Effects of Feeding Reduced-Fat Modified Distillers Grains with Solubles on Dietary Energy Values, Finishing Cattle Performance, and Beef Quality Characteristics

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INTRODUCTION

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

The predominant grain utilized in ethanol production in the United States is corn, where during the dry-grind ethanol production process, whole corn kernels are fermented with yeast and water to produce ethanol. The corn kernel is made up of two-thirds starch, which is fermented into ethanol. The remaining unfermented portions are removed from the bottom of the distillation columns as whole stillage and are referred to as wet cake. Concentration of unfermented portions (protein, oil, fiber, ash, and phosphorus) in whole stillage are increased 3-fold in DGS when compared to whole corn (Lim and Yildirim-Aksoy, 2008). Whole stillage then is centrifuged to separate solids from liquid portions to form distillers grains (DG) and thin stillage. Typically water is evaporated from thin stillage to produce condensed distillers solubles (CDS) which is then added back to DG to form DGS. Traditionally, DGS contained ether extract (EE) concentrations that ranged between 10 to 13% (Buckner et al., 2011). When DGS with EE concentrations ranging from 10 to 13% were included in cattle diets, the energy value of DGS was determined to be from 102 to 150% the energy value of corn (Erickson et al., 2005). However, the energy values are dependent on the method used to process the grain; whether the DGS were wet or dry, and the integrity of the fiber and protein after the grains underwent heating and fermentation process (Klopfenstein et al., 2008).

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

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 from previous research indicated no significant difference in DMI when various concentrations of full-fat (FF) DGS replaced basal corn or barley grain in diets (Buckner et al., 2008; Depenbusch et al., 2009; Anderson et al., 2011). Conversely, when DGS replaced steam-flaked corn (SFC), dry-rolled corn (DRC), or high-moisture corn (HMC)-based diets up to 40% of diet DM, DMI increased in feedlot cattle diets (Vander Pol et al., 2006; Depenbusch et al., 2009b; Luebbe et al., 2012); however, as inclusion of DGS was increased above 40%, DMI decreased. In other experiments, cattle fed 10 to 30% DGS performed better than those fed greater concentrations of DGS (Buckner et al., 2008). Furthermore, Vander Pol et al. (2006) fed cattle WDGS at increasing concentrations that resulted in a quadratic response by G:F as inclusion of WDGS increased with optimum inclusion between 30 to 40%. Traditional WDGS was reported to have 120 to 150% the energy value of corn in beef finishing diets. High energy values discovered for WDGS may be attributed to the energy contribution of EE as well as acidosis control, making this a primary advantage of utilizing DGS in finishing cattle diets (Erickson et al., 2005).

Beef quality 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).

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

MATERIALS AND METHODS

All animal use procedures were reviewed and approved by the University of Minnesota Institutional Animal Care and Use Committee. Steers in this experiment were housed at the

University of Minnesota's Beef Research and Education Complex located at UMore Park (Rosemount Research and Outreach Center) in Rosemount, MN.

Cattle

Fifty crossbred steers (initial BW 379 ± 32 kg) were utilized in a 181-d finishing experiment arranged in a completely randomized design. Upon arrival at the feedlot, steers were vaccinated with a modified-live viral vaccine (Pyramid 5 + Presponse SQ, Boehringer Ingelheim, Inc., Ridgefield, CT), an intranasal vaccine (Inforce 3, Zoetis, Florham Park, NJ), and rectal temperatures were recorded; cattle with temperatures above 39.7˚ C were treated with an antibiotic (Resflor Gold, Merck Animal Health, Madison, NJ). Initial BW was recorded after a 16-h period during which steers had no access to feed or water. Steers were implanted with Revalor-IS (Merck Animal Health, Madison, NJ) on d 28 and were re-implanted with Synovex Choice (Zoetis, Florham Park, NJ) on d 142.

Treatments and Design

Steers were randomly assigned to 1 of 4 dietary treatments and were individually fed in a Calan gate system (American Calan, Inc., Northwood, NH). Dietary treatment 1 was formulated to contain 14.3% RFMDGS along with 0.7% supplemental corn-oil to construe FF MDGS at 15% (FF15) of diet DM (Table 1). The remaining dietary treatments were formulated to contain RFMDGS at inclusions of 15, 30, or 45% (RF15, RF30, or RF45) of diet DM (Table 1). Dietary feedstuff inclusion achieved after weighing contribution of each load mixed throughout the study and respective dietary nutrient compositions consumed (corrected for weighted nutrient composition of feed offered and refused) are listed in Table 2. There was a single source of RFMDGS utilized that was processed by a dry-milling process with back-end centrifugation of thin stillage and contained 8.81% EE (Big River Resources, LLC, Boyceville, WI). When corn oil was added to RFMDGS in treatment 1, the MDGS represented FF MDGS containing 13.09% EE. A supplement was added to each diet to provide steers with 287 mg monensin/steer/d (Rumensin, Elanco Animal Health, Greenfield, IN).

Total mixed rations (TMR) were mixed once per week and stored on a feed pad in close proximity to the bunk line. A preservative (MYCO CURB, Kemin, Des Moines, IA) was added to all TMR batches to prevent mold growth.

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

On d 181, final BW was recorded after a 16h period without access to feed and water. Steers were then housed and fed a common diet for an additional 4d, 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.

Feed Sample Analysis

Prior to laboratory analysis, feedstuffs and feed refusal samples were dried in a drying oven (Blue M Electric, Thermal Product Solutions, New Columbia, PA) at 60˚ C for 48 h. All samples were then ground to pass through a 2-mm screen using a Thomas Model 4 Wiley Mill (Thomas Scientific, Swedesboro, NJ). The total weight of all feed refusals per steer were determined then each individual feed refusal was composited based on individual percentage of the total feed refused in order to obtain a single composite for each steer. Feed refusal composite samples and feedstuffs samples obtained each time diets were mixed were then prepared and nutrient compositions were analyzed. Individual samples were analyzed for CP (Method 992.15; AOAC, 1995), NDF (Van Soest et al., 1991), ADF (Method 973.18; AOAC, 2000), and EE (Method 920.39, AOAC, 2000). For CP analysis, all samples were prepared and shipped to an outside lab (University of Florida – North Florida Research and Education Center, Marianna, FL) to be analyzed following the procedure of Ciriaco et al. (2015). All other analysis was conducted on campus (University of Minnesota – Haecker Hall, St. Paul, MN). Neutral detergent fiber analysis was conducted utilizing an Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY), where samples were extracted for 60 min at 100˚ C in NDF solution with heat-stable α-amylase. Prior to NDF analysis, samples that contained EE concentrations greater than 5% (RFMDGS, DRC, and feed refusals) were pre-extracted following biphasic extraction procedures (Bremer et al., 2010). This procedure was utilized because samples that have EE concentrations greater than 5%, not all of the fat was dissolved during the NDF procedure; thus, decreasing the accuracy of feed sample NDF determination. Following NDF analysis, samples were dried at 100˚ C overnight (Thelco 130DM, Precision Scientific, Chicago, IL) then weighed and NDF percentage was calculated. Acid detergent fiber was then analyzed utilizing the same procedure as NDF; however, ADF solution was utilized and samples were extracted for 60 min at 100˚ C followed by drying overnight, weighing then calculating ADF percentage. Samples were analyzed for EE concentration by the use of an Ankom^{XT10} Extraction System (Ankom Technology, Macedon, NY) for 60 min at 90˚ C with petroleum ether.

Observed ME

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

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°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° 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° C at the geometric center (Type T thermocouple, Omega Engineering, Stanford, OH). Strip steaks were tempered to room temperature (22°C), reweighed to calculate cook loss percentage (cook loss percentage = (raw weight – cooked weight) / raw weight) * 100), and stored for further analysis at 2° C. Steaks were removed from refrigerated conditions two hours prior to analysis and tempered to room temperature (22°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°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°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^{o}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 6). 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^{o}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 2ºC 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 6). 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

Alf feedlot data were analyzed using the MIXED procedure of SAS 9.3 (SAS Institute Inc., Cary, NC). Experimental unit was the individual steer (FF15 and RF15 treatments contained 13 head per treatment and RF30 and RF45 treatments contained 12 head per treatment). Preplanned orthogonal contrasts were conducted on performance to determine the effects of feeding FF

MDGS compared to feeding RFMDGS (FF15 versus RF15, RF30 and RF45); effects of feeding low vs high MDGS inclusion regardless of EE content (FF15 and RF15 versus RF30 and RF45); or to contrast feeding FF MDGS vs RFMDGS at 15% inclusion (FF15 versus RF15).

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 beef quality 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.

Significance was defined at $\alpha \leq 0.05$ for all data while trends were defined at $0.10 \leq \alpha \geq 0.05$ within feedlot data. Trends were not defined within beef quality data and were not discussed. Outliers were removed within beef quality data 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

Interim Growth Performance

Cattle fed RFMDGS at 15% inclusion during d 1 to 28 had a tendency for greater ADG and improved G:F ($P = 0.06$) compared to cattle fed FF MDGS (Table 3). Although not statistically significant ($P = 0.34$), DMI was numerically lower for cattle fed FF15 compared to RF15 during d 1 to 28 thus potentially contributing to lower gains and decreased G:F. Adaptation to dietary treatments and metabolism of lipids for cattle fed FF15 during the first 28 d could have impacted gains and feed efficiencies. The MDGS source fed in FF15 treatment was the same as that of all other treatments but corn oil was added to formulate FF MDGS. It has been suggested that dietary fat added from WDGS is not hydrogenated to the same extent in the rumen as fat provided in the form of supplemental corn oil. Fat added as corn oil was 70% digested in the rumen while fat from WDGS was 81% digested (Vander Pol et al., 2007). Feeding cattle FF MDGS during the initial 28 d led to a tendency for reduced DMI ($P = 0.09$) compared to cattle fed RFMDGS (Table 3). Cattle fed 15% MDGS, regardless of EE content, consumed less DM between d 29 to 56, d 57 to 84, d 85 to 112, and d 141 to 168, respectively, than those fed greater MDGS concentrations ($P < 0.01$; Table 3). Observations gleaned from past research demonstrated that DMI was greater throughout the feeding period at higher concentrations of RF DGS (Veracini et al., 2013).

During d 29 to 56, cattle fed FF MDGS had lower ADG compared to all RFMDGS treatments ($P = 0.01$; Table 3). Lower ADG for cattle fed FF15 treatment found during the first 56 d on feed could have been related to decreased digestibility of supplemental corn oil added to the diet (Vander Pol et al., 2007). Furthermore, during d 29 to 56, cattle fed RFMDGS had greater ADG ($P = 0.01$) when compared to cattle fed FF MDGS (Table 3).

Cumulative Performance

Treatment effects on cumulative performance results over 181 d on feed are listed in Table 4. Cattle fed MDGS at 15% inclusion, regardless of EE content, consumed less DM ($P = 0.01$) over the 181 d feeding period. These results are consistent with one of the experiments by Veracini et al. (2013); where feeding increasing concentrations of RFMDGS from 0 to 70% resulted in increased DMI as inclusion increased. Similarly, feeding FF DDGS, FF MDGS, and FF WDGS at increasing concentration resulted in quadratic DMI increases (Bremer et al. 2011). In this review, Bremer et al. (2011) found that as DGS inclusion reached 40%, DMI began to decline. From d 1 to 56, cattle fed FF15 treatment tended to have lower ADG ($P = 0.08$) compared to cattle fed RF15 treatment. Cattle fed either FF or RFMDGS at 15% inclusion tended to have lower ADG from d 1 to 56 ($P = 0.09$); as well as lower ADG for cattle fed FF15 compared to all other treatments from d 1 to 56 ($P = 0.02$) and d 1 to 84 ($P = 0.05$). Due to lower ADG observed in cattle fed 15% FF MDGS during d 1 to 56, G:F also tended to be lower ($P = 0.08$). It appears that any potential negative impacts that supplemental corn oil had on cattle fed the FF15 treatment were resolved following d 84 on feed. Following d 84, cattle fed 15% MDGS regardless of EE content, had lower DMI ($P < 0.01$); however no other significant observations on growth performance traits were observed over 181 d on feed. These observations are similar to results found by Veracini et al., (2013). Furthermore, Jolly et al. (2014) fed FF or RF WDGS at 35, 50, and 65% of diet DM and observed that cattle fed WDGS at 65% inclusion, regardless of EE content, consumed less DM. However, ADG and G:F were unaffected. These results are similar to the current experiment where there was no difference in ADG or G:F between cattle fed FF MDGS at 15% inclusion or 15, 30, and 45% RFMDGS.

Carcass Adjusted Final Body Weight and Dietary Energy Values

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

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 7). Warner-Bratzler shear force values were higher in FF15 strip steaks compared to all other treatments (P < 0.01; Table 8). Purge loss (P = 0.39), drip loss (P = 0.09) and cook loss (P = 0.14) percentage did not differ among treatments (Table 8).

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 9). Subjective toughness values of steaks from FF15 were higher than RF15 (10.78 and 8.77, respectively; P = 0.01; Table 9). Subjective juiciness values of steaks from FF15 were higher than RF45 (8.50 and 6.94, respectively; P = 0.03; Table 9).

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 10). 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) (Figures 13 – 18).

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 12). Subjective overall liking was higher in RF45 compared to FF15 bologna samples (78.14 and 71.63, respectively; $P = 0.03$; Table 12). Subjective texture liking of bologna from RF45 were higher than FF15 (78.25 and 67.51, respectively; $P < 0.01$; Table 12). 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 12).

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 11).

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 13). 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 14). 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 14). 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 14). Both of the PUFA present were not impacted by treatment ($P = 0.34$, Table 14). There was no treatment effect on calculated iodine value ($P = 0.59$; Table 15).

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.

CONCLUSIONS

Feedlot Nutrition Conclusions

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

Beef Quality Conclusions

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

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TABLES

Table 1. Nutrient composition of feedstuffs

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

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

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

	Treatment[2]			
Item	FF15	RF15	RF30	RF45
Ingredient				
Straw, %	9.00	9.01	9.01	8.89
RFMDGS[3], %	14.93	15.60	30.84	46.27
DRC, %	72.01	72.06	56.84	41.55
Corn oil, %	0.74	-	-	-
Supplement[4,5], %	3.31	3.33	3.31	3.28
Composition				
DM, %	74.03	73.62	66.83	61.20
CP, %	11.23	11.47	14.80	18.20
NDF, %	20.21	20.52	24.85	28.87
ADF, %	6.93	7.00	8.04	9.03
Ether extract, %	4.58	3.92	4.79	5.52

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RFMDGS = reduced-fat MDGS (RFMDGS).
[2] Treatments included: FF15 = 15% RFMDGS inclusion with 0.7% added corn oil to constitute FF MDGS, RF15 = 15% RFMDGS inclusion, RF30 = 30% RFMDGS inclusion, RF45 = 45% RFMDGS inclusion.
[3] RFMDGS = reduced-fat modified wet distillers grains with solubles (Big River Resources, LLC, Boyceville, WI).
[4] Supplement formulated to provide 287 mg monensin/hd/d (Rumensin, Elanco Animal Health, Greenfield, IN).
[5] MYCO CURB (Kemin, Des Moines, IA) added to supplement to reduce mold contamination.

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

	Treatment[2]					Contrast[3]		
Item	FF15	RF15	RF30	RF45	SEM	1	2	3
Initial BW, kg	385	377	385	370	9.25	0.47	0.72	0.53
d1 to 28								
BW, kg	413	413	419	401	10.63	0.90	0.78	0.97
DMI, kg/d	6.32	6.55	6.94	6.49	0.17	0.09	0.11	0.34
ADG, kg	1.00	1.31	1.21	1.13	0.12	0.11	0.91	0.06
Gain:Feed	0.154	0.201	0.173	0.175	0.017	0.15	0.84	0.06
d29 to 56								
BW, kg	450	453	468	446	11.02	0.64	0.64	0.81
DMI, kg/d	8.58	8.19	9.56	9.28	0.44	0.39	0.02	0.52
ADG, kg	1.33	1.43	1.76	1.58	0.09	0.01	< 0.01	0.39
Gain:Feed	0.160	0.183	0.187	0.178	0.02	0.21	0.48	0.29
d57 to 84								
BW, kg	484	488	503	484	12.07	0.61	0.55	0.84
DMI, kg/d	9.45	7.83	10.58	10.39	0.62	0.83	< 0.01	0.06
ADG, kg	1.24	1.22	1.24	1.37	0.12	0.77	0.55	0.94
Gain:Feed	0.139	0.171	0.137	0.144	0.020	0.59	0.47	0.23
d85 to 112								
BW, kg	528	530	541	522	13.46	0.84	0.84	0.91
DMI, kg/d	9.86	8.15	11.64	10.75	0.91	0.76	0.02	0.17
ADG, kg	1.54	1.50	1.37	1.35	0.12	0.32	0.20	0.78
Gain:Feed	0.174	0.203	0.135	0.158	0.026	0.77	0.12	0.42

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RFMDGS = reduced-fat MDGS (RFMDGS).

[2] Treatments included: FF15 = 15% reduced-fat modified wet distillers grains with solubles (RFMDGS) inclusion with 0.7% added corn oil to constitute full-fat (FF) MDGS, RF15 = 15% RFMDGS inclusion, RF30 = 30% RFMDGS inclusion, RF45 = 45% RFMDGS inclusion.

[3] Preplanned orthogonal contrasts: 1 = FF vs RF (FF15 vs RF15, RF30, and RF45). 2 = Low inclusion vs. High inclusion (FF15 and RF15 vs. RF30 and RF45). 3 = 15 vs. 15 (FF15 vs. RF15). ($P < 0.05$ considered significant; $P > 0.05$ and $\leq$ 0.10 considered a trend).

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

	Treatment[2]					Contrast[3]		
Item	FF15	RF15	RF30	RF45	SEM	1	2	3
Initial BW, kg	385	377	385	370	9.25	0.47	0.72	0.53
d113 to 140								
BW, kg	565	567	576	560	14.03	0.89	0.88	0.94
DMI, kg/d	9.14	8.83	11.12	10.22	1.04	0.44	0.11	0.83
ADG, kg	1.35	1.32	1.26	1.37	0.13	0.81	0.86	0.87
Gain:Feed	0.192	0.162	0.126	0.204	0.042	0.55	0.78	0.60
d141 to 168								
BW, kg	603	601	617	593	15.20	0.97	0.86	0.93
DMI, kg/d	9.12	9.50	12.65	10.69	1.11	0.15	0.04	0.80
ADG, kg	1.35	1.23	1.44	1.19	0.11	0.63	0.83	0.45
Gain:Feed	0.193	0.169	0.120	0.135	0.030	0.13	0.08	0.55
d169 to 181								
BW, kg	605	598	615	591	14.70	0.83	0.89	0.71
DMI, kg/d	8.54	8.66	11.98	9.92	1.15	0.21	0.05	0.94
ADG, kg	0.14	-0.28	-0.11	-0.17	0.16	0.07	0.69	0.05
Gain:Feed	0.011	-0.058	-0.009	-0.046	0.023	0.06	0.87	0.03

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RFMDGS = reduced-fat MDGS (RFMDGS).

[2] Treatments included: FF15 = 15% reduced-fat modified wet distillers grains with solubles (RFMDGS) inclusion with 0.7% added corn oil to constitute full-fat (FF) MDGS, RF15 = 15% RFMDGS inclusion, RF30 = 30% RFMDGS inclusion, RF45 = 45% RFMDGS inclusion.

[3] Preplanned orthogonal contrasts: 1 = FF vs RF (FF15 vs RF15, RF30, and RF45). 2 = Low inclusion vs. High inclusion (FF15 and RF15 vs. RF30 and RF45). 3 = 15 vs. 15 (FF15 vs. RF15). ($P < 0.05$ considered significant; $P > 0.05$ and ≤ 0.10 considered a trend).

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

	Treatment[2]					Contrast[3]		
Item	FF15	RF15	RF30	RF45	SEM	1	2	3
Initial BW, kg	385	377	385	370	9.25	0.47	0.72	0.53
d1 to 28								
BW, kg	413	413	419	401	10.63	0.90	0.78	0.97
DMI, kg/d	6.32	6.55	6.94	6.49	0.17	0.09	0.11	0.34
ADG, kg	1.00	1.31	1.21	1.13	0.12	0.11	0.91	0.06
Gain:Feed	0.154	0.201	0.173	0.175	0.017	0.15	0.84	0.06
d1 to 56								
BW, kg	450	453	468	446	11.02	0.64	0.64	0.81
DMI, kg/d	7.43	7.35	8.23	7.87	0.29	0.24	0.03	0.84
ADG, kg	1.16	1.37	1.48	1.36	0.09	0.02	0.09	0.08
Gain:Feed	0.156	0.190	0.182	0.178	0.014	0.08	0.62	0.07
d1 to 84								
BW, kg	484	488	503	484	12.07	0.61	0.55	0.84
DMI, kg/d	8.17	7.56	9.09	8.78	0.38	0.48	0.01	0.24
ADG, kg	1.19	1.32	1.40	1.36	0.08	0.05	0.11	0.21
Gain:Feed	0.148	0.182	0.159	0.164	0.015	0.24	0.81	0.10
d1 to 112								
BW, kg	528	530	541	522	13.46	0.84	0.84	0.91
DMI, kg/d	8.62	7.72	9.76	9.30	0.49	0.58	0.01	0.19
ADG, kg	1.28	1.37	1.39	1.36	0.07	0.25	0.46	0.37
Gain:Feed	0.153	0.186	0.150	0.160	0.016	0.53	0.37	0.15

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RFMDGS = reduced-fat MDGS (RFMDGS).

[2] Treatments included: FF15 = 15% reduced-fat modified wet distillers grains with solubles (RFMDGS) inclusion with 0.7% added corn oil to constitute full-fat (FF) MDGS, RF15 = 15% RFMDGS inclusion, RF30 = 30% RFMDGS inclusion, RF45 = 45% RFMDGS inclusion.

[3] Preplanned orthogonal contrasts: 1 = FF vs RF (FF15 vs RF15, RF30, and RF45). 2 = Low inclusion vs. High inclusion (FF15 and RF15 vs. RF30 and RF45). 3 = 15 vs. 15 (FF15 vs. RF15). ($P < 0.05$ considered significant; $P > 0.05$ and ≤ 0.10 considered a trend).

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

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

[1] DRC = dry rolled corn, FF MDGS = full-fat modified wet distillers grains with solubles (FF MDGS), RF MDGS = reduced-fat MDGS (RF MDGS).

[2] Treatments included: FF 15 = 15% reduced-fat modified wet distillers grains with solubles (RF MDGS) inclusion with 0.7% added corn oil to constitute full-fat (FF) MDGS, RF 15 = 15% RF MDGS inclusion, RF 30 = 30% RF MDGS inclusion, RF 45 = 45% RF MDGS inclusion.

[3] Preplanned orthogonal contrasts: 1 = FF vs RF (FF 15 vs RF 15, RF 30, and RF 45). 2 = Low inclusion vs. High inclusion (FF 15 and RF 15 vs. RF 30 and RF 45). 3 = 15 vs. 15 (FF 15 vs. RF 15). ($P < 0.05$ considered significant; $P > 0.05$ and ≤ 0.10 considered a trend).

[4] Carcass adjusted final BW was calculated from HCW using a common dressing percentage of 61.70%.

[5] Observed ME intake calculated utilizing iterative procedures (NRC, 2000).

Table 6: 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 7. Effects of experimental treatment on hot 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 8. 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 9. 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 10. 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 11. 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 12. 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 13. 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 14. 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 $P \leq 0.05$.

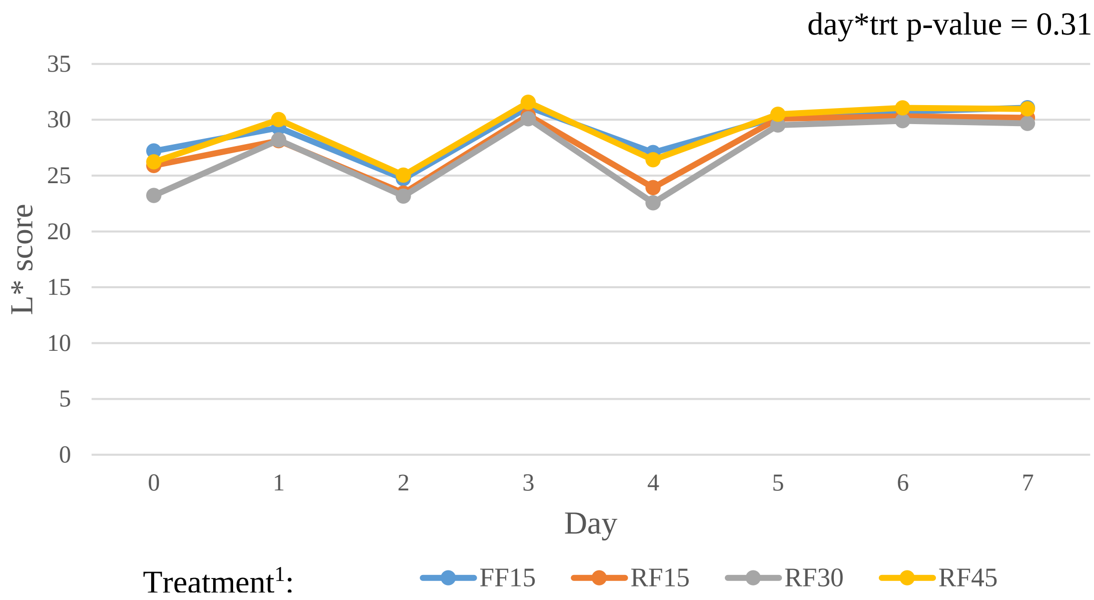
Table 15. Effects of experimental treatment on calculated iodine value from feedlot steers

	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 $P \leq 0.05$.

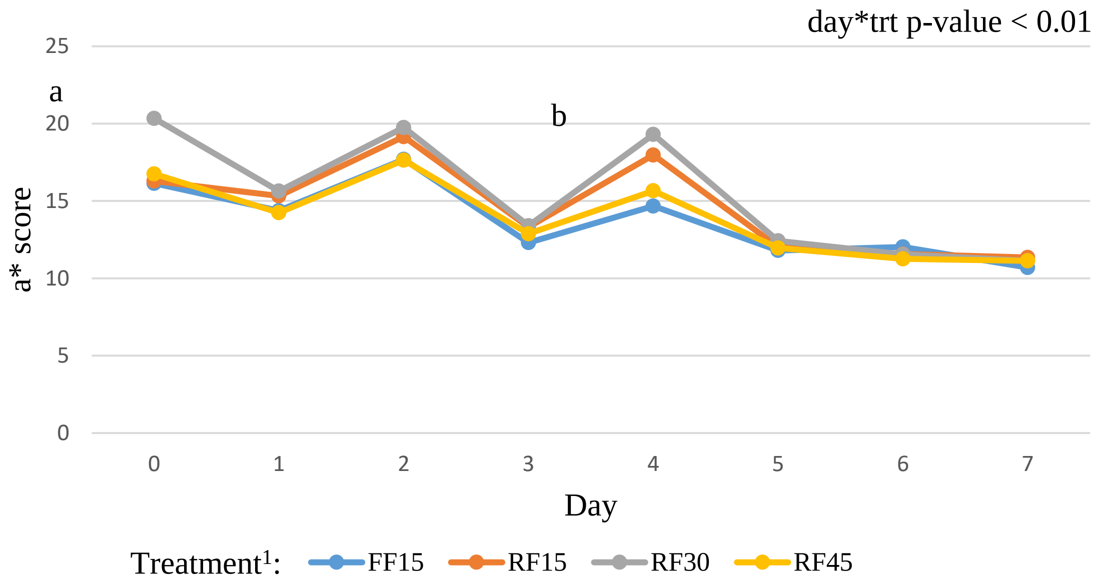
Figures

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



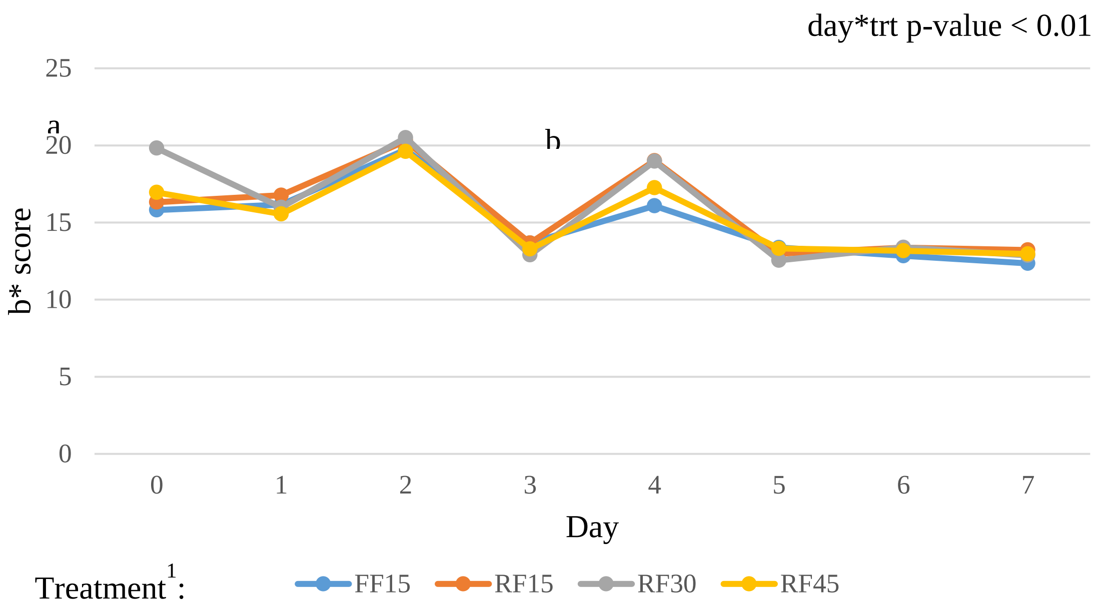
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



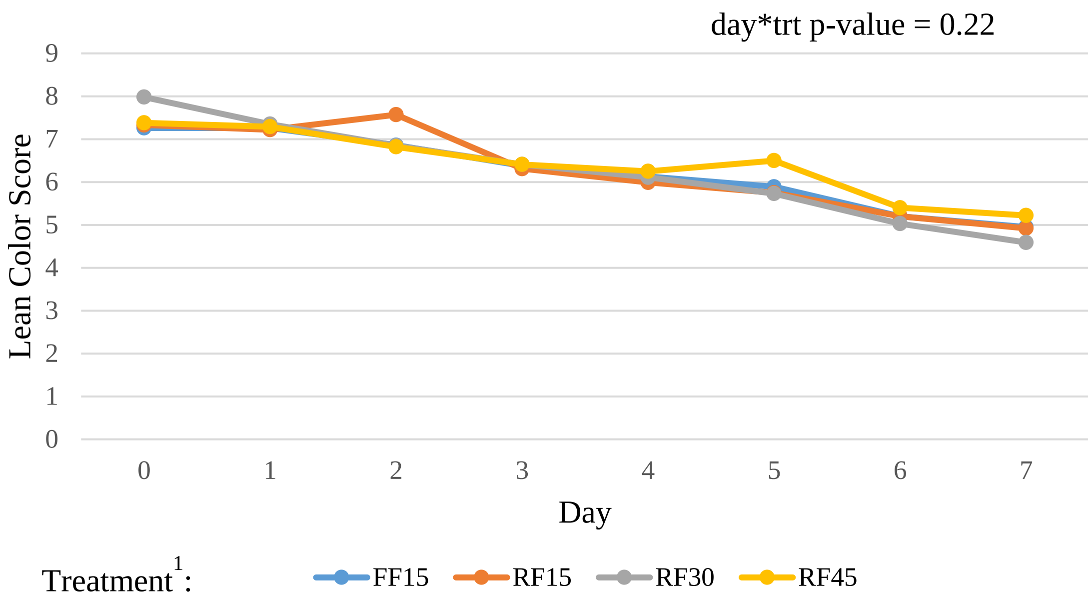
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[a]RF30 is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



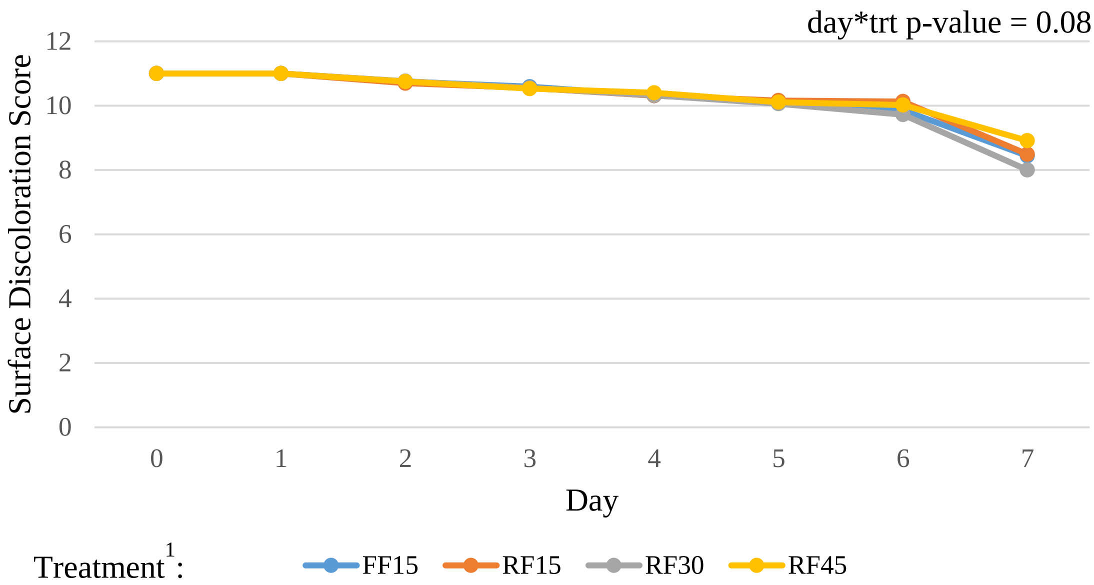
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[a]RF30 is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



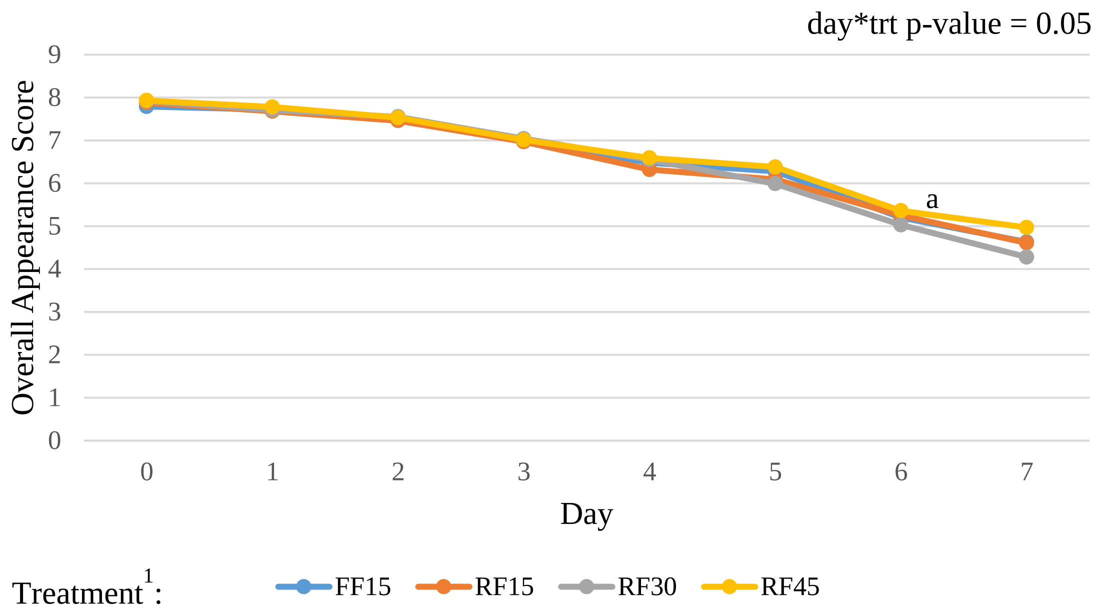
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



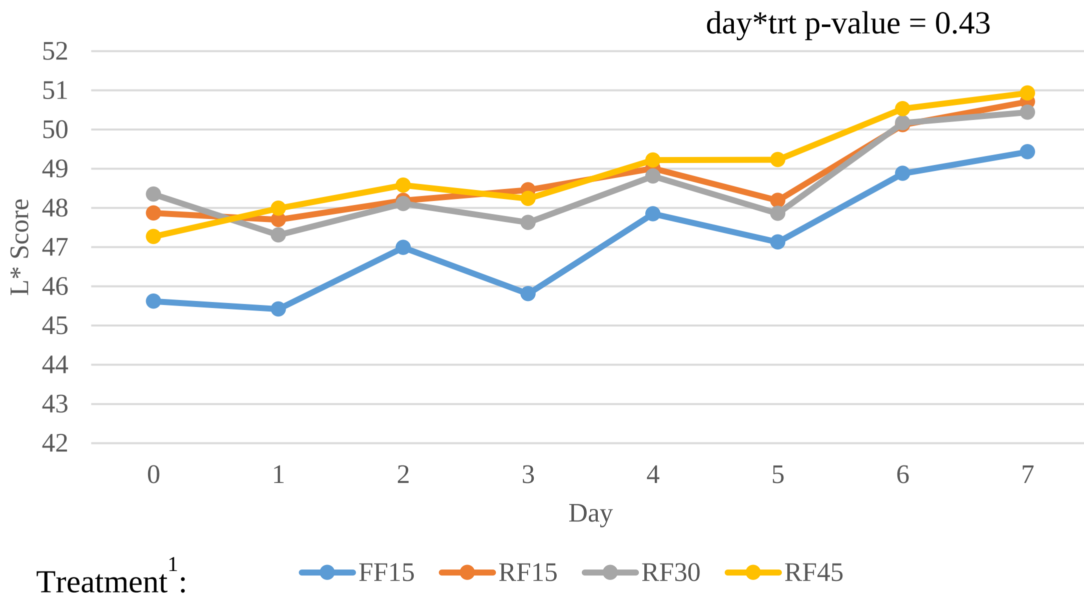
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



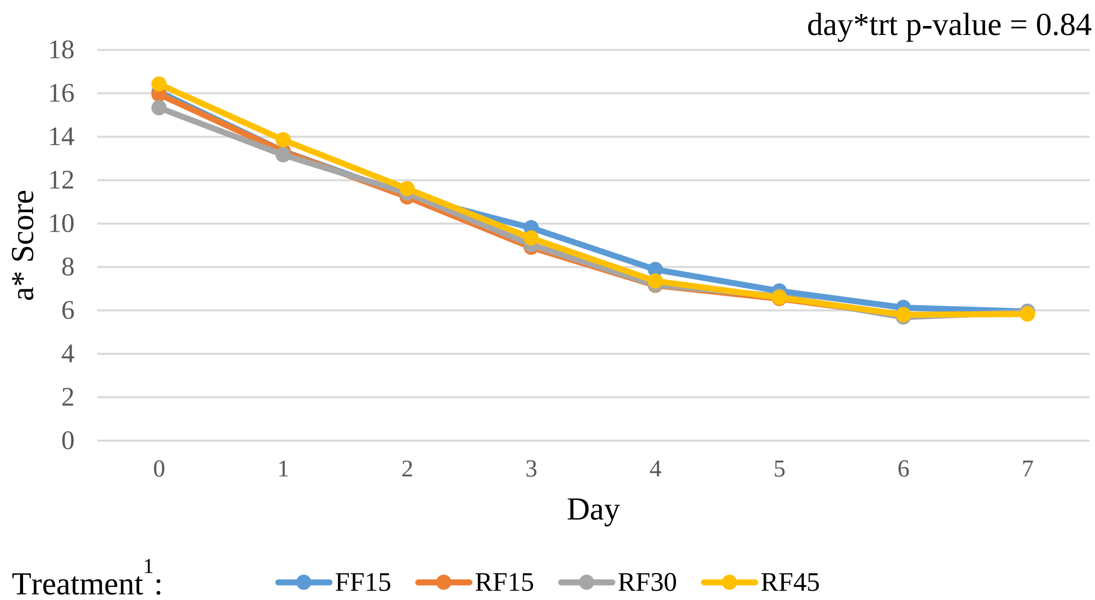
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).
[a]RF30 is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



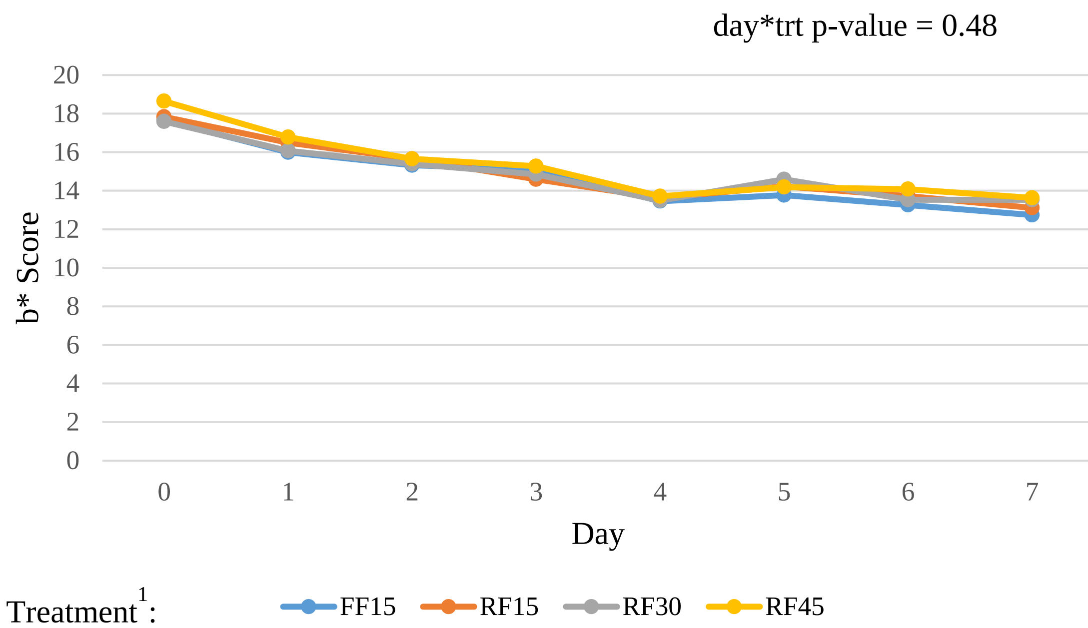
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



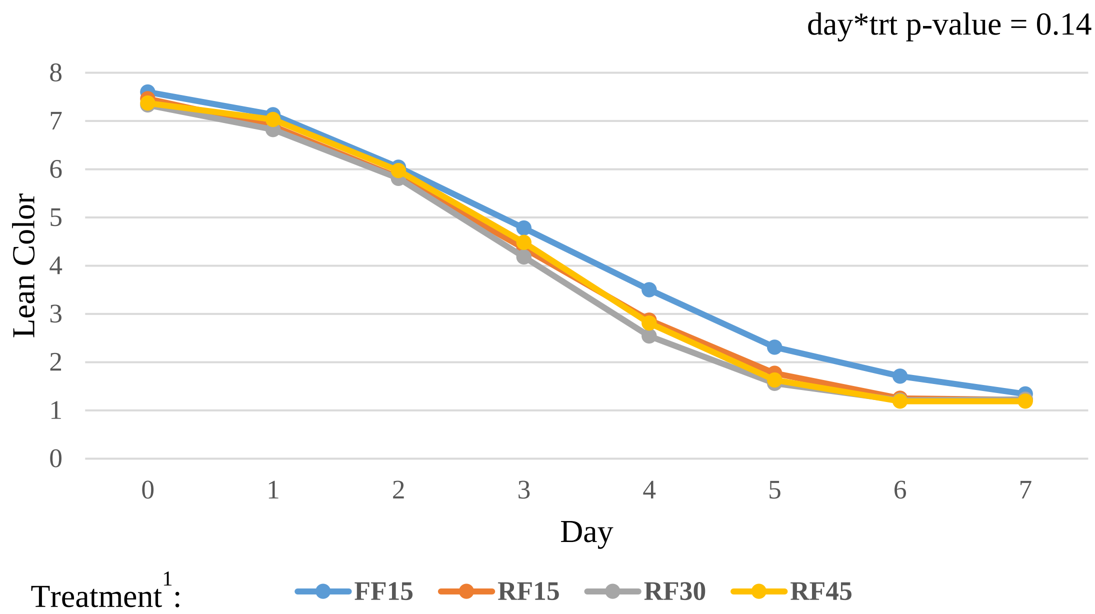
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



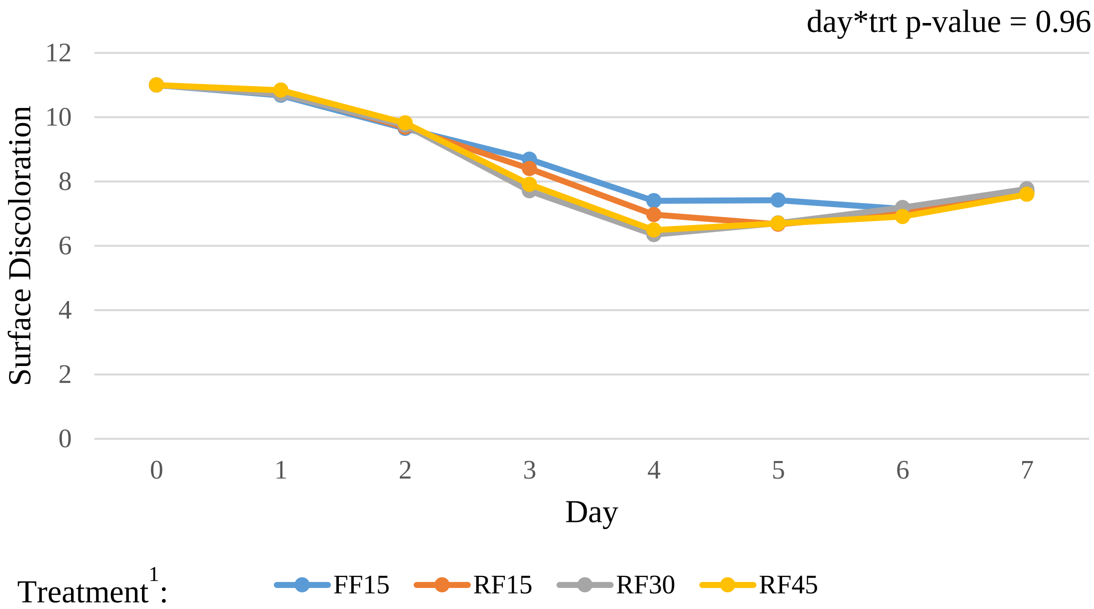
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



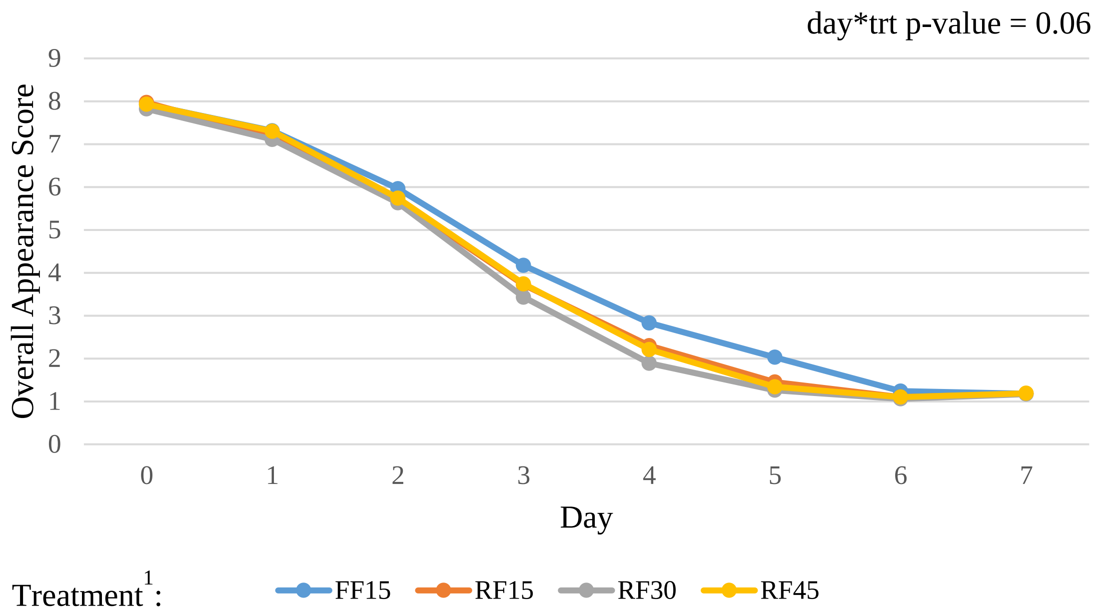
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



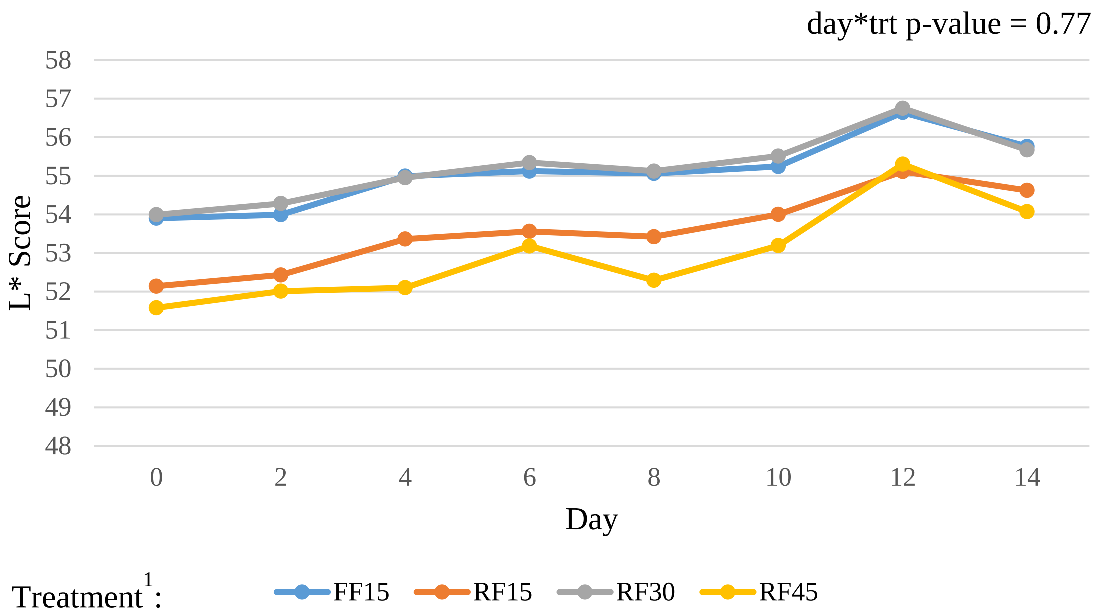
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



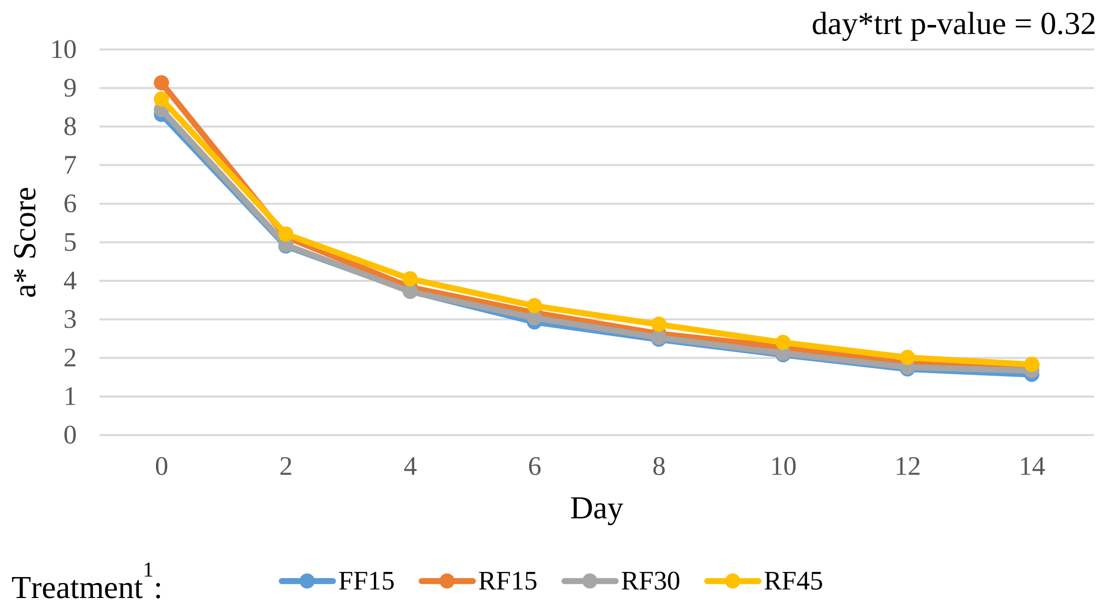
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



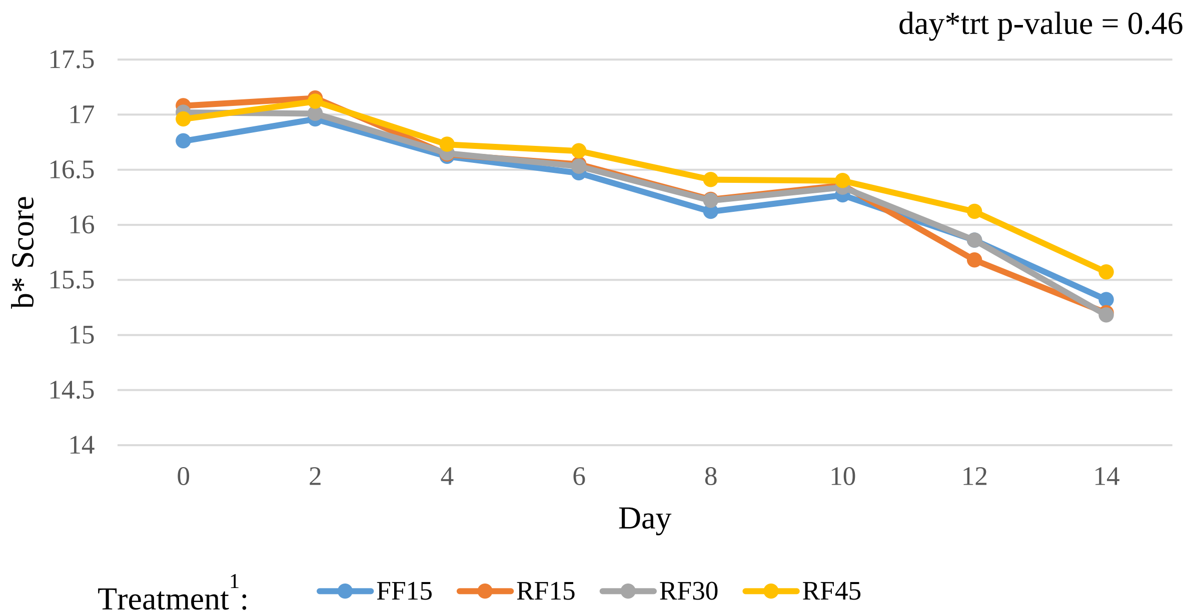
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



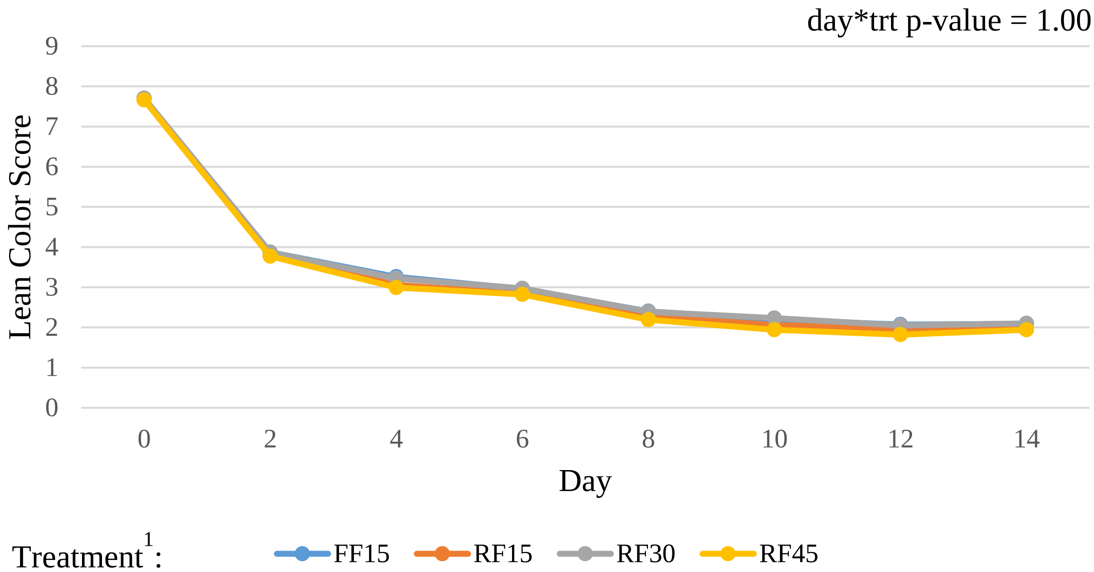
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



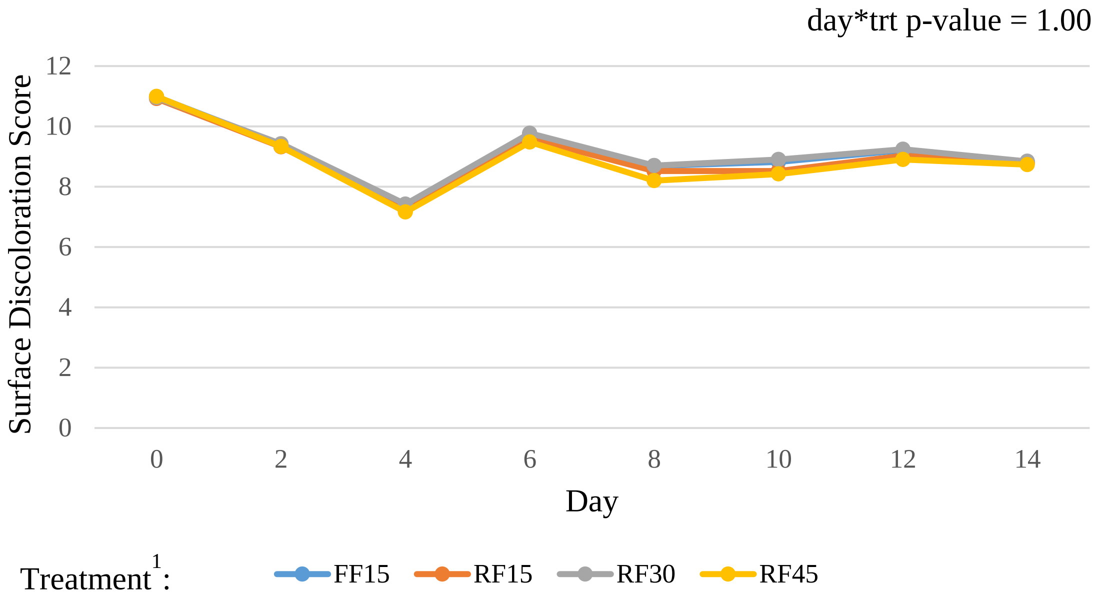
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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



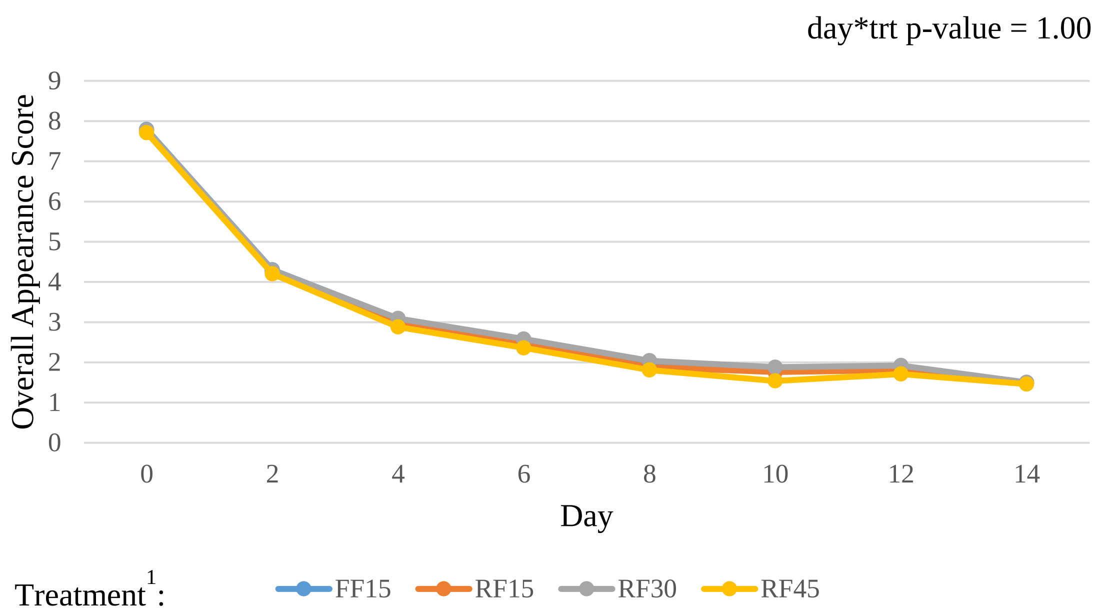
[1]Treatments: 14.3% reduced-fat modified distillers grains with solubles, 0.7% corn oil (FF15); 15.60% reduced-fat modified distillers grains with solubles (RF15); 30.84% reduced-fat distillers grains with solubles (RF30); 46.27% reduced-fat modified distillers grains with solubles (RF45).

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).

Literature Cited

AMSA. 1991. Guidelines for Meat Evaluation Color. American Meat Science Association, Chicago, IL.

AMSA. 1995. Research Guidelines for Cookery, Sensory Evaluation and Instrumental Tenderness Measurements of Fresh Meat. American Meat Science Association, Chicago, IL.

Anderson, V. L., B. R. Ilse, and R. Wiederholt. 2011. Effects of increasing levels of distillers grains in barley-based diets on growing and finishing feedlot performance, carcass traits, and nutrients in manure. Prof. Anim. Sci. 27:547–552.

AOCS. 2009. AOCS Official Method Ce 1j-07: Determination of cis-, trans-, Saturated, Monounsaturated, and Polyunsaturated Fatty Acids in Extracted Fats by Capillary GLC. Sampling and Analysis of Commercial Fats and Oils.

AOCS. 2009. AOCS Official Method Ce 2-66: Preparation of Methyl Ester of Fatty Acids. Sampling and Analysis of Commercial Fats and Oils.

Bothast, R. J., and M. A. Schlicher. 2005. Biotechnological processes for conversion of corn into ethanol. Appl. Microbiol. Biotechnol. 67:19–25.

Bremer, M., C. Bittner, D. Burken, G. Erickson, and J. MacDonald. 2015a. Response to Increasing Concentrations of De-oiled Modified Distillers Grains Plus Solubles in Beef Feedlot Diets. Nebraska Beef Cattle Report. MP101:74-76.

Bremer, Meredith L.; Harris, Marie E.; Hansen, Jake A.; Jenkins, Karla H.; and Matthew K. Luebe. 2015b. Feeding Value of De-oiled Wet Distillers Grains Plus Solubles Relative to Normal When Fed with Either Dry-Rolled Corn or Stem-Flaked Corn in Beef Finishing Diets. Nebraska Beef Cattle Reports. Paper 852.

Bremer, Meredith L.; Watson, Andrea K.; Burken, Dirk B.; MacDonald, Jim C.; and Galen E. Erickson. 2014. Energy Value of De-Oiled Modified Distillers Grains Plus Solubles in a Forage-Based Diet. Nebraska Beef Cattle Reports. Paper 766.

Bremer, V. R., A. Watson, A. Liska, G. Erickson, K. Cassman, K. Hanford, and T. Klopfenstein. 2011. Effect of distillers grains moisture and inclusion level in livestock diets on greenhouse gas emissions in the corn-ethanol-livestock life cycle. Prof. Anim. Sci. 27:449–455.

Buckner, C. D., M. F. Wilken, J. R. Benton, S. J. Vanness, V. R. Bremer, T. J. Klopfenstein, P. J. Kononoff, and G. E. Erickson. 2011. Nutrient variability for distillers grains plus solubles and dry matter determination of ethanol byproducts. Prof. Anim. Sci. 27:57–64.

Buckner, C. D., G. E. Erickson, T. L. Mader, S. L. Colgan, K. K. Karges, and M. L. Gibson. 2007. Optimum Levels of Dry Distillers Grains with Solubles for Finishing Beef Steers. Nebraska Beef Cattle Report. MP90:36-38.

Depenbusch, B. E.; Coleman, C. M.; Higgins, J. J.; and J. S. Drouillard. 2009. Effects of increasing levels of fried corn distillers grains with solubles on growth performance, carcass characteristics, and meat quality of yearling heifers. J. Anim. Sci. 87:2653-2663.

Diaz-Royon, Fernando; Garcia, Alvaro; and Kurt A. Rosentrater. 2012. Composition of Fat in Distillers Grains. iGrow.

Erickson, G. E., V. R. Bremer, T. J. Klopfenstein, L. Stalker, and R. J. Rasby. 2007. Utilization of Corn Co-Products in the Beef Industry 2nd ed. A joint project of the Nebraska Corn Board and the University of Nebraska–Lincoln Institute of Agriculture and Natural Resources Agricultural Research Division University of Nebraska–Lincoln Ext.

Jenkins, T. C.; Wallace, R. J.; Moate, P. J.; and E. E. Mosley. 2008. Board-invited review: Recent advances in biohydrogenation of unsaturated fatty acids within the rumen microbial ecosystem. J Anim. Sci. 86: 397-412.

Johnston, Justin. Impact of using Reduced-Fat Distillers Grains in Beef Feedlot Diets on Carcass and Meat Quality – Thesis. November 2014. University of Minnesota Conservancy.

Jolly, Molly L.; Nuttelman, Brandon, L.; Burken, Dirk; Schneider, Cody J.; Klopfenstein, Terry J.; and Galen E. Erickson. 2013. Effects of Modified Distillers Grains Plus Solubles and Condensed Solubles With or Without Oil Extraction on Finishing Performance. Nebraska Beef Cattle Report.

Jolly, Molly L.; Nuttelman, Brandon, L.; Burken, Dirk; Schneider, Cody J.; Klopfenstein, Terry J.; and Galen E. Erickson. 2014. Effects of Increasing Inclusion of Wet Distillers Grains Plus Solubles With and Without Oil Extraction on Finishing Performance. Nebraska Beef Cattle Report.

Klopfenstein, T. J.: Erickson, G. E.; and V. R. Bremer. 2008. Board-invited review: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86:1223–1231.

Koger, T. J.; Wulf, D. M.; Weaver, A. D.; Wright, C. L.; Tjardes, K. E.; Mateo, K. S.; Engle, T. E.; Maddock, R. J.; and A. J. Smart. 2010. Influence of feeding various quantities of wet and dry distillers grains to finishing steers on carcass characteristics, meat quality, retail-case life of ground beef, and fatty acid profile of the longissimus muscle. J. Anim. Sci. 88:3399 – 3408.

Lim, Chhorn and Mediha Yildirm-Aksoy. 2008. Distillers Dried Grains With Solubles As An Alternative Protein Source In Fish Feeds. International Symposium on Tilapia in Aquaculture.

Luebbe, M. K., J. M. Patterson, K. H. Jenkins, E. K. Buttrey, T. C. Davis, B. E. Clark, F. T. McCollum, N. A. Cole, and J. C. MacDonald. 2012. Wet distillers grains plus solubles concentration in steam-flaked-corn-based diets: Effects on feedlot cattle performance, carcass characteristics, nutrient digestibility, and ruminal fermentation characteristics. J. Anim. Sci. 90:1589–602.

McClements, D. J. and E. A. Decker. 2008. Lipids. In S. Damodaran, K. L. Parkin, and O. R. Fennema (eds), Fennema's food chemistry. 4th ed. CRC Press, Boca Raton, FL.

Mello Jr, A. S.; Calkins, C. R.; Jenschke, B. E.; Carr, T. P.; Dugan, M. E. R.; and G. E. Erickson. 2012. Beef quality of calf-fed steers finished on varying levels of corn-based wet distillers grains plus solubles. J. Anim. Sci. 90:4625 – 4633.

Mello Jr, A. S.; Jenschke, B. E.; Senaratne, L. S.; Carr, T. P.; Erickson, G. E.; and C. R. Calkins. 2012. Effects of feeding modified distillers grains plus solubles on marbling attributes, proximate composition, and fatty acid profile of beef. J. Anim. Sci. 90:4634 – 4640.

RFA. 2015a. Pocket Guide to Ethanol 2015. Available from: http://www.ethanolrfa.org/pages/rfa-pocket-guide-to-ethanol. (Accessed 6 June 2015).

RFA. 2015b. Going global. 2015 Ethanol Industry outlook. Available from: http://www.ethanolrfa.org/pages/annual-industry-outlook. (Accessed 6 June 2015).

Singh, V., D. B. Johnston, K. Naidu, K. D. Rausch, R. L. Belyea, and M. E. Tumbleson. 2005. Comparison of modified dry-grind corn processes for fermentation characteristics and DDGS composition. Cereal Chem. 82:187–190.

Sosnicki, Andrzej A. 2010. Pork Fat Quality. PIC. Available at: http://www.pic.com/Images/Users/1/SalesPortal/Newsletters/CuttingEdge/CuttingEdge1stQ10New.pdf. Accessed on: April 27, 2016.

Tarladgis, B. G.; Watts, B.M.; Younathan, M. T.; and L. Dugan Jr. 1960. A distillation method for the quantitative determination of malonaldehyde in rancide foods. J. Am. Oil Chem. Soc. 37:44-48.

Vander Pol, Kyle J.; Erickson, Galen E.; Klopfenstein, Terry J.; Greenquist, Matthew A.; and Thomas Robb. 2006. Effect of Dietary Inclusion of Wet Distillers Grains on Feedlot Performance of Finishing Cattle and Energy Value of Corn. Nebraska Beef Cattle Reports. Paper 120.

Watson, A. K.; Vander Pol, K. J.; Huls, T. J.; Luebbe, M. K.; Erickson, G. E.; Klopfenstein, T. J.; and M. A. Greenquist. 2014. Effect of dietary inclusion of wet or modified distillers grains plus solubles on performance of finishing cattle. The Prof. Anim. Scient. 30:585 – 596.

Weiss, B., M. Eastridge, D. Shoemaker, and N. St-Pierre. 2007. Distillers Grains Fact Sheet. Available from: http://ohioline.osu.edu/as-fact/distillers.html. (Accessed 6 June 2015).

Wood, J.D.; Richardson, R.I.; Nute, G.R.; Fisher, A.V.; Campo, M.M,; Kasapidou, E.; Sheard, P.R.; and M. Enser. 2003. Effects of fatty acids on meat quality: a review. Meat Sci. 66:21-32.

Zanton, Geoff and Jud Heinrichs. 2016. Opportunities and Challenges of Feeding Distillers Grains to Dairy Cows. PennState Extension. Available at: http://extension.psu.edu/animals/dairy/nutrition/nutrition-and-feeding/ration-ingredients/opportunities-and-challenges-of-feeding-distillers-grains-to-dairy-cows. Accessed on: April 26, 2016.