, an important consideration when feeding DDG is the variation in nutritional content. Variability in nutritional composition of DDG is due to variation in the process of making ethanol. Chase (1991) observed variability in nutrient content in DDGS as follows: 22 to 33% CP, 29 to 64% NDF, and 2 to 20% ether extract. Differences in nutrient content can be observed within the same plant and between different plants. Ten ethanol production plants in Minnesota and South Dakota were evaluated for nutrient content of DDGS by Spiehs et al. (2002). Samples were collected every two months form 1997 to 1999. They observed the following averages and coefficients of variation: 88.9% DM with CV of 1.7%; 30.2% CP with CV of 6.4%; 10.9% ether extract with CV of 7.8%; 8.8% crude fiber with CV of 8.7%; 5.8% ash with CV of 14.7%; 42.1% NDF with CV of 14.3%; 0.06% Ca with CV of 57.2%; and 0.89% P with CV of 11.7%. Research from both Chase (1991) and Spiehs et al. (2002) suggests that there is a large amount of variation in the nutritional content of distiller's grains between plants. Linn and Chase (1996) found that the major factors of variability are due to the type of grain, milling processes, grain quality, fermentation processes, drying temperatures, and proportion of solubles blended back into the unfermented fraction at the time of drying. Analyses of distiller's grains from different sources or different loads may be necessary to insure proper nutrient content of diets fed to cattle.

Dried distiller's grains are low in starch due to its removal during the fermentation process, increasing the concentration of the other nutrients (Linn and Chase, 1996). Protein, fat, fiber, and phosphorus concentrations are increased 3-fold in distiller's grains when compared to corn (Klopfenstein et al., 2008). According to the NRC (1996), DDG contain 10-15% ether extract, 40-45% NDF, 30-35% CP, and 5% ash. Distiller's grains with solubles, when compared to distiller's grains, have higher levels of phosphorus, and slight increases in protein and fat content due to the solubles (Schingoethe, 2006).

Protein concentrations in distiller's grains typically are three times that of corn. However, due to fermentation during ethanol production, the protein remaining in distiller's grains is mostly ruminal undegradable protein (RUP). Readily degradable protein is utilized during the fermentation process, predominately leaving ruminal undegradable protein in distiller's grains than in the original corn. Protein becomes unavailable due to the chemical "browning reaction"

known as Maillard reaction that occurs when protein is exposed to reducing sugars and high temperatures for a prolonged period. This is especially true for dried distiller's grains because of the additional drying step during the process. Researchers have noted varying levels of RUP in corn-based DDGS: Powers et al. (1995), reported 45% RUP; and Grings et al. (1992) reported 55% RUP. Additionally Stern et al. (1995) evaluated five samples of distiller's grains and observed RUP to be 56 ± 8%. The NRC (1996) stated that RUP of corn DDGS was 52% of the CP. Variation in RUP are due to differences in production processes or production plant.

Distiller's grains can present potential problems when feeding due to low levels of Ca, and high values of P and S (Tjardes and Wright, 2002). Excessive P is not a nutritional concern for feedlot cattle however, Ca:P ratios must be equal to or greater than 1.2:1, but not greater than 7:1 (NRC, 1996). Proper Ca:P ratios are needed to facilitate adequate performance and avoid urinary calculi (Tjardes and Wright, 2002). However, feeding excessive P could cause trouble when using manure for fertilizer, creating a nutritional waste problem. Klopfenstein et al. (2008) suggested that elevated S levels of 0.6% to 1.0% are a result of the sulfuric acid that is used to clean fermentation equipment and control pH during ethanol production. Sulfur is required by microorganisms, but at high dietary levels (above 0.4% of DM), it may cause polioencephalomalacia. High dietary levels may also result in decreased DMI, lower ADG, and lower liver Cu stores (Loneragan et al., 2001). The decrease in Cu stores is due to the fact that S interferes with Cu absorption and metabolism (Tjardes and Wright, 2002).

Feeding distiller's grains may be an inexpensive alternative to feeding corn, due to availability, and cost competitiveness. However, consideration must be taken of critical macromineral issues, feeding level, and accompanying grain type and/or method of grain processing.

Effects of Distiller's Grains on Feedlot Performance

Feeding distiller's grains in recent years has increased, and much research has evaluated distiller's grain interaction with grain processing types as well as levels of distiller's grains in SFC and DRC diets. Klopfenstein et al. (2008) suggested that there was an apparent interaction between levels of distiller's grains and type of grain processing applied.

Distiller's Grains Fed in Combination with Grains Processed by Different Methods

With differences in grain processing methods used across the U.S., differences in feeding values of distiller's grains have been observed. Vander Pol et al. (2009) fed DRC-based diets with and without wet distiller's grains and observed that digestibility was similar between treatments. On the other hand, Klopfenstein et al. (2008) observed that feeding DDGS in SFC-based diets decreased feeding value of DDGS. Uwituze et al. (2008b) suggested that decreased performance when replacing SFC with DDGS may be due to lower ruminal pH that is characteristic of cattle fed SFC. The authors suggested that the lower ruminal pH could decrease digestibility of DDGS. With lower ruminal pH in cattle fed SFC, digestion may be altered due to the effect of low ruminal pH on microorganisms. Matras et al. (1991) suggested that the activity of ruminal microorganisms and diet utilization depend on ruminal pH, quantity, degradability, and quality of energy and protein sources. Lower ruminal pH found in SFC-fed cattle may hinder the digestion of distiller's grains in SFC-based diets because of the high NDF content of distiller's grains. Uwituze (2008a) observed that in SFC-based diets, percentage of fiber (NDF) digested was similar for diets with and without DDGS. However, they also observed that cattle fed diets with DDGS had greater NDF intakes and NDF excretion than cattle fed no DDGS. The authors fed DDGS at 25% of diet DM and observed that feeding DDGS resulted in lower digestion of DM and OM compared to diets without DDGS. They suggested that the decrease in digestion of DM and OM was a result of the greater NDF intake, depression in digestion of CP, and poorer starch digestion when DDGS replaced a portion of SFC and urea. They also noted that ruminal ammonia concentrations were lower in cattle fed diets with 25% DDGS compared to diets without DDGS.

Uwituze (2008a) noted that diets with DDGS had lower DIP content when compared to diets with no DDGS. Lower DIP content is possibly due to the degradation of protein within DDGS during the ethanol production process. Klopfenstein et al. (2008) suggested that much of the protein in distiller's solubles is yeast cells, which have been heated during distillation and concentration. After 26 h of fermentation, yeast concentrations often reach 150 million cells per cubic centimeter in the mash (Hatch, 1995). Bruning and Yokoyama (1988) noted that yeast that has been subjected to heat is denatured which renders the distiller's solubles resistant to microbial degradation and lysis. Condensed distiller's solubles from wet milling are thought to be 20% degradable within the rumen (Herold, 1999). Nitrogen availability is limited when

portions of SFC are replaced by DDGS and urea. Limiting nitrogen availability may result in suboptimal rumen microbial activity leading to possible decreases in digestibility. Besides altering digestion, lower ruminal pH could decrease microbial activity, specifically proteolytic bacteria. Proteolysis is thought to be a rate-limiting step and key in controlling protein degradation (Nuget and Mangan, 1981). Bach et al. (2005) determined that the optimal ruminal pH for proteolytic enzymes varies between 5.5 and 7.0. With ruminal pH a level being below 5.5 in SFC-fed cattle, it is likely that protein digestion is decreased. When distiller's grains are fed in SFC-based diets, ruminal availability of protein might be the limiting factor for bacteria growth and subsequent fermentation.

As mentioned above, distiller's grains are high in fiber. Uwituze (2008a) noted that percentage of NDF digested was similar when feeding SFC-based diets with and without DDGS, however NDF intake and excretion was increased for diets containing DDGS. They observed that the increase in NDF in the diets due to DDGS, decreased apparent total tract digestibility of starch. Besides altering activity of proteolytic bacteria, lower pH will also decrease activity of fibrolytic bacteria (Russell and Wilson, 1996). The optimal ruminal pH range for fibrolytic bacteria is usually between 6.0 and 6.5 (Huang et al., 1988; McGavin and Forsberg, 1988; McGavin et al., 1989). Ruminal pH is typically below 6 in finishing cattle fed SFC (Zinn, 1990; Zinn et al., 1995; Sindt et al., 2006). Decreased microbial activity would suggest that addition of distiller's grains to SFC diets would result in decreased digestibility. Uwituze (2008a) fed SFC-based diets with DDGS and noted that the apparent total tract digestibility of OM was lower in cattle fed DDGS. They suggested that this was likely due to the low ruminal pH (< 5.5) observed in all treatment groups more than 12 h after feeding. The digestion of distiller's grains may be altered when feeding SFC, and potentially hinder cattle performance.

Contrary to the proposed idea that increasing fiber content in the rumen would increase pH, May et al. (2007b) observed a lower ruminal pH when feeding 25% DDGS in SFC-based diets compared to diets without DDGS. Corrigan et al. (2008) also showed a similar result when feeding 40% wet distiller's grains with solubles (WDGS) in diets with DRC, HMC or SFC, as cattle had a lower ruminal pH when fed WDGS compared to the control without WDGS. The observed decrease in pH when feeding distiller's grains is contradictory to the presumption that distiller's grains should increase pH. Klopfenstein et al. (2008) proposed that, when feeding distiller's grains, ruminal pH should increase due to the increased fiber, and decrease starch

content. Bhatti and Firkins (1995) suggested that this may be due to the lack of physical effective fiber to stimulate the rumen because of the small particle size of distiller's grains. Lack of fiber effect may explain the low ruminal pH that is observed when feeding distiller's grains. However, feeding SFC increases the amount of more rapidly fermentable carbohydrates that are available, allowing rapidly growing microbes that can handle a high percentage of carbohydrates to grow at a pH lower than where fiber digestion is optimized. Vander Pol et al. (2008) evaluated the use of 30% WDGS in diets containing SFC, DRC, and HMC. They observed that, when comparing SFC- and DRC-based diets containing 30% WDGS, DRC increased DMI, ADG, HCW, 12th rib fat thickness, and marbling score. Corrigan et al. (2007) conducted a similar study to evaluate SFC, DRC, and HMC with varying levels of WDGS (0, 15, 27.5, and 40% DM). They observed that, when WDGS was added to DRC-based diets, cattle had increased G:F; however, the same addition of WDGS to SFC diets resulted in no change in G:F. Corrigan et al. (2007) observed that WDGS had 34% greater feeding value than DRC across all levels of WDGS. They concluded that there was an interaction between grain type and level of WDGS but did not offer possible mechanisms for these differences. However, May et al. (2007b) observed that feeding 25% DDGS in SFC- or DRC-based diets had no deleterious effects on cattle performance. May (2007a) also noted that wet distiller's grains can replace a portion of the corn in finishing diets, but their nutritional value is greater in DRC diets compared to SFC diets. Cole et al. (2006) suggested that the lack of improvement in performance and efficiency response to distiller's grains in SFC-based diets may be the result of cattle already performing at or near their genetic potential, so dietary changes have limited capacity to improve performance. They also suggested that cattle fed DRC-based diets have lowered ME intake, leaving an opportunity to improve performance. Overall, feeding distiller's grains in DRC-based finishing diets leads to more efficient cattle.

Levels of Distiller's Grains in Feedlot Diets

Optimal level of distiller's grains depends on the grain type and degree of processing. Vander Pol (2006) evaluated levels of 0, 10, 20, 30, 40, and 50% WDGS in finishing diets replacing a portion of the corn. They observed a quadratic response in ADG and G:F in response to WDGS level with the optimal level being at 20%. They observed feed efficiency was greater for all levels of WDGS compared to the control corn diet. A similar trend was shown with

DDGS as Buckner (2008) observed a quadratic response in G:F when cattle were fed levels of 0, 10, 20, 30, and 40% DDGS compared to a corn control. Daubert et al. (2005) evaluated levels of WDGS (0, 8, 16, 24, 32, and 40%) in SFC-based diets fed to feedlot heifers. They found that DMI decreased linearly with the addition of WDGS, while ADG and G:F improved quadratically, peaking at 8 and 16% WDGS, respectively. A meta-analysis completed by Klopfenstein et al. (2008) showed a quadratic response in ADG and a cubic response in G:F as level of DDGS in diet increased from 0 to 40%. They noted that the maximum ADG was between 20 and 30% and maximum G:F was observed between 10 and 20% DDGS. Klopfenstein et al. (2008) also evaluated the differences between WDGS and DDGS and observed that inclusion levels for maximum ADG and G:F was lower for DDGS than for WDGS.

Carcass Characteristics of Cattle Fed Distiller's Grains

Not only do distiller's grains affect feedlot performance, but they also alter carcass characteristics. Carcass characteristics are directly related to how well an animal performs and, like performance, they are determining factors in profitability. May (2007a) observed that feeding 25% DDGS of diet DM increased dressing percentage compared to cattle fed 0% DDGS. Depenbusch et al. (2008) observed decreases in HCW and LM area when cattle were fed 25% WDGS in SFC-based diets. Daubert et al. (2005) evaluated levels of WDGS (0, 8, 16, 24, 32, and 40%), and observed that LM area decreased linearly, while yield grade increased linearly. When feeding varying levels of WDGS (0, 15, 27.5, and 40%) in finishing diets, Corrigan et al. (2007) observed that HCW and 12th rib fat thickness responded quadratically to inclusion of WDGS. Al-Suwaiegh et al. (2002) evaluated the effect of feeding corn or sorghum grain distiller's grains at 30% of the diet DM compared to DRC-based diets. They observed that the addition of distiller's grains to the diet increased HCW, 12th rib fat thickness, and yield grade compared to the control, but had no effect on marbling score. Daubert et al. (2005) found that increasing wet sorghum distiller's grains from 0 to 40% of the diet linearly increased yield grade and decreased marbling score. A meta-analysis using 21 individual feeding studies from 6 states to evaluate carcass fat distribution of feedlot cattle fed various levels of distiller's grains was completed by Reinhardt et al. (2007). They observed that feeding low levels of distiller's grains (16% and lower) increased marbling score; while high levels of distiller's grains (33% or higher)

depressed marbling score. Feeding moderate levels of distiller's grains (23%) resulted in high marbling scores yet more concerning was the change in overall body fatness (measured as yield grade), as it was even more dramatic than changes in marbling score in cattle fed distiller's grains. Distiller's grains typically increase HCW, but in spite of this LM area is decreased, 12th rib fat thickness, and yield grade are increased, producing heavier carcasses with more fat and less marbling.

Meat Quality of Cattle Fed Distiller's Grains

Distiller's grains, as suggested above, often will increase the amount of fat on the carcass, while potentially decreasing marbling at higher inclusion levels. If consumers have a poor opinion of meat or the appearance of the meat is undesirable to them, they simply may not make the purchase. Consumers are the market drivers in the beef industry.

Color is an important measure of a desirable meat product; however color can be altered by an increase in lipid oxidation (Mancini and Hunt, 2005). Depenbusch et al. (2009) observed no differences in lipid oxidation (thiobarbituric acid reactive substances; TBARS) when feeding six different levels of DDGS (0, 15, 30, 45, 60, and 75% DM basis). When they evaluated color, no differences where observed for a* or b* values. Observations by de Mello Junior et al. (2007) were in contrast, as they found that lipid oxidation was altered in the steaks from cattle fed WDGS, and they suggested that this would negatively affect shelf-life. The authors fed levels of WDGS (0, 15, and 30%) and observed that TBARS values were increased, whereas a* values were lower in steaks from cattle fed WDGS after a 3-d display. Gill et al. (2008) also observed that steaks from cattle fed distiller's grains had lower a* values, resulting in less red color, when compared to steaks from cattle fed no distiller's grains. Gill et al. (2008) also noted that steaks from cattle fed distiller's grains had greater L* and lower b* values than steaks from cattle fed SFC-based diets without distiller's grains. Roeber et al. (2005) noted that steaks from steers fed corn DDGS at 10% of the diet DM had greater a* values than cattle fed higher levels of DDGS in whole corn based diets. Koger et al. (2004) observed that steaks from cattle fed distiller's grains had greater a* values, compared to steaks from cattle fed cracked corn with no distiller's grains. Roeber et al. (2005) suggested that the potential explanation for higher a* values is due to the presence of xanthophylls, any of several neutral yellow to orange carotene pigments that are oxygen derivatives of carotene. Roberson et al. (2004) found that DDGS contain 30 mg/kg of

xanthophylls, and attributed increased a* values in egg yolk color (as the percentage of DDGS increased in the diet) to the presence of these pigments. Conflicting research (Koger et al., 2004; Roeber et al., 2005; Gill et al., 2008; Depenbusch et al., 2009) has been observed across both wet and dried distiller's grains, as well as within various levels.

Calculated values of color, hue angle, and saturation index refer to the perception of color rather than specific colors. Depenbusch et al. (2009) observed no significant differences in hue angle or saturation index when feeding diets with levels of DDGS (0, 15, 30, 45, 60, and 75% DM basis).

To prevent undesirable consumer experiences, research is needed to evaluate which attributes influence purchasing decisions. Roeber et al. (2005) observed that tenderness, juiciness, and flavor like/dislike scores were similar when comparing steaks from cattle fed diets with or without wet or dried distiller's grains. Depenbusch et al. (2009) observed similar results when feeding levels of DDGS (0, 15, 30, 45, 60, and 75% DM basis) in finishing diets. They observed that connective tissue amount, juiciness, flavor intensity, and off-flavor intensity were not different when comparing steaks from cattle fed DDGS compared to their counterparts fed the control diet without DDGS. Depenbusch et al. (2009) noted linear improvements in myofibrillar and overall tenderness in steaks from cattle fed levels of DDGS ranging from 0 to 75% of diet DM. Shand et al. (1998) evaluated steaks from cattle fed brewer's grains or wheat-based distiller's grains and observed no effects on sensory characteristics when compared to the control. Within sources of distiller's grains, differences were seen by Gill et al. (2008), as steaks from cattle fed corn distiller's grains diets were preferred over steaks from cattle fed sorghum distiller's grains. However, they observed no differences in juiciness or flavor of steaks fed with or without various levels of wet and dried distiller's grains.

Maintenance of flavor attributes such as beef flavor may be due to increased vitamin E content of distiller's grains. Koger et al. (2004) evaluated levels of both wet and dried distiller's grains (0, 20, and 40% of DM) and observed that feeding wet or dried distiller's grains increased vitamin E content of ground beef. Depenbusch et al. (2009) suggested that distiller's grains contain antioxidants that include alpha tocopherol (vitamin E). According to the NRC (1996), distiller's grains with solubles have 49.4 IU/kg of vitamin E. Arnold et al. (1993) fed steers additional vitamin E at levels of 0, 2,000 IU/d, 5.8 IU/kg live wt., and 8.6 IU/kg live wt. They observed that feeding vitamin E increased vitamin E content of the longissimus lumborum.

Higher levels of vitamin E in the muscle are desirable due to benefits in meat quality. Studies have been conducted that exhibited increased stability of color and lipids in beef from feeding cattle additional vitamin E supplement (Faustman et al., 1989; Arnold et al., 1992). Feeding distiller's grains may improve meat quality by preventing discoloration and lipid oxidation in meat.

Purge loss and cooking loss refer to the loss during wet aging and cooking, respectively. Shand et al. (1998) observed that purge loss during the aging process was similar for loin roasts from cattle fed wet distiller's grains compared to loin roasts from cattle fed no wet distiller's grains. Koger et al. (2004) observed that feeding wet or dried distiller's grains had a tendency to decrease weight loss during cooking. However, when Shand et al. (1998) evaluated loin roasts from cattle fed wet brewers grain or wet distiller's grains, there were no differences in cooking loss between treatments.

Besides meat quality, another important part of evaluating the effects of feeding distiller's grains is composition of the carcass. Feeding corn or sorghum distiller's grains in comparison to feeding no distiller's grains resulted in greater 12th rib fat thickness and higher yield grades for cattle fed distiller's grains (Al-Suwaiegh et al., 2002). Daubert et al. (2005) observed that feeding increasing levels of wet distiller's grains with solubles from 0 to 40% linearly increased USDA yield grade, while also decreasing marbling score linearly. These observations suggest that carcasses from cattle fed distiller's grains may be fatter, resulting in more trimming and less usable product.

Another possible implication of altering fat content of the diet is the potential to influence the fatty acid profile of beef. Evaluating the content of fatty acids in the meat is important, as diets can be influential on the composition of fatty acids. de Mello Jr. et al. (2007) noted that diet had no effect on concentrations of total saturated fatty acids. Lower levels of saturated fatty acids in meat could potentially decrease cholesterol concentration in the body. In contrast, Shand et al. (1998) observed that beef from cattle fed wet distiller's grains tended to have higher concentrations of total saturated fatty acids. Lancaster et al. (2007) fed 16% DDGS and observed that steaks from cattle fed DDGS had higher concentrations of oleic and palmitic acids. The authors suggested that increases in these fatty acids were due to elevated concentrations of total fatty acids in the diet compared to the control (76.8 and 54.3 mg/g DM, respectively). When evaluating the effect of feeding cattle distiller's grains on fatty acid profiles, Gill et al. (2008)

observed no differences in lauric, myristic, or palmitic acid concentrations in steaks from cattle fed diets with distiller's grains compared to diets without distiller's grains. Koger et al. (2004) observed that feeding distiller's grains increased stearic acid content of steaks, while decreasing margaric acid. The authors noted that the total concentration of saturated fatty acids was not different in beef from cattle fed diets with or without distiller's grains. Conflicting results have been shown in the various saturated fatty acids (Shand et al., 1998; Koger et al., 2004; de Mello Jr. et al., 2007; Lancaster et al., 2007; Gill et al., 2008).

Conflicting results have been observed with respect to effects of feeding distiller's grains on unsaturated fatty acid content of beef. Gill et al. (2008) found that steaks from cattle fed distiller's grains had higher concentrations of CLA 10-trans 12-cis when compared to steaks from cattle fed SFC, however differences were of little biological importance. Koger et al. (2004) found that steaks from cattle fed distiller's grains increased CLA 9-cis 12-cis compared to the corn-based control. de Mello Jr. et al. (2007) also noted that CLA concentration was increased when feeding WDGS compared to the control.

In a review of fatty acids and their effects on meat quality, Wood et al. (2003) noted that the ratio of unsaturated fatty acids to saturated fatty acids is important to human health, as saturated fatty acids have been linked to cancer and coronary heart disease. de Mello Jr. et al. (2007) noted no effect on total concentrations of unsaturated fatty acids; but they observed increased levels of polyunsaturated fatty acids (PUFA) when feeding WDGS compared to no WDGS. Koger et al. (2004) observed that steaks from cattle fed wet or dried distiller's grains had increased concentrations of PUFA in relation to the cracked corn control. As PUFA concentrations increase, meat quality decreases due to propensity for oxidation of PUFA. Wood et al. (2003) noted that the oxidation of unsaturated fatty acids (including polyunsaturated fatty acids) leads to the development of rancidity. The authors also noted that rancidity is due to the production of lipid oxidation products. This suggests that higher levels of unsaturated fatty acids should be avoided, to avoid development of rancid flavors in meat.

Conclusion

As the fuel ethanol industry continues to expand, the use of corn grains in cattle diets is likely to decrease due to demand for corn use in ethanol production, and the use of distiller's grains is likely to increase due to greater availability and lower relative price. To optimize

performance and maintain meat quality, it is suggested that distiller's grains be fed at slightly higher levels for wet distiller's grains (20 to 30%) than dried distiller's grains (10 to 20%). Feeding distiller's grains in conjunction with grain processed by different methods yields variable results on performance, carcass characteristics, and meat quality. Further research is needed to evaluate how various combinations of wet and dried distiller's grains with processed grains affect meat quality attributes and carcass composition.

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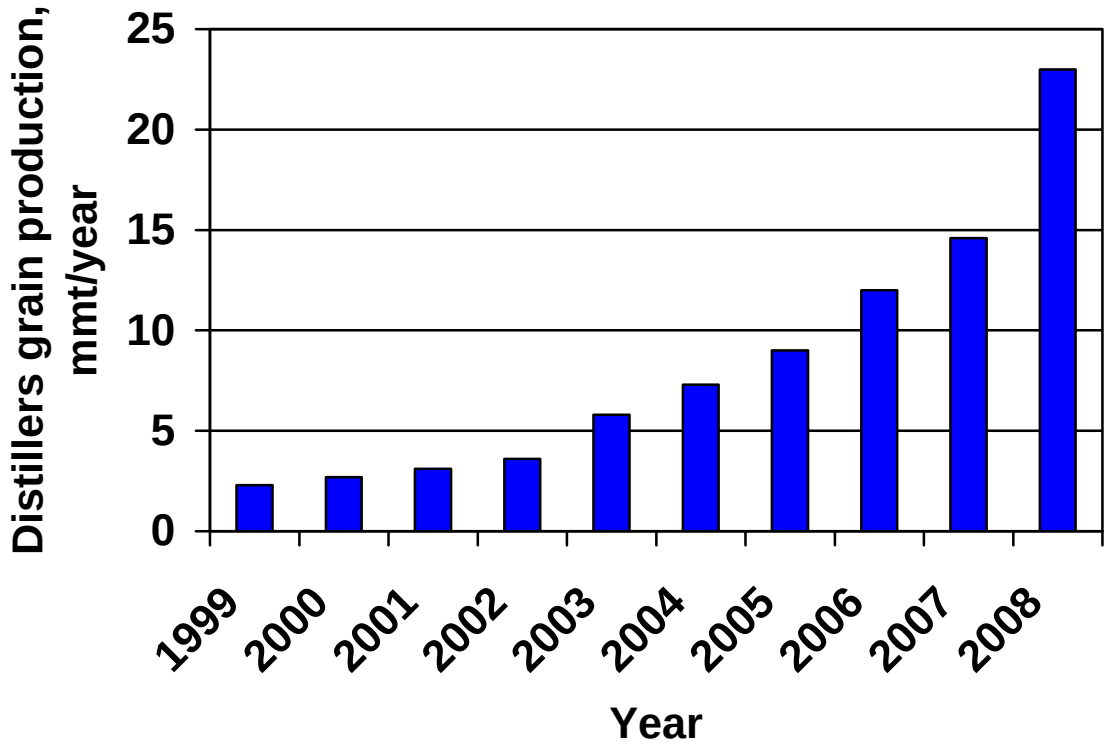
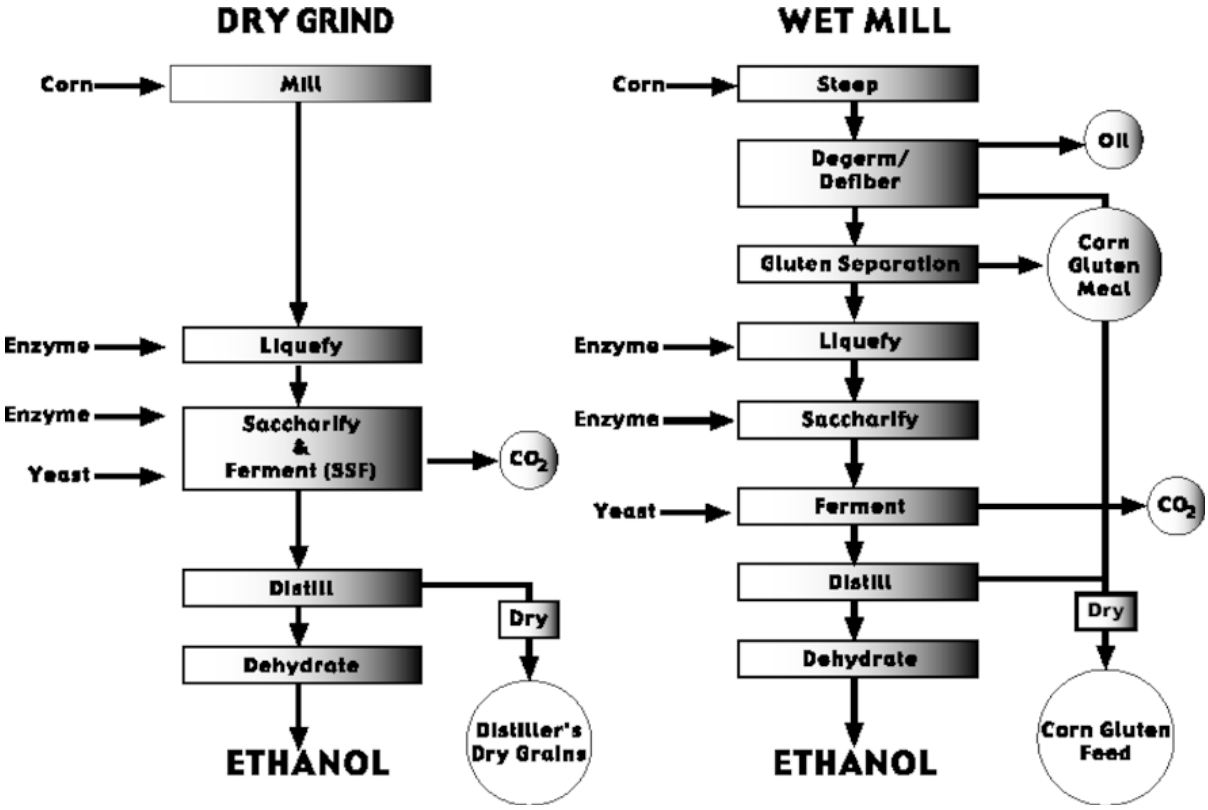
Figure 1-1 Distiller's grain production over the past decade



Source: Renewable Fuels Association, www.ethanolrfa.com

Figure 1-2 Dry and wet milling ethanol production processes



Source: Bothast and Schlicher, 2005

CHAPTER 2 - Combinations of steam-flaked corn, dry-rolled corn, and corn dried distiller's grains with solubles in diets fed to feedlot heifers

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Abstract

Seven hundred crossbred yearling heifers (302 ± 65 kg initial BW) were used in a randomized complete block experiment with a 2 × 2 factorial arrangement of treatments. Finishing diets were based on steam-flaked corn (SFC) with factors consisting of levels of dry-rolled corn (DRC; 0 or 25%) and dried corn distiller's grains with solubles (DDGS; 0 or 25%). In diets containing DRC or DDGS, these ingredients replaced portions of SFC. Diets without DDGS also included urea as a rumen degradable N source. Heifers were individually weighed and blocked into heavy and light weight groups. Heifers were assigned randomly to pens containing 25 animals each, with 7 pens per treatment. Heifers were fed once daily ad libitum for 137 or 157 d for heavy and light weight groups, respectively. Cattle were harvested according to weight block; value per kg and total carcass value were calculated by abattoir after harvest. On a live basis, cattle fed DDGS had greater ADG and improved G:F ($P < 0.05$), and cattle fed DRC had improved G:F ($P < 0.05$) compared to cattle fed diets without DRC. On a carcass-adjusted basis, ADG, DMI, and feed efficiency were not different among treatment groups ($P > 0.05$). Heifers fed DRC had greater dressing percentages ($P < 0.05$) compared to heifers fed no DRC. Cattle fed DDGS tended to have a greater dressing percentages ($P < 0.10$) compared to their counterparts fed no DDGS. There were no differences among treatments with respect to HCW, quality grade, 12th rib fat thickness, KPH, or total carcass value. An interaction between DRC and DDGS as observed for the percentage of yield grade 1 carcasses, but no differences were found for average yield grade. Heifers fed DRC tended to have larger LM areas ($P < 0.10$) compared to cattle fed diets without DRC. Cattle fed diets without DRC yielded carcasses that tended ($P < 0.10$) to have higher value per kg. An interaction was observed between DRC and DDGS, as cattle fed combination DDGS and DRC had decreased incidence of A^- liver abscesses ($P < 0.10$), but no differences were observed for A^0 or A^+. Partial replacement of SFC with DRC or DDGS can yield acceptable feedlot performance with no deleterious effects on carcass quality.

Introduction

U.S. ethanol production for 2007 was estimated at nearly 25 billion liters, a 33% increase from 2006. Twenty-three new ethanol plants started production during 2007, adding more than 7 billion liters of annual capacity (Urbanchuk, 2008). Ethanol production is at an all-time high and ethanol plants used over 58.5 billion kg of corn in 2007, or 18% of the total domestic corn crop (Renewable Fuels Association, 2008). As more of the domestic corn crop is used for ethanol production, the availability of ethanol by-products increases, creating feed resources such as distiller's grains. Just over 25.5 kg of corn can produce almost 8 kg of distiller's grains and 10.6 liters of ethanol (Renewable Fuels Association, 2008). According to the Renewable Fuels Association (2008), ethanol biorefineries produced approximately 14.6 million metric tons of distiller's grains. Distiller's grains are well-suited as a substitute for cereal grains in finishing cattle diets. Responses to distiller's grains have been variable, owing to differences in grain processing. May et al. (2007) noted that wet distiller's grains can replace a portion of the corn in finishing diets, but their nutritional value is greater in diets containing dry-rolled corn (DRC) diets compared to diets containing steam-flaked corn (SFC). This may be due in part, to the variation in ruminal parameters, specifically pH, when SFC is fed compared to DRC. Zinn et al. (1995) compared DRC and SFC and noted that ruminal pH was higher for cattle fed DRC than SFC (6.07 and 5.67, for DRC and SFC, respectively). This led us to hypothesize that low ruminal pH may impair digestion of distiller's grains when fed in conjunction with SFC. Replacing portions of SFC with DRC may increase ruminal pH and thereby improve performance. The objective of this study was to evaluate effects of replacing portions of SFC with DRC or dried distiller's grains with solubles (DDGS) on cattle performance and carcass characteristics.

Materials and Methods

All procedures for this finishing trial were approved by the Kansas State University Institutional Animal Care and Use Committee protocol number 2315. Seven hundred crossbred yearling heifers (302 ± 65 kg initial BW) were used in a randomized complete block experiment with a 2 × 2 factorial arrangement of treatments. All diets (Table 2-1) contained SFC, and treatments consisted of the levels of DRC (0 or 25%, DM basis) and DDGS (0 or 25%, DM basis). In diets containing DRC or DDGS, these ingredients replaced portions of the SFC. All

diets had a 6% level of ground alfalfa hay as the roughage source and were formulated to provide at least 14% CP, using corn steep liquor and urea as degradable nitrogen sources. No urea was included in diets containing DDGS.

Upon arrival at the feedlot, heifers were offered ad libitum access to chopped alfalfa hay and fresh water. After arrival, cattle were identified with uniquely numbered ear tags and vaccinated against viral and clostridial diseases with Bovi-Shield-4 and Fortress-7 vaccines (Pfizer Animal Health, Exton, PA). Also, heifers were treated with an endectocide (Phonenectin; VX Animal Health., St. Joseph, MO) and implanted with Revalor H (140 mg of trenbolone acetate + 14 mg of estradiol; Intervet Inc., Millsboro, DE). Heifers were also treated with Prostamate (Phoenix Scientific Inc., St. Joseph, MO) injections to eliminate pregnancies. During processing, cattle were individually weighed, blocked into light and heavy weight groups, and assigned randomly to the four treatments. Cattle were then sorted into assigned pens containing 25 animals per pen with seven replications per treatment for a total of 28 pens. Throughout the trial, 11 heifers were removed from the study for various reasons, all unrelated to treatment. Specifically, one heifer calved while on study, one heifer broke her leg, and the remaining heifers were removed due to foot abscesses or other forms of lameness. Statistical analyses for performance and carcass characteristics were completed using 689 head. Heifers were gradually transitioned to their final finishing diet (Table 2-1) by feeding a series of 4 step-up diets during the first 20 days on feed. Diets were fed once daily ad libitum. With each step up diet, alfalfa hay was decreased and concentrates (SFC, DRC, and DDGS) were incrementally increased. Feedlot pens provided 19.5 m^2 of pen surface area per animal, were equipped with fence-line feed bunks, providing 38 linear cm of bunk space per animal and had automatic water fountains. Pen weights were measured at the beginning of the study and immediately before cattle were shipped to a commercial abattoir.

At completion of the study, cattle were harvested by weight block, with the heavy weight group being shipped at 137 d and the light weight group at 157 d. Cattle were transported 182 km to a commercial abattoir in Emporia, KS, where they were harvested and carcass data were collected. The day of harvest, HCW and liver abscess scores were collected. Following a 24-h chill, KPH, LM area, and fat thickness over the 12th rib were measured. USDA meat graders determined quality grades, yield grades, and marbling scores. The commercial abattoir reported carcass weight, yield grade, quality grade with associated total carcass value of each harvested

animal, which was based on discounts and premiums. Final BW, ADG, and G:F were reported on live and carcass adjusted basis. Carcass adjusted data was calculated by diving carcass weight by a common dressed yield of 63.5%.

Statistical Analysis

The MIXED model procedure of SAS (Version 9.1, Cary, NC) was used to evaluate growth performance, carcass characteristics, and carcass value. The experimental unit was pen and fixed effects were level of DRC, level DDGS, and block, as well as interactions of DRC × DDGS. Values reported were calculated by using the LSMEANS procedure and separated by an F-test.

Results and Discussion

Finishing Performance

Animal performance data are summarized in Table 2-2. Substituting DRC or DDGS for SFC did not alter DMI appreciably ($P > 0.20$). When comparing cattle fed DRC and SFC on a live basis, cattle fed DRC had poorer feed efficiency ($P < 0.05$). Additionally, DDGS decreased both ADG and G:F in comparison to cattle fed no DDGS when expressed on a live weight basis ($P < 0.05$). However, no differences were observed when performance was compared on a carcass-adjusted basis, suggesting that live weight differences were due to differences in gut fill. Substitution of DRC or DDGS in the diet did not change carcass-adjusted ADG ($P > 0.15$) or carcass-adjusted feed efficiency ($P > 0.40$). Replacement of SFC with DRC or DDGS or a combination there of resulted in finishing performance comparable to that of cattle fed diets consisting principally of SFC.

Uwituze (2008) observed no differences in performance or carcass characteristics when feeding 25% DDGS in SFC-based diets. Klopfenstein et al. (2008) noted in a review of distiller's grains that the feeding value of DDGS decreased when fed in SFC-based finishing diets compared to DRC-based or high moisture corn (HMC)-based diets. Vasconcelos et al. (2007) observed a linear decrease in ADG and G:F when levels of sorghum wet distiller's grains (WDG; 0, 5, 10, and 15%) were fed in SFC-based diets. Uwituze et al. (2008) suggested that decreased performance when replacing SFC with DDGS may be due to low ruminal pH, which could decrease the digestibility of DDGS. Similarly, May et al. (2007) observed a lower ruminal pH

when feeding 25% DDGS in SFC diets compared to cattle fed diets without DDGS. Corrigan et al. (2008) observed that feeding 40% wet distiller's grains with solubles (WDGS) in diets with DRC, HMC, or SFC produced lower ruminal pH when compared to the control of no WDGS. The observed decrease in pH when feeding distiller's grains is contradictory to the presumption that distiller's grains should increase pH. Klopfenstein et al. (2008) speculated that, feeding distiller's grains should increase ruminal pH due to increased fiber levels and decreased starch content of distiller's grains. Bhatti and Firkins (1995) suggested that lower ruminal pH may be due to the lack of physically effective fiber to stimulate the rumen because of the small particle size of distiller's grains. Lack of fiber effect may explain the low ruminal pH that is observed when feeding distiller's grains, as larger fibrous particles would slow the rate of fermentation and acid production. We hypothesized that an interaction would be present between DRC and DDGS due to attenuation of ruminal pH with addition of DRC; however, there were no significant interactions with respect to feedlot performance. Conflicting research has been observed when feeding distiller's grains in finishing diets, which can be attributed to the use of different grains. Vander Pol et al. (2008) observed similar G:F for SFC- and DRC-fed cattle when 30% WDGS was included in the diet. Leibovich et al. (2009) found no differences in ADG for cattle fed DRC- or SFC-based diets with added sorghum WDGS. Previous research from Buckner (2008) showed a quadratic response in G:F when cattle were fed levels of 0, 10, 20, 30, and 40% DDGS compared to the corn control. Ham et al. (1994) showed that including of 40% WDGS in the diet improved feed efficiency when compared with feeding no WDGS. Improvements in cattle performance were observed when WDGS was added to DRC-based finishing diets (Ham et al., 1994; Firkins et al., 1985). Corrigan et al. (2008) conducted a study evaluating different grain processing types (SFC, DRC, and HMC) with varying levels of WDGS (0, 15, 27.5, and 40% DM) and observed that G:F was improved when WDGS were added to DRC-based diets, but the same addition of WDGS to SFC-based diets resulted in no improvement.

Carcass Characteristics

Carcass data are summarized in Tables 2-3, 2-4, and 2-5. Dressing percentages were greater for cattle fed DRC ($P < 0.05$) and tended to be greater for cattle fed DDGS ($P = 0.07$). Differences in dressing percentages are likely due to differences in gut fill. There were no

differences among treatments with respect to HCW, quality grade, yield grade, marbling score, 12th rib fat, KPH fat, or incidence of liver abscess. No interactions of DRC × DDGS were observed with the exception in liver abscess (A^- severity), as incidence was decreased and an increased percentage of cattle were classified as USDA yield grade 1 when both DRC and DDGS were fed. When comparing grain processing types, Leibovich et al. (2009) found that yield grade and fat thickness at the 12th rib were greater for steers fed SFC-based diets compared to steers fed DRC-based diets. In our trial, we observed that LM area tended to increase in cattle fed DRC ($P < 0.10$). Leibovich et al. (2009) also observed that LM area tended to be greater in cattle fed DRC-based diets in comparison to SFC-based diets.

May et al. (2007) observed that quality grade, marbling score, 12th rib fat, and KPH were not affected by addition of DDGS to diets containing DRC or SFC. Depenbusch et al. (2008b) found similar results in their study, as HCW, dressing percent, LM area, KPH fat, and 12th rib fat were similar to the SFC-based control diet when cattle were fed 13% distiller's grains with solubles. Depenbusch et al. (2008a) observed a decrease in both HCW and LM area when cattle were fed 25% WDGS in SFC-based diets. Using a different grain source, Ham et al. (1994) noted that 12th rib fat thicknesses, quality grades, yield grades, and liver abscess scores were comparable when feeding levels of ethanol by-products (0, 15, 25, or 40% DM) in DRC-based diets. LaBrune et al. (2008) observed that yield grade tended to be lower for steers fed DRC compared to steers fed SFC. Daubert et al. (2005) found that increasing sorghum WDGS from 0% to 40% linearly increased USDA yield grade while decreasing marbling score linearly. Changes in yield grade may be due to less ruminal escape of dietary starch (Owens and Gardner, 2000). Besides negatively affecting yield grade, lower levels of starch digestibility could affect marbling adipocytes deposition (Owens and Gardner, 2000; Pingel and Trenkle, 2006). Furthermore, research from Vander Pol et al. (2008) suggested that feeding combinations of flaked grains with distiller's by-products may be deleterious to marbling deposition and yield grades.

The value of carcasses is important to both feedlots and cattle owners, when cattle are marketed on a grid. After harvest, the abattoir provided us total value of each carcass. The sale value per kg reflected market prices including all premiums and discounts. Total carcass value was the sales value per kg multiplied by HCW. We observed a tendency ($P < 0.10$) for lower sale value per kg for cattle fed DRC, but this was compensated for by heavier carcass weights. The

addition of DDGS to the diet did not impact either sales value per kg or total carcass value ($P > 0.05$).

Conclusion

Overall, DDGS had little effect on feedlot performance or carcass characteristics. On the other hand, slight advantages in carcass characteristics were observed in cattle fed diets with DRC compared to cattle fed diets without DRC. Feeding SFC-based diets with 25% DRC or DDGS resulted in performance that was comparable to that of cattle fed diets with only SFC, indicating that these products can effectively substitute for part of the flaked corn in finishing diets.

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Table 2-1 Composition of steam-flaked corn (SFC) finishing diets with 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS)[1,2]

	SFC		SFC + 25% DRC	
Ingredient	0%DDGS	25%DDGS	0%DDGS	25%DDGS
SFC	82.1	58.2	56.8	33.1
DDGS	-	25.4	-	25.3
DRC	-	-	25.5	25.3
Alfalfa hay	5.9	5.9	5.9	5.8
Corn steep liquor	6.5	6.4	6.4	6.4
Urea	1.2	-	1.2	-
Supplement	4.3	4.1	4.2	4.1
Analyzed composition, %				
Dry matter	78.4	79.7	80.4	81.8
Crude protein	14.7	16.3	14.8	16.4
NDF	10.7	16.0	10.7	16.0
Calcium	0.7	0.7	0.7	0.7
Phosphorus	0.30	0.51	0.30	0.52
Potassium	0.7	0.7	0.7	0.7

[1]Formulated to provide 300 mg/d monensin (Elanco Animal Health, Greenfield, IN), 90 mg/d tylosin (Elanco Animal Health, Greenfield, IN), and 0.5 mg/d MGA (Pfizer Animal Health, Exton, PA), 2200 IU/kg added vitamin A, 22 IU/kg added vitamin E, 0.30% salt, 60 mg/kg Zn, 60 mg/kg Mn, 10 mg/kg I, 0.25 mg/kg Se, and 0.1 mg/kg Co.
[2]Optaflexx (Elanco Animal Health, Greenfield, IN) was included at 200 mg/animal daily for the final 42 days on feed.

Table 2-2 Performance of yearling heifers fed steam-flaked corn (SFC) diets with 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS)

	SFC		SFC + 25% DRC			*P*-values		
Item	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC×DDGS
No. of pens (heifers)	7 (172)	7 (172)	7 (172)	7 (173)	-	-	-	-
Live basis								
Initial BW, kg	307	307	307	307	6.6	0.97	0.98	0.98
Final BW, kg[1]	522	514	519	512	8.5	0.77	0.38	0.92
DMI, kg/d	8.42	8.57	8.67	8.74	0.173	0.23	0.55	0.83
ADG, kg	1.47	1.41	1.45	1.40	0.024	0.47	0.04	0.81
G:F	0.175	0.165	0.167	0.160	0.002	0.01	0.01	0.42
Carcass-adjusted basis[2]								
Final BW, kg	517	514	521	521	6.8	0.48	0.85	0.84
ADG, kg	1.44	1.42	1.46	1.46	0.022	0.15	0.65	0.67
G:F	0.171	0.166	0.168	0.167	0.004	0.91	0.43	0.58

[1]Weight after 4% pencil shrink
[2]Based on HCW divided by a common dressing percentage of 63.5%

Table 2-3 Carcass characteristics of yearling heifers fed steam-flaked corn (SFC) diets with 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS)

	SFC		SFC + 25% DRC			*P*-values		
Item	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC×DDGS
Dressing %	62.92	63.64	63.75	64.61	0.41	0.04	0.07	0.87
HCW, kg	329	327	331	331	1.9	0.12	0.65	0.66
LM area, cm^2	82.0	81.6	83.3	83.1	0.83	0.09	0.67	0.92
KPH, %	2.31	2.30	2.29	2.28	0.02	0.46	0.60	0.97
12th rib fat, cm	1.29	1.35	1.27	1.27	0.04	0.27	0.44	0.45
Liver abscess, %	2.9	2.9	4.0	2.9	1.35	0.67	0.66	0.66
Severity of abscess, %								
A^-	1.2	2.3	2.9	0.6	1.00	0.99	0.56	0.08
A^0	0.6	0.6	0	0	0.41	0.16	0.99	0.99
A^+	1.1	0	1.1	2.3	0.82	0.16	0.99	0.16

Table 2-4 Quality and yield grades of yearling heifers fed steam-flaked corn (SFC) diets with 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS)

	SFC		SFC + 25% DRC			*P*-values		
Item	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC×DDGS
USDA yield grade (YG)	2.7	2.8	2.8	2.7	0.07	0.79	0.98	0.18
YG 1, %	11.6	7.0	8.1	13.9	2.31	0.46	0.81	0.02
YG 2, %	26.3	29.3	30.4	26.7	3.46	0.82	0.92	0.34
YG 3,%	45.7	45.1	41.6	41.4	3.80	0.30	0.92	0.97
YG 4, %	14.5	16.2	16.8	15.0	2.73	0.83	0.98	0.52
YG 5, %	1.9	2.5	3.1	3.0	1.19	0.46	0.81	0.81
Marbling score[1]	492	493	499	485	5.8	0.97	0.27	0.22
USDA quality grade, %								
Prime	0	0.6	1.2	0	0.58	0.99	0.32	0.32
Premium Choice	11.4	10.3	8.0	7.4	2.16	0.14	0.68	0.89
Choice	43.2	41.4	47.8	39.5	3.79	0.72	0.18	0.38
Select	49.8	52.7	46.9	55.9	3.82	0.98	0.12	0.43
Standard	7.0	5.3	4.1	4.6	1.71	0.30	0.73	0.50
Sales value, $/kg	2.95	2.86	2.80	2.84	0.05	0.10	0.67	0.16
Total carcass value, $	935	932	948	935	8.5	0.33	0.36	0.60

[1]Marbling score: 400 = slight; 500 = small

CHAPTER 3 - Sensory attributes and shelf life of beef from cattle fed combinations of steam-flaked corn, dry-rolled corn, and corn dried distiller's grains with solubles[1]

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Abstract

Color shelf life, lipid oxidation, and sensory attributes of longissimus steaks were evaluated from crossbred heifers fed steam-flaked corn (**SFC**) finishing diets containing 0 or 25% dry-rolled corn (**DRC**), and 0 or 25% corn dried distiller's grains with solubles (**DDGS**) in a randomized complete block experiment with a 2 × 2 factorial arrangement of treatments. Meat for this study was collected from heifers used in a larger production experiment involving 700 animals. Within the large experiment, heifers were individually weighed and blocked into heavy and light groups. Within block, heifers were assigned randomly to pens containing 25 animals each; there were 7 pens per treatment. Heifers were fed once daily ad libitum, and the heavy and light weight blocks were harvested after 137 and 157 d, respectively. Four heifers were randomly selected from each of 24 pens (3 pens per treatment at each harvest point), and rib sections with plate attached were removed from the right side of each carcass following a 24-h chill. The 9th-10th-11th rib was removed from each rib section and separated into muscle, adipose, and skeletal tissue components. Separated muscle tissue from the 9th-10th-11th rib section was used to determine the content of vitamin E (alpha-tocopherol). Steaks (2.54 cm thick) were evaluated for purge loss during a 14-d aging period, color stability during a 7-d retail display period, lipid oxidation (thiobarbituric acid reactive substances; TBARS), weight loss during cooking, and heterocyclic amine formation. Sensory traits of initial tenderness, juiciness, chewiness, beef flavor identity, residual connective tissue, mealy texture, fiber awareness, bloody/serumy flavors, metallic flavors, and rancidity were evaluated by a 5-member professional profile panel using a point scale of 0 to 15. Steaks from cattle fed the different diets did not differ in color display attributes or TBARS ($P > 0.20$). Weight loss during cooking was less for steaks from heifers fed DRC compared with steaks from heifers fed diets without DRC ($P < 0.05$). Feeding DDGS decreased vitamin E content of muscle tissue ($P < 0.05$) compared to muscle from cattle fed diets without DDGS. Replacing portions of SFC with DRC or DDG had no effect ($P >0.10$) on sensory traits, lipid oxidation, or retail display color attributes.

Introduction

Ethanol production in the U. S. has increased rapidly during the past decade, and continued expansion is anticipated (Renewable Fuels Association, 2009). Increased production of ethanol leads to increased availability of distiller's grains. Research has shown that distiller's grains have different feeding values when added to diets containing steam-flaked corn (SFC) compared to diets containing dry-rolled corn (DRC). May et al. (2007) noted that ADG was greater in DRC diets compared to diets containing SFC when wet distiller's grains were included. We hypothesized that low ruminal pH may hinder digestion of distiller's grains fed in SFC-based diets. Zinn et al. (1995) compared DRC and SFC and noted that ruminal pH was higher for cattle fed DRC than SFC. May et al. (2007) observed that feeding 25% dried distiller's grains with solubles (DDGS) decreased ruminal pH compared to no DDGS. When evaluating carcass traits, yield grade increased linearly with a linear increase in inclusion rate of dried distiller's grains in the diet (Klopfenstein et al., 2008). This suggests that the addition of distiller's grains to the diet increases the fat content of the carcass. Roeber et al. (2005) conducted a study looking at the effects of DDGS on meat quality and observed no differences. Little other research has been done to characterize other meat attributes, such as propensity for lipid oxidation (TBARS), weight loss during cooking, heterocyclic amine formation during cooking, or vitamin E content of beef from cattle fed distiller's grains in combination with either SFC or DRC.

Materials and Methods

The animals used in this experiment were a randomly selected subset of a larger production trial. All procedures for the finishing trial were approved by the Kansas State University Institutional Animal Care and Use Committee protocol number 2315. Seven hundred crossbred yearling heifers (302 ± 65 kg initial BW) were acquired from sale barns in Kansas, Kentucky, and Oklahoma, and transported to the Kansas State University Beef Cattle Research Center in Manhattan, Kansas. The finishing trial was a randomized complete block design, with a 2 × 2 factorial arrangement of treatments. All diets contained SFC, and treatments consisted of the levels of DRC (0 or 25% of DM) and DDGS (0 or 25% of DM). In the diets containing DRC or DDGS, these ingredients replaced portions of the SFC.

Heifers were processed and blocked into light and heavy weight blocks, with 25 animals per pen and 7 pens per treatment. Cattle were fed a series of 4 step-up diets during the 20-d transition to their final finishing diets (Table 3-1). Cattle were fed ad libitum for 137 and 157-d for the heavy and light weight blocks, respectively. From 24 of 28 pens, 4 heifers per pen were randomly selected and placed in a separate harvest lot. Cattle were transported 182 km to a commercial abattoir in Emporia, KS for harvesting. Carcasses were followed through the harvest floor and identified individually. Following a 24-h chill, full rib sections (with plate attached) were obtained from the right side of the carcass for subsequent evaluation of sensory attributes, retail display life, and additional meat attributes. Two carcasses where subject to heavy trim loss during harvest, and ribs were not collected from these carcasses. Consequently, our analyses were limited to 94 carcasses. After removal of whole rib sections, they were transported to the Kansas State University Meats Laboratory in a refrigerated truck. Upon arrival, rib sections were placed in meat coolers to await processing 24 to 48 hr later. The 9th-10th-11th rib section was removed according to procedures described by Hankins and Howe (1946). The remaining 6th-7th-8th rib sections were weighed, packaged into vacuum bags (Cryovac Sealed Air Corporation, Duncun, SC), and wet aged for two wk. At the conclusion of the 2-wk aging process, samples were removed from the vacuum bags, patted dry with absorbent towels, and weighed to evaluate purge loss during storage. Following the measure of purge loss, longissimus steaks were cut from the 6th-7th-8th rib section and used for additional analyses.

From these samples, steaks (2.54 cm thick) were cut from the most posterior end and used to evaluate retail color stability during a 7-d simulated retail display. Steaks were placed cut side up on 17 S white foam trays (Dyne-A-Pak Inc., Laval, Quebec) with a Dri-Loc pad (Dri-Loc, Cryovac Sealed Air Corporation, Duncun, SC) and wrapped with PRV film (MAPAC M [23250 cc/m², 24 hrs, 72 gauge], Bordon Packaging and Industrial Products, North Andover, MA). Steaks were placed in a retail display case at a temperature of 3±1.6°C for 7 d. The display lighting consisted of 1614 ± 53.82 1x (45.72 ± 1.52 m candles) light intensity, 40 W Del Warm White 3000°K (Phillips Lighting Company, Somerset, NJ). Instrumental color was evaluated for CIE L*, a*, and b* values for illuminant A and reflectance from 400 to 700 nm at 10 nm increments with a Hunter Miniscan XE spectrophotometer (3.18 cm diameter aperture, 10° observer; Hunter Associates Laboratory, Reston, VA). On each d of evaluation, readings were taken from 3 locations on the longissimus muscle, being careful to avoid large fat depots.

Readings were averaged for statistical purposes. Steaks were rotated left to right and front to back of the display case twice daily.

Once the 7-d display period was complete, steaks were analyzed for lipid oxidation using a modified thiobarbituric acid reactive substances (TBARS) procedure (Witte, 1970). The steaks were chopped, frozen with liquid N_2, and pulverized to a powdery consistency in a Waring blender (Waring Products Division, Hartford, CT). Duplicate 10-g samples of the frozen pulverized sample were weighed into mini-Waring blender cups (100 mL capacity). Fifteen milliliters of 7.2% cold perchloric acid and 20 mL of cold distilled deionized water were added to precipitate protein and extract malonaldehyde from the sample. Samples were then blended for 15 s and gravity filtered through Whatman no. 2 filter paper (Whatman International LTD., Maidstone, UK). Five milliliters of 0.02 M thiobarbituric acid reagent solution (1.4415 g TBA and 500 mL deionized water) were then added to the filtrate and mixed. The resulting mixture was stored at 20°C for 18 to 24-h in complete darkness to allow the color reaction to develop, after which absorbance was measured at 530 nm on a spectrometer (Spectronic 21, Bausch & Lomb, Rochester, NY). The resulting values are reported as mg of malonaldehyde per kg of steak.

Steaks (2.54 cm thick) were cut (second) from the most posterior end of the 6th-7th-8th rib section to be used for sensory analyses, which were performed by the Sensory Analysis Center in the Department of Human Nutrition, Kansas State University, Manhattan, KS. For flavor profiling, steaks were thawed and cooked to an internal temperature of 71°C on an electric broiler and cut into 1.27 × 1.27 × 2.54 cm samples. The sensory steaks were evaluated for 10 attributes: initial tenderness, juiciness, chewiness, mealy texture, fiber awareness, residual connective tissue, beef flavor identity, bloody/serumy flavor, metallic flavor, and rancid flavor. Each steak was evaluated by a 5-member professional panel using a 0 to 15 point scale graded in increments of 0.5. Samples were presented to each panelist along with reference samples. Each attribute utilized a specific reference sample to establish baseline values of sensory attributes. These reference values are shown in Table 3-2. Using the reference sample, panelists determined a score for each steak. Higher values would be considered desirable for initial tenderness, juiciness, and beef flavor identity, whereas lower values would be desirable for chewiness, fiber awareness, residual connective tissue, mealy texture, bloody/serumy flavor, metallic flavor, and rancid flavor. Eight steaks were tasted and scored each day, with two steaks from each treatment.

Weight loss during cooking was measured from these same steaks by weighing the steaks before and after cooking.

Steaks (2.54 cm thick) cut from most posterior end (third cut) 6th-7th-8th rib section were evaluated for formation of heterocyclic amines (HCAs) during cooking. Formation of heterocyclic amines was achieved by cooking rib steaks on a Teflon covered electric grill with a temperature controller (Toastmaster, Denver, CO) at 204°C for 5 min per side. The temperature profile of the grill surface was measured with a surface probe thermometer (Barnant Company, Barrington, IL) prior to cooking steaks. Steaks were placed in the middle section of the grill each time to ensure they were cooked under similar conditions and at similar temperatures. Internal temperature profile of the steaks were monitored with a thermocouple (Barnant Company, Barrington, IL) placed diagonally into the center of the steak. After cooking, steaks were refrigerated until cooled. Approximately 2 mm of the surface was removed from chilled steaks using a commercial grade meat slicer. The surface material was ground using a Waring blender (Waring Products Division, Hartford, CT) and used for extraction of HCAs. Ground samples were stored frozen (-18°C) if not assayed immediately. Three grams of ground sample were homogenized in 12 mL 1 M NaOH, mixed thoroughly with EXtrelut NT refill material (Merck KGaA, Darmstadt, Germany), and loaded onto an empty EXtrelut column (Merck KGaA, Darmstadt, Germany). Bond elut propylsulfonic acid (PRS) tubes were coupled to the EXtrelut column and the HCAs were eluted to PRS with 60 mL ethyl acetate using a Supelco Visiprep solid phase extraction (SPE) vacuum manifold (Sigma Aldrich, St. Louis, MO). The PRS tubes were preconditioned with 7 mL ethyl acetate. The PRS was dried under a stream of nitrogen and rinsed with 6 mL 0.1 M HCl, 15 mL methanol/0.1 M HCl (45:55 vol/vol), and 2 mL distilled water. The PRS tubes were then coupled to 100 mg C-18 tubes that had been preconditioned with 1 mL methanol and 10 mL water. The HCAs were concentrated in C-18 tubes by passing 20 mL 0.5 M ammonium acetate (pH 8) through the PRS tubes. The C-18 tubes were then rinsed with 2 mL of distilled water and dried under a stream of nitrogen. The HCA were eluted from the C-18 tubes into 4 mL vials with 1 mL of methanol/ammonium hydroxide (9:1, vol/vol), concentrated until dry, and dissolved in 25 μL of methanol. The flow rate was 1 mL/min throughout extraction. The EXtrelut columns and refill material were obtained from VWR (West Chester, PA), and the PRS and C-18 tubes were obtained from Varian Inc (Palo Alto, CA). The final extract (25 μL) was analyzed on an HP1090A, series II HPLC (Agilent Technologies, Palo

Alto, CA) coupled with a photodiode array UV-visible detector (HP 1040) and an HP 1046A programmable fluorescence detector. The column used was TSK gel ODS-80 TM column (25 cm × 4.6 mm × 5 μm, Tosohass, Montgomeryville, PA) with a mobile phase of 0.01 M triethylamine pH 3.6 (A), and acetonitrile (B). The HCAs were separated with a linear gradient starting with 95% A, 5% B, change to 75% A, 25% B in 30 min, flow rate of 1 mL/min at a column temperature of 40°C. After 30 min, the mobile phase returned to its original ratio (95% A, 5 % B) for 10 min to allow the column to re-equilibrate before the next injection. The UV detector was set at 252 nm for 2-amino-3-methylimidazo[4,5-f]quinoxaline (IQx) and 2-amino-3,8-dimethylimidazo[4,5-f]quinoxaline (MeIQx), whereas the fluorescence detector was programmed according to the excitation/emission wavelengths of 229 and 437 for 2-amino-1-methyl-6-phenylimidazo[4,5-b]pyridine (PhIP). The HCA were confirmed by comparing the retention times and the UV absorbance spectrum of each peak with retention times and library spectra acquired from standard solutions.

Samples of the muscle portion (100 g) from the separated 9th-10th-11th rib section were sent to DSM Nutritional Products (Parsippany, NJ) for determination of the concentration of the alcohol form of alpha tocopherol (vitamin E). Values were reported as mg alpha tocopherol per kg wet tissue.

Statistical Analysis

The MIXED model procedure of SAS (Version 9.1, Cary, NC) was used to evaluate meat attributes and sensory traits. The experimental unit was animal, and fixed effects included day, level of DRC or DDGS, block, as well as the interactions of DRC × DDGS, day × DRC, day × DDGS, and day × DRC × DDGS. Values are reported as least-squares means.

Results and Discussion

Loss of Weight During Storage (Purge Loss) and Cooking

Purge loss and cooking loss values are summarized in Table 3-4. Purge loss and shrink during cooking were unaffected by the use of distiller's grains in the diet ($P > 0.05$). In contrast to our findings, Koger et al. (2004) reported that cooking loss increased in steaks from cattle fed distiller's grains compared to cattle fed diets without distiller's grains. Purge loss also was

similar in diets with and without DRC ($P > 0.15$). However, we observed that addition of DRC to finishing diets decreased weight loss during cooking ($P < 0.05$).

Simulated Retail Display

Color attributes, L*, a*, and b*, hue angle, and saturation index values are shown in Tables 3-5, 3-6, and 3.7, respectively. As expected, an effect of day was observed for all color attributes ($P < 0.001$). No DRC × DDGS interactions were observed ($P > 0.20$) for L*, a*, b*, hue angle or saturation index values. No interactions of day × DRC, day × DDGS, and day × DRC × DDGS were observed ($P > 0.05$). No effects of DRC or DDGS were observed for lightness (L*) and redness (a*) values ($P > 0.05$) across all days. However, for yellowness (b*) values, steaks from cattle fed DRC tended to have lower values for days 0, 1, 3, and 4 ($P < 0.10$). When evaluating the remaining days, DRC had no effect, DDGS had no effect on b* values over the 7-d display ($P > 0.05$). We also observed that DRC and DDGS had no effect on saturation index ($P > 0.05$). For hue angle, we observed a DRC effect as cattle fed DRC had lower values for days 0 to 4 ($P < 0.05$), and a tendency to decrease values for day 5 when compared to cattle fed no DRC ($P < 0.10$).

Gill et al. (2008) found that steaks from cattle fed SFC had lower L* (darker), greater a* (redder), and greater b* (more yellow) throughout the retail display period compared to steaks from animals fed a combination of SFC and distiller's grains. Koger et al. (2004) observed that steaks from cattle fed distiller's grains were redder (greater a* values) than steaks from cattle fed no distiller's grains. Conversely, Gill et al. (2008) observed that steaks from cattle fed distiller's grains had lower a* values (less red color) when compared with steaks from cattle fed no distiller's grains. Gill et al. (2008) also noted that steaks from cattle fed distiller's grains had greater L* and lower b* values than cattle fed no distiller's grains. In contrast to previous findings, Roeber et al. (2005) noted that steaks from steers fed corn DDGS at 10% of diet DM were redder (greater a* values) than cattle fed higher levels of DDGS. Roeber et al. (2005) also noted that the potential explanation for higher a* values may be due to the presence of xanthophylls. Xanthophylls are one of several carotenoid pigments that are neutral yellow to orange in color and are a result of oxygen derivation of carotenes. Roberson et al. (2004) found that corn dried distiller's grains contains 30 mg/kg of xanthophylls and attributed increasing a* values in chicken egg yolk color (as the percentage of DDGS increased in the diet) to the

presence of these xanthophylls. However, Depenbusch et al. (2009) found that a* and b* values were similar across all levels of DDGS (0, 15, 30, 45, 60, and 75%, DM basis).

In addition to measuring single color attributes, hue angle and saturation index were calculated. Hue angle is a measurement of true redness, and as hue angle decreases, redness is perceived to increase visually. Hue angle is calculated from a* and b* values [i.e., $(b^*/a^*)^{tan-1}$] and its measurement signifies the degree of departure from the true red axis. Cattle fed DDGS produced steaks that were comparable to those of cattle fed no DDGS with respect to hue angle ($P > 0.05$). Depenbusch et al. (2009) observed no significant differences in hue angle when feeding diets with levels of DDGS ranging from 0 to 75% of the diet. On the contrary, in our trial, there was a tendency for steaks from cattle fed DRC compared to no DRC to have lower hue angles ($P = 0.07$). Saturation index is a measure of the color vividness (higher values suggest a more vivid color) and is calculated using a* and b* values [i.e., $(a^{*2} + b^{*2})^{-1/2}$]. Substituting DRC or DDGS for portions of SFC resulted in steaks with comparable saturation indices over the 7-d display ($P < 0.27$).

Overall, feeding DDGS had no effect on retail display color attributes, suggesting that feeding DDGS is unlikely to alter consumers' opinions of color attributes. Steaks from cattle fed DRC did have minor differences in b* and hue angle, but these differences were small and are not likely of practical importance.

Thiobarbituric Acid Reactive Substances (TBARS)

Thiobarbituric acid reactive substance values are a measurement of the lipid oxidation that occurs within meat over time. Lipid oxidation can accelerate color change and form objectionable flavors in beef. Thiobarbituric acid reactive substance values are summarized in Table 3-4. There were no interactions of DRC × DDGS for TBARS values ($P > 0.05$). No main effects were observed in lipid oxidation for either DRC or DDGS ($P > 0.05$). Lipid oxidation is the primary reason for detection of off-flavors as it produces rancid flavors in meat. Rancidity develops with oxidation of unsaturated fatty acids of phospholipids (Tang et al., 2005). Depenbusch et al. (2009) also observed no differences in TBARS when feeding six different levels of DDGS (0, 15, 30, 45, 60, and 75% DM basis). Replacing portions of SFC with DDGS or DRC did not affect lipid oxidation values.

Sensory Attributes

Sensory attributes are summarized in Table 3-3. Feeding DDGS had no effect on tenderness, juiciness, chewiness, mealy texture, fiber awareness, or residual connective tissue ($P > 0.39$). Also, no differences were observed for beef flavor identity, bloody/serumy, metallic, or rancid flavors ($P > 0.43$). However, feeding DRC tended to yield steaks with greater chewiness ($P = 0.07$), decreased mealy texture ($P = 0.09$), decreased beef flavor identity ($P < 0.09$), and increased metallic flavor ($P = 0.08$) compared to steaks from cattle fed diets without DRC. An interaction was observed for effects of DRC × DDGS on beef flavor identity; steaks from cattle fed both DRC and DDGS had lower values ($P < 0.05$) compared to DRC and DDGS alone. The remaining attributes—tenderness, juiciness, fiber awareness, residual connective tissue, bloody/serumy flavors, and rancid flavors—were not different among diets containing DRC compared to cattle fed diets without DRC ($P > 0.05$). LaBrune et al. (2008) noted that overall tenderness, juiciness, and connective tissue amount were similar for diets containing DRC compared to the SFC control. Roeber et al. (2005) also revealed similar results for tenderness, juiciness, and flavor like/dislike scores in cattle fed diets with or without wet or dried distiller's grains. Depenbusch et al. (2009) noted that connective tissue amount, juiciness, flavor intensity, and off-flavor intensity were not different when comparing cattle fed levels of DDGS ranging from 0 to 75% of the diet DM. However, they did note a linear improvement in myofibrillar and overall tenderness in steaks when cattle were fed DDGS. Shand et al. (1998) evaluated steaks from cattle fed brewer's grains and wheat-based distiller's grains and documented no effects on sensory characteristics of steaks from cattle fed brewers grains or wheat-based distiller's grains. Gill et al. (2008) observed differences within sources of distiller's grains, as steaks from cattle fed corn distiller's grains diets were preferred over steaks from cattle fed sorghum distiller's grains. However, Gill et al. (2008) observed no differences in juiciness or flavor of steaks from cattle fed with or without various levels of wet and dried distiller's grains. In general, feeding DDGS had no effects on sensory attributes of LM steaks, whereas adding DRC to finishing diets resulted in minor differences.

Heterocyclic Amine Concentration

Heterocyclic amines (HCAs) are carcinogenic chemicals formed when amino acids and creatine react at high cooking temperatures. Heterocyclic amine concentrations are summarized

in Table 3-4. There were no significant DRC × DDGS interactions for formation of HCAs. Among treatments, there were no differences for the addition of DRC or DDGS ($P > 0.05$) to SFC-based diets. Production of HCAs are formed when intermediate products of Maillard reactions react with creatine (Abdulkarim, 1997). High cooking temperatures will increase the browning of meat, leading to increased Maillard reactions. Powrie et al. (1982) and Wie et al. (1981) postulated that the non-enzymatic browning reaction (Maillard reaction) plays an important role in the formation of HCAs. Research has shown that anti-oxidants, such as alpha tocopherol (vitamin E), act as free radical scavengers, thus stabilizing Maillard reaction intermediates, thereby decreasing formation of HCAs in ground beef patties (Chen et al., 1992; Johansson et al., 1995). Dried distiller's grains are higher in vitamin E content when compared to SFC or DRC, suggesting there is potential to increase vitamin E content of the meat. When evaluating the adipose content in meat and the relation to concentration of HCAs, Skog (1993) observed that ground beef patties with 8% adipose resulted in the lowest levels of HCAs compared to 15% adipose that resulted in the highest levels of HCAs. However, they also observed that levels of HCAs were slightly less when evaluating ground beef patties with 30% adipose content. Arnoldi et al. (1990) suggested that adipose acts to enhance the production of pyrazines in the Maillard reaction, which would lead to increases in HCAs formation. A measure of adipose content was not determined in the longissimus steaks utilized for HCAs concentrations. In our trial, feeding DRC or DDGS did not impact yield grades or marbling scores of animals, suggesting that adipose contents are similar and as a result did not increase the formation of HCAs.

Alpha Tocopherol Concentration

Alpha tocopherol (vitamin E) concentrations are summarized in Table 3-4. No interaction of DRC × DDGS was observed for vitamin E concentrations in muscle ($P > 0.55$). Muscle tissue from cattle fed DRC had vitamin E concentrations similar to beef from cattle fed diets without DRC ($P > 0.05$). Cattle fed DDGS yielded muscle tissue with lower vitamin E concentrations ($P < 0.05$) in comparison to the SFC-based control. This is in contrast to the observation of Koger et al. (2004), who found that cattle fed wet and dried distiller's grains had higher alpha tocopherol (vitamin E) concentrations in ground beef compared to cattle fed diets without distiller's grains. The authors fed wet and dried distiller's grains at 0, 20, and 40% of the diet DM, with the

addition of distiller's grains replacing portions of cracked corn and soybean meal. According to the NRC (1996), DDGS contains approximately 50 IU/kg vitamin E. Diets fed to cattle on our trial were analyzed for vitamin E content and contained 10.8, 16.15, and 17.85 IU/kg of alpha tocopherol in the alcohol form for SFC, DRC, and DDGS, respectively. In our study, it is conceivable that the drying of distiller's grains destroyed alpha tocopherol activity, resulting in lower alpha tocopherol content within the diet. Alternatively, it is possible that a greater proportion of alpha tocopherol was expended due to greater presence of free radicals. Unfortunately, Koger et al. (2004) did not present data on the concentrations of vitamin E in feedstuffs. Thus, it is hard to speculate the cause of differences between our trial and that of Koger et al. (2004).

Conclusion

Overall, meat quality was comparable across all treatments, as DRC and DDGS created few differences in meat attributes. DRC tended to negatively affect flavor and chewiness of steaks and increase cooking loss, but these differences likely would be too minor for most consumers to discern. Meat from cattle fed DDGS had decreased vitamin E concentrations in relation to the control, but resulted in no other discernible differences in meat quality. We conclude that DRC or DDGS can replace portions of SFC without negatively effecting sensory and shelf-life attributes of beef.

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Table 3-1 Composition of steam-flaked corn (SFC) finishing diets with 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS)[1,2]

	SFC		SFC + 25% DRC	
Ingredient	0%DDGS	25%DDGS	0%DDGS	25%DDGS
SFC	82.1	58.2	56.8	33.1
DDGS	-	25.4	-	25.3
DRC	-	-	25.5	25.3
Alfalfa hay	5.9	5.9	5.9	5.8
Corn steep liquor	6.5	6.4	6.4	6.4
Urea	1.2	-	1.2	-
Supplement	4.3	4.1	4.2	4.1
Analyzed composition, %				
Dry matter	78.4	79.7	80.4	81.8
Crude protein	14.7	16.3	14.8	16.4
NDF	10.7	16.0	10.7	16.0
Calcium	0.7	0.7	0.7	0.7
Phosphorus	0.30	0.51	0.30	0.52
Potassium	0.7	0.7	0.7	0.7

[1]Formulated to provide 300 mg/d monensin (Elanco Animal Health, Greenfield, IN), 90 mg/d tylosin (Elanco Animal Health, Greenfield, IN), and 0.5 mg/d MGA (Pfizer Animal Health, Exton, PA), 2200 IU/kg added vitamin A, 22 IU/kg added vitamin E, 0.30% salt, 60 mg/kg Zn, 60 mg/kg Mn, 10 mg/kg I, 0.25 mg/kg Se, and 0.1 mg/kg Co.
[2]Optaflexx (Elanco Animal Health, Greenfield, IN) was included at 200 mg/animal daily for the final 42 days on feed.

Table 3-2 Reference values for sensory attributes.

Sensory attribute	Reference sample	Base score for reference sample
Beef flavor ID	Dillon's brisket	12.0
Bloody/serumy	Dillon's strip steak 60 °C	5.5
Chewiness	Tyson boneless skinless chicken breast	7.5
Fiber awareness	Hillshire Farm Lit'l Beef Smokies	6.0
	Tyson boneless skinless chicken breast	7.5
Juiciness	Hormel Cure 81 Extra Lean Boneless ham	6.5
Mealy texture	Beef liver	10.0
Metallic flavor	0.10% Potassium chloride solution	1.5
	Dillon's Select strip steak	4.0
Rancid flavor	Crisco vegetable oil	7.0
Residual connective tissue	Grilled beef brisket	7.0
Tenderness	Hormel Cure 81 Extra Lean Boneless ham	12.0

Table 3-3 Sensory attributes of longissimus steaks from cattle fed steam flaked corn (SFC) diets containing 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS).

	SFC		SFC + 25% DRC			*P*-values		
Item[1]	0%DDGS	25%DDGS	0%DDGS	25%DDGS	SEM	DRC	DDGS	DRC×DDGS
Initial tenderness	10.26	9.96	9.84	10.15	0.197	0.56	0.98	0.14
Juiciness	4.66	4.70	4.63	4.93	0.196	0.62	0.39	0.52
Chewiness	9.10	9.23	9.39	9.27	0.084	0.07	0.97	0.15
Mealy texture	1.98	2.03	1.87	1.70	0.127	0.09	0.66	0.41
Fiber awareness	8.77	8.81	8.92	8.85	0.095	0.32	0.86	0.59
Residual connective tissue	2.37	2.50	2.61	2.48	0.123	0.37	0.98	0.31
Beef flavor identity	11.40	11.05	10.92	11.14	0.110	0.09	0.59	0.02
Bloody/serumy flavor	3.89	3.75	3.75	3.90	0.132	0.94	0.96	0.29
Metallic flavor	1.57	1.66	1.85	1.78	0.106	0.08	0.91	0.49
Rancid flavor	0.05	0.05	0.08	0.15	0.048	0.30	0.43	0.48

[1]Attributes were scored by a 5-member trained panel on a scale from 0 to 15 using 0.5 increments. Reference samples specific for each attribute (Table 3-2) were provided to each panelist to provide a reference point. A score of 0 would note the lowest expression of that trait, whereas 15 would represent the highest expression of that trait. High values would be desirable for initial tenderness, juiciness, and beef flavor identity. Low values would be desirable for chewiness, mealy texture, fiber awareness, residual connective tissue, bloody/serumy flavor, metallic flavor, and rancid flavor.

Table 3-4 Meat quality evaluations of meat from cattle fed steam-flaked corn (SFC) diets containing 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS).

	SFC		SFC + 25% DRC			*P*-values		
Item	0%DDGS	25%DDGS	0%DDGS	25%DDGS	SEM	DRC	DDGS	DRC×DDGS
Purge loss, %[1,2]	0.50	0.51	0.42	0.65	0.097	0.80	0.18	0.21
Cooking loss, %[1,3]	28.3	28.4	26.9	27.0	0.67	0.03	0.85	0.98
TBARS[3,4]	0.57	0.79	0.76	0.80	0.082	0.22	0.11	0.25
Alpha tocopherol[5,6]	3.4	3.17	3.48	2.91	0.220	0.56	0.05	0.55
Heterocyclic amine[3,7]	0.67	0.61	0.74	0.49	0.112	0.84	0.19	0.41

[1]Values represent weight loss expressed as a percentage of original weight.
[2]Evaluated using 6th-7th-8th rib section
[3]Conducted on longissimus steaks from the 6th-7th-8th rib section
[4]Values are mg malonaldehyde per kg of wet tissue
[5]Values indicate mg alpha tocopherol per kg wet tissue
[6]Utilized muscle tissue from separation of 9th-10th-11th rib sections
[7]Reported as the level of heterocyclic amines formed (μg/100g)

Table 3-5 Lightness (L*) values measured during a 7-d simulated retail display on steaks from cattle fed steam-flaked corn (SFC) diets containing 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles

	SFC		SFC + 25% DRC			*P*-values		
Day	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC× DDGS
L*[1, 2, 3, 4]								
0	48.34	48.14	47.12	47.95	0.52	0.16	0.52	0.28
1	46.05	45.66	45.61	46.38	0.52	0.76	0.69	0.20
2	45.81	45.83	44.92	46.01	0.52	0.54	0.34	0.36
3	45.36	45.27	44.67	45.70	0.52	0.77	0.27	0.22
4	44.06	44.84	44.77	45.17	0.52	0.29	0.23	0.67
5	43.22	43.92	43.20	44.13	0.52	0.86	0.12	0.84
6	43.16	42.79	42.18	42.81	0.52	0.37	0.81	0.35
7	42.84	43.09	42.11	42.59	0.52	0.24	0.48	0.84

[1]Effect of day, $P < 0.001$
[2]Day × DRC interaction, $P > 0.05$
[3]Day × DDGS interaction, $P > 0.10$
[4]Day × DRC × DDGS interaction, $P > 0.10$

Table 3-6 Redness (a*) and yellowness (b*) values measured during a 7-d simulated retail display on steaks from cattle fed steam-flaked corn (SFC) diets containing 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS).

	SFC		SFC + 25% DRC			*P*-values		
Day	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC× DDGS
a*[1, 2, 3, 4]								
0	30.73	30.29	30.12	30.37	0.64	0.35	0.71	0.21
1	30.15	30.40	29.90	30.17	0.64	0.38	0.34	0.93
2	28.68	29.42	28.86	29.25	0.64	0.99	0.13	0.72
3	28.35	28.82	28.05	28.55	0.64	0.42	0.17	0.85
4	28.16	28.52	27.39	28.30	0.64	0.27	0.16	0.53
5	24.31	25.05	24.48	25.82	0.64	0.55	0.18	0.73
6	19.33	20.08	19.56	19.63	0.64	0.92	0.69	0.70
7	15.42	15.28	15.65	15.70	0.64	0.69	0.96	0.94
b*[1, 2, 3, 4]								
0	23.96	23.43	23.05	23.17	0.40	0.08	0.53	0.34
1	23.44	23.47	22.88	23.05	0.40	0.09	0.74	0.84
2	22.27	22.47	21.91	22.02	0.40	0.25	0.66	0.96
3	22.40	22.61	21.80	22.09	0.40	0.08	0.43	0.84
4	22.38	22.71	21.46	22.30	0.40	0.08	0.12	0.50
5	20.13	20.30	19.78	20.43	0.40	0.81	0.39	0.61
6	15.26	18.61	18.01	18.30	0.40	0.59	0.53	0.91
7	16.57	16.36	16.35	16.44	0.40	0.87	0.87	0.73

[1]Effect of day, $P < 0.0001$
[2]Day × DRC interaction, $P > 0.10$
[3]Day × DDGS interaction, $P > 0.10$
[4]Day × DRC × DDGS interaction, $P > 0.10$

Table 3-7 Hue angle and saturation index values measured during a 7-d simulated retail display on steaks from cattle fed steam-flaked corn (SFC) diets containing 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS).

	SFC		SFC + 25% DRC			*P*-values		
Day	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC× DDGS
Hue angle[1, 2, 3, 4]								
0	37.89	37.67	37.36	37.32	0.58	0.03	0.52	0.86
1	37.85	37.65	37.38	37.34	0.58	0.03	0.52	0.80
2	37.84	37.35	37.18	36.97	0.58	0.01	0.09	0.54
3	38.34	38.11	37.81	37.74	0.58	0.03	0.44	0.83
4	38.48	38.53	38.03	38.23	0.58	0.05	0.52	0.79
5	39.88	39.40	39.20	38.46	0.58	0.09	0.21	0.84
6	44.20	43.78	43.72	43.72	0.58	0.78	0.82	0.76
7	47.76	47.91	47.09	46.94	0.58	0.38	0.99	0.94
Saturation index[1, 2, 3, 4]								
0	38.98	38.30	37.95	38.21	0.71	0.16	0.61	0.22
1	38.20	38.41	37.66	37.97	0.71	0.20	0.49	0.89
2	36.32	37.02	36.24	36.62	0.71	0.62	0.28	0.81
3	36.14	36.64	35.54	36.11	0.71	0.21	0.24	0.84
4	39.98	36.47	34.80	36.04	0.71	0.16	0.13	0.51
5	31.58	32.28	31.49	32.93	0.71	0.75	0.23	0.69
6	26.66	27.47	26.68	26.90	0.71	0.80	0.63	0.74
7	22.71	22.49	22.72	22.80	0.71	0.85	0.93	0.88

[1]Effect of day, $P < 0.0001$
[2]Day × DRC interaction, $P > 0.10$
[3]Day × DDGS interaction, $P > 0.10$
[4]Day × DRC × DDGS interaction, $P > 0.10$

CHAPTER 4 - Effects of grain processing method and use of corn dried distiller's grains on beef carcass composition

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Abstract

Carcass composition and fatty acid profiles were estimated from separated 9th-10th-11th rib sections of crossbred heifers (n = 94) fed steam-flaked corn (**SFC**) finishing diets with combinations of dry-rolled corn (**DRC**) and corn dried distiller's grains with solubles (**DDGS**). The study was a randomized complete block experiment with a 2 × 2 factorial arrangement of treatments. Factors consisted of the level of DDGS (0 or 25%) and level of DRC (0 or 25%). Heifers were individually weighed and blocked into heavy and light groups. While on study, heifers were fed once daily ad libitum, and were harvested at 137 and 157 d for the heavy and light weight blocks, respectively. A subset of heifers was randomly selected from a larger experiment, with 4 head removed from each of 24 pens. A total of 96 heifers were selected, however, two whole rib sections were not collected due to excessive trim to the carcass. Whole rib sections with plate attached were removed from one side of the selected carcasses after a 24 h chill. The 9th-10th-11th rib sections were removed from the whole rib and physically separated into muscle, adipose, and bone. Separated portions of muscle and adipose were evaluated by proximate analyses and for fatty acid profiles. Percentages of muscle, adipose, and bone of the dressed carcass were calculated utilizing equations from Hankins and Howe. There were no differences among treatments with respect to separable portions of muscle, adipose, and bone; or percentages of protein, moisture, and ether extract ($P > 0.10$). In the fatty acid triglyceride portion, oleic acid decreased, whereas proportions of stearic and linoleic acids increased ($P < 0.05$) in response to feeding DDGS. Diet had little impact on fatty acids within the phospholipid fraction. We conclude that DDGS and DRC can be added to SFC diets with little effect on composition fatty acid profile of the carcass.

Introduction

Distiller's grains are a by-product of ethanol production and are widely used in feedlots throughout the Midwest and High Plains. Research has shown that distiller's grains can have negative consequences for feedlot performance and meat quality. The variation in performance and carcass traits of cattle fed distiller's grains can be attributed to feeding different processed grains. Vander Pol et al. (2008) fed 30% wet distiller's grains in finishing diets utilizing 6 different processing methods. They observed that when cattle were fed steam-flaked corn (SFC) in comparison to dry-rolled corn (DRC), cattle fed SFC had lower 12th rib fat, marbling scores, and yield grades. Therefore, feeding different processed grains in combination with distiller's grains can alter carcass characteristics, specifically, adipose content of the carcass. Effects of feeding distiller's grains are due to the difference in feeding value when compared with corn. Ham et al. (1994) evaluated feeding values of both wet and dried distiller's grains and concluded that the feeding value of wet and dried distiller's grains exceed that of corn by 47 and 24%, respectively. Differences in feeding value could be attributed to differences in ruminal pH due to impact of pH on digestion on fiber and protein. Research has shown that feeding SFC results in lower ruminal pH than DRC (Barajas and Zinn, 1998; Corona et al., 2006; May et al., 2007), potentially lowering the digestibility of distiller's grains due to the higher NDF content. Another issue with distiller's grains suggested by Reinhardt et al. (2007) was that increases in yield grade were accompanied by a decrease in marbling score in cattle fed distiller's grains. Therefore, feeding different processed grains with distiller's grains could potentially alter carcass composition. Our objectives for this study were to evaluate carcass composition and fatty acid profiles from meat from cattle fed SFC-based diets with combinations of DRC and DDGS.

Materials and Methods

All procedures for this finishing trial were approved by the Kansas State University Institutional Animal Care and Use Committee protocol number 2315. Seven hundred crossbred yearling heifers (302 ± 65 kg initial BW) were acquired from feedlots in Kansas, Kentucky, and Oklahoma, and transported to the Kansas State University Beef Cattle Research Center, Manhattan, KS. The finishing trial was a randomized complete block experiment with a 2 × 2 factorial arrangement of treatments. All diets contained SFC, and factors consisted of the level of

DRC (0 or 25%, DM basis) and DDGS (0 or 25%, DM basis). In the diets (Table 4-1) containing DRC or DDGS, these ingredients replaced portions of the SFC.

Cattle were fed a series of four step-up diets during the 20-d transition to their final finishing diets (Table 4-1). Heifers were processed and blocked into a light and heavy weight blocks with 25 head per pen and 7 pens per treatment. Cattle were fed ad libitum for 137 or 157 d for the heavy and light weight blocks, respectively. Cattle were transported 182 km to a commercial abattoir in Emporia, KS for harvest. Once harvested, tags were placed on the carcass until grading occurred after a 24-h chill. During fabrication, whole rib sections with the plate attached were removed and identified. These whole rib sections were transported to the Kansas State University Meats Laboratory in a refrigerated truck. At arrival, rib sections were placed in meat coolers (-2°C) until physical separation.s were completed 24 to 48 h later. Separation was performed according to methods described by Hankins and Howe (1946). The whole rib with plate attached was held for measurements, marked, and the selected 9th-10th-11th rib section was removed using a hand saw and boning knives. Once removed from the whole rib, sections were weighed, then separated into muscle, adipose, and bone portions. Rib sections were separated over the next wk, with an equal number of sections from each treatment completed each day. Once separated into bone, muscle, and adipose portions, each portion was vacuum packed, and weight was recorded. Carcass composition was determined using equations published by Hankins and Howe (1946). These equations provided values for the bone, muscle, and adipose percentages of the 9th-10th-11th rib section, as well as the dressed carcass. Equations also were used to calculate percentages of muscle and adipose of the edible carcass. The edible carcass was defined as the portion that could be consumed (i.e., not bone).

Muscle and adipose portions from the separated 9th-10th-11th rib section were used for fatty acid analyses. Adipose and muscle from each rib section were ground twice with a meat grinder to homogenize the sample. Between each sample the meat grinder was taken apart and cleaned, with all removable parts rinsed with cold water to prevent cross contamination of samples. After grinding, a subsample was taken for further analyses. The subsample was frozen with liquid N_2 and pulverized to a powdery consistency in a Waring blender (Waring Products Division, Hartford, CT). To accomplish this, samples were formed into balls, and then dropped into liquid N_2 for 30 s, then removed and placed into the Waring blender. Samples were blended for at least 30 s or until finely ground, and then placed in a freezer at -80°C.

Processed samples were used to estimate the protein, moisture, ether extract, and ash content of carcasses. Analyses were conducted using methods from Association of Analytical Chemists (AOAC). Specific methods used were procedures 990.13, 985.14, 920.39, and 923.03 for protein, moisture, ether extract, and ash, respectively.

Homogenized samples of muscle and adipose were analyzed for triglyceride and phospholipid fatty acids. Triglycerides and phospholipids were separated according to procedures described in general by Noci et al. (2005) with minor modifications. Briefly, samples were weighed out in amounts of 0.5 g and 0.1 g, respectively, for muscle and adipose tissue. To extract the adipose within each sample, 10 mL of a 2:1 (vol/vol) ratio of chloroform methanol was added to the sample. The sample was then homogenized (Polyscience Tissue Homogenizer model X-120; Polysciences Co., Niles, IL) for 1 min and filtered through glass microfiber filter paper (Whatman 934-AH; Whatman, Clifton, NJ) into a test tube. The tube and filter paper were rinsed with chloroform methanol, 10 and 5 mL, respectively, and added to a second test tube. After collection of all sample and chloroform methanol, 6.5 mL 0.02% CaCl solution were added to the tube. The tube was then shaken vigorously and centrifuged (500 × *g*) for 10 min. After centrifuging, the top layer was removed with suction and the bottom layer was transferred to a new test tube and dried down with N_2 gas. After drying, the sample was reconstituted with 1 mL chloroform and made ready to put through the solid phase extraction (SPE) column (Supelco LC-NH_2; Supelco, Bellefonte, PA). The SPE columns were first prepped with two rinses of 3 mL chloroform. Once the column was prepped, the sample was added to the column. The sample tube and column were then rinsed twice each with 1 mL chloroform and the eluent was collected. This eluent contained the triglyceride fraction and was used to determine profile fatty acid methyl esters (FAME). To obtain the phospholipid fraction, the column was rinsed with 1 mL 1:1 (vol/vol) solution of chloroform methanol. The column was then ready collect the phospholipids, as the column was rinsed twice with 2.5 mL methanol, and collected. Once both fractions were collected, they were dried under N_2 gas. Dried samples were then prepped for characterization of FAME, by adding 2 mL internal standard in benzene, and 3 mL freshly made methanolic-HCl. Rehydrated samples were then gassed with N_2, capped tightly, and vortexed for 20 s. Tubes were then placed in an 80°C water bath for 135 min, and vortexed after 45 and 90 min. Tubes were removed from water bath the 80°C and allowed to cool to room temperature by placing into a cool water bath for 10 min. Once tubes reached room temperature, 5 mL 6%

K_2CO_3 and 2 mL benzene were added to the sample and vortexed. Tubes were centrifuged (500 × *g*) for 5 min and supernatant was collected and transferred to GC vials. Phospholipid samples were prepped slightly differently, adding only 1 mL internal standard in benzene before the water bath, and 1 mL benzene after the water bath. Separation and quantification of fatty acid methyl esters in the separated portions were conducted on a flame ionization gas chromatograph (model 5890 series II; Hewlett Packard, Palo Alto, CA) fitted with a Supelco 2560 capillary column (100 m × 0.25 mm × 0.20 μfilm). Helium was used as the carrier gas, with a flow rate of 1.1 mL/min, and initial temperature of 140°C, followed by a 4°C/min temperature increase to reach the final temperature of 240°C. The final temperature was held for 15 min, and injection and detector temperatures were maintained at 260°C. Concentrations of fatty acids ranging from C6 to C24 were determined.

Statistical Analyses

The MIXED models procedure of SAS (Version 9.1, Cary, NC) was used to evaluate composition and fatty acid profiles of tissue samples. The experimental unit was individual animal and the fixed effects were level of DRC, DDGS, block, as well as DRC × DDGS interaction. Values reported were calculated using the LSMEANS option and separated by an F-test.

Results and Discussion

Carcass Composition

Calculated carcass composition values are reported in Table 4-3. Replacing SFC with DRC or DDGS had no effect on composition of the 9th-10th-11th rib section ($P > 0.05$) or predicted carcass composition ($P > 0.05$). There were no differences in the percentage of muscle or adipose in the edible portion between treatments ($P > 0.05$). When muscle and adipose portions were analyzed for protein, moisture, ether extract, and ash, no differences were observed among treatments ($P > 0.05$).

Other research has shown that feeding DDGS results in increased yield grades and decreased marbling, thus potentially altering the composition of beef. Daubert et al. (2005) found that yield grade increased and marbling decreased linearly with increasing level of distiller's grains (0, 15, 30, 45% of DM). Koger et al. (2004) noted greater 12th rib fat thickness, greater

average USDA yield grade, and fewer yield grade 1 and 2 carcasses when cattle were fed distiller's grains. Reinhardt et al. (2007) conducted a meta-analysis and observed that feeding low levels of distiller's grains (16% and lower) increased marbling score; whereas high levels of distiller's grains (33% or higher) depressed marbling score. Feeding moderate levels of distiller's grains (23%) resulted in higher marbling scores; however overall body fatness (measured as yield grade) increased more dramatically than changes in marbling score in cattle fed distiller's grains.

Corrigan et al. (2008) observed that feeding 40% wet distiller's grains (WDGS) in diets with high moisture corn (HMC), DRC, or SFC decreased ruminal pH compared to animals fed diets without WDGS. May et al. (2007) found that when feeding 25% DDGS in SFC or DRC diets, ruminal pH was lowered in cattle fed DDGS. The observed decrease in pH when feeding distiller's grains is contradictory to the presumption that distiller's grains should increase pH. Klopfenstein et al., 2008 suggested that feeding distiller's grains should increase ruminal pH due to the increased fiber and decreased starch content relative to cereal grains. The lack of physically effective fiber to stimulate the rumen because of the small particle size of distiller's grains may contribute to the decrease in ruminal pH (Bhatti and Firkins, 1995). Lower ruminal pH could decrease digestion of distiller's grains. Decreasing the digestibility of the distiller's grains in the rumen may shift the site of digestion to the small intestine. Uwituze (2008) observed a decrease in starch digestion when DDGS were fed. Owens and Gardner (2000) found that lower levels of starch digestibility within the rumen could affect marbling adipocyte deposition. They also noted that less ruminal escape of dietary starch could increase yield grade due to increases in fat deposition. However, our findings did not confirm that carcasses from cattle fed distiller's grains were fatter and we did not measure pH. We observed that DDGS can be fed without altering carcass composition. Unlike previous studies conducted with distiller's grains, we observed no deleterious effects of feeding DDGS in terms of changes in carcass composition. Carcass characteristics are shown in Table 4-2, and reveal that carcass composition was unaltered by addition of DRC or DDGS.

Fatty Acids, Triglyceride Fraction

Fatty acid concentrations for adipose and muscle portions, reported as a percentage of total triglycerides, are summarized in Tables 4-4 and 4-5, respectively. Comparisons of adipose

tissue revealed that cattle fed DRC had increased concentrations of erucic (C22:1n9), and tricosanic acid (C23:0), but decreased concentrations of elaidic acid (C18:1n9t; $P < 0.05$). DRC also tended to increase capric (C10:0), lauric (C12:0), myristic (14:0), and myristoleic (C14:1) acids ($P < 0.10$) compared to the SFC control. When feeding cattle DDGS compared to cattle fed no DDGS, adipose tissue contained higher levels of linoleic (C18:2), linolenic (C18:3) acids, CLA 10t 12c, and CLA 9t, 11t while decreasing oleic (C18:1n9c) and vaccenic acids (C18:1n11c; $P < 0.05$). DDGS also tended to increase capric (C10:0), lauric (C12:0), stearic (C18:0), and elaidic acids (C18:1n9t), while decreasing palmitoleic (C16:1) and margaric acids (C17:0; $P < 0.10$) compared with no DDGS. Interactions between DRC and DDGS were observed in myristoleic (C14:1) as the interaction of DRC × DDGS tended to increase the content. The interaction of DRC × DDGS was observed for henicosanoic acid (C21:0) as concentration increased significantly in adipose tissue from cattle fed combination of DRC and DDGS.

Evaluation of muscle tissue from cattle fed DRC in comparison to cattle fed no DRC resulted in few differences in the triglyceride portion of fatty acids. Muscle tissue from cattle fed DRC had increased levels of lauric (C12:0), myristic (14:0), myristoleic (C14:1), and arachidic (C21:0) acids but decreased levels of oleic acid (C18:1n9c; $P < 0.05$) compared to cattle fed no DRC. Dry rolled corn also tended to increase undecanoic (C11:0) and decrease vaccenic acid (C18:1n11t; $P < 0.10$). Feeding DDGS had a greater effect on fatty acid composition in muscle tissue, decreasing palmitic (C16:0), oleic (C18:1n9c), and vaccenic acids (C18:1n11c; $P < 0.05$), while increasing linoleic (C18:2), linolenic (C18:3), arachidic (C21:0), and docosahexaenoic (C22:6n3) acids, and CLA 10t, 12c ($P < 0.05$) when compared with no DDGS. Tendencies were observed for DDGS to increase CLA 9t, 11t and arachidonic acid (C20:4n6; $P < 0.10$) for muscle tissue. Within the muscle tissue DRC × DDGS interactions were observed, as concentrations of myristoleic (C14:1), henicosanoic (C21:0), and trieicosanoic (C23:0) acid ($P < 0.05$) increased.

Gill et al. (2008) evaluated fatty acid profiles in fresh steaks and noted differences in concentrations in steaks from cattle fed distiller's grains compared to diets without distiller's grains. They observed increased concentrations of margaric (C17:0) and stearic (C18:0) acids. This is in contrast to a decrease in margaric (C17:0) acid in the adipose portion, but no significant effect was observed in muscle tissue. On the other hand, stearic (C18:0) acid was increased in both muscle and adipose tissues in our trial. However, increasing concentrations of

margaric (C17:0) and stearic (C18:0) acids are of little concern as Baghurst (2004) noted that margaric (C17:0) and stearic (C18:0) acids have no influence on human plasma cholesterol concentrations.

Fatty acids that are primarily responsible for increasing plasma low density lipoprotein and total cholesterol concentrations in the body include lauric (C12:0), myristic (C14:0), and palmitic (C16:0) acids (Hegsted et al., 1965). Gill et al. (2008) found no increases in these three fatty acids when feeding distiller's grains. However, in our trial, feeding DDGS decreased palmitic (C16:0; $P < 0.05$), whereas no differences were observed for lauric (C12:0) or myristic (C14:0) acids ($P > 0.05$) compared with feeding no DDGS. There was a tendency for DDGS to increase lauric (C12:0) acid in adipose tissue when compared to no DDGS ($P < 0.10$). On the other hand, when DRC-fed cattle were compared with the SFC-based control, tendencies to increase concentration were seen in adipose tissues for both lauric (C12:0) and myristic (C14:0) acids ($P < 0.10$), and significant increases were observed for lauric (C12:0) and myristic (C14:0) acid concentrations in muscle tissue. Hegsted et al. (1965) noted that myristic acid is suspected to be the most cholesterol-raising fatty acid. This raises a slight concern, but differences were relatively small, myristic acid only accounted for approximately 4% of the total fatty acid concentration.

Akoh and Min (2002) found that linoleic acid is important because it plays a role in synthesizing proinflammatory eicosanoids. Koger et al. (2004) noted an increase in linoleic acid in steaks from cattle fed distiller's grains compared with the corn-based control. In our trial, both muscle and adipose tissue from cattle fed DDGS had higher concentrations of linoleic acid. An isomer of linoleic acid, CLA 10t, 12c, is not a main form of linoleic acid in meat; however, it still is important because it has potential health benefits. McGuire and McGuire (2000) observed that CLA 10t, 12c reduces lipogenesis, thus impeding obesity. Gill et al. (2008) found that steaks from cattle fed distiller's grains had higher concentrations of CLA 10t, 12c compared with cattle fed the SFC control. We found similar results, as DDGS-fed cattle had higher concentrations of CLA 10t, 12c in both muscle and adipose portions compared to cattle fed no DDGS. These advantages suggest that feeding DDGS may be beneficial to human health, by potentially reducing cholesterol, and reducing obesity. The same was not true for cattle fed DRC compared to cattle fed diets without DRC, as no differences were seen in linoleic acid concentrations in either muscle or adipose tissue.

Overall, with respect to triglyceride fractions in both the muscle and adipose portions, beef from cattle fed DDGS was similar when compared with beef from cattle fed diets without DDGS. With a few minor exceptions, feeding cattle DRC produced beef that was comparable in terms of the triglyceride portion of fatty acid concentration. Fatty acids in the triglyceride portion, while statistically significant, are relatively small and are unlikely to have major biological importance.

Fatty Acids, Phospholipid Fraction

Phospholipids in muscle and adipose tissues, expressed as a percentage of total phospholipids in the sample are summarized in Tables 4-6 and 4-7, respectively. Unlike triglycerides, few differences due to treatments were seen. Few interactions of DRC × DDGS were found within the phospholipids portion of either adipose or muscle tissue. In the adipose fraction, concentration of undecanoic acid (C11:0) tended to increase when feeding both DRC and DDGS ($P < 0.10$). Within the muscle portion, interactions of DRC × DDGS were observed as concentrations of heptadecanoic acid (C17:0), an isomer of oleic acid (C18:1n11t), and docosahexaenoic acid (C22:6n3) tended to increase when both DRC and DDGS were fed ($P < 0.10$). When evaluating both adipose and muscle tissue for phospholipids, DRC tended to alter concentrations of several individual fatty acids. In adipose and muscle tissues, DRC tended to increase and decrease margaric (C17:0) acid, respectively ($P < 0.10$) when compared with cattle fed no DRC. Reasons for this incongruence are not readily apparent. In adipose tissue, DRC tended to decrease trans-vaccenic (C18:1n11t) and hexacosanoic (C23:0) acids compared with no DRC ($P < 0.10$). Muscle tissue from DRC-fed cattle however, had increased concentrations of linoleic (C18:2n6c) and decreased concentrations of vaccenic (C18:1n11c) acids compared with muscle tissue from the SFC-fed control cattle ($P < 0.05$). Overall, within the phospholipid fraction, DRC changed few fatty acids in comparison to diets without DRC.

However, when adipose and muscle tissue from cattle fed DDGS were evaluated; more fatty acid concentrations were modified from the control (no DDGS). When comparing cattle fed DDGS compared to those without, margaric (C17:0) and vaccenic (C18:1n11c) acids were decreased and linoleic (18:2n6c) acid was increased in the adipose tissue ($P < 0.05$). Cattle fed DDGS also tended to have lower concentrations of hepadecenoic (C17:1) acid in adipose tissue

in comparison to cattle fed diets without DDGS ($P < 0.10$). Margaric acid, although saturated, has been shown to have no effect on increasing cholesterol levels in plasma (Baghurst, 2004).

More effects were observed for muscle tissue when evaluating DDGS in finishing cattle diets in muscle tissue. Muscle tissue from cattle fed DDGS had increased concentrations of linoleic (C18:2n6c) acid and decreased concentrations of oleic (C18:1n9c) acid, alpha-linolenic (C18:3n3) acid, eicosatrienoic (C20:3n6) acid, docosapentaenoic (C22:5n3) acid, and CLA 9t, 11t compared with muscle tissue from cattle fed no DDGS ($P < 0.05$). DDGS also had a tendency to decrease docosahexeanoic (C22:6n3) acid compared with no DDGS ($P < 0.10$). Oleic acid had no effect on cholesterol concentrations and thus is not a concern in coronary heart disease (Tholstrup, 1994). Again, increasing linoleic acid provides health benefits by decreasing cholesterol levels (Zock and Katan, 1998; Akoh and Min, 2002).

In general, DDGS had no major effects on the fatty acid concentrations of phospholipids in muscle or adipose tissues compared with the control of no DDGS. The same was true for DRC, despite minor changes in fatty acid concentrations.

Total Saturated and Unsaturated Fatty Acids

Fatty acid values from both triglyceride and phospholipid fractions were summed and analyzed for concentrations of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) in adipose and muscle tissues (Table 4-8). Concentrations of SFA, MUFA, and PUFA concentrations were not different among treatments for adipose or muscle tissue ($P > 0.05$). Gill et al. (2008) found that feeding distiller's grains did not alter concentrations of SFA or MUFA in beef. However, they observed increased concentrations of PUFA when distiller's grains were fed to cattle. Koger et al. (2004) observed similar results; SFA and MUFA levels were unchanged in diets containing distiller's grains, but PUFA levels were elevated in meat from cattle fed distiller's grains. In our study, PUFA were unchanged, likely due to a lack of major differences when fatty acids were expressed separated.

Conclusion

Results of our study suggest that DDGS can be fed at 25% of the diet without appreciably altering meat composition or fatty acid profiles. Additionally, DRC can replace portions of SFC without negative consequences. Replacing a portion of SFC with either DRC or DDGS can reduce feed costs, while maintaining similar carcass composition and fatty acid profiles of beef.

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Table 4-1 Composition of steam-flaked corn (SFC) finishing diets with 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS)[1,2]

	SFC		SFC + 25% DRC	
Ingredient	0%DDGS	25%DDGS	0%DDGS	25%DDGS
SFC	82.1	58.2	56.8	33.1
DDGS	-	25.4	-	25.3
DRC	-	-	25.5	25.3
Alfalfa hay	5.9	5.9	5.9	5.8
Corn steep liquor	6.5	6.4	6.4	6.4
Urea	1.2	-	1.2	-
Supplement	4.3	4.1	4.2	4.1
Analyzed composition, %				
Dry matter	78.4	79.7	80.4	81.8
Crude protein	14.7	16.3	14.8	16.4
NDF	10.7	16.0	10.7	16.0
Calcium	0.7	0.7	0.7	0.7
Phosphorus	0.30	0.51	0.30	0.52
Potassium	0.7	0.7	0.7	0.7

[1]Formulated to provide 300 mg/d monensin (Elanco Animal Health, Greenfield, IN), 90 mg/d tylosin (Elanco Animal Health, Greenfield, IN), and 0.5 mg/d MGA (Pfizer Animal Health, Exton, PA), 2200 IU/kg added vitamin A, 22 IU/kg added vitamin E, 0.30% salt, 60 mg/kg Zn, 60 mg/kg Mn, 10 mg/kg I, 0.25 mg/kg Se, and 0.1 mg/kg Co.
[2]Optaflexx (Elanco Animal Health, Greenfield, IN) was included at 200 mg/animal daily for the final 42 d on feed.

Table 4-2 Carcass data from cattle selected for evaluation of carcass composition using the 9th-10th-11th rib section. Cattle were fed steam-flaked corn (SFC) diets containing 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS)

	SFC		SFC + 25% DRC			*P*-values		
Item	0%DDGS	25%DDGS	0%DDGS	25%DDGS	SEM	DRC	DDGS	DRC×DDGS
No. animals selected	23	24	24	23	-	-	-	-
Final BW, kg	528	529	526	509	9.1	0.24	0.37	0.36
Dressed yield, %	62.03	63.81	64.01	65.48	0.01	0.20	0.25	0.91
HCW, kg	329	336	338	328	5.0	0.99	0.75	0.10
USDA quality grades, %								
Choice	56.4	33.4[x]	41.7[x]	56.3[y]	10.5	0.69	0.69	0.07
Select	39.3	58.3	54.2	43.7	10.5	0.99	0.68	0.16
Standard	4.3	8.3	4.1	0	3.7	0.55	0.55	0.56
USDA yield grade	2.65	2.63	2.71	2.65	0.18	0.82	0.82	0.91
KPH, %	2.40	2.30	2.26	2.31	0.06	0.25	0.64	0.22
12th rib fat, cm	1.24	1.35	1.40	1.24	0.04	0.78	0.76	0.21
Marbling score[1]	544	487	496	500	16.2	0.27	0.10	0.06
Longissimus area, cm^2	82.4	82.6	84.5	82.0	2.45	0.76	0.62	0.58

[1]Marbling score: Slight = 400, Small = 500

Table 4-3 9th-10th-11th rib separation values, actual and calculated from cattle fed steam-flaked corn (SFC) diets containing 0 or 25% dry-rolled corn (DRC) and 0 or 25% corn dried distiller's grains with solubles (DDGS)

	SFC		SFC + 25% DRC			*P*-values		
Item	0%DDGS	25%DDGS	0%DDGS	25%DDGS	SEM	DRC	DDGS	DRC×DDGS
9th-10th-11th rib section								
Separated bone, %	19.0	21.3	19.6	19.6	0.70	0.44	0.11	0.11
Separated muscle, %	50.6	47.9	49.8	50.0	1.06	0.56	0.23	0.18
Separated adipose, %	30.4	30.8	30.6	30.4	1.27	0.96	0.92	0.82
Dressed carcass[1]								
Bone, %	15.3	16.2	15.5	15.5	0.31	0.44	0.11	0.11
Muscle, %	56.1	54.0	55.4	55.6	0.84	0.56	0.23	0.18
Adipose, %	28.4	28.7	28.5	28.4	1.06	0.96	0.92	0.82
Edible portion[2]								
Muscle , %	62.6	61.1	62.0	62.2	1.40	0.85	0.64	0.56
Adipose, %	37.4	38.9	38.0	37.8	1.40	0.85	0.64	0.56
Protein[1], %	15.8	16.0	15.9	16.0	0.25	0.71	0.56	0.85
Moisture[1], %	50.4	50.4	50.9	50.4	0.67	0.74	0.75	0.67
Ether extract[1], %	32.1	31.9	31.4	31.8	0.95	0.67	0.90	0.81
Ash, %	0.019	0.019	0.020	0.021	0.001	0.09	0.84	0.58

[1]Values were calculated using equations from Hankins and Howe (1946).
[2]Edible portion is the sum of muscle and adipose tissues

Table 4-4 Fatty acid concentrations of triglycerides extracted from separated adipose fraction of the 9th-10th-11th rib section, as a percentage of total fatty acids in sample

	SFC		SFC + 25% DRC			*P*-values		
Fatty acid[1]	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC× DDGS
6:0	0.023	0.023	0.022	0.036	0.007	0.35	0.29	0.28
8:0	0.109	0.110	0.112	0.104	0.007	0.80	0.62	0.51
10:0	0.066	0.075	0.075	0.077	0.003	0.10	0.07	0.25
11:0	0.012	0.012	0.012	0.012	0.001	0.27	0.51	0.92
12:0	0.087	0.095	0.095	0.101	0.004	0.06	0.08	0.81
14:0	3.70	3.79	3.83	4.03	0.11	0.08	0.16	0.61
14:1	0.79	0.74	0.79	0.89	0.04	0.06	0.53	0.08
15:0	0.71	0.69	0.71	0.73	0.03	0.54	0.87	0.51
16:0	26.75	26.23	26.68	26.65	0.33	0.59	0.40	0.46
16:1	3.49	3.31	3.52	3.33	0.10	0.81	0.06	0.98
17:0	2.87	2.69	2.79	2.58	0.11	0.37	0.08	0.86
18:0	16.40	16.87	16.06	17.00	0.33	0.75	0.04	0.48
18:1n9c	38.79	37.99	38.97	37.39	0.47	0.66	0.01	0.40
18:1n11c	1.46	1.36	1.51	1.31	0.03	0.92	0.01	0.12
18:1n9t	0.29	0.37	0.27	0.31	0.02	0.04	0.01	0.33
18:1n11t	0.60	0.65	0.54	0.57	0.05	0.20	0.41	0.84
18:2n6c	2.52	3.53	2.65	3.45	0.18	0.89	0.01	0.55
18:2n6t	0.017	0.020	0.016	0.019	0.001	0.44	0.01	0.93
CLA 9c, 11c	0.014	0.015	0.013	0.013	0.001	0.12	0.31	0.23
CLA 9c, 11t	0.150	0.155	0.148	0.157	0.008	0.99	0.38	0.82
CLA 9t, 11t	0.25	0.29	0.25	0.27	0.013	0.55	0.03	0.43
CLA 10t, 12c	0.050	0.061	0.049	0.057	0.003	0.48	0.01	0.58
18:3n3	0.17	0.20	0.17	0.20	0.007	0.76	0.01	0.92
18:3n6	0.011	0.012	0.011	0.012	0.001	0.57	0.25	0.99
20:3n3	0.010	0.011	0.010	0.011	0.001	0.72	0.15	0.76
20:3n6	0.052	0.062	0.057	0.065	0.004	0.35	0.04	0.88
20:4n6	0.024	0.026	0.024	0.026	0.002	0.96	0.39	0.97
20:5n3	0.001	0.001	0.001	0	0.00	0.71	0.02	0.20
21:0	0.010	0.010	0.009	0.011	0.001	0.37	0.11	0.01
22:1n9	0.004	0.004	0.006	0.005	0.001	0.01	0.48	0.67
22:5n3	0.019	0.020	0.020	0.019	0.001	0.99	0.80	0.59
22:6n3	0.001	0.002	0.001	0.001	0.001	0.27	0.47	0.57
23:0	0.004	0.002	0.004	0.004	0.001	0.03	0.11	0.18
24:1	0.001	0.002	0.001	0.001	0.001	0.39	0.24	0.24

[1]Fatty acids are represented as number of carbon atoms:number of carbon double bonds. The "n" in fatty acid notation followed by a number denotes the location of the first C=C double bond, counting from the methyl end of the chain. The notations "c" and "t" characterize the double bond as cis or trans isomeric forms.

Table 4-5 Fatty acid concentrations of triglycerides extracted from separated muscle portion of the 9th-10th-11th rib section, as a percentage of total fatty acids in the sample

	SFC		SFC + 25% DRC			*P*-values		
Fatty acid[1]	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC× DDGS
6:0	0.035	0.035	0.035	0.036	0.002	0.71	0.82	0.84
8:0	0.112	0.122	0.116	0.127	0.012	0.68	0.37	0.96
10:0	0.070	0.078	0.076	0.075	0.005	0.85	0.49	0.40
11:0	0.014	0.014	0.015	0.016	0.001	0.07	0.39	0.92
12:0	0.093	0.094	0.105	0.109	0.004	0.01	0.58	0.71
14:0	3.66	3.64	3.92	4.00	0.10	0.01	0.76	0.60
14:1	0.81	0.70	0.82	0.89	0.04	0.01	0.56	0.02
15:0	0.68	0.65	0.70	0.71	0.03	0.16	0.84	0.41
16:0	3.78	3.38	3.75	3.59	0.10	0.38	0.01	0.23
17:0	2.54	2.44	2.50	2.36	0.10	0.51	0.19	0.80
18:0	15.53	16.72	15.79	16.33	0.04	0.85	0.01	0.34
18:1n9c	39.20	38.23	38.26	37.37	0.46	0.04	0.04	0.93
18:1n9t	0.32	0.41	0.36	0.42	0.03	0.36	0.01	0.68
18:1n11c	1.47	1.35	1.47	1.32	0.04	0.60	0.01	0.69
18:1n11t	0.69	0.72	0.62	0.61	0.05	0.07	0.74	0.68
18:2n6c	2.58	3.37	2.69	3.42	0.18	0.64	0.01	0.88
18:2n6t	0.018	0.020	0.017	0.020	0.001	0.77	0.04	0.70
CLA 9c, 11c	0.017	0.021	0.016	0.017	0.002	0.13	0.30	0.49
CLA 9c,11t	0.145	0.144	0.129	0.144	0.008	0.26	0.36	0.27
CLA 9t, 11t	0.27	0.29	0.27	0.29	0.013	0.63	0.07	0.98
CLA 10t, 12c	0.051	0.053	0.048	0.055	0.003	0.72	0.04	0.48
18:3n3	0.19	0.21	0.20	0.22	0.01	0.21	0.01	0.77
18:3n6	0.013	0.013	0.014	0.015	0.001	0.13	0.79	0.51
20:3n3	0.010	0.011	0.009	0.008	0.001	0.17	0.78	0.50
20:3n6	0.054	0.061	0.056	0.061	0.004	0.82	0.14	0.71
20:4n6	0.034	0.040	0.033	0.043	0.005	0.85	0.09	0.65
20:5n3	0.001	0.004	0.001	0.002	0.002	0.54	0.19	0.69
21:0	0.009	0.012	0.011	0.012	0.001	0.02	0.01	0.04
22:1n9	0.003	0.004	0.003	0.003	0.001	0.22	0.31	0.57
22:5n3	0.022	0.023	0.025	0.024	0.002	0.24	0.84	0.67
22:6n3	0.001	0.002	0	0.001	0.001	0.55	0.05	0.58
23:0	0.004	0.003	0.002	0.004	0.001	0.58	0.36	0.01
24:1	0.001	0.001	0.002	0.000	0.001	0.89	0.23	0.14

[1]Fatty acids are represented as number of carbon atoms: number of carbon double bonds. The "n" in fatty acid notation followed by a number denotes the location of the first C=C double bond, counting from the methyl end of the chain. The notations "c" and "t" characterize the double bond as cis or trans isomeric forms.

Table 4-6 Fatty acid profile of phospholipids extracted from the separated adipose portion of the 9th-10th-11th rib section, reported as a percentage of total fatty acids from phospholipid in sample

	SFC		SFC + 25% DRC			*P*-values		
Fatty acid[1]	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC× DDGS
8:0	41.54	42.60	40.91	41.98	2.25	0.78	0.64	0.99
11:0	0.95	0.83	0.83	0.89	0.06	0.55	0.61	0.10
12:0	1.87	2.20	1.76	1.89	0.24	0.39	0.33	0.67
14:0	1.29	1.42	1.31	1.40	0.14	0.99	0.41	0.90
15:0	0.41	0.37	0.52	0.50	0.11	0.27	0.81	0.92
15:1	0.019	0	0.042	0.001	0.023	0.62	0.19	0.64
16:0	10.08	10.11	10.77	10.61	0.63	0.34	0.92	0.88
17:0	0.64	0.30	0.84	0.60	0.16	0.10	0.05	0.84
17:1	0.56	0.23	0.35	0.26	0.11	0.42	0.06	0.25
18:0	7.97	8.35	8.36	8.66	0.37	0.34	0.35	0.90
18:1n9c	14.49	14.78	15.59	14.76	0.97	0.57	0.78	0.56
18:1n11c	2.43	1.10	2.18	0.49	0.67	0.52	0.02	0.78
18:1n11t	1.14	1.56	0.85	0.96	0.24	0.07	0.28	0.53
18:2n6c	4.33	5.56	4.67	5.25	0.32	0.95	0.01	0.31
CLA 9t, 11t	0	0.02	0	0.01	0.01	0.88	0.16	0.85
20:3n6	4.80	4.40	3.79	4.69	0.74	0.62	0.73	0.38
20:4n6	4.70	3.94	4.67	4.74	0.35	0.26	0.33	0.23
20:5n3	0.06	0	0.06	0.27	0.14	0.35	0.59	0.32
22:5n3	0.33	0.29	0.59	0.27	0.13	0.35	0.17	0.28
23:0	0.47	0.31	0.04	0.09	0.15	0.04	0.72	0.49
24:1	0.034	0	0.014	0.001	0.018	0.59	0.18	0.57

[1]Fatty acids are represented as number of carbon atoms:number of carbon double bonds. The "n" in fatty acid notation followed by a number denotes the location of the first C=C double bond, counting from the methyl end of the chain. The notations "c" and "t" characterize the double bond as cis or trans isomeric forms.

Table 4-7 Fatty acid profile of phospholipids extracted from the separated muscle portion of the 9th-10th-11th rib section, reported as a percentage of total fatty acids from phospholipid in sample.

	SFC		SFC + 25% DRC			*P*-values		
Fatty acid[1]	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC× DDGS
6:0	0.14	0.23	0.30	0.30	0.09	0.22	0.59	0.59
8:0	9.77	10.36	9.44	10.14	0.56	0.62	0.24	0.91
11:0	0.19	0.20	0.17	0.19	0.02	0.59	0.56	0.95
12:0	0.25	0.33	0.20	0.19	0.06	0.12	0.56	0.41
14:0	0.27	0.36	0.35	0.35	0.04	0.38	0.29	0.32
14:1	0	0.011	0	0.006	0.01	0.67	0.20	0.67
15:0	0.22	0.61	0.23	0.24	0.20	0.36	0.31	0.32
15:1	0.40	0.39	0.40	0.33	0.08	0.80	0.49	0.79
16:0	9.81	10.07	9.57	10.56	0.44	0.76	0.15	0.40
17:0	0.62	0.65	0.62	0.53	0.04	0.09	0.39	0.10
17:1	0.71	0.54	0.61	0.09	0.23	0.23	0.13	0.43
18:0	12.60	13.17	13.03	13.21	0.24	0.31	0.11	0.40
18:1n9c	12.59	10.35	12.52	10.63	0.63	0.86	0.01	0.78
18:1n11c	1.36	1.28	1.37	1.20	0.54	0.48	0.21	0.40
18:1n11t	0.33	0.44	0.43	0.16	0.11	0.38	0.44	0.07
18:2n6c	21.37	23.71	20.75	24.06	0.78	0.86	0.01	0.53
CLA 9t, 11t	0.06	0.02	0.07	0.02	0.02	0.94	0.02	0.59
18:3n3	0.48	0.37	0.49	0.40	0.04	0.54	0.01	0.83
18:3n6	0.18	0.11	0.16	0.17	0.03	0.48	0.27	0.15
20:3n6	3.46	3.17	3.40	3.24	0.10	0.93	0.02	0.52
20:4n6	16.02	15.35	16.58	16.06	0.67	0.33	0.36	0.90
20:5n3	1.48	1.41	1.63	1.27	0.12	0.97	0.85	0.23
22:5n3	4.46	3.93	4.44	3.76	0.24	0.69	0.01	0.75
22:6n3	0.58	0.57	0.68	0.50	0.05	0.82	0.06	0.09
23:0	0.32	0.34	0.32	0.37	0.03	0.66	0.32	0.66
24:1	0.20	0.16	0.17	0.14	0.03	0.46	0.22	0.78

[1]Fatty acids are represented as number of carbon atoms:number of carbon double bonds. The "n" in fatty acid notation followed by a number denotes the location of the first C=C double bond, counting from the methyl end of the chain. The notations "c" and "t" characterize the double bond as cis or trans isomeric forms.

Table 4-8 Total saturated and unsaturated fatty acids extracted from the separated muscle and adipose portions of the 9th-10th-11th rib section, reported as a percentage of total fatty acids.

	SFC		SFC + 25% DRC			*P*-values		
Fatty acid	0% DDGS	25% DDGS	0% DDGS	25% DDGS	SEM	DRC	DDGS	DRC× DDGS
Muscle portion								
SFA[1]	42.34	43.88	43.12	44.06	1.16	0.68	0.28	0.80
MUFA[2]	31.19	29.48	31.28	28.87	2.30	0.91	0.37	0.88
PUFA[3]	26.47	26.64	25.60	27.07	3.39	0.95	0.81	0.85
Adipose portion								
SFA[1]	58.24	58.75	58.25	59.16	1.37	0.88	0.60	0.88
MUFA[2]	32.92	31.87	32.97	30.99	2.03	0.84	0.45	0.82
PUFA[3]	8.84	9.38	8.78	9.85	0.91	0.82	0.37	0.77

[1]SFA refers to the sum of saturated fatty acids expressed as a percent of total fatty acids in the sample. [2]MUFA refers to the sum of monounsaturated fatty acids expressed as a percent of total fatty acids in the sample.
[3]PUFA refers to the sum of polyunsaturated fatty acids expressed as a percent of total fatty acids in the sample.