Effects of Varying Levels of Reduced-Fat Modified Distillers Grains with Solubles in Finishing Diets of Feedlot Steers on Beef Quality Characteristics

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Abstract

The impact of utilizing varying concentrations of reduced-fat modified distillers grains with solubles (RFMDGS) was evaluated using fifty crossbred (Angus x Gelbvieh X Holstein x Jersey) steers (initial body weight: 379 ± 32 kg) that were randomly assigned to one of four dietary treatments. Dietary treatments consisted of: 14.93% RFMDGS of diet dry matter (DMD) with 0.74% corn oil DMD (FF15); 15.60% RFMDGS DMD (RF15); 30.84% RFMDGS DMD (RF30); and 46.27% RFMDGS DMD (RF45). All steers received Rumensin. Steers were fed dietary treatments for 181d utilizing a Calan gate system then fed a common diet for 3d before harvesting at a commercial abattoir. Hot carcass weight (HCW), 12^{th} rib backfat (BF), ribeye area (REA), percent kidney, pelvic, and heart fat (KPH), and marbling score data were collected 24h postmortem. Strip loins (IMPS #180) were collected for vacuum purge loss evaluation, fabricated into 2.54cm steaks for drip loss, cook loss, Warner-Bratzler shear force (WBSF), sensory evaluation (n = 122), and retail shelf life evaluation (n = 8). Shoulder clods (IMPS # 114) were used to create ground beef and bologna. Ground beef was utilized for retail shelf life evaluation (n = 10) and thiobarbituric acid reactive substances (TBARS) analysis while bologna samples were evaluated for sensory attributes (n = 108) and retail shelf life evaluation (n = 8). Twelfth rib backfat was analyzed for objective color, fatty acid composition and calculated iodine value. All data was analyzed using PROC MIXED procedure in SAS.

There was no treatment effect for HCW (P = 0.96), BF (P = 0.63), REA (P = 0.62), KPH (P = 0.27), or marbling score (P = 0.67). All moisture loss attributes did not

differ among treatments (P = 0.09). Warner-Bratzler shear force values for FF15 were greater compared to all other treatments (P < 0.01). There was no treatment effect for overall liking (P = 0.15), flavor liking (P = 0.75), texture liking (P = 0.07), or off-flavor (P = 0.72) in steak sensory analysis. Subjective toughness values of steaks from FF15 were higher than RF15 (10.78 and 8.77, respectively; P = 0.01). Subjective juiciness values of steaks from FF15 were higher than RF45 (8.50 and 6.94, respectively; P = 0.03). Treatment had no impact on L* (P = 0.31), subjective lean color (P = 0.22), or subjective surface discoloration (P = 0.08) within strip steal retail shelf life. Objective redness (a*) and b* of strip steaks was highest in RF30 on d-0 (P < 0.01) compared to all other treatments. Day-4 a* and b* values of strip steaks were highest in RF30 and RF15 compared to FF15 and RF15 (P = 0.02, P < 0.01, respectively). Subjective overall appearance values in strip steaks were highest in RF45 on day-7 compared to all other treatments (P < 0.01). Treatment did not impact L* (P = 0.43), a* (P = 0.84), b* (P = 0.48), subjective lean color (P = 0.14), subjective surface discoloration (P = 0.96), or subjective overall appearance (P = 0.06) in ground beef retail shelf life. There was no treatment effect for ground beef percent moisture (P = 0.96) or percent fat (0.97) composition. There was no treatment effect for d-0 or d-7 TBARS (P = 0.94 and P = 0.27, respectively). Treatment did not impact L* (P = 0.77), a* (P = 0.32), b* (P = 0.46), subjective lean color appearance (P = 1.00), subjective surface discoloration (P = 1.00), or subjective overall appearance (P = 1.00) in bologna retail shelf life. There was no treatment effect for flavor liking or off-flavor in bologna sensory analysis. Subjective overall liking was higher in RF45 compared to FF15 bologna samples (78.14 and 71.63, respectively; P = 0.03). Subjective texture liking of bologna from RF45 were higher than

FF15 (78.25 and 67.51, respectively; P <0.01). Subjective toughness liking of bologna from RF30 and RF45 were higher compared to FF15 (77.21, 78.25, and 67.51, respectively; P <0.01). The lowest percentage of pentadecanoic and margaric acid was within RF45 (P < 0.01 and P = 0.02, respectively). Myristic acid percentage was impacted by treatment as RF30 had the lowest percentage of overall fatty acid composition (P < 0.01).Treatment did not impact percentage of all other fatty acids (P = 0.06). There was no treatment effect on calculated iodine value (P = 0.59). Treatment did not affect lipid L*, a*, or b* color scores (P = 0.59, P = 0.62, and P = 0.54; respectively).

Although results indicate feeding 45% RFMDGS had no effect on carcass characteristics or processed meat quality, it did decrease fresh beef quality and had minimal effects on fatty acid composition.

Key words: reduced-fat; modified distillers grains; beef quality

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Chapter I: Review of Literature

Introduction

Total U.S. beef consumption has been decreasing annually since the early 2000s (USDA ERS, Cattle & Beef, 2016). In 2002, U.S. beef consumption totaled 27.9 billion pounds while consumption decreased to 24.1 billion pounds in 2014 (USDA ERS, Cattle & Beef, 2016). While overall consumption is decreasing, average price per pound of Choice beef has steadily increased (USDA ERS, Cattle and Beef, 2016). In 2002, the average cost of Choice beef per pound was $3.32 while consumers paid $5.97 per pound of Choice beef in 2014 (USDA ERS, Cattle & Beef, 2016). The high cost of beef per pound in 2014 was partially attributed to the U.S. droughts in 2011 and 2012, decreasing both crop yield and cattle herd size (Henderson, 2015).

While beef demand has slowly decreased, cattle numbers are increasing. In February 2016, 1.59 million cattle were marketed, which had increased by five percent compared to number of marketed cattle in 2015 (USDA, Cattle on Feed, 2016). U.S. cattle and calf production was worth 60.8 million dollars in 2014 and continues to fluctuate based on export trends and yearly weather (USDA ERS, Cattle & Beef, 2016).

Grass-fed Versus Corn-fed: Overview

Historically, cattle have been raised on forage pastures for 12 – 18 months of their life and transitioned to dry feedlots fed a conventional feedlot diet or total mixed ration (TMR), consisting of 70 – 80 percent grain; 10 – 15% hay, silage, or other sources of forage; and 0 – 10 % soybean meal, cottonseed meal, or other sources of protein (Mathews and Johnson, 2013; National Cattlemen's Beef Association, 2016). Feeder

cattle, or cattle ranging from 700 to 850 pounds, should be fed 11% crude protein in their total mixed rations (Comerford et al., 2013).

Conventional beef production refers to cattle that are fed high corn grain diets within their finishing feedlot diet. Conventional beef productions accounts for 80% of beef production, with grass-fed; all-natural; and organic comprising the other 20% of beef production (Mathews and Johnson, 2013). Conventionally fed beef achieve the highest quality grades of Prime, Choice, and Select while grass-fed beef result in lower levels of marbling, achieving Choice and Select quality grades (Mathews and Johnson, 2013). Conventional beef gain 2.5 – 4.0 pounds per day (Mathews and Johnson, 2013; National Cattlemen's Beef Association). Grass-fed cattle gain roughly 1 pound per six pounds of feed consumed (National Cattlemen's Beef Association).

Decreasing Beef Production Costs

Producers are continually looking for ways to decrease input cost of cattle production, ensuring their economic livelihood. They achieve decreased production costs through utilizing alternative feed sources and decreasing their operating costs.

Cost of feed accounts for roughly 60 to 70 percent of production costs (Lawrence and Strohbehn, 2016; Lawrence et al., 2016). One tool producers can utilize to cut production cost is feeding co-products, such as corn distillers grains from ethanol product.

Behind cost of feed, the second highest cost of beef production is operating cost (Lawrence and Stronhehm, 2016). Operating costs account for any input items which include cattle, vaccines, ear tags, etc. (Lawrence and Stronhehm, 2016). Producers require many of these input items that have non-negotiable costs, therefore producers

need to focus on changes they can make to improve efficiency while maintaining performance (Stewart et al., 2013). Areas producers should focus on are understanding and implementing nutrition, pasture management, financial management, health, and genetics (Stewart et al., 2013). According to Stewart et al. (2013), producers can focus on the following six management priorities: understanding and controlling basic input costs in the cow herd; evaluating heard nutrition program; soil testing and fertilization; improving grazing management when applicable; maintaining a sound herd health program and moving herd genetics forward. When beginning to make reductions in production cost, producers should identify the largest input cost and begin decreasing it (Stewart et al., 2013). Many times decreasing costs means making and implementing difficult management choices.

Alternative Feeds for Cattle

There are a number of feed alternatives that are utilized when formulating beef feedlot rations. These alternatives range from bread co-product to potato silage and more and the alternative used greatly depends on region (Lardy and Anderson, 2009). Even though producers are utilizing more and more corn alternatives, beef diets still contain roughly 50% corn (Crawford, 2011). Regardless of the alternative feed utilized, all rations should be balanced to meet the nutritional needs of an animal while still combining the least cost for producers.

Feed alternatives that have been gaining popularity within the Midwest include co-products from corn ethanol production which include distillers grains. Feedlots within the upper Midwest utilize corn distillers grains while more southern feedlots utilized barley

and wheat distillers grains. Other corn alternatives utilized within the Midwest include corn gluten feed, corn screenings, corn syrup, crude glycerin, soybean hulls, beet pulp, brewers' grains, and potato waste (DiCostanzo, 1996; Crawford, 2011).

Corn distillers grains is a cost effective feed source for beef producers as it is 75 – 85% the cost of corn (SDSU, 2011). When fed between 6-15% of the diet dry matter (DM), distillers grains is fed as a protein source (Klopfenstein, 2001). Feeding above 20% of the diet DM results in distillers grains being fed as an energy source (Klopfenstein, 2001). When utilized, producers need to feed wet distillers grains within seven days of production in the summer and two to three weeks within the winter due to high moisture values (Lardy and Anderson, 2009).

From Kernel to Distillers Grains

Ethanol and distillers grains are products of starch fermentation and since corn is comprised of 70% starch, corn is the one of the most valuable sources of ethanol (Bothast and Schlicher, 2005). In 2003, 10% of the United States corn was utilized in the formation of ethanol. Dry milling and wet milling are the two main processes that result in ethanol production from corn starch fermentation. The main focus within the dry milling process is increasing the capital return per gallon of ethanol and is utilized by 67 - 90% of ethanol plants within the United States (Bothast and Schlicher, 2005; RFA, 2015). The incentive to capitalize returns is evident in the production of ethanol per bushel of corn as the dry milling processes results in 2.8 gallons of ethanol per bushel of corn compared to the 2.5 gallons of ethanol per bushel of corn achieved through wet milling (Bothast and Schlicher, 2005).

A co-product that is produced through ethanol production is distillers grains, which can be utilized as a high quality feed source within livestock diets. Dry milling results in wet cake and thin stillage. The wet cake can be sold as is, which results in the product known as wet distillers grains (WDG), or it can be dehydrated to form either modified distillers grains (MDG) or dry distillers grains (DDG). Wet distillers grains contains roughly 60 – 65% water; MDG contains 45 - 50% water; and DDG contains roughly 8 – 35% water (Lardy and Anderson, 2009; DiCostanzo, 2012). While producers can purchase WDG, MDG, or DDG, it is not common as distillers grains with added solubles as the solubles portion adds nutritional value and increases performance of animals. Distillers grains with solubles is produced at a rate of 17 pounds per bushel of corn through the dry milling process (Bothast and Schlicher, 2005).

The solubles portion of the feed is achieved through evaporation of the thin stillage which is added back to the distillers grain to achieve wet distillers grains with solubles (WDGS), modified distillers grains with solubles (MDGS), and dry distillers grains with solubes (DDGS) (Liu, 2011).

Nutritional Composition of Distillers Grains

There is some disagreement in regards to nutrient composition of distillers grains. The NRC (1996), reported that distillers grains contains 10-15% ether extract (EE); 40-45% neutral detergent fiber (NDF); 30-35% crude protein (CP); and 5% ash while Klopfenstein et al. (2006), reported distillers grains contains 12% EE, 36% NDF, 30% CP, and 0.9% phosphorous. According to Lardy and Anderson (2009), corn dry distillers grains contain 92.0% dry matter (DM); 29.5% crude protein on a dry matter basis (CP);

86.0% total digestible nutrients (TDN); 0.96 Mcal/lb net energy for maintenance (NEm); and 0.66 Mcal/lb net energy or gain (NEg). Lemenager at al. (2006), concluded that corn distillers grains with solubles (DGS) contain roughly 28 – 30% CP. According to a meta-analysis done by Zanton and Heinrichs (2016), the range of CP within dried distillers grains with solubles (DDGS) is 30.6 – 33.5% on a dry matter basis with 29.5 – 37.4% neutral detergent fiber (NDF). Lim and Yildieim-Askoy (2008), concluded that DDGS and DDG both contain 94% DM, 29.4% CP on a dry matter basis, and 9.8% crude fat on a dry matter basis. Corn wet distillers grains contains 20.0% DM; 29.5% CP; 126.0% TDN; 1.42 Mcal/lb NEm; and 0.98 Mcal/lb NEg (Lardy and Anderson, 2009). DiCostanzo (2012), concluded that distillers grains ranges in 25 – 35% protein and corn wet distillers grains contains 25 -35% DM.

Corn distillers grains is not the only distillers grain utilized in feedlot diets. Other distillers grains that can be utilized include dried barley, sorghum, and wheat distiller grains. Barley dry distillers grains contains 92.0% DM; 30.1% CP; 69.1% TDN; 0.70 Mcal.lb NEm; and 0.43 Mcal/lb NEg while wheat dry distillers grains contains 93.0% DM; 33.5% CP; 78.9% TDN; 0.85 Mcal/lb NEm; and 0.56 Mcal/lb NEg (Lardy and Anderson, 2009).

Producing Reduced-Fat Distillers Grains

Reduced-fat distillers grains is another feed co-product from ethanol product that is formed from extracting corn oil from the thin stillage produced from dry milling. Corn oil is removed through back-end centrifugation, which extracts 4% of the 30% of the oil that remains in the thin stillage after dry milling (Lardy and Anderson, 2009; Rutherford,

2014). After back-end centrifugation, the thin stillage is evaporated to produce the solubles that are added back to the distillers grains product from dry milling. This additional corn oil extraction results in a livestock feed source that contains 4% less EE when compared to full fat distillers grains (Lardy and Anderson, 2009; Rutherford, 2014).

In 2013, the ethanol industry expanded and plants began extracting corn oil through back-end centrifugation of the thin stillage (Lundy and Loy, 2014). This resulted in the formation of reduced-fat distillers grains that contain 7-9% EE and 3 – 9% corn oil compared to 10 – 12% EE and 12 – 15% corn oil within full-fat distillers grains (Anderson and Engel, 2014). When comparing the energy within corn oil and starch, corn oil has 2.25 greater energy value (Anderson and Engel, 2014).

Due to the reduced ether extract levels, reduced-fat distillers grains can be fed at 0.34 – 3.27 percent higher inclusion rate when compared to full-fat distillers grains (Diaz-Royon et al., 2012). This increase in inclusion levels is due to fat content being the second limiting factor when formulating a beef cattle ration, after sulfur content (Loy, 2008). Today, over 85% of ethanol plants continue to extract corn oil and market reduced-fat distillers grains to livestock producers (Lundy and Loy, 2014).

The nutritional value of fat-reduced distillers grains is very similar to that of full-fat distillers grains. Buckner et al. (2007), determined that mean composition of fat in wet distillers grains plus solubles (WDGS) and modified distillers grains with solubles (MDGS), collected from six ethanol plants, was 11.9% while 0.84% of the co-product consisted of phosphorus and 0.77% was sulfur. Fat levels differed depending on ethanol plant while dry matter varied per plant, per day (Buckner et al., 2011).

While fat and DM content vary per distillers grains source, fatty acid composition also varies. A recent meta-analysis concluded that the fatty acid with the highest composition within distillers grains is linoleic acid (C18:2) with 49.0 g/100g of total fatty acid profile (Diaz-Royon et al., 2012). Oleic acid (C18:1) was the second highest at 35.0 g/100g of total fatty acid profile and the fatty acid with the lowest overall concentrate was eicosadienoic acid (C20:2) with 0.06 g/100g of total fatty acid profile (Diaz-Royon et al., 2012).

Full-Fat Distillers Grains in Finishing Feedlot Diets

When comparing WGDS, MDGS, and DDGS based on cattle performance and resulting carcass characteristics, WDGS has the highest level of efficiency; however, MDGS and DDGS tend to outperform conventional feedlot diets.

Wet Distillers Grains

In a 2014 study, authors concluded feeding 60% wet distillers grains with solubles (WDGS) had no impact on feed efficiency but had decreased dry matter intake (DMI) when compared to steers fed 30% WDGS (Ponce et al., 2014). Gut fill linearly increased when feeding 0, 30, or 60% WDGS (Ponce et al., 2014).

When feeding 0 or 30% WDGS of diet dry matter in the last 21 days before harvest, 0% WDGS had a greater average daily gain (ADG) (Hales et al., 2014). However, when 0 or 30% WDGS were fed throughout the entire finishing feedlot diet, cattle fed 30% had greater ADG; gain to feed ratio (G:F); and dressing percent (Hales et al., 2014).

When fed 0, 15, or 30% WDGS on a dry matter basis, it was concluded that there was a linear increase in PUFA but no treatment influence on total lipid content, marbling

texture, marbling distribution, Warner-Bratzler shear force, or sensory attributes ribeye steaks (Mello, Jr. et al., 2012a). Feeding 30% WDGS resulted in lower values of L* on day 3 of retail shelf life analysis and higher levels of oxidation in 7 day retail shelf life analysis (Mello, Jr. et al., 2012a). Higher levels of oxidation were attributes to linear increases in total trans fatty acids, poly unsaturated fatty acids (PUFA), and linoleic acid (C18:2) (Mello, Jr. et al., 2012a).

Larson et al. (1993), observed increased efficiencies in yearlings and calves fed wet distillers byproducts when compared to conventional feedlot diets which was attributed to increased energy utilization. Wet distillers byproducts provided 169% and 128% of the energy value of corn when fed to yearlings and calves, respectively (Larson et al., 1993). Watson et al. (2014), observed a 178 to 121% decrease in the value of WDGS compared to the value of feeding corn when WDGS from increased from 10% to 50% inclusion in the diet DM. Quadratic responses have been observed in DMI, final BW, ADG, and gain to fed ratio (G:F) as WDGS inclusion increased from 0, 10, 20, 30, 40, and 50% of the diet dry matter (Watson et al., 2014). The highest level of G:F was observed when feeding 40% WDGS (Watson et al., 2014).

Vander Po et al. (2009), l performed a cannulation study which revealed that feeding 40% WDGS had numerically less rumen pH when compared to animals fed tallow or high moisture corn. It should be noted that while there was a numerical difference, it was not significant. These cattle also had higher levels of total tract fat digestion; a larger proportion of unsaturated fatty acids reaching the duodenum; and had lower acetate: propionate proportions (Vander Pol et al., 2009).

The overall effect of WDGS on performance has been observed to be influenced by corn processed utilizing different methods. Wet distillers grains with solubles and dry-rolled corn (DRD) increased final BW and ADG compared to finely ground corn (FGC), steam-flaked corn (SFC), and whole corn (WC) (Vander Pol et al., 2008). High-moisture corn (HMC) fed with WDGS also had similar final BW and ADG as DRD + WDGS but also increased G:F (Vander Pol et al., 2008).

Contrary to previous studies discussed, Vander Pol et al. (2006), observed no difference in carcass characteristics when WDGS was fed at 0, 10, 20, 30, 40, and 50% diet DM. As WDGS inclusion increased from 10 to 50%, the value of WDGS compared to corn decreased from 178 to 121% (Vander Pol et al., 2006).

Modified Distillers Grains

Prior to the expansion of the ethanol industry and corn oil extraction, modified distillers grains with solubles (MDGS) was a common feed ingredient for feedlot diets within the Midwestern regions. A study done at the University of Minnesota concluded feeding 35% MDGS in the finishing feedlot diets of crossbred steers did not affect sensory attributes in cooked strip steaks (Compart, 2013). Mello Jr, et al. (2012b), concluded that feeding 10, 20, 30, 40, and 50% MDGS had no effect on ribeye area but did increase steric, linoleic, poly unsaturated fatty acids, and omega-6 fatty acids within 12^{th} rib back fat samples from crossbred feedlot steers. When evaluating 0, 25, 40, and 70% MDGS in finishing feedlot steer diets, steers fed 70% MDGS had lower DMI compared to steers fed lower MDGS inclusions (Veracini et al., 2013). Steers fed 70% MDGS also had lower ribeye areas and linearly decreasing trend towards lower USDA quality grades (Veracini et al., 2013). Similar to Mello Jr, et al. (2012b), findings,

Veracini et al. (2013), concluded that increasing MDGS inclusions led to increasing concentrations of poly unsaturated fatty acids (PUFA).

Final BW, ADG, and DMI had quadratic responses when MDGS was fed from 0 to 50% inclusion rates within the diet DM at 10% increase intervals while G:F exhibited a linear response (Watson et al., 2014). As MDGS inclusions increased from 0 to 50% within the diet DM, the feeding value of MDGS, relative to corn, decreased from 125% to 111% (Watson et al., 2014). Feeding 26.9% MDGS increased body weight gain and hot carcass weight while decreasing ribeye area (Arias et al., 2012).

Dry Distillers Grains

Feeding 50% dry corn distillers grains plus solubles (DDGS) has shown to linearly decrease total tract dry matter and starch digestibility while having no negative effect on nutrient retention (Salim et al., 2012). However, as DDGS supplementation increased, total excretion of nitrogen, phosphorous, calcium, magnesium, sulphur, and potassium increased (Salim et al., 2012). On the contrary, total-tract digestion increased due to increasing levels of DDGS supplementation in pasture raised steers and was evident with increasing digestibility in neutral detergent fiber (NDF) and ether extract (EE) (Martinez-Perez et al., 2013).

In a meta-analysis conducted by Griffin et al. (2013), it was discovered that supplementing dried distillers grains with solubles (DDGS) to cattle raised on pasture linearly increased final bodyweight (BW) and average daily gain (ADG). Supplementing DDGS in growing diets also increased final BW and ADG (Griffin et al., 2012). Martinez-Perez et al. (2013), also noted increased ADG with increasing DDGS supplementation to pasture raised steers. When feeding DDGS and MDGS, DDGS

increased dry matter intake (DMI) by seventeen percent; however, there was little to or no difference ruminal metabolism observed in ruminal cellulose activity or ruminal methane concentration due to MDGS or DDGS (Schroeder et al., 2014).

Feeding DDGS lowered monounsaturated fatty acids (MUFA) and increased polyunsaturated fatty acids (PUFA) within backfat samples when compared to steers fed a barley-based finishing diet (Aldai et al., 2010a).

Buckner et al. (2007), observed quadratic trends in final BW and ADG and increased F:G when steers were fed 0, 10, 20, 30, 40, and 50% DDGS compared to conventional finishing feedlot diets. The greatest responses in final BW, ADG, and G:F were observed at 20% DDGS (Buckner et al., 2007).

When feeding 0, 15, 30, 45, 60, and 75% DDGS on a dry matter basis, Depenbusch et al. (2009) observed a quadratic response in DMI, ADG, and final BW with maximal levels achieved at 15% DDGS inclusion. Marbling scores were not influenced by feeding increasing levels of DDGS but tenderness increased linearly as inclusion levels increased from 0 to 75% (Depenbusch et al., 2009). Treatment linearly increased linoleic acid (C18:2n-6), total n-6 fatty acids, and total polyunsaturated fatty acids (PUFA) (Depenbusch et al., 2009).

Leupp et al. (2009), observed increased a* values in strip steaks from feeding 30% DDGS to feedlot steers when compared to steaks from control animals. No differences in strip steak tenderness, juiciness, or flavor in strip steaks were perceived by untrained panels between control and 30% DDGS strip steaks (Leupp et al., 2009). On the contrary, Koger et al. (2010), did not observe a difference in L*, a*, or b* values between strip steaks from animals fed 20 and 40% WDGS or DDGS.

Comparing Wet, Modified, and Dry Distillers Grains with Solubles

The feeding value of WDGS, MDGS, and DDGS has been observed as being 45.7%, 26.5%, and 9.3% above the feeding value of corn, respectively (Nuttelman et al., 2011). Of the three distillers grains, WDGS had the highest overall feeding value as it was 35.4% and 17.8% greater than DDGS and MDGS, respectively (Nuttelman et al., 2011). It was observed that DMI increased in DDGS and MDGS compared to WDGS and WDGS had higher G:F compared to both DDGS and MDGS (Nuttelman et al., 2011).

Alternative Distillers Grains

There was no difference in ADG, DMI, or G:F between corn DDGS, sorghum DDGS, or soybean meal finishing feedlots diets; however, steers fed sorghum DDGS reached final finishing weights 23.9 days before corn DDGS and 19.4 days before soybean meal finishing diets (Wood et al., 2011). Sorghum DDGS fed cattle had smaller hot carcass weights (HCW) compared to corn DDGS and soybean meal, but no other carcass characteristics were influenced by treatment (Wood et al., 2011).

When comparing corn versus wheat dried distillers grains with solubles (DDGS), corn DDGS resulted in more desirable carcass characteristics (Aldai et al., 2010a). Overall, steaks from cattle fed corn DDGS was perceived to be more tender and palatable compared to a standard barley-based finishing diet (Aldai et al., 2010a). Consumers noted that cattle fed 20% corn DDGS resulted in increased beef flavor intensity and desirability when compared to 40% corn DDGS (Aldai et al., 2010a). Barley-based diets tended to increased dark color and shear force values compared to both wheat and corn DDGS (Aldai et al., 2010a). Feeding corn DDGS increased overall trans-18:1 fatty acid

percentage within backfat compared to wheat DDGS and barley-based finishing diets (Aldai et al., 2010b).

Reduced – Fat Distillers Grains in Finishing Feedlot Diets

When looking at research utilizing reduced-fat modified distillers grains with solubles (RFMDGS), there are varying results. In a study that utilized crossbred steers (n = 225), results showed that feeding 40% RFMDGS during the finishing feedlot phase increased final body weight and average daily gain, reduced feed to gain ratio, and increased hot carcass weight when compared to full-fat MDGS (Jolly et al., 2013). On the contrary, another study concluded that feeding 70% RFMDGS did not affect animal performance or carcass characteristics in finishing diets of Angus crossbred steers (n = 130) (Veracini et al., 2013).

Hot carcass characteristics, ribeye area, and marbling score were increased by feeding 20% reduced-fat distillers grains to Jersey (n = 12) and Limousin x Jersey (n = 24) steers; however, there was no treatment affect on Warner-Bratzler shear force or thiobarbituric acid reactive substances (TBARS) (Johnston, 2014).

Vander Pol et al. (2009), observed a difference in overall performance of animals fed full-fat WDGS compared to animals fed 5% corn oil, suggesting that the fat within WDGS has more caloric value compared to corn oil (Vander Pol et al., 2009).

De-Oiled MDGS fed at 20 and 40% of diet DM resulted in similar final BW, DMI, ADG, and F:G as steers fed full-fat MDGS at the same inclusion levels (Bremer et al., 2014). Jolly et al. (2013), observed no difference in live animal performance or carcass characteristics between animals fed 27% de-oiled or full-oil condensed distillers grains (CDG) or 40% de-oiled or full-oil MDGS. However, it should be noted that steers

fed either CDG or MDGS exhibited higher final BW, ADG, and HCW compared to control animals fed conventional feedlot diets (Jolly et al., 2013).

When comparing full-fat to reduced-fat WDGS diets, steers fed full-fat WDGS out performed steers fed reduced-fat WDGS in respect to efficiency (Bremer et al., 2015). A linear response was also observed for increased ADG and F:D when steers were fed 0%, 17.5%, and 35% reduced-fat WDGS compared to controls (Bremer et al., 2015). On the contrary, Jolly et al. (2014), observed no difference in final BW, DMI, F:G; HCW; ribeye area (REA); 12th rib fat; calculated yield grade; or marbling score between steers fed conventional feedlot diets; 35% FF or RF WDGS; 50% FF or RF WDGS; or 65% FF or RF WDGS. The only difference in performance that was observed was an increase of DMI by 1 pound per day within steers fed RF WDGS versus FF WDGS (Jolly et al., 2014).

When comparing responses between RF WDGS and FF WDGS, both fed at 35% diet DM, there was no difference in performance of carcass characteristics (Gigaz et al., 2011). It should also be noted that there was no difference between live animal performance and carcass characteristics of steers fed conventional feedlot diets consisting of dry-rolled and high-moisture corn when compared to steers fed WDGS, regardless of fat content (Gigaz et al., 2011).

No treatment difference in final BW, overall ADG, overall G:F, HCW, dressing percent (DP), REA, fat thickness (FT), % KPH, or yield grade (YG) were observed between steers fed control (2.44% oil), low-fat DDGS (5.47% corn oil), medium-fat DDGS (8.05% corn oil), or high-fat DDGS (12.96%) were observed (Anderson and Engel, 2014). It should be noted that DMI had an overall quadratic effect during the day

29- finish phase (Anderson and Engel, 2014). This was due to high DMI in cattle fed high-fat DDGS and low DMI in cattle fed low-fat DDGS (Anderson and Engel, 2014). Marbling score also had a linear effect as corn oil levels increased and there was a trend for higher percent USDA Choice carcasses as corn-oil percentage increased (Anderson and Engel, 2014).

Kelzer et al. (2011), observed similar results in ADG, overall DMI, F:G, HCW, YG, BF, % KPH, REA, and marbling score as these traits were not influenced by dietary treatment. Dietary treatments included feeding either a control, 35% DDGS (5.96% fat), or 35% low-fat DG (3.53% fat) (Kelzer et al., 2001). Diets consisting of DDGS and low-fat DDGS had similar responses while the conventional control had greater levels of DMI (Kelzer et al., 2011).

Variability within Ether Extract Levels Results in Varying Responses

Ether extract content is rarely similar within studies, which could account for the variability in live animal responses and carcass characteristics. Differences in ether extract concentration can be due to differing production practices across ethanol plants (Zanton and Heinrichs, 2016). The range of fat within full-fat distillers grains is 9.4 – 15.7% on a dry matter basis with average fat content at 12.6% on a dry matter basis (Diaz-Royon et al., 2012).

Studies have shown that increased levels of fat within the diet decrease DMI (Jolly et al., 2014; Ponce et al., 2014; Watson et al., 2014; Veracini et al., 2013). This could lead to varying responses with carcass quality as well.

Distillers Grains and Processed Meat Quality

A major concern when feeding distillers grains to animals raised for human consumption is the content of linoleic acid (C18:2) that becomes deposited within the animal's subcutaneous fat. Of the fat that is in full-fat distillers grains, 49% of it is linoleic acid, which is a PUFA that readily oxidizes when present in meat products. Monogastric animals such as pigs cannot breakdown linoleic acid, thus increasing the deposition of linoleic acid within their fat (Sosnicki, 2010). Due to biohydrogenation, ruminants such as cattle, can further break-down PUFA thus decreasing the composition of linoleic acid within their fat (Jenkins et al., 2008).

High contents of linoleic acid within adipose not only increase oxidation and reduce retail shelf life stability, but they also lead to what is commonly referred to as soft fat (McClements and Decker, 2008; Wood et al., 2003). This phenomenon is widely seen within the swine industry when distillers grains is fed above 30% of the diet dry matter (Sosnicki, 2010). Soft fat leads to muscle separation within the loin, ham, and shoulder of a pork carcass (Sosnicki, 2010). Soft fat in bellies leads to decreased bacon slice yield and inconsistent slice width (Sosnicki, 2010). While diet plays a key role in firmness of pork fat, it is also influenced by genetics (Sosnicki, 2010).

The amount of saturation within a fatty acid is responsible for the melting point or firmness of the fat product (Sosnicki, 2010). The higher the saturation level, the higher the melting point and the firmer the fat (Sosnicki, 2010). The current standard for measuring the saturation level within a fat sample is calculated iodine value.

A concern within beef production is at what level, if any, soft fat will be achieved. While soft fat has not yet been achieved in beef, pasture-fed animals deposit higher levels

of linoleic acid within backfat samples when compared to grain-fed animals (Fincham et al., 2009).

Influence of Breed Characteristics on Carcass Characteristics and Beef Quality

Feed ingredients are not the only thing that affects the overall performance and carcass characteristics of a beef animal. Breed effects vary amongst groups of cattle and can affect body size, milking potential, age at puberty, climate adaptability, fleshing ability, muscle expression, cutability, and marbling (Hammack, 1914). Webster dictionary defines breed as, "a stock of animals or plants within a species having a distinctive appearance and typically having been developed by deliberate selection". Within the cattle breed, there are seven functional types that consist of British beef, Continental beef, Continental dual purpose, Dairy, Bos indicus, American, and lastly Specialty (Hammack, 1914). The most common breeds utilized within Midwestern feedlots are British, Continental, Continental Dual Purpose, and Dairy (Hammack, 1914). The present study utilized a four-way crossbred steer that was achieved utilizing an Angus x Gelbvieh sire and Holstein x Jersey dam.

British beef breeds are defined as originating from the British region and utilized for beef production (Hammack, 1914). An example of a British beef breed is Angus which were first brought to the United States in 1873 from Scotland (Angus: The Business Breed, 2016). Angus cattle are known to exhibit maternal behaviors are have high growth rates with a moderate to high size; early onset of puberty; moderate muscling; low cutability; and high marbling (Hammack, 1914).

Continental beef originated from European regions that are also utilized for beef production, but may be referred to as "exotic" beef animals (Hammack, 1914). An

example of a Continental beef breed that is commonly utilized within the United States is Limousin. Limousin cattle originated in France and are known for their muscle growth and efficiency (OSU, 1994). Limousin also exhibit high size; late age onset of puberty; very high muscling and cutability; and very low levels of marbling (Hammack, 1914).

Continental Dual Purpose cattle mainly originated from Continental Europe and are a combination of beef and dairy breeds, also commonly referred to as "exotic" beef animals (Hammack, 1914). Gelbvieh cattle are widely used within the United States and originated from Bavaria (American Gelbvieh Association, 2016). They are recognized for their outstanding maternal traits and exhibit high growth rates; calving ease; early onset of puberty; high muscling high cutability; and low marbling (American Gelbvieh Association, 2016; Hammack, 1914).

Dairy cattle are cattle that originated from Continental Europe and the British Isles (Hammack, 1914). Female dairy cattle are utilized primarily for milk production while castrated males are utilized within feedlot systems. Two dairy breeds that are commonly utilized throughout the United States are Holstein and Jersey cattle. Holsteins were first established within the United States in 1852 with origins from Holland (Holstein Association USA, 2016). Jerseys originated in Island of Jersey and were brought to the United States during the 1850s (OSU, 1994b). Holstein cattle are known for having very large frame size while Jerseys are known for their much smaller frame size. Holsteins exhibited early onset of puberty; extremely high milking potential; low muscling; high cutability; and average marbling while Jerseys exhibit very high milking potential; very low muscling; very low cutability; and very high marbling (Hammack, 1914).

Cross-bred cattle are known for having great performance and carcass characteristics through increasing the outstanding qualities of multiple breeds. It should come as no shock that increasing number of crossbred cattle are being breed in the United States, within both the beef and dairy industries. It is not uncommon for Holstein producers to breed their heifers and young females to Jersey sires to produce Jersey x Holstein males. This cross ensures high calving ease for the Holstein dams while producing a feedlot steer that will have increased marbling from the Jersey influence and increased muscling from the Holstein. Beef breeds are regularly crossed as well with Angus x Gelbvieh being very common. This cross exploits the growth and muscling of Angus along with the marbling of Gelbvieh.

Conclusion

The 2013 expansion within the ethanol industry has introduced a new alternative livestock feed source: reduced-fat distillers grains with solubles. Previous studies indicate a wide array of results in live animal performance and meat quality when animals were fed reduced-fat distillers grains. A continued concern among meat scientists is how changes within feed sources will affect meat quality; specifically, how corn oil extraction will impact meat quality. An objective of the present study was to quantify the effects of varying levels of reduced-fat distillers grains with solubles on carcass characteristics and meat quality to increase our overall knowledge of the impact of reduced-fat distillers grains with solubles.

Chapter II: Effects of Varying Levels of Reduced-Fat Distillers Grain in Finishing Diets of Feedlot Steers on Carcass and Meat Quality Characteristics

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INTRODUCTION

Distillers grains is a co-product of ethanol production that has been utilized in beef rations since the 1800s. Corn distillers grains is a cost effective feed source for beef producers as it is 75 – 85% the cost of corn (SDSU, 2011). When fed between 6-15% of the diet dry matter (DM), distillers grains is fed as a protein source while feeding above 20% of the diet DM results in distillers grains being fed as an energy source (Klopfenstein, 2001).

In 2013, the ethanol industry expanded and plants began extracting corn oil through back-end centrifugation of the thin stillage. This resulted in the formation of reduced-fat distillers grains (RFDG) that contain 7-9% ether extract (EE) and 3 – 9% corn oil compared to 10 – 12% EE and 12 – 15% corn oil within full-fat distillers grains (Anderson and Engel, 2014; Rutherford, 2014). Due to the reduced EE levels, reduced-fat distillers grains can be fed at 0.34 – 3.27 percent higher inclusion rate when compared to full-fat distillers grains (Diaz-Royon et al., 2012).

Today, over 85% of ethanol plants continue to extract corn oil and market reduced-fat distillers grains to livestock producers (RFA, 2015). The nutritional value of fat-reduced distillers grains is very similar to that of full-fat distillers grains (Buckner et al., 2011). However, EE levels differ depending on ethanol plant and DM varies per

plant, per day (Buckner et al., 2011). These varying levels can impact live animal performance.

While EE and DM content vary per distillers grains source, fatty acid composition also varies. A recent meta-analysis concluded that the fatty acid with the highest composition within distillers grains is linoleic acid (C18:2) with 49.0 g/100g of total fatty acid profile (Diaz-Royon et al., 2012). High contents of linoleic acid not only increase oxidation and reduce retail shelf life stability, but they also lead to what is commonly referred to as soft fat (McClements and Decker, 2008; Wood et al., 2003). This phenomenon is widely seen within the swine industry when distillers grains is fed above 30% of the diet dry matter (Sosnicki, 2010). A concern within beef production is at what level, if any, soft fat will be achieved. Another concern within the meat industry is oxidation rates within products from animals fed high levels of distillers grains.

Results vary among studies utilizing reduced-fat modified distillers grains with solubles (RFMDGS). In a study that utilized crossbred steers (n = 225), results showed that feeding 40% RFMDGS during the finishing feedlot phase increased final body weight and average daily gain, reduced feed to gain ratio, and increased hot carcass diets when compared to full-fat MDGS (Jolly et al., 2013). On the contrary, another study concluded that feeding 70% RFMDGS did not affect animal performance or carcass characteristics in finishing diets of Angus crossbred steers (n = 130; Veracini et al., 2013).

Hot carcass characteristics, ribeye area, and marbling score were increased by feeding 20% reduced-fat distillers grains to Jersey (n = 12) and Limousin x Jersey (n =

24) steers; however, there was no treatment effect on Warner-Bratzler shear force or thiobarbituric acid reactive substances (TBARS; Johnston, 2014).

The objective of the present study is to quantify the effects of varying levels of RFMDGS on carcass characteristics, fresh meat quality, and processed meat quality. Due to previous research, it was hypothesized that treatment will likely have no effect on carcass characteristics or fresh meat quality, but could detrimentally effect processed meat quality.

MATERIALS AND METHODS

Treatments and Experimental Design

Animal care complied with procedures approved by the University of Minnesota Institutional Animal Care and Use Committee. Animals were housed and fed at the University of Minnesota's Beef Research and Education Complex within UMore Park (Rosemount Research and Outreach Center) located in Rosemount, Minnesota, USA.

Fifty crossbred (Angus x Gelbvieh X Holstein x Jersey; initial bodyweight 379 ± 32 kg) were randomly assigned into four treatment groups and fed individually with a Calan gate system (American Calan, Inc., Northwood, NH) in a completely randomized study design. Dietary treatments consisted of 14.93% RFMDGS of diet dry matter (DMD) with 0.74% corn oil DMD containing 4.58% ether extract (EE; FF15); 15.60% RFMDGS DMD containing 3.92% EE (RF15); 30.84% RFMDGS DMD containing 4.79% EE (RF30); and 46.27% RFMDGS DMD containing 5.52% EE (RF45; Table 1). All steers received Rumensin to provide each steer with 287 mg monensin/steer/d

(Rumensin, Elanco Animal Health, Greenfield, IN; Table 1). The first diet, FF15, was formulated to mimic full-fat modified distillers grains with solubles fed at 15% inclusion within DMD. The RFMDGS utilized in this experiment was processed through a dry-milling process with back-end centrifugation of thin stillage. The RFMDGS used contained 8.81% EE and was from a single source (Big Rivers Resources, LLC, Boyceville, WI). Dietary inclusions of RFMDGS were corrected for the composition of the feed that was offered versus refusals (Table 1). Dietary treatments were mixed once per week and stored on a feed pad. A feed preservative (MYCO CURB, Kemin, Des Moines, IA) was added to each ration to preserve the dietary treatment through the prevention of mold growth.

Harvest, Hot Carcass Characteristics, and Fabrication

Steers were fed dietary treatments for the first 181 days, fed a common finishing diet for 3 days, and were individually weighed prior to shipping, as one group, to a commercial abattoir. Steers were humanely harvested, on the same day, at an abattoir in Dakota City, NE (Tyson, Inc.). Hot carcass weight (HCW); 12th rib back fat (BF); rib eye area (REA); percent kidney, heart, and pelvic fat (KPH); and marbling score were collected 24 hours postmortem by trained plant personnel. Strip loins (longissimus lumborum; IMPS #180) and shoulder clods (IMPS # 114) were collected from the right side of each carcass, labeled, vacuum packaged, and transported under refrigerated conditions to the University of Minnesota Meat Laboratory. Shoulder clods were re-packaged if necessary and frozen 60 hr postmortem. Strip loins were processed 72 hr postmortem.

Strip Loins

Vacuum sealed strips loin (IMPS #180) were weighed; vacuum seal bags were removed; and strips loins and vacuum bags were blotted dry with paper towel. Dried, individual strip loins and vacuum seal bags were reweighed to calculated vacuum purge loss (vacuum purge loss percentage = ((sealed loin – (dried loin + dried bag))/sealed loin) x 100).

Seven 2.54 cm steaks were serially cut from the anterior end of each strip loin for drip loss percentage (1), cook loss (2), retail shelf life color analysis (2), and Warner-Bratzler shear force analysis (2). One 2.54 cm strip steak was weighed, suspended at 2^{o}C for 24 hr in an isolated environment. Steaks were reweighed to calculate drip loss percentage (drip loss percentage = ((initial – final weight / initial weight) * 100).

Two 2.54 cm strip steaks were placed on polystyrene trays; wrapped in polyvinylchloride (PVC) overwrap (oxygen transmission rate: 1400 cc/m^2); and stored at 2^{o} C for 7 days under cool white fluorescent lighting (Sylvania H968, 100w). Subjective color scores of lean color, surface discoloration, and overall appearance were evaluated by an eight-member trained panel (AMSA, 1991). Lean color was evaluated on a 1-8 scale with 1 = extremely brown and 8 = extremely bright, cherry red. Surface discoloration was evaluated on a 1-11 scale with 1 = 91-100% discoloration and 11 = 0% discoloration. Overall appearance was evaluated on a 1-8 scale with 1 = extremely undesirable and 8 = extremely desirable (AMSA, 1991).

Objective color scores of L*, a*, and b* were taken at six locations on each steak and were evaluated the same day subjective color scores were obtained. Measurements were recorded using a spectrophotometry (HunterLab Miniscan ES, Hunter Associates Laboratory Inc., Reston, VA; AMSA, 1991). L* was evaluated on a 0-100 scale with 0 =

black and 100 = white; a* was evaluated on a -100-100 scale with -100 = green and 100 = red; and b* was evaluated on a -100-100 scale with -100 = blue and 100 = yellow (AMSA, 1991).

Two 2.54 cm strip steaks were weighed and cooked using a standard electric kitchen oven (Whirlpool, MI, USA) to an internal temperature of 71^{o} C at the geometric center (Type T thermocouple, Omega Engineering, Stanford, OH). Strip steaks were tempered to room temperature (22^{o}C), reweighed to calculate cook loss percentage (cook loss percentage = (raw weight – cooked weight) / raw weight) * 100), and stored for further analysis at 2^{o} C. Steaks were removed from refrigerated conditions two hours prior to analysis and tempered to room temperature (22^{o}C). Six maximum force readings per strip steak (1.27 cm diameter cores) were recorded for maximum force and Warner–Bratzler shear force values and averages were reported (Shimatzu Texture Analyzer, Model: EZ-SX, Kyoto, Japan). Each core was removed parallel to the muscle fiber by a hand corer.

Strip steak sensory evaluation was conducted by University of Minnesota Department of Food Science and Nutrition within the Sensory Center according to ASMA guidelines (ASMA, 1995). The Sensory Center is located in St. Paul, Minnesota, USA. Strip steak evaluation utilized one 2.54 cm strip steak that was individually wrapped in aluminum foil and cooked to an internal temperature of 71^{o}C at the geometric center using a standard electrical oven (Type T thermocouple, Omega Engineering, Stanford, OH; General Electric® Range, JAS02; Fairfield, CT, USA). After reaching an internal temperature of 71^{o}C at the geometric center, steaks were removed from the oven and immediately cut into 1 x 1 x 2.54 cm cubes. Cubes were placed in double boilers

(60°C) until served to panelists (n = 122). Each untrained panelist received two samples per dietary treatment in lidded 2 oz. plastic cups with random 3-digit numbers. Panelists were 18+ years, with no food allergies, consumed beef at least twice a month, and were compensated for participating. Panelists were served balanced for order and carry over effect. Panelists were asked to taste one sample piece and rate it for overall liking, flavor liking, and texture liking separate 120-point labeled affective magnitude scales (AMSA, 1995; Table 2). Panelists were then asked to taste the second sample piece and rate it for intensity of off flavor, juiciness, and toughness separate 20-point line scales labeled non at the left-most and labeled extremely intense for off-flavor, extremely tough for toughness, and extremely juicy for juiciness at the far right (AMSA, 1995).

Shoulder Clods

Shoulder clods (IMPS #114) were ground individually twice with a 0.375 cm grinder plate. Ground beef (0.91 kg) was placed on polystyrene trays and overwrapped with PVC (oxygen transmission rate: 1440 cc/m^2) overwrap, placed under cool white fluorescent lighting (Sylvania H968, 100w), and stored at 2°C for 7 days.

Subjective and objective color scores were evaluated every day using the same scales and methods as strip steak subjective and objective color analysis (AMSA, 1991).

Samples of ground beef on day zero were collected for percent moisture and percent fat analysis. Samples were vacuum packaged, frozen immediately, and later thawed for percent moisture and percent fat analysis. Samples were analyzed by SMART Turbo and SMART TRAC with a raw beef method and standardize frequency of 23.35 – 23.42 (Smart Trac II; CEM; Matthews, NC).

Samples of ground beef on day 0 and day 7 were collected for thiobarbituric acid reactive substances (TBARS) analysis, frozen immediately, and later thawed when analyzed using the thiobarbituric acid assay developed by Tarlagid et al., 1960. Thiobarbituric acid reactive substances analysis was measured using a spectrophometer (Spectronnic 20 $^{+}$, Spectronic Instruments, Inc., 532 nm). Analysis of TBARS was done at Agricultural Utilization Research Institute (AURI) located in Marshall, Minnesota, USA.

Blended meat blocks (11.34 kg, 3 animals/treatment, 2 blocks/treatment) were utilized to make an emulsified bologna product. Ground beef was chopped mixed (Alipina, PB 80-890-II Gossau S G, Switzerland) with a commercial seasoning blend (Bologna Frank SSNG Unit, Newly Wed Foods, Chicago, IL.), sodium nitrite cure (Heller's Modern Cure #47765, Newly Wed Foods, Chicago, IL), and ice for four minutes; stuffed in inedible collagen casings (Handtmann VF-608, Albert Handtmann Machimen Fabrik GmbH & Co., Biberach, Germany; Bologna 10.8 Walsrober Casings, Mar/Co Sales, Burnsville, MN); and cooked and cooled according to Appendix C. Two logs were produced per meat block. Once cooled, three 0.375 cm slices (Globe Slicer, Model 400, Globe Slicing Machine Co, Inc., Stamford, CT) were collected per log, placed on polystyrene trays, and vacuum sealed (3mil standard barrier, Bunzle PD, North Kansis City, MO). Slices were placed under fluorescent lighting (Sylvania H968, 100w) and stored at 2^{o}C for 14 days. Subjective and objective color score were evaluated every other day. Subjective color scores were obtained by an 8-member trained panel with lean color evaluated on a 1-8 scale with 1 = extremely brown and 8 = extremely bright, pink. Surface discoloration was evaluated on a 1-11 scale with 1 = 91-100% discoloration and

11 = 0% discoloration. Overall appearance was evaluated on a 1-8 scale with 1 = extremely undesirable and 8 = extremely desirable. Objective color analysis was obtained using the same methods as loin steaks and ground beef samples (AMSA, 1991).

Bologna sensory evaluation was conducted by University of Minnesota Department of Food Science and Nutrition within the Sensory Center according to AMSA guidelines (AMSA, 1995). The Sensory Center is located in St. Paul, Minnesota, USA. Bologna slices (0.375 cm; Globe Slicer, Model 400, Globe Slicing Machine Co, Inc., Stamford, CT) were served to untrained panelists (n = 108) for sensory attribute evaluation. Panelists were 18+ years, with no food allergies, consumed bologna within the last six months, and were compensated for participating. Two samples per dietary treatment were served to each panelist at 2^{o}C in lidded 2 oz. plastic cups and serving was balanced for order and carry over effects. Subjects were asked to taste one sample piece and rate it for overall liking, flavor liking, and texture liking on separate 120-point labeled affective magnitude scales (AMSA, 1995; Table 2). Subjects were asked to taste the second sample piece and rate it for intensity of off flavor and toughness on separate 20- point line scales labeled none at the left-most end and labeled extremely intense for off-flavor and extremely tough for toughness at the far right end (AMSA, 1995).

Backfat

Ten grams of backfat was collected from each strip steak utilized for Warner-Bratzler shear force analysis. Objective color scores of L*, a*, and b* were obtained using a spectrophotometer (HunterLab Miniscan ES, Hunter Associates Laboratory Inc., Reston, VA). L* was evaluated on a 0-100 scale with 0 = black and 100 = white; a* was evaluated on a -100-100 scale with -100 = green and 100 = red; and b* was evaluated on

a -100-100 scale with -100 = blue and 100 = yellow (AMSA, 1991). Samples were then vacuum packaged per animal and stored frozen until fatty acid composition analysis.

Gas chromatography (HP 6890 series, Santa Clara, CA) with flame ionization detection was used to obtain fatty acid profiles according to AOCS Official Method Ce 2-66 (2009) and AOCS Official Method Ce 1j-07 (2009). Total content of myristic (C14:0), pentadecanoic (C15:0), palmitic (C16:0), heptadecanoic (C17:0), stearic (C18:0), nonadecanoic (C19:0), eicosanoic (C20:0), tetradecenoic (9c-C14:1), palmitoleic (9c-C16:1), oleic (6t-C18:1), vaccenic (11t-C18:1), petroselenic (6c-C18:1), oleic (9c-C18:1), vaccenic (11c-C18:1), nonadecenoic (10c-C19:1), linoleic (9c,12c-C18:2), nonadecanoic (10c,13c-C19:2) and alpha linolenic (9c,12c,15c-C18:3) acid were recorded. Postmortem fatty acid analysis occurred at AURI in Marshall, Minnesota, USA. Fatty acid profile was used to calculate the iodine value (iodine number = [16:1]*0.95 + [18:1]*0.86 + [18.2]*1.732 + [18:3]*2.616 + [20:1]*0.785 + [22:1]*0.723).

Data Analysis

Sensory data was analyzed using the MIXED procedure in SAS using LSMEANS with PDIFF function and Tukey's adjustment (SAS Inst. Inc., Cary, NC). Response variables were overall liking, flavor liking, texture liking, off-flavor intensity, juiciness intensity, and toughness intensity.

Retail shelf life data was the only repeated measures analysis and was analyzed using the MIXED procedure in SAS using LSMEANS with PDIFF function and Tukey's adjustment (SAS Inst. Inc., Cary, NC). A day by treatment interaction was also utilized. Experimental unit was individual steer for strip steak and ground beef retail shelf life as

all animals were fed individually using a Calan gate system. Log was the experimental unit for bologna retail shelf life as ground beef was mixed to form a meat block. Response variables were L*, a*, b*, subjective lean color, subjective surface discoloration, and subjective overall appearance.

All other data were analyzed using the MIXED procedure in SAS using LSMEANS with PDIFF function and Tukey's adjustment (SAS Inst. Inc., Cary, NC). Experimental unit was individual steer, as all animals were fed individually using a Calan gate system. Response variables evaluated included carcass characteristics and fresh and processed meat quality characteristics.

Outliers were removed and one outlying carcass was removed as it was a dark cutter. Outliers were determined when extreme responses existed. Data was sorted by treatment and extreme responses were defined as a data point outside the lower and upper quartile range.

RESULTS AND DISCUSSION

Carcass Characteristics and Fresh Meat Quality

There was no treatment effect for HCW ($P = 0.96$), BF ($P = 0.63$), REA ($P = 0.62$), KPH ($P = 0.27$), or marbling score ($P = 0.67$) (Table 3). Warner-Bratzler shear force values were higher in FF15 strip steaks compared to all other treatments ($P < 0.01$; Table 4). Purge loss ($P = 0.39$), drip loss ($P = 0.09$) and cook loss ($P = 0.14$) percentage did not differ among treatments (Table 4).

It was hypothesized treatment would have no effect on carcass characteristics or fresh meat quality. Veracini et al., (2013) observed similar responses in Angus crossbred steers fed 70% RFMDGS in the diet dry matter. On the contrary, Jolly et al., (2013) observed increased HCW in animals fed 40% de-oiled MDGS, but did not observe differences in other carcass characteristics or fresh meat quality. Ribeye area was increased due to feeding 25% RF distillers grains with solubles (DGS) within the finishing feedlot phase (Johnston, 2014). Johnston, (2014), also saw no treatment effect on WBSF values between Jersey and Jersey x Limousin steers fed 20% RF DGS when compared to control. The difference in responses could be due to varying levels of ether extract (EE) that fluctuate based on ethanol plant procedures (Zanton and Heinrichs, 2016). Additionally, Johnston's (2014), control diet contained 3.3% EE while 20% RF DGS diet contained 4.1% EE. The present study contained 4.58, 3.92, 4.79, and 5.52% EE within FF15, RF15, RF30, and RF45 diets, respectively.

Strip Steak Sensory Evaluation

There was no treatment effect for overall liking (P = 0.15), flavor liking (P = 0.75), texture liking (P = 0.07), or off-flavor (P = 0.72) in steak sensory analysis (Table 6). Subjective toughness values of steaks from FF15 were higher than RF15 (10.78 and 8.77, respectively; P = 0.01; Table 6). Subjective juiciness values of steaks from FF15 were higher than RF45 (8.50 and 6.94, respectively; P = 0.03; Table 6).

These results were not expected as it was hypothesized feeding high levels of RFMDGS within the finishing feedlot phase would have no effect on fresh meat quality.

These data were also supported by Depenbusch et al. (2009), as no treatment difference was observed in juiciness and off-flavor of strip steaks from feedlot heifers fed 0, 15, 30, 45, 60, or 75% dried distillers grains with solubles (DDGS; 3.7 – 8.0% EE across diets) on a dry matter basis (P = 0.23 and P = 0.16, respectively).

Ground Beef Quality

Treatment did not affect percent moisture (P = 0.96) or percent fat (P = 0.97) in ground beef samples (Table 5). These results were expected as it was hypothesized treatment would have no effect on fresh meat quality. Data indicates fat is not a covariate when analyzing ground beef and bologna analysis.

Objective and Subjective Color Evaluation of Strip Steaks

Treatment did not impact L* (P = 0.31), subjective lean color appearance (P = 0.22), or subjective surface discoloration (P = 0.08; Figures 1, 4, and 5). Strip steak a* values of RF30 were higher on Day 0 compared to all other treatments (P < 0.01; Figure 2). Day 4 a* values were highest in RF30; however, RF30 and RF45 a* values were similar but different from FF15 and RF15 (P = 0.02, Figure 2). Similar to a* values, day 0 b* values were highest within RF30 strip steaks compared to all other treatments (P < 0.01; Figure 3). Day 4 b* values were similar and numerically higher within RF30 and RF45 samples when compared to FF15 and RF15 samples (P < 0.01; Figure 3). Subjective overall appearance was impacted by treatment on day 7 when RF30 strip steaks were different than RF45 strip steaks, but similar to FF15 and RF15 strip steaks (P

< 0.01; Figure 6). Numerically, RF45 had the highest day 7 subjective overall appearance score while RF30 had the lowest values (Figure 6).

It was hypothesized feeding high levels of RFMDGS within the finishing feedlot phase would likely have no effect on fresh meat quality; however, of the fat within distillers grains, 49% of the total fatty acid profile is linoleic acid (Diaz-Royon et al., 2012). Linoleic acid is a poly unsaturated fatty acid that leads to increased levels of oxidation and reduced shelf life stability (McClements and Decker, 2008).

Depenbusch et al. (2009), noted no treatment difference in a* or b* scores on d-0, d-3, or d-5 retail shelf life (P = 0.13) when conducting a seven day retail shelf life with diets containing 3.7 – 8.0 % EE. On d-7, strip steaks from heifers fed 60% DDGS (7.1% EE) had the lowest a* value (15.0) while 0% DGGS (3.7% EE) exhibited the highest a* value (19.5; P = 0.04). There was no difference in L* or b* values on d-7 retail shelf life (P = 0.36 and P = 0.37, respectively; Depenbusch et al., 2009). On d-0, L* values of strip steaks from heifers fed 75% DDGS were the lowest (44.0) while scores from 30.0% DDGS fed heifers were the highest (46.9; P = 0.04; Depenbusch et al., 2009). The differences in results may be due to varying levels of EE within the distillers grains between the present study and Depenbusch et al. (2009).

Objective and Subjective Color Evaluation of Ground Beef

Treatment had no impact on L* (P = 0.43), a* (P = 0.84), b* (P = 0.48), subjective lean color appearance (P = 0.14), subjective surface discoloration (P = 0.96), or subjective overall appearance (P = 0.06; Figures 7-12).

These results were not expected as it was hypothesized feeding high levels of RFMDGS in the finishing feedlot phase would have a detrimental effect on process products through increased oxidation and reduced retail shelf life stability. Johnston (2014), noted similar results as no treatment effect in L*, subjective lean color, subjective surface discoloration, or subjective overall appearance was observed, in ground patties, from steers fed 47% RFDGS (5.0% EE) on a DM basis.

Objective and Subjective Color Evaluation of Bologna

Treatment did not impact L* (P = 0.77), a* (P = 0.32), b* (P = 0.46), subjective lean color appearance (P = 1.00), subjective surface discoloration (P = 1.00), or subjective overall appearance (P = 1.00).

These results were not expected as it was hypothesized feeding high levels of RFMDGS in the finishing feedlot diet would have a detrimental effect on process products through increased oxidation and reduced retail shelf life stability. Similar results were observed as no treatment effect was observed during 7d retail shelf life in a*, b*, subjective lean color, subjective surface discoloration, or subjective overall appearance when comparing control and 47% RFDGS (5.0%) inclusion rates over all 7 days (Johnston, 2015).

Bologna Sensory Evaluation

There was no treatment effect for flavor liking or off-flavor in bologna sensory analysis (Table 7). Subjective overall liking was higher in RF45 compared to FF15 bologna samples (78.14 and 71.63, respectively; P = 0.03; Table 7). Subjective texture

liking of bologna from RF45 were higher than FF15 (78.25 and 67.51, respectively; P <0.01; Table 7). Subjective toughness liking of bologna from RF30 and RF45 were higher compared to FF15 (77.21, 78.25, and 67.51, respectively; P <0.01; Table 7).

These results were expected as it was hypothesized feeding high levels of RFMDGS in the finishing feedlot diet would have a detrimental effect on process products through increased oxidation and reduced retail shelf life stability. Contrary to the results observed, Johnston (2015), observed no dietary effects in overall liking, flavor liking, and off-flavor of bologna from steers fed up to 47% RFDGS (P = 0.07, P = 0.09, and P = 0.45, respectively; 3.3 – 5.1% EE). Bologna from steers fed a high-fat DDG diet (5.0% EE) had the lowest subjective toughness score (3.8, P < 0.01; Johnston, 2015).

Thiobarbituric Reactive Substances (TBARS) Evaluation

There was no treatment effect for Day 0 or Day 7 TBARS (P = 0.94 and P = 0.27, respectively; Table 8). These results were not expected as it was hypothesized feeding high levels of RFMDGS in the finishing feedlot diet would increase linoleic acid composition within backfat, leading to increased oxidation. Due to biohydrogenation, ruminants such as cattle, can further break-down PUFA thus decreasing the composition of linoleic acid within backfat which could be the reason there is no difference within TBARS observed (Jenkins et al., 2008). Johnston, (2015), observed no treatment effect when feeding Jersey and Jersey x Limousin steers fed 20% RF DGS (4.1% EE) when compared to control diets (3.3% EE; P = 0.96). Depenbusch et al. (2009), also observed no treatment effect in TBARS due to feeding 0, 15, 30, 45,60, or 75% DDGS (3.7 – 8.0% EE; P = 0.75).

Lipid Evaluation

Treatment did not impact L* (P = 0.59), a* (P = 0.62), or b* (P = 0.54) scores from lipid samples (Table 9).

There were fifteen fatty acids that were present within the backfat samples. Of those fifteen fatty acids, five were saturated fatty acids; eight were mono-unsaturated fatty acids (MUFA); and two were poly-unsaturated fatty acids (PUFA; Table 10). Within the saturated fatty acids, pentadecylic and margaric acid were the only ones impacted by treatment. Pentadecylic acid (C15:0) composition was lowest in RF45 lipid compared to all other treatments (P < 0.0) while margaric acid (C17:0) composition was higher in FF15, RF15, and RF30 when compared to RF45; however, FF15 and RF45 were similar (P = 0.02; Table 10). Of the MUFA, tetradecenoic acid (9c-C14:1) was the only one impacted by treatment and FF15 had a higher composition of tetradecenoic acid compared to all other treatments (P < 0.01, Table 10). Both of the PUFA present were not impacted by treatment (P = 0.34, Table 10).

There was no treatment effect on calculated iodine value (P = 0.59; Table 11).

It was hypothesized that treatment may have a detrimental effect of processed meat quality, due to increased levels of linoleic acid deposited within the backfat of the animal from feeding high levels of RFMDGS within the finishing feedlot phase. We did not observe this response as linoleic acid composition was not affected by treatment. This could be due to varying fatty acid composition within distillers grains that is observed within an ethanol plant and across different ethanol plants (Zanton and Heinrichs, 2016).

Contrary to the results observed, Koger et al. (2010), observed differences in linoleic acid composition between control (4.5% EE), 20% DDGS (6.3% EE), and 40% DDGS (7.7% EE) inclusion rates ($P < 0.01$). Backfat from animals fed 40% DDGS (7.7%) had the highest level of linoleic acid while control samples had the lowest (3.69 and 2.63, respectively). The differences in results could be due to differences within EE levels as the range of EE within the present study is 3.92 – 5.52% while Koger et al. (2010), utilized diets containing 4.5 – 7.7% EE.

CONCLUSION

Results indicated that feeding 45% RFMDGS of the diet DM had no effect on carcass characteristics; increased subjective toughness scores in fresh and processed meat, and decreased retail shelf life stability within fresh meat products while having minimal impacts on processed meat retail shelf life stability. Results also indicate that feeding 45% RFMDGS had minimal effects on fatty acid composition. Results indicate that feeding up to 45% RFMDGS within finishing feedlot diets may lead to minimal detrimental meat quality impacts.

ACKNOWLEDGEMENTS

Funding for this project was provided by Minnesota Corn Growers Association and Agriculture Utilization Research Institute.

Tables

Table 1. Experimental Diets

Ingredients (% DM)	Treatment[1]			
	FF15	RF15	RF30	RF45
Wheat Straw	9.00	9.01	9.01	8.89
Distillers Grain, Corn, Mod.	14.93	15.60	30.84	46.27
Corn Grain, Rolled, Dry	72.01	72.06	56.84	41.55
Corn Oil	0.74	0.00	0.00	0.00
Supplement[2]	3.31	3.33	3.31	3.28

[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[2]Supplement: 287 mg mpnensin/hd/d (Rumensin, Elanco Animal Health Geenfield, IN) and MYCO CURB (Kemin, Des Moines, IA) for mold prevention.

Table 2: Reference captions and point values of the labeled affective magnitude scale

Reference Caption	Point Value
Greatest imaginable disliking	0
Dislike extremely	13
Dislike very much	25
Dislike moderately	39.5
Dislike slightly	53
Neutral	60
Like slightly	67
Like moderately	81
Like very much	93
Like extremely	104
Greatest imaginable liking	120

Table 3. Effects of experimental treatment on carcass characteristics in feedlot steers

Carcass Traits	Treatment[1]				SEM[2]	P-Value[3]
	FF15	RF15	RF30	RF45		
HCW, kg	371.44	369.74	374.72	366.16	26.77	0.96
BF, cm	1.22	1.73	1.45	1.24	0.13	0.63
REA, sq. cm	86.39	86.84	83.29	87.48	0.36	0.62
KPH, %	2.46	2.67	2.41	2.62	0.11	0.27
Marbling score[4]	486.13	525.36	474.19	514.02	33.40	0.67

[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[2]Standard error of least square means, n = 12 or 13 steers /treatment.
[3]Significance is declared at $P \leq 0.05$.
[4]Marbling scores: 400.00=slight, 500.00=small.

Table 4. Effects of experimental treatment on moisture loss and shear force in feedlot steers

Characteristic	Treatment[1]				SEM[2]	P-value[3]
	FF15	RF15	RF30	RF45		
Purge loss, %	0.73	0.63	0.81	0.83	0.09	0.39
Drip loss, %	0.31	0.40	0.43	0.33	0.04	0.09
Cook Loss, %	25.07	23.83	24.13	22.33	0.89	0.14
Shear force, kg	4.56[a]	3.52[b]	3.57[b]	3.45[b]	0.26	<0.01

[a,b]Means within a row with different letters differ significantly.

[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

[2]Standard error of least square means, n = 12 or 13 steers /treatment.

[3]Significance is declared at $P \leq 0.05$.

Table 5. Effects of experimental treatments on sensory attributes in cooked strip steaks from feedlot steers

Sensory Attributes	Treatment[1]				SEM[2]	P-value[3]
	FF15	RF15	RF30	RF45		
Overall Liking[4]	66.27	71.73	70.33	69.15	1.74	0.15
Flavor Liking[4]	69.21	71.62	70.52	71.41	1.73	0.75
Texture Liking[4]	64.08	71.49	68.11	69.41	2.04	0.07
Toughness[5]	10.78[a]	8.77[b]	9.77[a,b]	9.41[a,b]	0.43	0.01
Juiciness[5]	8.50[a]	7.96[a,b]	7.42[a,b]	6.94[b]	0.39	0.03
Off Flavor[5]	4.35	3.85	4.47	4.07	0.41	0.72

[a,b]Means within a row with different letters differ significantly.

[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

[2]Standard error of least square means, n = 12 or 13 steers /treatment.

[3]Significance is declared at $P \leq 0.05$.

[4]Liking ratings were on a 120-point labeled affective magnitude scales, with the left most end labeled *strongest dislike imaginable* and the right most end labeled *strongest like imaginable*.

[5]Intensity ratings were on a 20-point line scale with the left most ends labeled *none* and the right most ends labeled *extremely tough, extremely juicy,* and *extremely intense*.

Table 6. Effects of experimental treatment on percent moisture and percent fat in ground beef from feedlot steers

Attribute	Treatment[1]				SEM[2]	P-Value[3]
	FF15	RF15	RF30	RF45		
Moisture, %	58.16	57.94	57.38	57.67	1.07	0.96
Fat, %	23.74	23.72	24.50	24.34	1.42	0.97

[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[2]Standard error of least square means, n = 12 or 13 steers /treatment.
[3]Significance is declared at $P \leq 0.05$.

Table 7. Effects of experimental treatment on thiobarbituric acid reactive substances (TBARS) in ground beef from feedlot steers

TBARS	Treatment[1]				SEM[2]	P-Value[3]
	FF15	RF15	RF30	RF45		
Day 0	0.48	0.46	0.53	0.53	0.10	0.94
Day 7	1.82	2.23	2.24	2.08	0.22	0.27

[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[2]Standard error of least square means, n = 12 or 13 steers /treatment.
[3]Significance is declared at $P \leq 0.05$.

Table 8. Effects of experimental treatments on sensory attributes in cooked bologna from feedlot steers

Sensory Attributes	Treatment[1]				SEM[2]	P-value[3]
	FF15	RF15	RF30	RF45		
Overall Liking[4]	71.63[a]	74.73[a,b]	77.16[a,b]	78.14[b]	1.64	0.03
Flavor Liking[4]	73.35	75.96	77.66	77.84	1.72	0.22
Texture Liking[4]	67.51[a]	73.38[a,b]	77.21[b]	78.25[b]	1.76	<0.01
Toughness[5]	6.86[a]	4.85[b]	3.99[b]	4.82[b]	0.40	<0.01
Off Flavor[5]	5.09	4.87	4.46	4.23	0.44	0.51

[a,b]Means within a row with different letters differ significantly.

[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

[2]Standard error of least square means, n = 12 or 13 steers /treatment.

[3]Significance is declared at $P \leq 0.05$.

[4]Liking ratings were on a 120-point labeled affective magnitude scales, with the left most end labeled *strongest dislike imaginable* and the right most end labeled *strongest like imaginable*.

[5]Intensity ratings were on a 20-point line scale with the left most ends labeled *none* and the right most ends labeled *extremely tough, extremely juicy,* and *extremely intense*.

Table 9. Objective color scores for lipid from feedlot steers

Score	Treatment[1]				SEM[2]	P-value[3]
	FF15	RF15	RF30	RF45		
L*	63.35	62.67	63.60	62.01	0.96	0.59
a*	0.57	0.72	0.50	0.22	0.31	0.62
b*	7.52	8.18	7.74	7.40	0.49	0.54

[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[2]Standard error of least square means, n = 12 or 13 steers /treatment.
[3]Significance is declared at $P \leq 0.05$.

Table 10. Effects of experimental treatment on beef fatty acid composition from feedlot steers

Fatty Acid (%)	Treatment[1]				SEM[2]	P-Value[3]
	FF15	RF15	RF30	RF45		
C14:0	3.48	3.57	3.09	3.33	0.14	0.12
C15:0	0.39[a]	0.45[a]	0.38[a]	0.23[b]	0.04	<0.01
C16:0	23.65	24.75	23.20	23.06	0.45	0.06
C17:0	0.91[a]	1.09[a]	1.01[a]	0.84[a,b]	0.06	0.02
C18:0	11.84	12.85	12.73	12.22	0.51	0.47
9c-C14:1	1.56[a]	1.13[b,c]	1.05[b]	1.47[a,c]	0.11	<0.01
9c-C16:1	4.47	4.07	4.05	4.81	0.22	0.48
6t-C18:1	0.31	0.35	0.28	0.18	0.09	0.61
11t-C18:1	5.07	5.26	4.81	5.20	0.24	0.55
6c-C18:1	0.00	0.00	0.00	0.00	0.00	1.00
9c-C18:1	38.71	37.88	40.94	40.19	0.83	0.06
11c-C18:1	1.67	1.59	1.65	1.58	0.06	0.70
11c-C20:1	0.05	0.00	0.04	0.11	0.39	0.28
9c,12c-C18:2	3.36	3.73	3.38	3.41	0.17	0.34
10c,13c-C19:2	0.12	0.05	0.10	0.05	0.04	0.46

[a,b,c]Means within a row with different letters differ significantly.

[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

[2]Standard error of least square means, n = 12 or 13 steers /treatment.

[3]Significance is declared at $P \leq 0.05$.

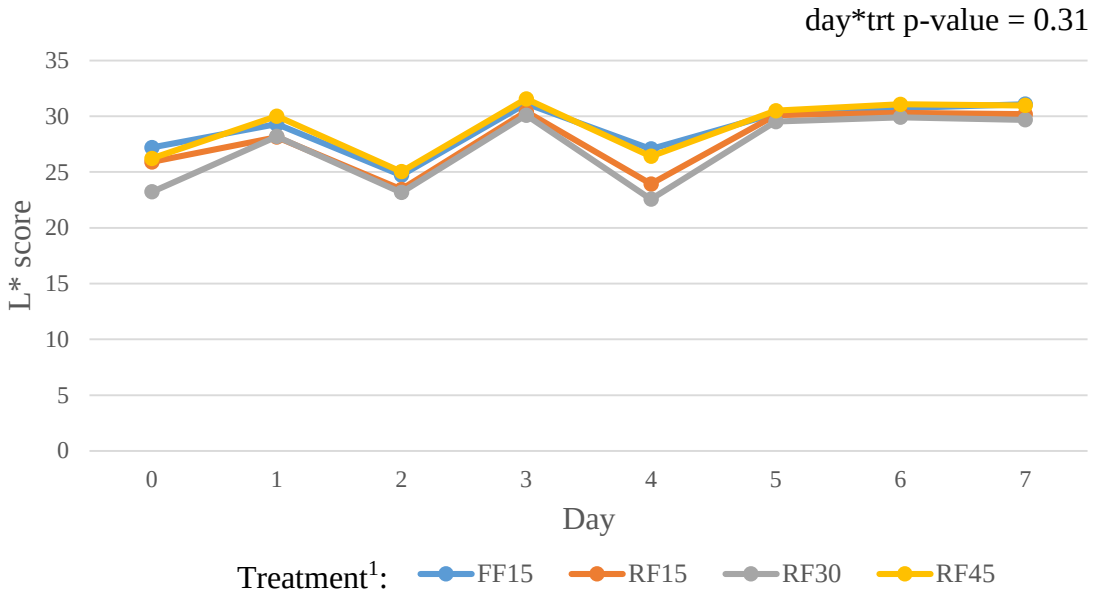
Table 11. Effects of experimental treatment on calculated iodine value from feedlot steers

	Treatment[1]				SEM[2]	P-Value[3]
	FF15	RF15	RF30	RF45		
Iodine Value	49.78	48.80	49.25	50.19	0.75	0.59

[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[2]Standard error of least square means, n = 12 or 13 steers /treatment.
[3]Significance is declared at $P \leq 0.05$.

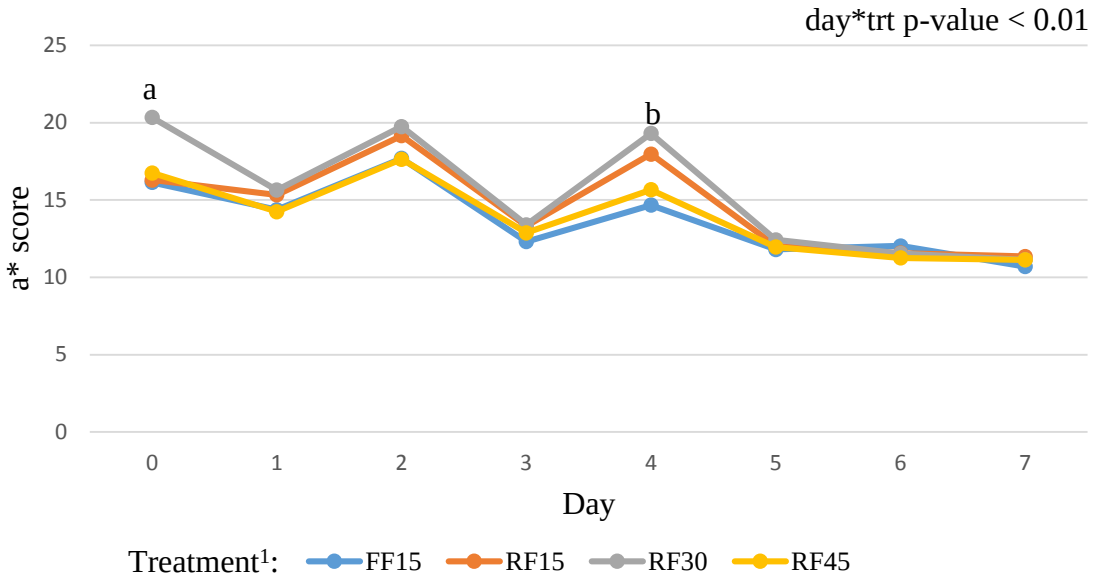
Figures

Figure 1: Effects of experimental treatment on objective lightness values (L*) of strip steaks (longissimus lumborum) from feedlot steers over seven-day retail shelf life



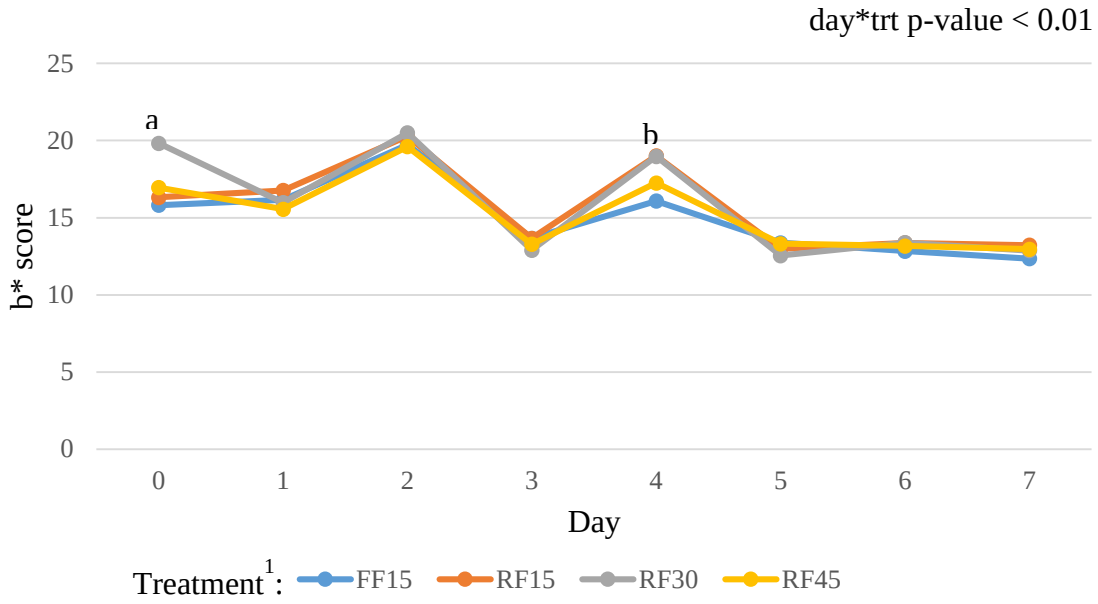
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 2: Effects of experimental treatment on objective redness values (a*) of strip steaks (longissimus lumborum) from feedlot steers over seven-day retail shelf life



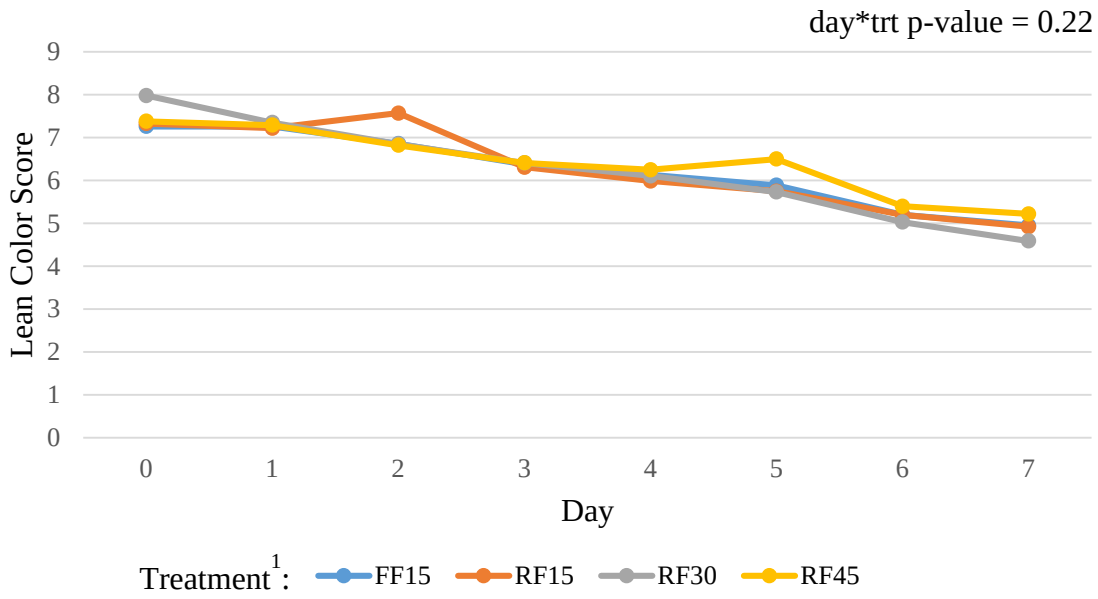
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[a]RF30 is different than FF15, RF15, and RF45 ($P < 0.01$).
[b]RF30 is different than FF15 and RF45 but similar to RF15 ($P = 0.02$).

Figure 3: Effects of experimental treatment on objective yellowness values (b*) of strip steaks (longissimus lumborum) from feedlot steers over seven-day retail shelf life



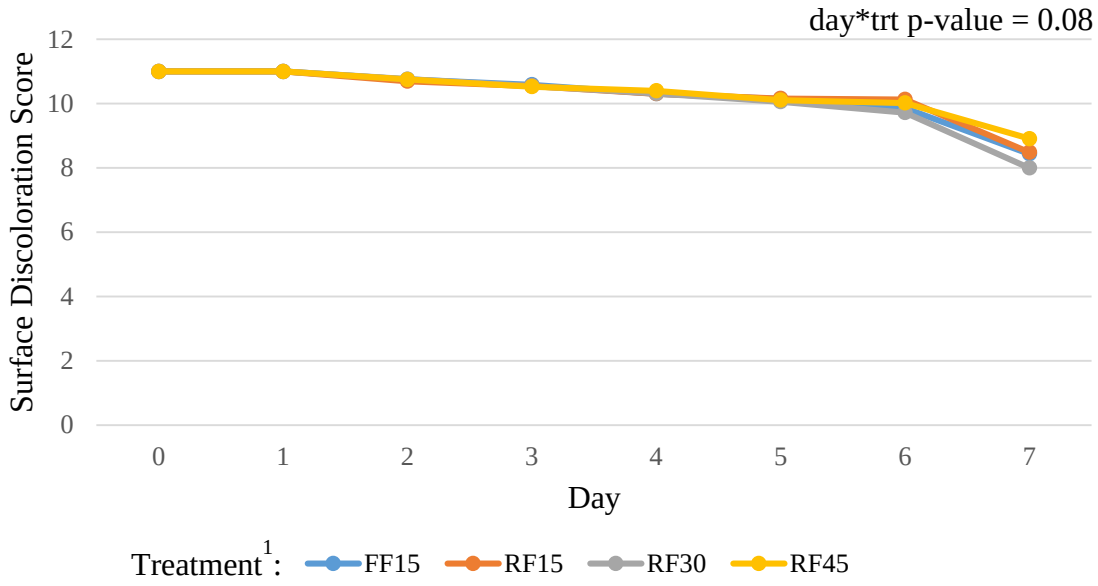
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[a]RF30 is different than FF15, RF15, and RF45 ($P < 0.01$).
[b]RF30 is different than FF15 and RF45 but similar to RF15 ($P < 0.01$).

Figure 4: Effects of experimental treatment on subjective lean color appearance of strip steaks (longissimus lumborum) from feedlot steers over seven-day retail shelf life



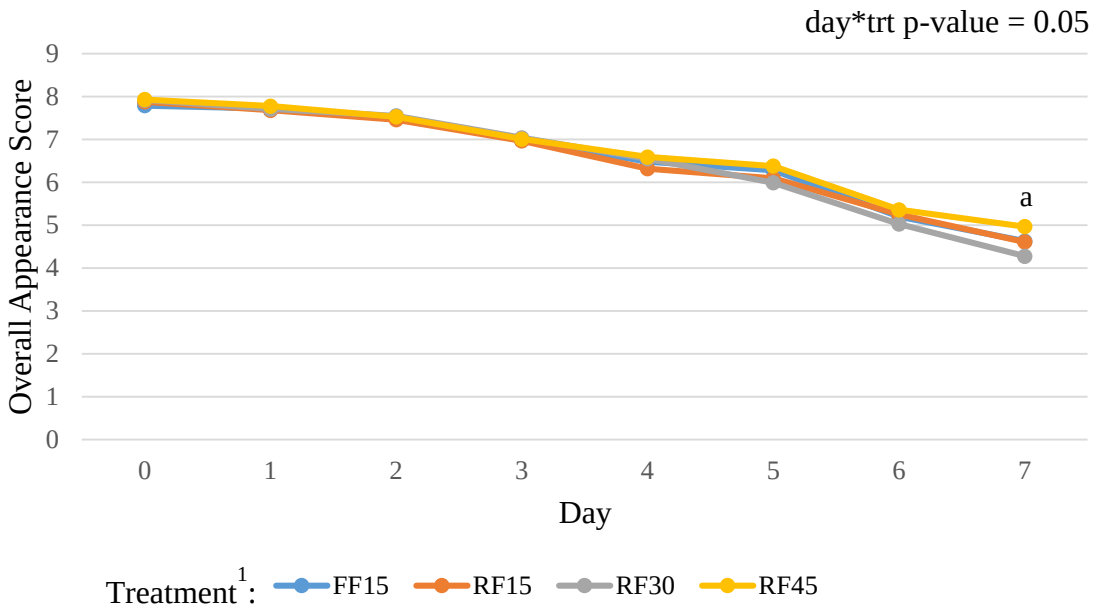
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 5: Effects of experimental treatment on subjective surface discoloration of strip steaks (longissimus lumborum) from feedlot steers over seven-day retail shelf life



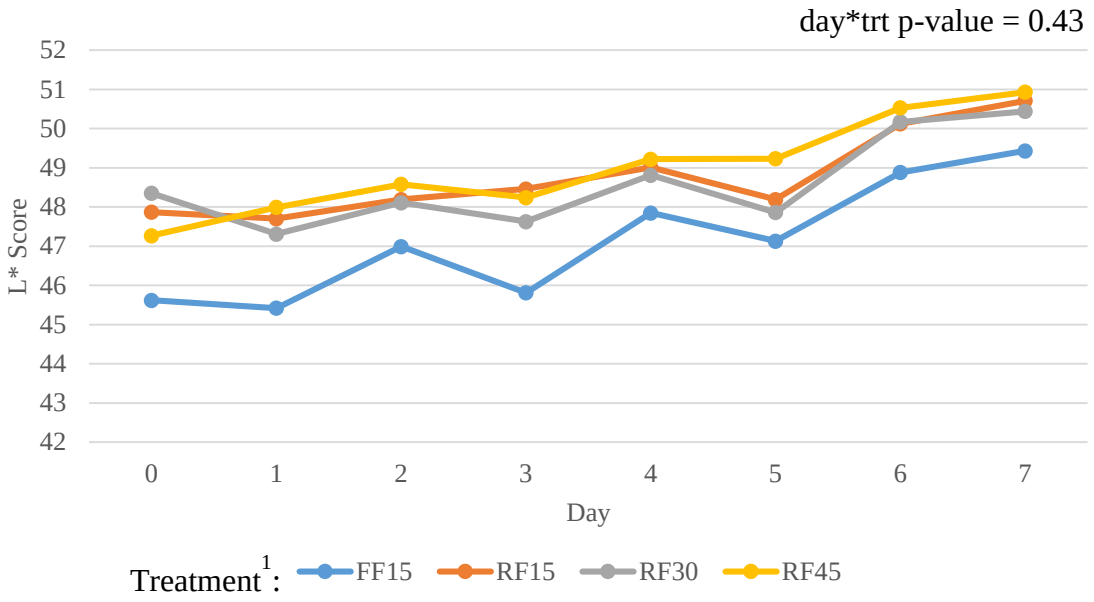
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 6: Effects of experimental treatment on subjective overall appearance of strip steaks (longissimus lumborum) from feedlot steers over seven-day retail shelf life



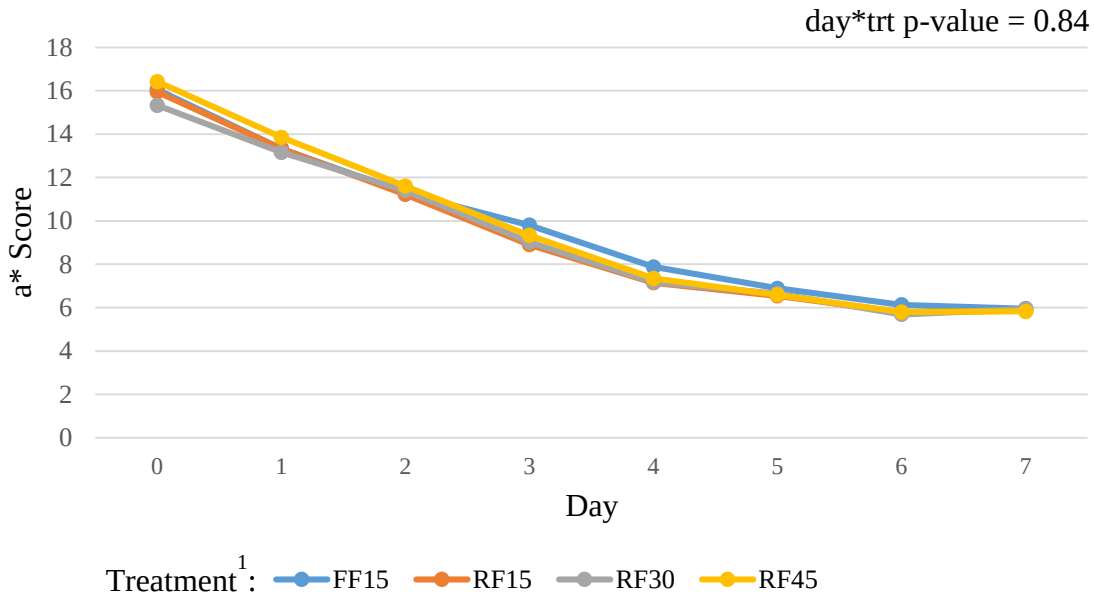
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[a]RF30 is different than RF45 but similar to FF15 and RF15 ($P < 0.01$).

Figure 7: Effects of experimental treatment on objective lightness values (L*) of ground beef from feedlot steers over seven-day retail shelf life



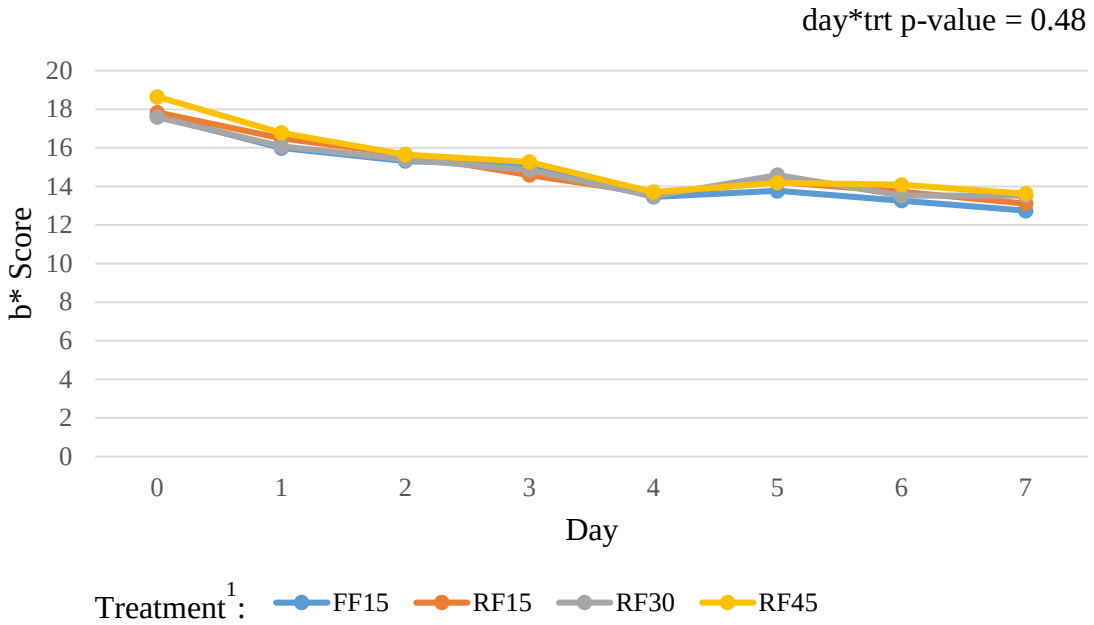
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 8: Effects of experimental treatment on objective redness values (a*) of ground beef from feedlot steers over seven-day retail shelf life



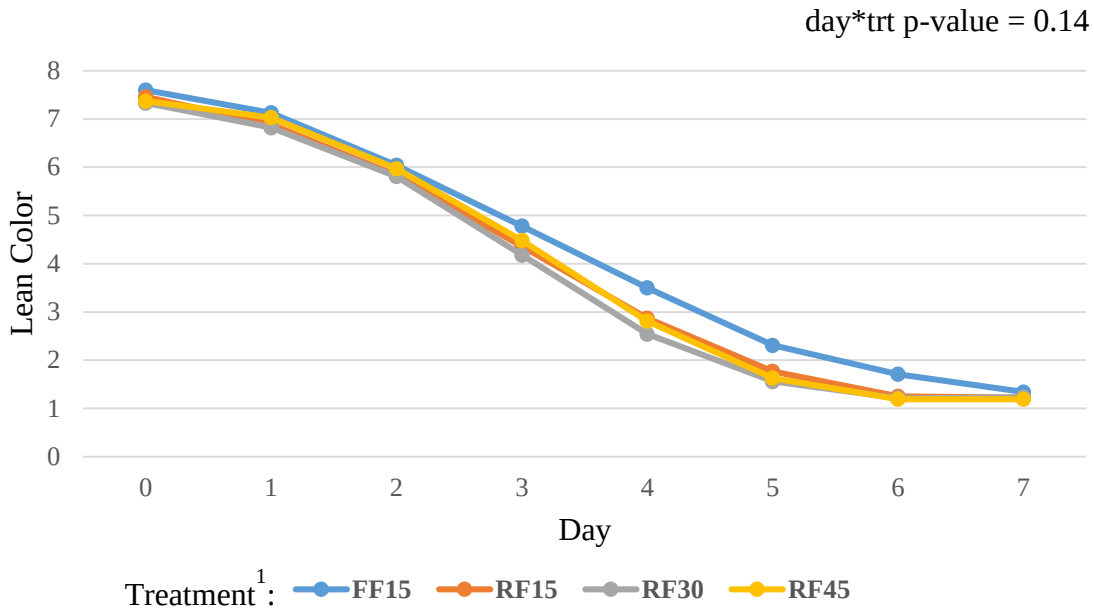
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 9: Effects of experimental treatment on objective yellowness values (b*) of ground beef from feedlot steers over seven-day retail shelf life



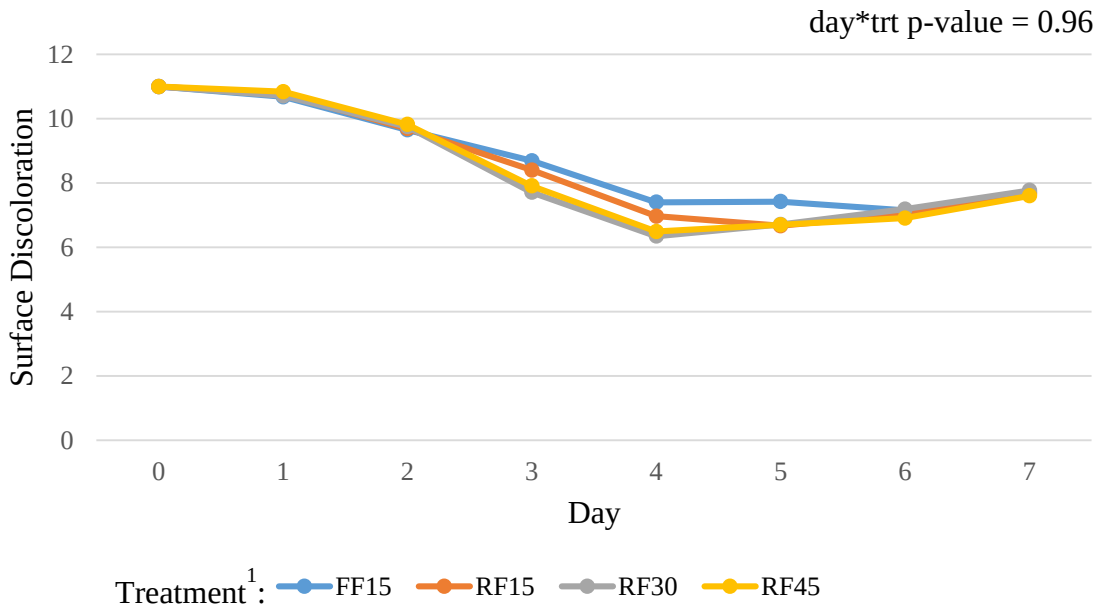
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 10: Effects of experimental treatment on subjective lean color appearance of ground beef from feedlot steers over seven-day retail shelf life



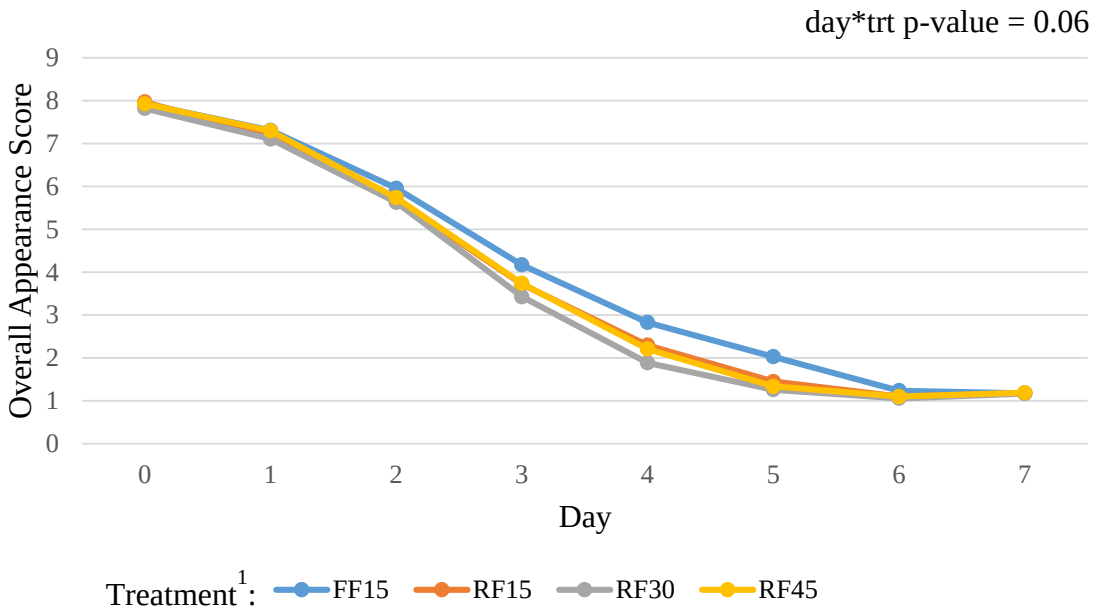
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 11: Effects of experimental treatment on subjective surface discoloration of ground beef from feedlot steers over seven-day retail shelf life



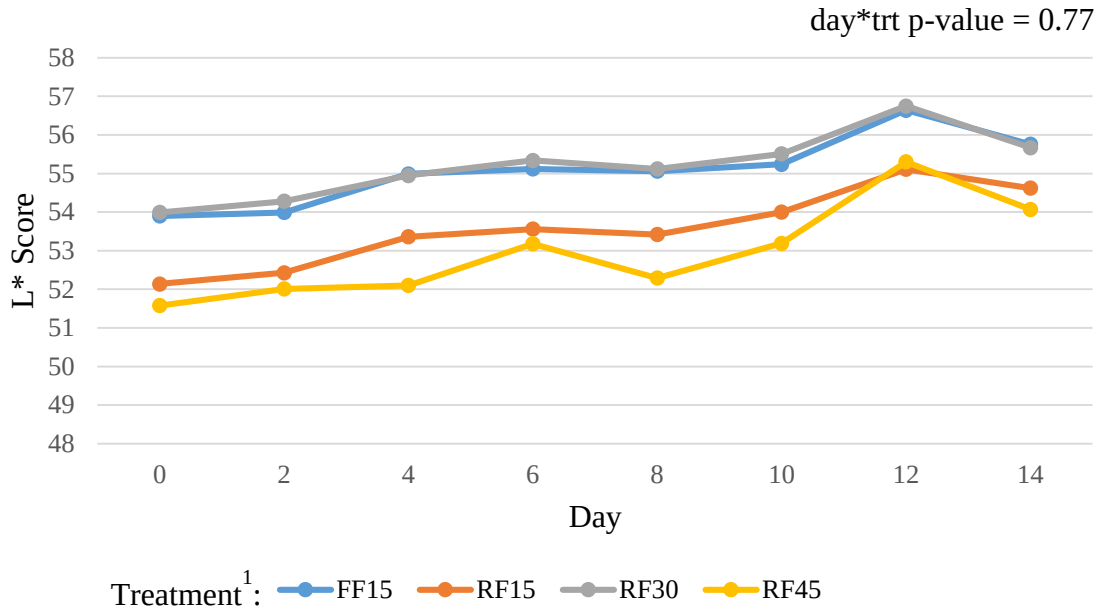
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 12: Effects of experimental treatment on subjective overall appearance of ground beef from feedlot steers over seven-day retail shelf life



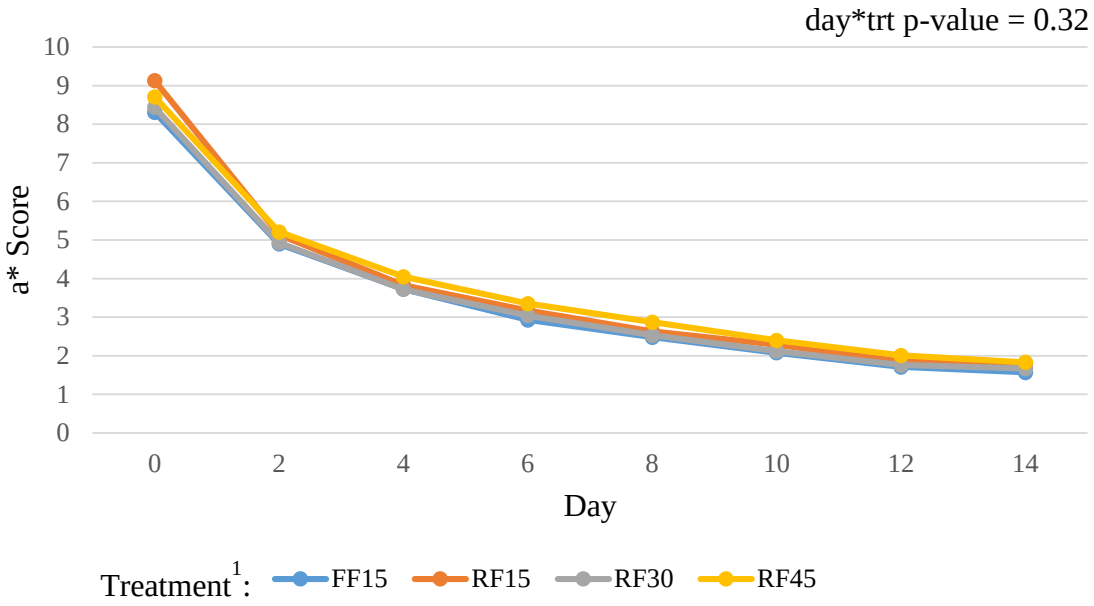
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 13: Effects of experimental treatment on objective lightness values (L*) of bologna from feedlot steers over fourteen-day retail shelf life



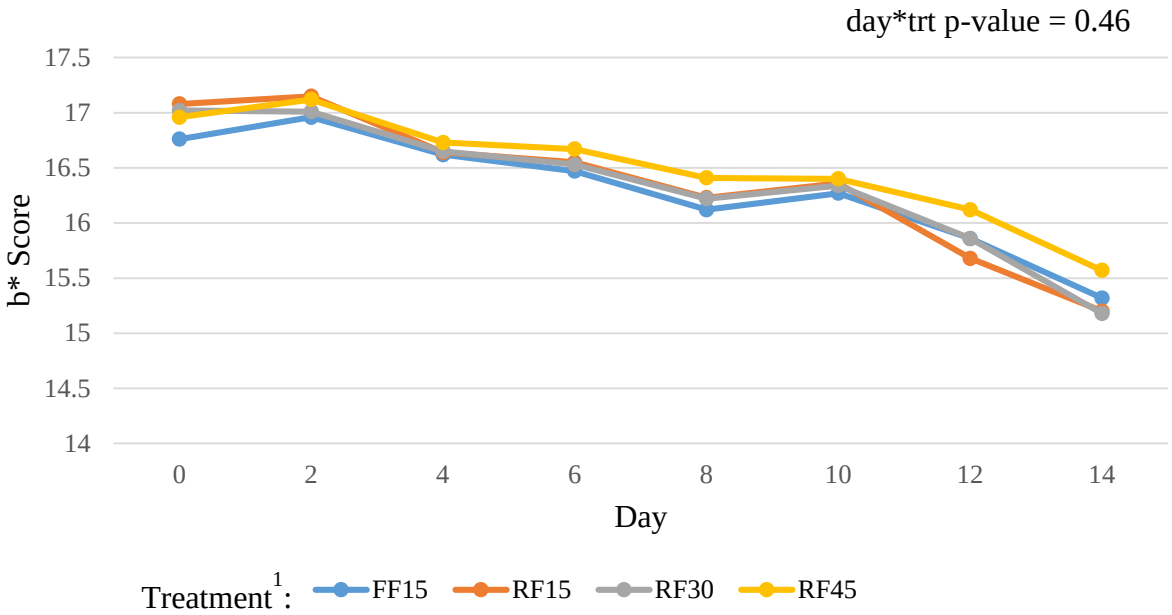
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 14: Effects of experimental treatment on objective redness values (a*) of bologna from feedlot steers over fourteen-day retail shelf life



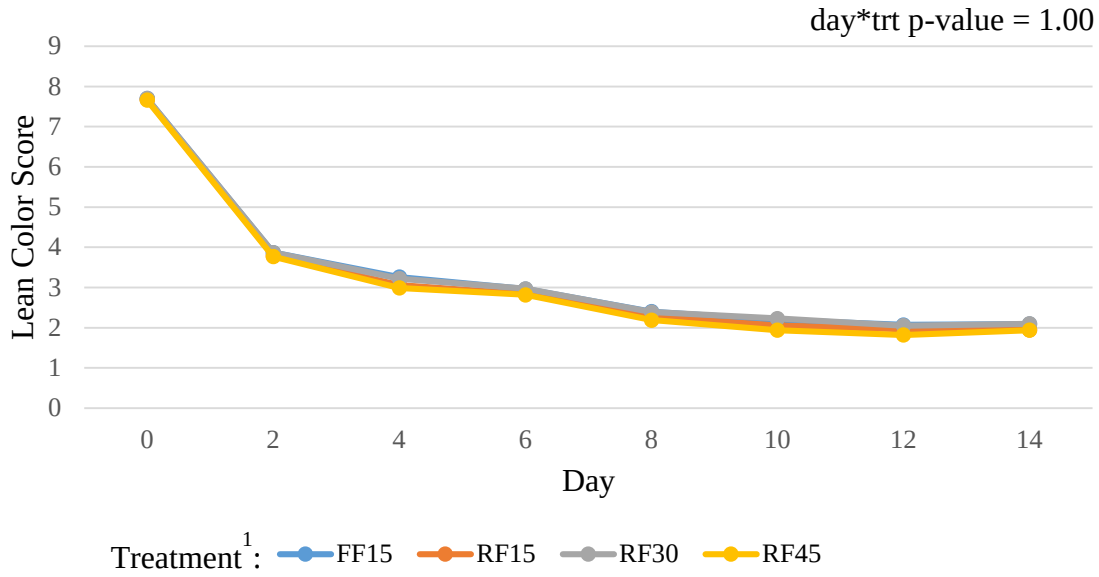
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 15: Effects of experimental treatment on objective yellowness values (b*) of bologna from feedlot steers over fourteen-day retail shelf life



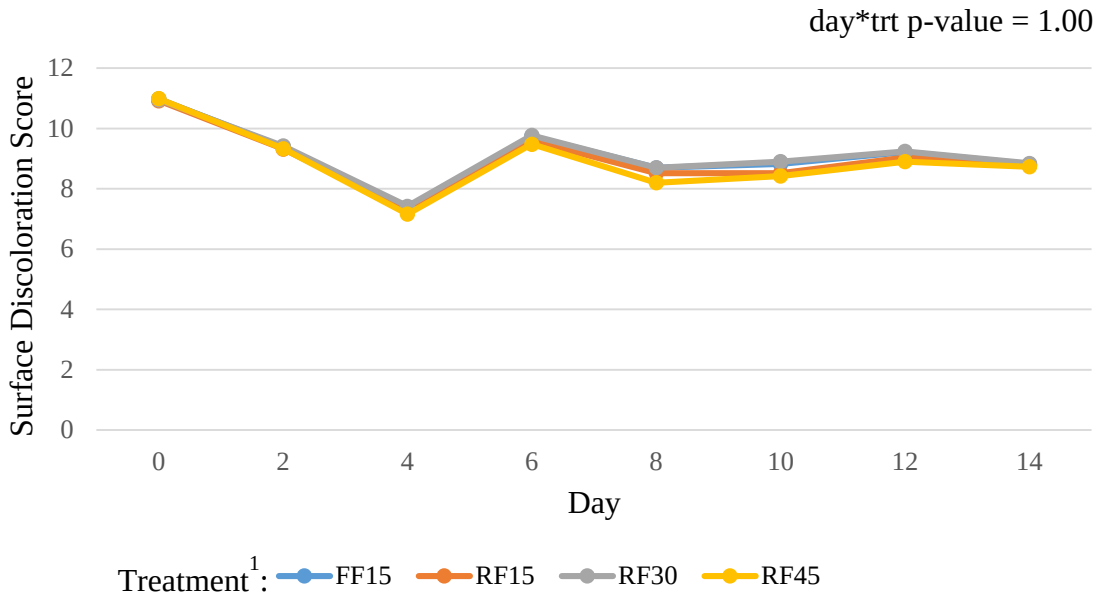
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 16: Effects of experimental treatment on subjective lean color appearance of bologna from feedlot steers over fourteen-day retail shelf life



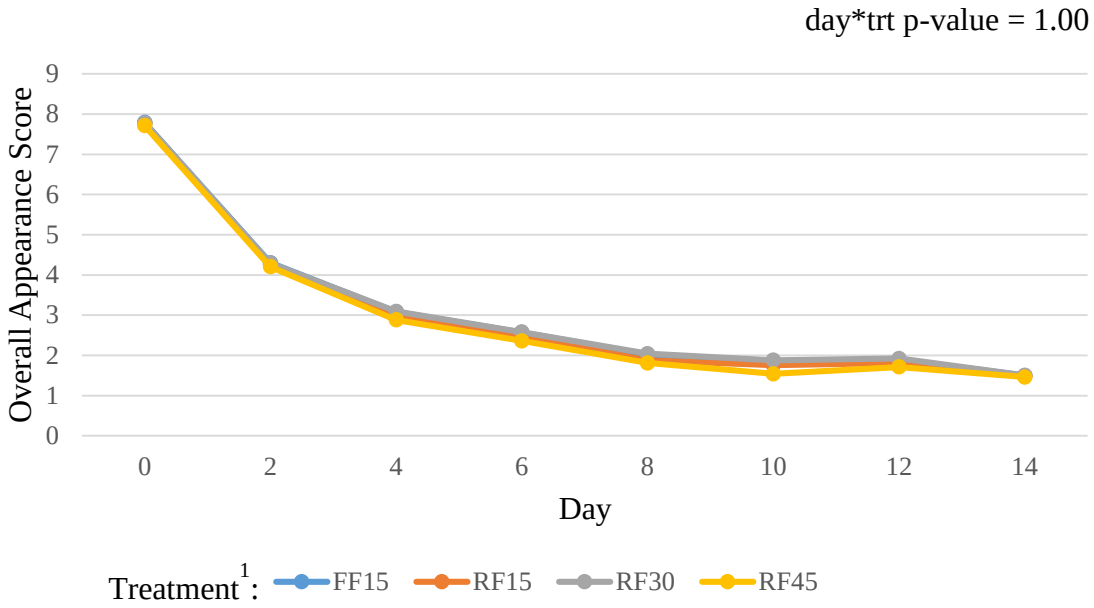
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 17: Effects of experimental treatment on subjective surface discoloration of bologna from feedlot steers over fourteen-day retail shelf life



[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

Figure 18: Effects of experimental treatment on subjective overall appearance of bologna from feedlot steers over fourteen-day retail shelf life



[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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Appendix A

Standard Operating Procedure for TBAR Analysis

Agricultural Utilization Research Institute **SAM** # 04

Marshall Fats and Oils Laboratory
Standard Analytical Method

Title: TBARS Distillation Method

I. Reagents/Materials

A. Hydrochloric Acid: ACS grade, VWR Catalog No. VW3110-3

B. 2-Thiobarbituric Acid: CAS 504-17-6, Sigma Catalog No. T-5500

C. Dow Antifoam: Dow Corning Antifoam Catalog No. 1520-US

D. 1:2 Hydrochloric Acid: Carefully combine 1 part concentrated HCl and 2 parts distilled water. Mix well.

E. 0.02M Thiobarbituric Acid (TBA): Dissolve 0.2882 g thiobarbituric acid in 100 mL distilled water. Mix well.

F. Water: AURI distilled water

II. Instrumentation

A. Spectrophotometer: Spectronic 20^{+}, Spectronic Instruments, Inc. B. Water Bath: VWR

III. Procedure

A. Obtain a 250 mL flat-bottomed round flask and place two glass beads inside.

B. Weigh out 10 g of sample, record the weight, and blend with 50 mL of distilled water in a laboratory blender.

C. Carefully transfer the blended sample into the 250 mL flask.

D. Wash the blender with 47.5 mL of distilled water and add to the flask

E. Add 2.5 ml of 1:2 hydrochloric acid and 3-4 drops of Dow Antifoam.

F. Distill the contents of the flask at the highest temperature possible on a hot plate and collect the distillate into a 100 mL beaker.

G. Continue to distill the contents of the flask until you have collected 50 mL of distillate in the beaker.
H. Mix the distillate.
I. Pipette 5 mL of distillate and 5 mL of 0.02M TBA into a scintillation vial and mix well.
J. Prepare a blank by pipetting 5 mL of distilled water and 5 mL of 0.02M TBA into a scintillation vial.
K. Immerse the vials in a 95º C water bath for 35 minutes.
L. Allow the vials to reach room temperature by immersing them in cold water for 3-5 minutes.
M. Turn on the spectrophotometer by turning the Power Switch/Zero Control (knob on the left side of the instrument) clockwise.
N. Wait 15 minutes for the spectrophotometer to warm up.
O. Set the Wavelength Control (knob on top) to 532 nm.
P. Set the filter lever (small lever at the bottom) to the 340-599 nm wavelength position.
Q. Adjust the meter to 0% T with the Power Switch/Zero Control knob. Make sure the sample compartment is empty and the sample cover is closed when you do this.
R. Wash a spectrophotometer test tube twice with a small amount of the blank solution.
S. Fill the test tube with the rest of the blank solution.
T. Wipe of the outside of the test tube to remove dust and fingerprints and place it in the sample compartment.
U. Align the guide mark on the test tube with the guide mark at the front of the sample compartment. Close the lid and adjust the meter to 100% T with the Transmittance/Absorbance Control (knob on the front right side of the instrument).
V. Remove the test tube from the sample compartment and discard the solution.

W. Press the Mode button to switch the instrument from percent transmittance to absorbance.

X. Using the same test tube used for the blank solution, rinse the test tube with small amounts of sample and read each sample solution recording the absorbance value.

IV. Calculations

Sample Absorbance x 7.8 = TBARS(ppm)

V. Reference

A. Tarladgis et al. (1960)

B. Spectronic 20^{+} Series manual

Appendix B

Standard Operating Procedure for Fatty Acid Composition

Agricultural Utilization Research Institute **SAM** # 06

Marshall Fats and Oils Laboratory
Standard Analytical Method

Title: Fatty Acid Composition

I. **Safety**

A. Flammable solvents are used during the procedure. Refer to SOP 07 for details on proper handling of flammable solvents.

B. Perform heptane evaporation and sample refluxing in the fume hood.

C. Normal laboratory hazards are present - chemical, biological, and physical. Standard laboratory safety practices and personal protective equipment will be exercised while working in the laboratory.

D. Eye protection, lab coat, chemical resistant gloves, and close-toed shoes will be worn when working in the laboratory.

II. **Reagents / Materials**

A. Tritridecanoin C13:0 Reference Standard: Nu-Check cat. # T-135, 500 mg ampoule

B. GLC-80 Reference Standard: Nu-Chek cat. # GLC-80 methyl ester

C. GLC-463 Reference Standard: Nu-Chek cat. # GLC-463 methyl ester

D. GLC-546B Reference Standard: Nu-Chek cat. # GLC-546B methyl ester

E. GLC-714 Reference Standard: Nu-Chek cat. # GLC-714 methyl ester. Be sure to request a COA with individual standard weights and purities.

F. Methyl Octadecadienoic [conjugated linoleic acid (CLA)]: Nu-Chek cat. # UC-59-M

G. Boron Trifluoride Methanol Solution, 14%: CAS 16045-88-8, Sigma cat. # B1252-250ML

H. Sodium Hydroxide: CAS 1310-73-2, VWR cat. # VW6720-1

I. Methanol: CAS 67-56-1, EMD cat. # EM-MX0488P-1

J. Sodium Chloride: CAS 7647-14-5, EMD cat. # EM-7710

K. Sodium Sulfate, Anhydrous, Granular: CAS 7757-82-6, Sigma cat. # 239313-500G

L. Heptane: CAS 142-82-5, EMD cat. # HX0078-6

M. 5 mg/mL C13:0 Internal Standard Solution: Weigh 500 mg of C13:0 into a 100 mL volumetric flask. Dissolve in and dilute to volume with heptane. Store the solution in the refrigerator in a well-sealed amber bottle when not in use.

N. 0.5 M Sodium Hydroxide in Methanol: Add 20 g of sodium hydroxide to a 1000 mL volumetric flask. Dissolve in and dilute to volume with methanol. Mix well.

O. Saturated Sodium Chloride Solution: Dissolve 360 g of sodium chloride in 1000 mL of deionized water. Mix well.

P. Borosilicate Glass Beads: 5 mm diameter, VWR cat. # 89001-518

Q. Compressed Air: American Welding, distributor, industrial grade

R. Helium: American Welding, distributor, ultra high purity

S. Hydrogen: American Welding, distributor, ultra high purity

T. Autosampler Vials: 2 mL wide top crimp, write-on, Agilent part # 5182-0543

U. Autosampler Vial Crimp Caps: 11 mm silver aluminum, clear PTFE/red natural rubber septa, Agilent part # 5181-1210

III. **Instrumentation**

A. Gas Chromatograph: Hewlett-Packard 6890 Plus Gas Chromatograph equipped with a split/splitless injection port and autosampler.

B. Detector: Hewlett-Packard Flame Ionization Detector.

C. Data Acquisition System: Agilent ChemStation chromatography software.

D. Analytical Column: SP™-2560, 0.25 mm ID x 100 m, 0.20 µm thickness, Supelco part # 24056

E. Injector Liner: split, 4 mm i.d., 6.3 mm o.d. x 78.5 mm based deactivated precision (Focus) split liner with glass wool, Agilent part # 210-4004-5

F. Non-Stick Flip-Top Liner O-Ring: Agilent part # 5188-5366

G. Inlet Septa: general purpose red septa, Agilent part # 5181-1263

H. Column Ferrule: Graphite (short) Ferrule, 0.5 mm ID, Agilent part # 5080-8853

I. Gas Purifiers: OMI-2 Purifier Tube, Supelco part # 23906

J. Syringe: 10 µL syringe, tapered, fixed 23-26s/42/HP needle, Agilent part # 5181-3360

K. FID Jet: Capillary Series 530 mm jet (0.011 in ID tip), Agilent part # 19244-80560

IV. **GC Operating Parameters**

A. Gas Flows: (all measured at 100°C)

1.	Column Inlet Pressure	≈63.29 psi
2.	Column Flow	≈2.0 mL/min helium (constant)
3.	Split Vent Flow:	≈200 mL/min
4.	Split Ratio:	≈100:1
5.	Hydrogen:	≈40 mL/min
6.	Compressed Air:	≈450 mL/min
7.	Auxiliary Gas:	≈45 mL/min

B. Temperatures:

1.	Injection Port:	235°C
2.	Column Oven:	Initial: 180°C hold for 32 min
		Ramp: 20°C / min to 215°C hold for 31.25 min
3.	Detector:	325°C

C. Injection Volume: 1 µL

D. Run Time: ≈70 min / injection

V. **Standard Preparation**

When not in use, standards should be stored between -25 to -10°C.

Individually dissolve each of the following standards as indicated to prepare 20 mg/mL working standard solutions. Mix well. Transfer to autosampler vials.

A. GLC-80: 100 mg in

5.0 mL of heptane

B. GLC-463: 100 mg in

5.0 mL heptane

C. GLC-546B: 100 mg

in 5.0 mL heptane

D. GLC-714: 100 mg in

5.0 mL heptane

Note: Three individual solutions should be prepared for GLC-714. Each of these solutions will be injected singly into the GC. The resulting peak areas will be used for the determination of TCF-ECF.

E. CLA: 100 mg in 5.0 mL heptane

Sample Preparation

A. Pipet 2.0 mL of 5 mg/mL C13:0 internal standard solution into a 50-mL round bottom flask.

B. Evaporate the solvent to dryness in a fume hood.

C. Weigh 0.100 - 0.150 g of sample (fat or oil) into the flask containing the dried internal standard.

D. Add approximately 4 mL of 0.5 M methanolic sodium hydroxide and a glass bead to the flask.

E. In the fume hood, attach flask to condenser and heat the mixture until the fat globules go into solution. This should take 5 - 10 minutes.

F. Add 5 mL of boron trifluoride methanol solution through top of condenser

G. Allow to reflux for another 2 minutes.

H. Add 5 mL of heptane through top of condenser.

I. Allow to reflux for another 1 minute.

J. Remove flask from reaction set up.

K. Add 15 mL of saturated sodium chloride solution, stopper, and shake vigorously for 15 seconds.

L. Remove stopper and add more saturated sodium chloride solution to float organic layer into the neck of the flask.

M. When layers have fully separated, transfer a portion of the organic (top) layer to a small test tube.

N. Add a small amount of anhydrous sodium sulfate to the test tube to dry the sample.

O. Cork the test tube and mix well.

P. Allow the sodium sulfate to settle and the solution to become clear.

Q. Transfer prepared sample to an autosampler vial.

VII. **GC Operation**

Using the conditions listed in **Section IV**, equilibrate the GC column by passing enough carrier gas through it to achieve a stable flat baseline. This should require no more than 60 minutes.

A. Conditioning a New Column (or follow specific instructions that came with the column)

1. Cool all heated zones to ambient. Turn off detectors, hydrogen, compressed air, and helium. Remove old column.

2. Install the new column into the inlet only. DO NOT connect the column to the detector.

3. Cap the detector fitting with the no-hole ferrule and column nut.

4. Set the column head pressure to ~40 psi. Let helium flow through the column at room temperature for 30 minutes to remove air. Leave oven door open.

5. Place the end of the column into a beaker containing isopropyl alcohol. Verify the presence of bubbles. This will ensure that there is flow through the column. If there is no flow, troubleshoot for carrier gas leaks, column blockage, or improper inlet operation.

6. Close the oven door and program the oven temperature to ramp ambient to 240°C

   at 15°C/min. Hold at 240°C for 30 minutes or until baseline is stable.

7. Maximum column temperature is 250°C.

8. After conditioning, allow the column to cool to room temperature and proceed with installing the end of the column in the detector.

. Injection Sequence

Using the conditions listed in **Section IV**, inject working standards in the following

order: Heptane (in duplicate), GLC-714, GLC-714, GLC-714, GLC-80, GLC-463, GLC-

546B, and other standards as needed. Inject prepared samples. Following the final sample injection, heptane should be injected in duplicate.

VIII. **Calculations**

A. Identification of Peaks

1. Analyze the standard mixtures of known composition and measure retention times for the constituent esters.

2. Identify the peaks for the sample from these standard retention times. (Reference

Table 2 of Method Ce 1j-07 for elution order.)

B. Using the Excel spreadsheet entitled, fatty acid composition Ce 1j-07, calculate results in the following manner:

Under the TCF-ECF Calc tab, enter the standard weights and purities from the GLC-714 COA. Enter the peak areas from the three GLC-714 standard injections. The spreadsheet will then calculate TCF-ECF.

2. Under the Results tab, enter the sample peak areas, sample weight, ISTD weight, and the % fat from the fat extraction. The spreadsheet will then calculate % Fatty Acids and % Triacylglycerols.

3. When reporting individual fatty acid composition, report % FA results. When reporting saturated and unsaturated data for nutritional labeling, report % TAG results.

IX. **Waste Generated and Disposal Methods**

A. Retrieve the glass bead by pouring the remaining sample solution through a strainer.

Collect sample waste from the round bottom flask and the test tube containing sodium sulfate in a closed head, high density polyethylene (HDPE) container. Affix a hazardous waste label.

B. Dispose of waste through the University of Minnesota Chemical Safety Day Program using Form B: Chemical Mixtures Waste Form http://www.dehs.umn.edu/hazwaste_csdp.htm

X. **Reference**

AOCS Ce 2-66: Preparation of Methyl Esters of Fatty Acids

AOCS Ce 1j-07: Determination of *cis*-, *trans*-, Saturated, Monounsaturated, and Polyunsaturated Fatty Acids in Extracted Fats by Capillary GLC

Appendix C

Smoke House Procedure for Bologna

Thermal Processing

The internal should be held at 140ºF for at least 12 min to meet 6.5 log reduction stipulated in the USDA/FSIS Appendix A.

The thermal processing schedule is as follows:

Step	Process	Time	Dry Bulb (ºF)	Wet Bulb (ºF)	Relative Humidity
1	Smoke	01:00	75	-	-
2	Cook	03:30	150	130	30%

Cook to an internal temperature of 150ºF.

Cooling Process

It is very important that cooling be continuous through the given time/temperature control points.

1. During cooling, the product's maximum internal temperature should not remain between 130°F and 80°F for more than 1.5 hours nor between 80°F and 40°F for more than 5 hours. This cooling rate can be applied universally to cooked products (e.g., partially cooked or fully cooked, intact or non-intact, meat or poultry) and is preferable to (2) below.

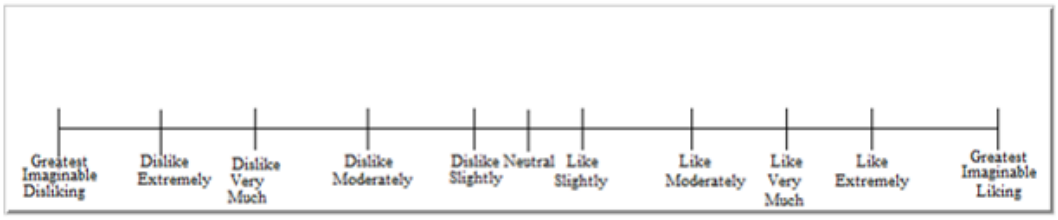
2. Over the past several years, FSIS has allowed product to be cooled according to the following procedures, which are based upon older, less precise data: chilling should begin within 90 minutes after the cooking cycle is completed. All product should be chilled
from 120°F (48°C) to 55°F (12.7°C) in no more than 6 hours. Chilling should then continue until the product reaches 40°F (4.4°C); the product should not be shipped until it reaches 40°F (4.4°C).

3. The following process may be used for the slow cooling of ready-to-eat meat and poultry cured with nitrite. Products cured with a minimum of 100 ppm ingoing sodium nitrite may be cooled so that the maximum internal temperature is reduced from 130 to
80 °F in 5 hours and from 80 to 45 °F in 10 hours (15 hours total cooling time

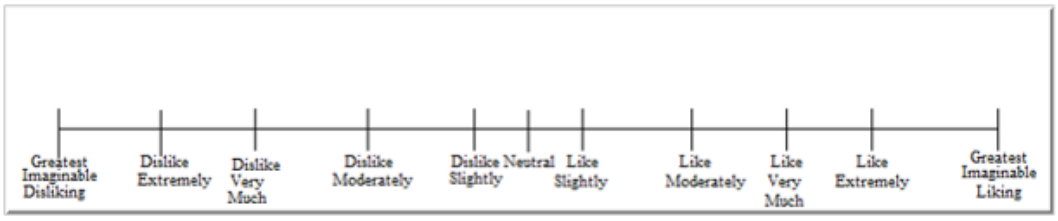
Appendix D

Labeled Affective Magnitude Scale

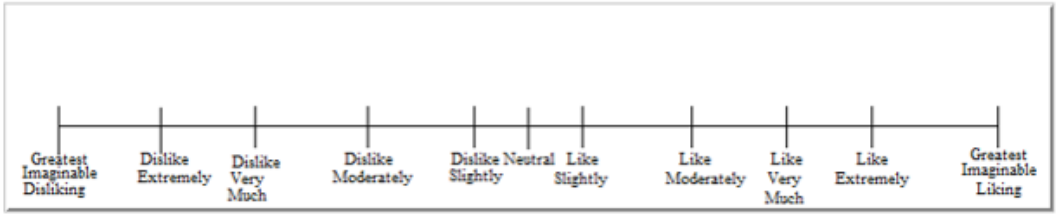
Overall Liking



Flavor Liking



Texture Liking



Toughness

Juiciness

Off Flavor