Impact of feeding de-oiled wet distillers grains plus solubles on beef shelf life

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ABSTRACT: Research was conducted to determine the effect of feeding de-oiled wet distillers grains plus solubles (WDGS) on beef fatty acid profile, retail shelf life and development of oxidation products during retail display (RD). A total of 336 crossbred yearling steers (initial BW = 351.08 ± 19.05 kg) were fed 1 of 7 dietary treatments: an all corn control (1:1 blend of dry rolled and high moisture corn), 35%, 50%, or 65% inclusion of WDGS, either full-fat or de-oiled. Within each treatment 15 Choice carcasses were randomly selected (n = 105), strip loins were obtained, aged 7 and 21 d, and representative steaks from each strip loin were placed in RD conditions for 7 d. Fatty acid profiles were determined (mg/100 g tissue basis) and differences (P ≤ 0.05) were found in the C16:1, C18:1T, C18:2 and total polyunsaturated fatty acids (PUFA) among dietary treatments. Palmitoleic acid (C16:1) was predominant (P < 0.0001) in the corn control group, intermediate in the 35% de-oiled WDGS group, but no differences (P > 0.05) were observed between all other diets. Elaidic acid (C18:1T) was greater (P = 0.01) in the 65% full-fat WDGS group, least for the corn control group, and intermediate for all other diets. Linoleic acid (C18:2) was greater (P = 0.0001) in all 3 full-fat WDGS groups and 65% de-oiled WDGS group (290.98 mg/100 g, on average), intermediate in the 50% and 35% de-oiled WDGS groups (231.08 and 227.16 mg/100 g, respectively) and least for the corn control group (177.70 mg/100 g). The PUFA content was greater (P < 0.01) in all 3 full-fat WDGS groups and 65% de-oiled WDGS group (337.13 mg/100 g, on average), intermediate in the 50% and 35% de-oiled WDGS groups (274.77 and 273.84 mg/100 g, respectively) and least for the corn control group (223.98 mg/100 g). Dietary treatment did not alter discoloration (P = 0.30) or lipid oxidation (P = 0.36). Shear force decreased with age and RD (P < 0.0001) but dietary treatment had no effect on shear force (P = 0.93). In general, feeding 35% and 50% de-oiled WDGS had intermediate PUFA content relative to a corn control or full-fat WDGS diet. Feeding de-oiled WDGS did not seem to increase beef shelf life and does not negatively alter beef quality parameters in relation to full-fat WDGS.

Key words: beef, de-oiled wet distillers grains plus solubles, fatty acid profile, oxidation, retail display

INTRODUCTION

Feeding wet distillers grains plus solubles (WDGS) is a common practice in the state of Nebraska as WDGS are a by-product generated by ethanol production from corn that decreases beef production cost while providing great nutritional value and is widely available to producers. During ethanol production, by-products such as distillers grains and carbon dioxide are generated (Saunders and Rosentrater, 2009a, b). Previous research done at the University of Nebraska-Lincoln has found that feeding WDGS increases the polyunsaturated fatty acid (PUFA) content of beef, resulting in greater lipid oxidation (Mello et al., 2008a, b).

More recently, the ethanol industry has been extracting soluble fats from WDGS via centrifugation to maximize profits (Berger and Singh, 2010). As explained by Winlker-Moser and Breyer (2011), the oil removal process can occur at different processing stages. Oil removed from the corn prior to fermentation is primarily utilized for human consumption, while oil removed after fermentation is utilized for cattle feed, biodiesels, and potentially for human consumption if food grade oil quality parameters are met (Winlker-Moser...
In 2012 over 50% of ethanol plants were removing the soluble fat portion of WDGS, and this percentage continues to increase (Jolly et al., 2013). Given the growing availability of de-oiled WDGS in the market, it is imperative to understand how their inclusion in feedlot diets will affect beef quality. The working hypothesis is that the reduction of the oil fraction in WDGS could alter the fatty acid composition of beef by diminishing the PUFA content and consequently aiding shelf stability. Thus, the objectives of this study were to evaluate how feeding de-oiled WDGS affected fatty acid profiles, lipid oxidation, and shelf life of beef in comparison to full-fat WDGS and a corn control diet consisting of a 1:1 blend of dry rolled corn and high moisture corn.

### MATERIALS AND METHODS

University of Nebraska-Lincoln’s Animal Care and Use Committee approved of all animal use protocols (IACUC# 902).

### Cattle and Dietary Treatments

A total of 336 crossbred yearling steers (initial BW = 351.08 ± 19.05 kg) were fed (University of Nebraska feedlot, Mead, NE) 1 of 7 finishing diets: an all corn control (1:1 blend of dry-rolled and high moisture corn), 35%, 50%, or 65% inclusion of WDGS, either full-fat or de-oiled. Upon arrival at the feedlot (d 1) steers were implanted with Revalor-XS (Merck Animal Health, Summit, NJ). Steers were blocked by body weight and randomly assigned to pens (8 hd/pen with 6 replications for a total of 42 pens). All WDGS were produced from a single ethanol plant (KAAPA Ethanol, Minden, NE) and steers were finished for 147 d.

All dietary treatments are presented in Table 1. As inclusion of WDGS increased, for both full-fat and de-oiled diets, the percentage of dry rolled corn and high moisture corn (1:1) were adjusted accordingly to formulate all diets with equal amounts of corn silage (12% DM basis) and supplement (5% DM basis). The supplement was formulated to provide approximately 380 mg/steer per d of Rumensin as well as 90 mg/steer per d of Tylan throughout the feeding period, irrespective of dietary treatment. Sufficient vitamin E was fed to ensure the nutritional requirements were met.

### Sample Collection and Fabrication

At harvest (Greater Omaha Packing, Omaha, NE), 15 Choice carcasses were randomly selected within each treatment (n = 105) making sure sampling was done on a within pen basis. Strip loins (Longissimus lumborum) were collected, vacuum packaged, and aged for 7 and 21 d (2°C) under dark storage. After 7 d of aging, loins were fabricated by hand-cutting from anterior to posterior into 2.54 cm steaks for visual discoloration and tenderness [2 steaks; 1 for d 0 retail display (RD) and one for d 7 RD]. Two 1.27 cm steaks were utilized for fatty acid profile, proximate composition and lipid oxidation (1 of the steaks was split in half for fatty acid profile, proximate composition and lipid oxidation for 0 d RD while the second steak was split in half for 4 and 7 d RD lipid oxidation). The remaining portion of the loin was vacuum sealed (3mil STD barrier, Prime Sources, St. Louis, MO) with a Multivac Packaging machine (Mutivac C500, Multivac, Kansas city, MO) and the same fabrication scheme was used at 21 d postmortem. For both aging periods, steaks for visual discoloration, tenderness and lipid oxidation were placed on foam trays (21.6 × 15.9 × 2.1 cm).

### Table 1. Diet composition (DM basis) fed to finishing steers receiving either 35%, 50%, or 65% De-oiled or Full-fat WDGS or a corn control diet

| Ingredient, % of DM | Control | 35% WDGS | 50% WDGS | 65% WDGS |
|---------------------|---------|----------|----------|----------|
| DRC                 | 41.5    | 24       | 24       | 16.5     | 16.5     | 9         | 9         |
| HMC                 | 41.5    | 24       | 24       | 16.5     | 16.5     | 9         | 9         |
| WDGS: De-Oiled 1    | 35      | –        | –        | 50       | –        | 65        | –         |
| WDGS: Full-Fat 1    | –       | 35       | –        | –        | 50       | –         | 65        |
| Corn Silage         | 12      | 12       | 12       | 12       | 12       | 12        | 12        |
| Supplement 2        | 5       | 5        | 5        | 5        | 5        | 5         | 5         |

**Analyzed Composition, %**

| Ingredient | Control | 35% WDGS | 50% WDGS | 65% WDGS |
|------------|---------|----------|----------|----------|
| Fat        | 4.5     | 5.5      | 7.1      | 6.0      | 8.2      | 6.4       | 9.3       |
| CP         | 11.4    | 15.2     | 14.8     | 18.7     | 18.1     | 22.1      | 21.4      |
| Sulfur     | 0.09    | 0.32     | 0.31     | 0.42     | 0.41     | 0.52      | 0.51      |
| NDF        | 13.5    | 26.6     | 27.8     | 32.3     | 34.0     | 38.0      | 40.2      |

1DRC = Dry rolled corn; HMC = High moisture corn; WDGS = Wet distillers grains plus solubles.

2Formulated to contain 383 mg/hd per d of Rumensin and 90 mg/hd per d of Tylan.
cm, Styro-Tech, Denver, CO), overwrapped with oxygen permeable film (PVC-OW; PSM18, Prime Source, St. Louis, MO) and placed under RD conditions for 4 and 7 d (2.7°C under white fluorescence lighting at 1,000 to 1,800 lux). Steaks used for fatty acid profile, proximate composition and 0 d RD were vacuum packaged and frozen until further processing (-80°C). Samples trimmed of all subcutaneous fat for proximate analysis, fatty acids, and lipid oxidation were frozen in liquid nitrogen and powdered in a metal cup blender (Model 51BL32, Waring Commercial, Torrington, CT). Powdered samples were stored at -80°C.

**Proximate Analysis**

Proximate analysis was conducted to determine fat, moisture and ash content; and protein content was determined by difference. Fat was quantified following the Soxhlet procedure (AOAC, 1990). Samples were measured in triplicate in Whatman #2 filter paper (Whatman, Clifton, NJ) and fat was extracted with ether. Fat percentages were averaged per sample and used to convert fatty acid percent data to mg/100 g tissue basis. Moisture and ash were determined with a LECO thermogravimetric analyzer (LECO Corporation, Model 604–100–400, St. Joseph, MI), and samples were measured in duplicate. Moisture was determined in nitrogen atmosphere with a start temperature of 25°C and an end temperature of 130°C (17 min ramp rate). Ash was determined in oxygen atmosphere with a start temperature of 130°C and an end temperature of 600°C (30 min ramp rate).

**Fatty Acid Composition**

Fatty acids were extracted as described by Folch et al. (1957) and quantified via gas chromatography as detailed by Morrison and Smith (1964) and Metcalfe et al. (1966). Briefly, 1 g of powdered sample was weighed into a 15 mL conical tube to which 5 mL of 2:1 chloroform:methanol was added and vortexed for 5 s. After 1 h, samples were filtered through Whatman #2 filter paper onto a 13 × 150 mm glass Waring Commercial, Torrington, CT). Powdered samples were stored at -80°C.

Fatty Acid Composition

were centrifuged (1000 × g for 5 min). The top hexane layer was carefully pipetted into gas chromatography glass vials, nitrogen purged and lids were crimped on. Chromatography was done using a Chrompack CP-Sil (0.25 mm × 100 m) column with an injector temperature of 270°C and a detector temperature of 300°C (Hewlett-Packard 6890 FID GC System; Agilent Technologies, Santa Clara, CA). The head pressure was set at 40 psi with a flow rate of 1.0 mL/min. The fatty acids were identified by their retention times in relation to known commercial standards (# GLC-68D, GLC-79, GLC-87, GLC-455 and GLC-458; NU-Chek Prep, Inc., Elysian, MN) and the percentage of fatty acids were determined by the peak areas in the chromatograph. Values were adjusted according to percent fat and values were converted to mg/100 g tissue with the following equation:

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\text{Fatty acid mg/100 g tissue} = (\text{Fatty acid peak area} * \% \text{fat of sample}) * \frac{1000}{10} = (\text{Fatty acid mg/100 g tissue})
\]

**Subjective Color (Discoloration)**

Visual discoloration was assessed daily during retail display with a trained 5-person panel. Prior training consisted of panelists becoming familiar with a visual discoloration guide to be used as a reference to evaluate individual steaks under RD. A percentage scale was used were 0% meant no discoloration and 100% meant complete discoloration. The provided reference consisted of 10 steel images ranging from 0% to 100% discoloration exemplifying surface discoloration with increments of 10%. Panelists were instructed to perform the evaluation at the same time each day to minimize variation. Samples were randomly redistributed once daily to minimize any possible steak tray and lighting location effects.

**Lipid Oxidation**

Lipid oxidation was determined with the 2-thiobarbituric acid reactive substances protocol (TBARS) as described by Ahn et al. (1998). Briefly, 5 g of powdered sample was weighed into a 50 mL conical tube to which 14 mL of deionized distilled water and 1 mL of BHA (10% BHA: 90% ethanol) were added. After homogenizing samples with a Polytron (Kinmatica AG, Lucern, Sui) for 15 s the samples were centrifuged (2000 × g for 5 min). One mL of the supernatant was transferred to a 15 mL conical tube and 2 mL of the sample were added and vortexed before placing samples in a water bath (70°C for 30 min). After cooling, samples were centrifuged (2,000 × g for 5 min) and 200 μL of supernatant were transferred to a 15 mL conical tube and 2 mL of the sample were added and vortexed before placing samples in a water bath (70°C for 30 min). After cooling, samples were centrifuged (2,000 × g for 5 min) and 200 μL of supernatant were transferred.
to 96-well plates. All 96-well plates had standards to calculate standard curves and ultimately mg of malonaldehyde per kg of tissue read at 540 nm.

**Tenderness (Warner-Bratzler Shear Force)**

Tenderness was measured via Warner-Bratzler Shear Force (WBSF). Samples were thawed (4°C) 24 h prior to cooking and internal temperature was monitored with a thermocouple (5SC-TT-T-30–120, OMEGA Engineering, Inc., Stamford, CT) inserted in the geometric center of each steak. Steaks were cooked on Hamilton Beach grills (Model 31605A, Proctor-Silex, Inc., Washington, NC) until an internal temperature of 35°C was achieved at which time steaks were flipped to continue cooking until a final internal temperature of 71°C. Following cooking steaks were refrigerated for 24 h and 6 cores (1.27 cm diameter) were taken parallel to the muscle fiber with a drill press and sheared using a portable Warner-Bratzler shear machine (3000, WBS 25 kg scale, 115 motor, 1/2 coring cutter, G-R Manufacturing Co., Manhattan, KS). All samples were sheared with the triangular WBSF attachment and the average of the 6 cores was calculated for statistical analysis.

**Statistical Analysis**

Data were analyzed as a 7 × 2 × 3 factorial (7 dietary treatments × 2 aging times × 3 retail display times) with SAS (version 9.2, SAS Inst. Inc., Cary, NC). The main effects of dietary treatment, aging, retail display, and their interactions were tested. Individual animal served as the experimental unit while pen was considered a random variable. The PROC MIXED procedure was used for repeated measures of visual discoloration and the most appropriate covariance structure was selected based on the best fit model. The PROC GLIMMIX procedure was utilized to evaluate all other variables measured. Means were separated with the LS MEANS statement and the TUKEY adjustment was used with an a level of 0.05.

**RESULTS AND DISCUSSION**

**Proximate Analysis**

There were no differences between treatments for marbling score (P > 0.05; data not shown). Finishing diet had no effect (P > 0.05) on moisture (71.70%), protein (20.26%), fat (6.48%), or ash (1.56%) content in beef. Given that de-oiled WDGS is more recently available as an ethanol by-product for cattle feed, there is limited information on their impact on nutritional composition of beef in the literature. However, one study examined feeding full-fat WDGS at 0%, 15% and 30% inclusion on corn based diets indicated that the finishing diet did not affect the moisture, fat, or ash content of Infraspinatus (top blade) and Psoas major (tenderloin) steaks (Mello et al., 2012b). A similar observation was made by Mello et al. (2012a) in a study with six diets containing varying levels (0% to 50% DM basis) of modified wet distillers grains plus solubles (MWDG: distillers grains with partial drying for a moisture level of 50% to 54%). Although these diets included full-fat corn distillers grains these did not affect moisture, fat, or ash content of beef. In addition, the fat percentage reported ranged from 7.43 to 8.68%, slightly higher than that observed in the current study. On the other hand, Buttrey et al. (2013) reported that after finishing crossbred steers with 35% WDGS, steaks tended (P < 0.10) to increase total fat content compared to diets without WDGS.

**Fatty Acid Composition**

Table 2 provides the fatty acid profiles of all the dietary treatments reported in mg/100 g of tissue basis. No differences (P > 0.05) were observed in the amounts of monounsaturated fatty acids (MUFA), saturated fatty acids (SFA), unsaturated fatty acids (UFA), the SFA:UFA ratio, or the total amount of fatty acids. Similarly, Mello et al. (2012b) reported that these fatty acids were unaffected in beef from cattle fed diets containing WDGS vs. cattle finished on a corn control diet. Buttrey et al. (2013) reported a decreased ratio of MUFA:SFA in the longissimus muscle of cattle feed 35% WDGS vs. cattle with no inclusion of WDGS. Caution is advised regarding direct comparisons to the fatty acid data reported by previously published data as there are reported on a percent of fatty acid composition basis and not mg/100 g of tissue basis, as in the current study.

In the current study, differences (P < 0.05) were found in the C16:1, C18:1T, C18:2 and PUFA content among dietary treatments. Palmitoleic acid (C16:1) was predominant (P < 0.0001) in beef from cattle on the corn control diet, intermediate in beef from cattle on the 35% de-oiled WDGS diet, with lower values found in cattle on all other dietary treatments (Fig. 1). These results are consistent with the findings of Buttrey et al. (2013) that explain that palmitoleic acid is the desaturated product of palmitic acid (C16:0) and that feeding corn WDGS decreases palmitoleic acid (P ≤ 0.01). In a similar study conducted by Mello et al. (2012b), decreases in both C16:0 and C16:1 contents were observed in the Longissimus thoracis, Psoas major and Infraspinatus muscles as inclusion levels of WDGS increased from 0, 15 to 30% on a percentage basis. These decreases in C16:0 and C16:1 were also observed with increasing concentrations of modified wet distillers grains plus solubles (MGDS; Mello et al., 2012a). Plascencia et al. (2003) has also
shown that ruminal digestion of C16:0 is decreased with increasing concentrations of fat in cattle diets. Elaidic acid (C18:1T) content was greatest \((P = 0.01)\) in beef from cattle finished on 65% full-fat WDGS, least for the corn control fed cattle, and intermediate in beef from all other dietary treatments (256.20 mg/100 g, 120.12 mg/100 g, and 210.36 mg/100 g, respective average values; Fig. 2). Similar results were also reported by Mello et al. (2012b) which reflected an increase in C18:1T content with increasing levels of WDGS in the Longissimus thoracis and Infraspinatus muscles. However, this difference was not observed in the Psoas major. Research conducted by Vander Pol et al. (2009) using ruminal and duodenal cannulated steers aimed to evaluate differences in dietary lipids comparing corn distillers grains versus corn finishing diets. Vander Pol et al. (2009) indicated that cattle fed WDGS had greater total fat digestion as well as a greater amount of unsaturated fatty acids reaching the duodenum \((P < 0.10)\). These findings suggest a plausible explanation for the increased availability and ultimately deposition of unsaturated fatty acids in meat of cattle fed WDGS.

**Table 2. Amount\(^1\) of fatty acids from steers feed different inclusion levels of De-oiled or Full-fat WDGS (\(L. lumborum\)).**

| Fatty acid | Treatment | Control | 35% | 50% | 65% | Control | 35% | 50% | 65% | SEM | \(P\)-value |
|-----------|-----------|---------|-----|-----|-----|---------|-----|-----|-----|-----|--------|
| C14:0     | Corn      | 180.61  | 156.49 | 139.36 | 150.35 | 171.89  | 155.00 | 162.89 | 14.82 | 0.47  |
| C14:1     | De-oiled WDGS | 40.66 | 33.03 | 29.98 | 28.01 | 33.35 | 27.36 | 30.37 | 3.43 | 0.11  |
| C15:0     | Full-fat WDGS | 31.90 | 32.17 | 27.68 | 104.03 | 32.30 | 31.71 | 30.59 | 2.62 | 0.71  |
| C15:1     | 33.55 | 35.15 | 28.32 | 30.45 | 30.27 | 29.01 | 30.73 | 5.29 | 0.53  |
| C16:0     | 1679.52 | 1588.06 | 1364.32 | 1501.57 | 1706.01 | 1543.98 | 1609.64 | 1087.8 | 0.31  |
| C16:1     | 194.26b | 149.67ab | 132.58b | 115.32b | 145.11b | 120.71b | 128.23b | 11.14 | <0.0001  |
| C17:0     | 98.83 | 103.35 | 86.42 | 93.81 | 103.89 | 104.32 | 98.18 | 8.03 | 0.67  |
| C17:1     | 80.07 | 73.43 | 64.38 | 59.95 | 66.60 | 65.26 | 61.78 | 5.81 | 0.18  |
| C18:0     | 927.89 | 1017.22 | 874.61 | 1029.27 | 1126.37 | 1109.31 | 1119.00 | 15.21 | 0.12  |
| C18:1T    | 120.12b | 156.98ab | 170.91ab | 227.49ab | 248.40ab | 256.20a | 31.04 | 0.01  |
| C18:1     | 2590.88 | 2514.37 | 2180.72 | 2243.01 | 2697.93 | 2383.59 | 2514.37 | 179.47 | 0.35  |
| C18:1V    | 318.34 | 252.13 | 245.10 | 256.12 | 268.89 | 255.38 | 286.60 | 24.41 | 0.17  |
| C18:2     | 177.70b | 227.16ab | 231.08ab | 287.89a | 294.87a | 279.78a | 301.36a | 19.49 | 0.0001  |
| C18:3     | 0.00 | 0.00 | 5.59 | 8.63 | 10.06 | 12.03 | 8.94 | 2.28 | 0.52  |
| C20:1     | 30.89 | 31.94 | 26.69 | 28.58 | 38.48 | 30.85 | 33.51 | 3.56 | 0.22  |
| C20:4     | 46.29 | 47.62 | 42.39 | 45.41 | 45.33 | 42.77 | 45.83 | 2.34 | 0.50  |
| C22:0     | 12.04 | 18.31 | 14.51 | 14.83 | 16.10 | 14.39 | 16.09 | 2.36 | 0.44  |
| Total     | 6545.69 | 6414.15 | 5637.85 | 6134.96 | 7005.20 | 6427.48 | 6692.61 | 443.02 | 0.42  |
| SFA       | 2947.00 | 2901.25 | 2494.55 | 2811.00 | 3151.19 | 2947.00 | 3024.60 | 201.02 | 0.38  |
| UFA       | 3624.53 | 3512.90 | 3143.30 | 3323.96 | 3854.01 | 3480.48 | 3668.00 | 248.10 | 0.45  |
| SFA:UFA   | 0.81 | 0.82 | 0.79 | 0.85 | 0.82 | 0.85 | 0.83 | 0.02 | 0.25  |
| MUFA      | 3400.54 | 3288.13 | 2869.46 | 2988.93 | 3512.47 | 3156.32 | 3320.22 | 228.91 | 0.38  |
| PUFA      | 223.98b | 273.77ab | 273.84ab | 335.03a | 341.54a | 324.15a | 347.79a | 20.75 | 0.0003  |

\(^1\)Amount (mg/100 g tissue) of fatty acid in powdered loin sample determined by gas chromatography.

\(^a,b\)Means in the same row with different superscripts differ \((P < 0.05)\).

**Figure 1.** C16:1 differences \((P < 0.0001; \text{SEM} = 11.14)\) of beef from steers fed either 35%, 50%, or 65% De-oiled or Full-fat WDGS or a corn control diet. \(^a,b\)Different superscripts indicate differences \((P \leq 0.05)\).

**Figure 2.** C18:1T differences \((P = 0.01; \text{SEM} = 31.04)\) of beef from steers fed either 35%, 50%, or 65% De-oiled or Full-fat WDGS or a corn control diet. \(^a,b\)Different superscripts indicate differences \((P \leq 0.05)\).
Linoleic acid (C18:2) was greater \( (P = 0.0001) \) in beef from cattle finished on the 3 full-fat WDGS and 65% de-oiled WDGS diets (290.98 mg/100 g, on average), intermediate in cattle fed 50% and 35% de-oiled WGDS (231.08 and 227.16 mg/100 g, respectively) and least for meat from the corn control group (177.70 mg/100 g; Fig. 3). Enser et al. (1996) indicated that linoleic acid is an essential fatty acid for cattle which means that it is mostly derived from the diet and not synthesized in the body. In monogastric animals, linoleic acid is unchanged as it passes through the stomach and is absorbed into the bloodstream and is deposited in muscle tissue. In the case of ruminants, this fatty acid can be degraded into MUFA and SFA because of biohydrogenation of ruminal bacteria. Around 10% of dietary linoleic acid is available to be deposited in muscle tissue in ruminants (Enser et al., 1996). However, Vander Pol et al. (2009) observed that when feeding WDGS there is an increased concentration of linoleic acid in the duodenum, indicating a protection phenomenon when WDGS are fed. This would then suggest less ruminal biohydrogenation of linoleic acid, thus increasing linoleic acid’s availability to be deposited in muscle.

The PUFA content of beef was different \( (P = 0.0003) \) between dietary treatments. Beef from cattle fed either of the 3 full-fat WDGS diets or the 65% de-oiled WDGS diet had the greatest amount of PUFA (337.13 mg/100 g, on average), cattle on the 50% and 35% de-oiled WGDS diets had intermediate amounts (274.77 and 273.84 mg/100 g, respectively), while beef from cattle on the corn control diet had the least amount of PUFA (223.98 mg/100 g; Fig. 4).

Biohydrogenation occurs following lipolysis and is dependent on ruminal pH (Plascencia et al., 1999). Grain inclusions in cattle diets, particularly in elevated proportions, create a more acidic ruminal environment which in turn suppresses lipolysis and hence microbial biohydrogenation of fatty acids is inhibited (Atkinson et al., 2006; Plascencia et al., 1999). As fatty acids pass the rumen unchanged, these fatty acids reach the duodenum where bile salt micelles form and increase fat digestibility (Zinn et al., 2000).

Wood et al. (2008) suggested that monogastric animals have the ability of depositing the PUFA from the diet directly into muscle mass; whereas ruminants, due to bacterial biohydrogenation, can only deposit a limited amount of PUFA in muscle. Although containing limited fat, ruminant diets are rich in PUFA; this is particularly true when considering WDGS in relation to regular corn based diets (Vander Pol et al., 2009). Yet due to biohydrogenation, SFA are dominant in muscle of ruminants in relation to PUFA (Ham et al., 1994; Warren et al., 2008). However, contemplating the low ruminal pH environment (Plascencia et al., 1999) in diets with greater grain inclusions and the bile salt formation (Zinn et al., 2000) in the duodenum there is a feasible explanation for the more elevated PUFA deposition in cattle finished on higher levels of WDGS.

Particularly for ruminants the use of unprotected lipids has been explored as well as protected lipids. Incorporation of unprotected lipids such as plant and fish oils has been attempted with some degree of success (Scollan et al., 2001). Although unprotected from the harsh environment of the rumen, some PUFA can bypass the rumen and go directly into the small intestine where these are released into the blood stream and subsequently deposited in muscle (Enser et al., 1996; Scollan et al., 2014).

Subjective Color (Discoloration)

Dietary treatment had no effect on discoloration in samples aged for 7 d \( (P = 0.69) \) or on samples aged for 21 d \( (P = 0.30; \) Table 3). As expected, discoloration at both aging periods increased as retail display time increased, irrespective of dietary treatment \( (P < 0.0001) \). At 21 d aging, discoloration from 0 to 4 d RD was not significant (0.94%, on average). However, significant \( (P < 0.0001) \) discoloration was evident at 21 d age after 5 d RD reaching a maximum discoloration of 64.32% by d 7 of RD.
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Table 3. Discoloration (%) of strip loin steaks (L. lumborum) aged for 21 d from steers fed different inclusion levels of De-oiled or Full-fat WDGS or a corn control diet (SEM = 1.80)

| Treatment               | Days on retail display |
|-------------------------|------------------------|
|                         | 0          | 1          | 2          | 3          | 4          | 5          | 6          | 7          |
| 35% De-oiled WDGS       | 0.12       | 0.32       | 0.33       | 0.88       | 1.53       | 4.35       | 17.75      | 52.98      |
| 50% De-oiled WDGS       | 0.50       | 0.88       | 1.07       | 1.73       | 3.10       | 15.42      | 39.50      | 67.75      |
| 65% De-oiled WDGS       | 0.28       | 0.60       | 0.75       | 1.00       | 3.43       | 9.38       | 40.20      | 69.88      |
| 35% Full-fat WDGS       | 0.38       | 0.80       | 1.02       | 1.73       | 2.50       | 4.48       | 25.83      | 67.67      |
| 50% Full-fat WDGS       | 0.17       | 1.05       | 0.33       | 0.55       | 1.87       | 11.95      | 31.30      | 57.30      |
| 65% Full-fat WDGS       | 0.50       | 1.50       | 1.15       | 1.67       | 3.75       | 14.98      | 50.30      | 76.72      |
| Corn control            | 0.38       | 1.56       | 1.17       | 2.22       | 6.87       | 20.03      | 31.77      | 60.60      |
| Average of all dietary  | 0.33d      | 0.96d      | 0.83d      | 1.40d      | 3.29d      | 11.51c     | 33.81b     | 64.70a     |

*–dMeans in the same row with different superscripts differ (P < 0.05)

No significant triple or double interactions were detected (P > 0.05) for discoloration.

Consumer studies have reported a significant decline in purchasing decisions with 20% surface discoloration on retail displayed beef, resulting in sale reductions of up to 50% (Hood and Riordan, 1973). Data from this study suggest that after 21 d of aging, the 20% discoloration threshold was first met by steaks from corn control fed cattle at d 5 of retail display. However, samples aged 21 d with 6 d of retail display, all surpassed the 20% discoloration threshold except the samples from cattle having been fed 35% de-oiled WDGS (Table 3). The fact that at d 5 of retail display the corn control samples reached this threshold first was unexpected as one would anticipate these samples to have greater color stability due to the lower PUFA content in relation to cattle fed WDGS. Typically, color of meat is a balance between oxymyoglobin oxidation and metmyoglobin reduction (Gatellier et al. 2001) and has been closely related to lipid oxidation (Greene, 1969) which should be increased with increased PUFA content. When oxidation of oxymyoglobin occurs to form metmyoglobin, intermediate radicals are generated that, through propagation, can further accelerate color oxidation as well as lipid oxidation (Faustman et al., 2010).

Lipid Oxidation

Lipid oxidation, measured by the amount of TBARS, indicated there was an age by retail display interaction (P < 0.0001) where the rate of lipid oxidation was greater in samples aged 21 d vs. those aged for 7 d, particularly at 4 and 7 d of RD (Fig. 5). Dietary treatment did not significantly alter (P = 0.36) lipid oxidation values (Table 4).

It has been established in the literature that increased unsaturated fatty acid content in meat products will greatly diminish shelf life, particularly due to less color stability and lipid rancidity (Ladeira et al., 2014). By-products generated as a result of lipid oxidation are responsible for the development of off-flavors in meat products (Gatellier et al., 2001). Campo et al. (2006) concluded that a TBARS value of 2 can be considered as the limiting threshold for oxidized beef acceptability. According to the current study, beef from the corn control, 65% and 35% full-fat WDGS treatment groups reached this threshold first by the fourth d of retail display when aged for 21 d (Table 4). These results also suggest a faster reduction in beef shelf life in several of the full-fat WDGS in relation to de-oiled WDGS. Interestingly though, the corn control steaks presented decreased color and lipid stability, despite their decreased PUFA content.

A potential oxidation protection phenomenon could be taking place with cattle fed WDGS due to the sulfur concentration of the diets (Chao, 2015). One of the limiting factors in the inclusion levels of WDGS is the sulfur content given that levels at or above 0.40% could result in a condition called polioencephalomalomalacia which is caused by the accumulation of hydrogen sulfide in the rumen resulting in sulfur toxicity (U.S. Grains Council, 2012). However, it has been demonstrated that sulfur concentrations up to 0.50% are feasible without the risk...
of sulfur toxicity if roughage close to 15% is provided in the finishing diet (U.S. Grains Council, 2012); standards met in the finishing diets of the current study. In pork, an increase in sulfur content in the diet is associated with an increase in sulfur containing amino acids which have been known for their antioxidant capabilities (Song et al., 2013). This may explain why the corn control diet in this study presented greater TBARS values in comparison to several finishing diets containing WDGS despite the more elevated PUFA content of the WDGS diets.

**Tenderness (WBSF)**

There was an increase in tenderness from 7 to 21 d of aging ($P < 0.0001$) and as retail display time progressed ($P < 0.0001$), dietary treatment had no effect on WBSF ($P = 0.93$). These results are in agreement with those observed by Mello et al. (2012b) with beef aged for 7 d that were finished with 0%, 15%, or 30% corn WDGS. On the other hand, a subset group of samples from the current study were used by Chao (2015) looking to compare beef from cattle fed the corn control diet vs. 50% WDGS to evaluate tenderness at 2, 7, 14, and 21 d postmortem. Chao (2015) stated that at 2 d of aging, steaks from cattle finished on WDGS were more tender than the corn control steaks ($P < 0.01$). These differences in tenderness did not persist with increased aging time. Chao (2015) hypothesizes that at early postmortem there is greater membrane instability of the sarcoplasmic reticulum given the increased PUFA content associated with feeding WDGS. The greater membrane fluidity results in greater calcium flux released from the sarcoplasmic reticulum and ultimately increases early proteolysis.

**Conclusion**

Feeding lower inclusion levels (35% and 50%; DM basis) of de-oiled WDGS resulted in intermediate PUFA content relative to a corn control diet and full-fat WDGS. At 7 and 21 d of aging, steaks increased surface discoloration regardless of dietary treatment. Just as well, lipid oxidation increased with increasing aging and retail display time.

The de-oiling process poses an economical advantage for ethanol plants and producers alike as ethanol plants can further diversify corn distillers by-products and at the same time producers can obtain greater feed shelf life. The removal of the soluble oil fraction of WDGS does not seem to augment Choice beef shelf life and does not negatively affect basic beef quality parameters relative to full-fat WDGS.

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**Table 4. Lipid oxidation (TBARS) means by aging period and retail display times from steers fed different levels of either De-oiled or Full-fat WDGS or a corn control diet**

| Retail display, d | 7 d age | 21 d age | Overall average SEM |
|------------------|---------|---------|---------------------|
| Dietary treatment |         |         |                     |
| 35% De-oiled WDGS | 0.04    | 0.53    | 1.38                | 0.15    | 1.47    | 3.21    | 1.15    | 0.32    |
| 50% De-oiled WDGS | 0.11    | 0.36    | 1.26                | 0.50    | 1.52    | 3.03    | 1.21    | 0.32    |
| 65% De-oiled WDGS | 0.06    | 0.58    | 1.30                | 0.14    | 1.36    | 3.85    | 1.07    | 0.32    |
| 35% Full-fat WDGS | 0.32    | 1.16    | 2.01                | 0.8     | 2.21    | 4.16    | 1.70    | 0.35    |
| 50% Full-fat WDGS | 0.30    | 0.72    | 1.65                | 0.23    | 1.35    | 2.84    | 1.24    | 0.32    |
| 65% Full-fat WDGS | 0.61    | 1.09    | 1.88                | 0.65    | 2.23    | 4.23    | 1.88    | 0.32    |
| Corn control     | 0.59    | 1.47    | 1.89                | 1.59    | 2.58    | 3.74    | 1.78    | 0.32    |
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