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ABSTRACT: The objective of this study was to evaluate the meat quality and shelf life of steaks from steers fed dried distillers grains with solubles (DDGS) or dried corn gluten feed (CGF) compared with soybean meal with corn (SBM) as a protein supplement from weaning to slaughter. Angus cross steers (n = 81; BW = 306 ± 26.1 kg) were randomly assigned to pens (n = 9) and fed a stocker diet of corn silage (75% of DM) with DDGS, CGF, or SBM and ground ear corn. After 84 d of stockering, 12 steers (BW = 397 ± 15.3 kg) were randomly selected from each treatment and finished using the same protein supplement at 25% of DM for 100 d. Carcass data were collected (24 h) and the longissimus lumborum was fabricated into steaks at 48 h postmortem. Steaks were assigned to proximate analysis, Warner-Bratzler shear force (7-, 14-, or 21-d aging), and retail display (1, 3, 6, or 9 d). Protein source did not affect carcass yield, quality, or longissimus lumborum composition ($P > 0.05$). After 7 d of aging, DDGS and CGF steaks were more tender ($P < 0.01$) than SBM, but were similar ($P = 0.30$) after 14 and 21 d of aging. Feeding corn by-products did not influence subjective overall color acceptance ($P = 0.17$) in this study, but acceptance declined over time ($P < 0.01$). Subjective redness was similar ($P > 0.05$) among diets except SBM steaks were more red ($P < 0.01$) than DDGS after 9 d. On d 3 and 6 of retail display, CGF steaks exhibited more discoloration ($P < 0.04$) than SBM or DDGS steaks. However, after 9 d DDGS steaks were more discolored ($P < 0.01$) than CGF or SBM. Objective L* was lighter for CGF ($P < 0.04$) over 9 d of display, and all treatments became darker ($P < 0.01$) as time increased. Redness (a*) declined ($P < 0.01$) over time with SBM steaks maintaining more color in the red spectrum than CGF and DDGS after 6 d of display. Protein source did not affect ($P > 0.05$) the rate of lipid oxidation. Total SFA concentrations were similar ($P > 0.05$) among treatments; however, total MUFA were less ($P < 0.05$) and total PUFA concentrations were greater ($P < 0.05$) in DDGS steaks compared with SBM or CGF steaks. These data show that DDGS or CGF can be fed as a protein supplement at 25% DM from weaning until slaughter while maintaining meat quality when compared with steers fed soybean meal as a protein supplement.

Key words: beef, corn gluten feed, dried distillers grains, meat quality, shelf life

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INTRODUCTION

Increases in traditional feed costs have beef producers examining more cost-effective production methods and sources of protein and energy. Stockering calves with supplement to a greater than normal BW may allow for cheaper BW gains and less time in the feeding phase (Segers, 2010). Furthermore, access to local grain processing plants has advanced the use of corn coproducts in all segments of US beef production. Inclusion of corn gluten feed and dried distillers grains plus solubles has been used in the beef cattle finishing industry (Firkins et al., 1985; Ham et al., 1994; Klopfenstein et al., 2007; Gunn et al., 2009; Vander Pol et al., 2009). However, research on meat quality and shelf life of beef from cattle fed corn gluten feed and dried distillers grains plus solubles from weaning to slaughter is lacking (Leupp et al., 2009).

Meat color is one of the most influential factors determining beef purchases for consumers (Mancini and Hunt, 2005). Animal diet can affect glycogen storage, chilling rate, and antioxidant accumulation, which may influence muscle pH, oxygen usage, metmyoglobin reduction, and ultimately product color (Mancini and Hunt, 2005). Additionally, tenderness is considered the most important beef palatability attribute (Stephens et

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al., 2004) and can be affected by several antemortem factors including diet (Muchenje et al., 2009). Furthermore, fatty acid composition is the determining factor behind fat quality, rate of lipid oxidation, and flavor (Wood et al., 2002).

As new feeding systems are introduced, maintaining the integrity of the resulting meat product is essential. Therefore, the objective for this study was to examine the composition, tenderness, shelf-life stability, and fatty acid profiles of beef strip steaks from steers fed dried corn gluten feed, dried distillers grains plus solubles, or soybean meal with ground ear corn.

MATERIALS AND METHODS

All live animal practices and procedures used in this study were examined and approved by the University of Georgia Animal Care and Use Committee.

Animals and Diets

Angus cross bred steers (n = 81, pen = 9) were stockered for 84 d on 1 of 3 diets consisting of 75% corn-silage and 25% 1) dried corn gluten feed (**CGF**), 2) dried distillers grains plus solubles (**DDGS**), or 3) soybean meal with ground ear corn (60:40; **SBM**; Segers, 2010) at the Georgia Mountains Experiment Stations, Blairsville. Steers were vaccinated at weaning with Triangle 4, Type II BVD, Ultra Vac 7, and Pyramid 5 (Fort Dodge Animal Health, Overland Park, KS) and dewormed using transdermal ivermectin (Dectomax, Pfizer Animal Health, New York, NY). After stockering, 4 steers were randomly selected from each pen for feeding (36 animals total) and delivered to Wilkins Beef Research Unit (Rayle, GA) in late March. The steers were backgrounded for 30 d on tall fescue (*Festuca arundinacea* cv., Kentucky 31) and Bermuda grass hay until feedlot diets were available. At −10 d of feeding, steers were assigned to pens for individual feeding (American Calan Inc., Northwood, NH) and diet acclimation. Steers were assigned to 1 of 3 feedlot rations with differing protein supplements maintaining consistency with the same supplement they received during the stocker period. Protein supplement was included at 25% of the diet DM: 1) CGF, 2) DDGS, and 3) SBM (Table 1). Diets were formulated to be isonitrogenous and mixed daily using a Calan Data Ranger (American Calan Inc.). Feedlot performance data are reported in Segers (2010). After 100 d, when backfat of steers was estimated at 1.27 cm by ultrasound (Designer Gene Technologies, Harrison, AR), steers were randomly divided by pen into 2 slaughter groups with each treatment equally represented. On d 101 and 108, respectively, a group was transported (32 km) to the University of Georgia Meat Science Technology Center (Athens) and slaughtered under federal inspection. Steers that remained in the feedlot until the second slaughter date were fed a maintenance ration of the same feedlot diets utilizing their assigned protein supplements (NRC, 1996). Steers from both groups were held for 18 h without feed but had access to water before slaughter.

Table 1. Dry matter composition of feedlot diets supplemented with dried corn gluten feed (CGF), dried distillers grains plus solubles (DDGS), or soybean meal with corn (SBM) as the main protein source

	Protein source		
Item	CGF	DDGS	SBM
Ingredient,[1] % of DM			
Soybean meal	0.0	0.0	9.6
Corn gluten feed	24.5	0.0	0.0
Dried distillers grains plus solubles	0.0	24.5	0.0
Ground corn	47.9	47.9	62.6
Soyhulls	8.2	8.2	8.2
Cottonseed hulls	8.2	8.2	8.3
Citrus pulp	8.2	8.2	8.3
Vitamin premix	3.0	3.0	3.0
Chemical composition, %			
DM	90.56	90.91	90.21
CP	13.37	15.88	14.16
NDF	28.23	25.53	19.99
ADF	11.67	11.28	9.92
Ash	5.31	4.42	5.00

[1]All sources were procured from the same distributor and are expressed on a DM basis. Different loads of corn gluten feed, dried distillers grains plus solubles, and soybean meal were averaged.

Carcass Data Collection

Immediately postslaughter, HCW were collected and carcasses were chilled (−2°C) for 24 h. Twenty-four hours postmortem, the right side of each carcass was split at the 12th- to 13th-rib junction and allowed to bloom for 30 min. Carcass data were collected, including LM area, 12th-rib fat thickness, marbling score, percent KPH, lean maturity, skeletal maturity, subjective lean color, subjective fat color, muscle pH, and objective lean and fat color. Objective lean color was recorded in triplicate on the exposed surface of the LM dorsal to ventral, and subcutaneous fat color was measured in triplicate approximately 2 cm anterior to the 12th-rib cut surface and between 2 to 8 cm ventral to the spinal process. Objective CIE color (L* measures brightness: 0 = black, 100 = white; a* measures red to green: positive = red, negative = green; and b* measures yellow to blue: positive = yellow, negative = blue) was measured with a Minolta Chromo Meter (CR-310, Konica Minolta Sensing, Americas Inc., Ramsey, NJ) at illuminant D65, 2° viewing angle, and 50 mm diameter measuring area. The Minolta was calibrated against a standard white tile daily before data were collected.

Strip Loin Fabrication

After collection of carcass data, the longissimus lumborum (**LL**) was removed from the right side of each carcass. The anterior end was squared and a 2.54-cm-thick steak was removed, vacuum-packaged (B-620 se-

ries; 30 to 50 mL O_2/m^2 per 24 h; 101,325 Pa; 23°C; Cryovac, Duncan, SC) using an A300/16 (Multivac, Cryovac) vacuum packager, and immediately frozen at −20°C for proximate analysis and fatty acid determination. Seven additional steaks (2.54 cm) were then fabricated from the anterior end of the LL and vacuum-packaged for Warner-Bratzler shear force (**WBSF**) analysis or retail display. The 7 steaks were randomly assigned either WBSF for 7, 14, or 21 d of aging or retail display for 1, 3, 6, or 9 d.

Proximate Analysis

Composition of the LL was determined as percent moisture, CP, and total lipid. Steaks were thawed for 24 h at 4 ± 3°C. All external fat and connective tissue was removed. Steaks were minced, frozen in liquid N, and homogenized (Waring Laboratory, Torrington, CT).

Moisture was determined according to the methods of the AOAC (1990). Disposable aluminum pans were dried at 90°C in a forced-air oven (Fisher Scientific, Pittsburgh, PA) overnight, then air equilibrated for 10 min in a desiccator. Pan weight was recorded and homogenized samples weighing 1 ± 0.1 g were dried in duplicate at 90°C on the aluminum pans in a forced-air oven for 48 h. Samples were removed and allowed cool for 5 to 10 min in a desiccator. The following formula was then used to calculate percent moisture: % moisture = (dry sample weight/wet sample weight) × 100%.

Crude protein was determined, in duplicate, by analyzing N content (0.1 ± 0.05 g) with a Nitrogen Autoanalyzer (Leco FP-528 Nitrogen Analyzer, Leco Company, St. Joseph, MI).

For lipid extraction, LL tissue samples were frozen in liquid N and powder homogenized. Total lipids were extracted in duplicate according to the procedure of Folch et al. (1957). To calculate percent lipid, 12 × 75 mm culture tubes were dried overnight in a forced-air oven at 90°C and allowed to equilibrate in a desiccator for 10 min. The total lipid extract was vortexed, and 2 mL of lipid extract was transferred to labeled culture tubes. Chloroform was then evaporated from the culture tube under N_2 gas. The tubes were dried for 30 min in a forced-air oven at 90°C and allowed to equilibrate in a desiccator for 10 min. Percent lipid was determined using the following equation: % lipid = ({[(tube + lipid weight)/tube weight] × 5}/wet tissue weight) × 100. The remaining lipid extract was stored (−54°C) for further analysis.

WBSF

Steaks assigned to WBSF were labeled and aged at 1 ± 1°C. After their respective aging period, steaks were frozen at −20°C until further analysis. Steaks were allowed to thaw (4 ± 1°C) for 18 h. Steaks were cooked on broilers (model 450N Open-Hearth Broiler, Farberware, Bronx, NY), preheated for 20 min, to an internal temperature of 71°C and were turned once when their internal temperature reached 35°C (AMSA, 1995). Internal temperature was monitored by a Digi-Sense 12-channel scanning thermometer (model 9200-00, Cole-Palmer, Vernon Hills, IL) with copper-constantan thermocouples (Omega Engineering, Stamford, CT). Steaks were cooled for 12 h (4 ± 1°C) and 6 cores (1.27-cm diameter) were removed parallel to the longitudinal orientation of the muscle fibers. Cores were sheared once perpendicular to the longitudinal orientation of the muscle fibers with an Instron Universal Testing Machine (Dual Column Model 3365, Instron Corp. Worldwide Headquarters, Norwood, MA) equipped with a Warner-Bratzler shear head with a 51-kg force load cell with a crosshead speed of 25 cm/min. The peak shear force for each core was recorded (Bluehill software, Instron Corp. Worldwide Headquarters) and analyzed to obtain an average value for each steak.

Simulated Retail Display

After 7 d of vacuum aging, steaks were placed on absorbent pads (Dri-Loc AC-40, Cryovac Sealed Air Corporation, Duncan, SC) in polystyrene trays (Cryovac thermoformed polystyrene processor trays), which were then overwrapped with an O_2 permeable polyvinyl chloride overwrap (O_2 transmission = 23,250 mL/m^2/24 h, 72 gauge; Pro Pack Group, Oakland, NJ). Steaks were displayed at 4 ± 1°C in a cold storage room with 24-h fluorescent luminescence (General Electric F48T12 CW/HO, 960 lx; Fairfield, CT). Objective color was measured every 24 h for 9 d. Objective CIE color space was measured with a Minolta Chromo Meter (CR-310, Americas Inc.) as described previously. Objective measurements were taken in triplicate.

Subjective color was evaluated by a trained 6 member panel of University of Georgia personnel on d 1, 3, 6, and 9 for redness (8 = light cherry red, to 1 = extremely dark red), overall color (8 = extremely desirable, to 1 = extremely undesirable), and discoloration (8 = 0% no discoloration, to 1 = 100% discolored) as outlined by Hunt et al. (1991) and adapted by Gill et al. (2008). Color measurements ceased when the average overall color was determined to be slightly undesirable or less (Roeber et al., 2005; Gill et al., 2008). All panelists recorded <60 for the total error score on the Farnsworth-Munsell 100-Hue Test (Xrite, Grandville, MI). On d 1, 3, 6, and 9 designated steaks were removed from display, vacuum-packaged, and frozen (−20°C) for lipid oxidation analysis.

Lipid Oxidation

Steaks were thawed for 12 h in vacuum bags, trimmed of all external fat and connective tissue, minced, and mixed thoroughly. Thiobarbituric acid reactive substance (**TBARS**) analysis was conducted by the procedures outlined by Ahn et al. (1998). Absorbance was read at 531 nm (Jasco V-630 Spectrophotometer, Jasco Inc., Easton, MA). Samples were analyzed in dupli-

cate and lipid oxidation was expressed in milligrams of malonaldehyde (**MDA**) per kilogram of tissue.

Fatty Acid Methyl Esters

Lipid extract containing 2 mg of total lipids, based on the calculated percentage of lipids on a wet-tissue basis, was transmethylated (Park and Goins, 1994). Fatty acid methyl esters were analyzed using an Agilent 6850 gas chromatograph (Agilent Technologies, Santa Clara, CA) equipped with an Agilent 6850 automatic sampler. Separations were accomplished using a 100-m Sp2560 capillary column (5 mm i.d. and 0.20-μm film thickness; Supelco, Bellafonte, PA) according to the method of Duckett et al. (2002). Sample injection volume was 1 μL. Hydrogen was the carrier gas at a flow rate of 1 mL/min. Individual fatty acids were identified by comparisons of retention times with standards (Sigma, St. Louis, MO; Supelco; Matreya, Pleasant Gap, PA). The fatty acids were quantified by incorporation of an internal standard, methyl heptacosanoic acid (C27:0), into each sample during methylation and were expressed as a percentage of total fatty acids.

Statistical Analysis

All data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC). Means were separated using the PDIFF option in LSMEANS for all analyses. Carcass data, proximate analysis, fatty acid analysis, and lipid oxidation were analyzed as a completely randomized design with either carcass or steak from each animal serving as experimental and observational unit. Carcass within treatment was considered the random variable. Data for WBSF were analyzed in a similar fashion with the exception that muscle core was considered the observational unit and degree of doneness was analyzed as a covariate. Data for objective and subjective color were analyzed using REPEATED measures with day as the repeated variable. Steak was considered the experimental and observational unit. Carcass within treatment was considered the random variable. Multiple value recordings were not averaged before statistical analysis. Differences among means were considered significant at $\alpha < 0.05$.

RESULTS AND DISCUSSION

Carcass Data

Carcass characteristics for steers fed CGF, DDGS, or SBM at a 25% DM basis are shown in Table 2. Hot carcass weight, KPH, LM area, and 12th-rib fat thickness were not different between treatments ($P \geq 0.25$), leading to similar USDA calculated yield grades ($P = 0.96$). These data indicate that steers fed CGF or DDGS from weaning to slaughter at the current levels will produce carcasses with a similar percentage of boneless, closely trimmed retail cuts as steers stockered and fed a soybean meal and corn-based ration. In addition, after an 18-h feed restriction the carcass dressing percent was similar for all 3 treatments ($P = 0.33$). Similarly, Leupp et al. (2009) reported no differences in yield grade traits when steers were fed dried distillers grains plus solubles at 0 or 30% from growing through feeding periods. After feeding corn gluten feed from 0 to 80% (0, 40, 60, and 80%, DM basis), Kampman and Loerch (1989) report that HCW decreased as corn gluten concentration increased; however, USDA yield grade was similar among all treatments.

Marbling and overall maturity were not different among dietary treatments ($P \geq 0.19$) at an average of 461 (400 = small^0) and 137 (100 = A^0), respectively. Lean maturity was more advanced ($P < 0.04$) for SBM when compared with DDGS or CGF carcasses; however, there was no difference in subjective lean color ($P = 0.74$). Lean maturity differences were most likely due to variations in lean texture and firmness among the treatments (data not shown). These findings are in agreement with others that reported dried distillers grains plus solubles fed near 25% inclusion did not influence marbling scores or quality grade (Aldai et al., 2010, 20 to 40% inclusion; Leupp et al., 2009, 0 to 30% inclusion). Loe et al. (2006) also reported that including wet corn gluten feed in the finishing ration at 17 or 35% DM did not affect marbling scores when compared with 0% wet corn gluten feed. Currently there is a lack of data comparing the long-term use of corn gluten feed or dried distillers grains plus solubles to a soybean meal and corn-based finishing ration. The current research agrees with other feeding trials showing that steers fed dried distillers grains plus solubles or corn gluten feed during the finishing phase will have carcass characteristics similar to those that were fed a traditional ration.

Carcasses from CGF steers were lighter (L*; $P < 0.02$) and more yellow (b*; $P < 0.01$) in LM color than DDGS or SBM carcasses. This may be attributed to the numerical differences ($P = 0.19$) in marbling between CGF and the other protein sources. Increases in marbling could cause greater reflectance and therefore greater L* and b* values. This disagrees with Kim and Lee (2002), who found that cattle with increased marbling had similar lean color characteristics. However, Depenbusch et al. (2009) reported darker color in strip steaks from heifers fed dried distillers grains plus solubles in excess of 45% of the diet DM compared with steam-flaked corn. The data from this study also disagree with those of Gill et al. (2008), who noted that strip steaks from cattle fed dried distillers grains plus solubles were brighter in color than those from cattle fed no distillers grains. Steers fed DDGS had reduced ($P < 0.05$) L* values for fat color, and SBM had reduced ($P < 0.05$) a* values for external fat compared with CGF or DDGS. This difference in brightness and redness is likely the result of the increased DMI of ground corn in the SBM ration compared with DDGS and CGF rations. Dried distillers grains plus solubles derived from corn have increased xanthophyll concentrations from

Table 2. Least squares means for carcass characteristics for feedlot steers fed dried corn gluten feed (CGF), dried distillers grains plus solubles (DDGS), or soybean meal with corn (SBM) as the main protein source

	Protein source			
Characteristic	CGF	DDGS	SBM	SEM
HCW, kg	354.0	350.0	341.0	7.33
Dressing %	63.80	62.90	63.50	0.59
LM area, cm^2	77.65	77.68	79.23	3.25
12th-rib fat thickness, cm	1.20	1.11	1.20	0.07
KPH, %	2.30	2.20	2.20	0.11
Yield grade[1]	3.10	3.11	3.05	0.18
Marbling[2]	494	433	458	23.44
Skeletal maturity[3]	134	137	136	4.29
Lean maturity[3]	140[b]	146[b]	155[a]	3.09
Overall maturity[3]	136	131	145	6.57
Lean color[4]	6.42	6.25	6.17	0.25
Lean CIE L*	43.73[a]	41.21[b]	40.67[b]	0.78
Lean CIE a*	31.29	29.54	30.74	1.17
Lean CIE b*	12.68[a]	10.96[b]	11.02[b]	0.38
Fat color[5]	1.83	1.61	1.75	0.17
Fat CIE L*	73.08[ab]	72.14[b]	74.30[a]	0.63
Fat CIE a*	10.32[a]	9.47[ab]	7.35[b]	0.93
Fat CIE b*	16.50	13.37	14.46	1.38

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Yield grade was calculated using adjusted carcass fat thickness.

[2]400 = Small[00], 500 = Modest[00].

[3]100 = A[00], 200 = B[00].

[4]1 = extremely dark red, 2 = very dark red, 3 = dark red, 4 = moderately dark red, 5 = slightly dark red, 6 = cherry red, 7 = moderately bright cherry red, 8 = light cherry red.

[5]1 = white, 2 = creamy white, 3 = slightly yellow, 4 = moderately yellow, 5 = yellow.

the breakdown of fat-soluble carotenoids, which may contribute yellow pigmentation (Roberson, 2004).

Proximate Analysis

Moisture content tended to be greater ($P = 0.07$) in steaks from steers fed DDGS than those fed CGF with SBM being intermediate (Table 3). Protein and lipid contents were similar ($P \geq 0.13$) among treatments. Similar results were reported by Jenschke et al. (2008), who found no differences in the moisture, protein, or lipid content in beef when steers were fed wet distillers grains with alfalfa hay, corn stalks, or corn silage, indicating that concentration of distillers grains in the diet has no effect. As well, Aldai et al. (2010) reported no difference in beef lean tissue composition when corn, wheat dried distillers grains, or a barley-based finishing diets were fed to beef cattle.

WBSF

There was a treatment × day of aging interaction for percent thaw loss ($P = 0.02$) with steaks from all treatments having a greater percentage of moisture lost during thawing for d 7 compared with d 14 or 21 steaks. The only difference within treatments that occurred after 14 d of aging was a continued 1% reduction of thaw loss for SBM steaks after 21 d of aging (Table 4). There was not a treatment × day of aging interaction effect for percent cook loss ($P = 0.83$); as well, the main effects of treatment and day were not different among the steaks from the different diets or aging periods ($P = 0.21$ and $P = 0.16$, respectively). Warner-Bratzler shear force had a treatment × day of aging interaction ($P = 0.02$; day of aging effect $P < 0.01$). After 7 d of aging SBM was less tender than CGF or DDGS; however, after 14 and 21 d of aging LL steaks from all 3 diets were similar in tenderness. There were not many differences among CGF, DDGS, and SBM between d 7 and 14 of aging with the exception of CGF having a shear force 0.30 kg greater after 14 d of aging than 7 d of aging. The reason for the slight increase in WBSF for CGF LL steaks between 7 and 14 d of aging is not known. All samples had similar ($P \geq 0.09$) end point

Table 3. Least squares means for proximate analysis of longissimus lumborum steaks from steers fed dried corn gluten feed (CGF), dried distillers grains plus solubles (DDGS), or soybean meal with corn (SBM) as the main protein source

	Protein source			
Characteristic, %	CGF	DDGS	SBM	SEM
Moisture	71.38	73.11	72.29	0.52
Protein	22.83	23.08	23.51	0.39
Lipid	5.31	3.83	4.22	0.54

temperatures (71.73 ± 0.64°C), cook times (19.76 ± 0.58 min), and degree of doneness scores (4.22 ± 0.52). Steaks from all 3 dietary treatments became more tender after 21 d of aging when compared with steaks after 7 and 14 d of aging. The results from the current study are similar to those of Koger et al. (2004), Roeber et al. (2005), and Gill et al. (2008), who reported no differences in WBSF values when the inclusion of distillers grains was increased compared with soybean meal-based diets. Little information exists on the effects of feed corn gluten feed (wet or dry) on beef tenderness. This research demonstrates that dried corn gluten feed or dried distillers grains plus solubles can be used as a long-term supplement in place of soybean meal in cattle diets with limited effects on meat tenderness. Furthermore, Shackelford et al. (1991) documented the US consumer threshold for "slightly tender" in retail food service industries is 3.9 to 4.6 kg of WBSF. All steaks from the current study fell well below this threshold.

Shelf Life

A treatment × day interaction ($P = 0.04$) was detected for subjective steak redness when evaluated by a trained color panel (Figure 1). At d 9, steaks from steers fed SBM were considered redder ($P = 0.01$) than DDGS steaks. These findings were corroborated by greater ($P < 0.05$) a* values at d 6 and 9 for SBM steaks (Figure 2). Redness scores in the current study confirm findings by Zerby et al. (1999), who reported that visual redness scores were moderately to highly correlated to instrumental a* values. In addition, Roeber et al. (2005) reported that a trained panel found strip steaks from soybean meal-supplemented steers were redder than those from steers fed 40% dried distillers grains plus solubles. No difference ($P = 0.17$) was found among treatments for overall color, but overall color based on a visual score did decline over time ($P < 0.01$). Subjective steak discoloration also had a treatment × day interaction ($P < 0.01$) in which CGF LL steaks had a greater percentage of discoloration ($P < 0.04$) at d 3 and 6, but by d 9 DDGS steaks were more discolored ($P < 0.01$) than SBM steaks with CGF steaks being intermediate. These data agree with Gill et al. (2008) and Nelson et al. (2000), who attributed decreasing shelf-life characteristics to meat deterioration resulting from lipid oxidation during time on retail display. However, Gill et al. (2008) also reported no treatment effects for steaks from steers fed corn dried distillers grains plus solubles or sorghum dried distillers grains plus solubles compared with steam-flaked corn. Roeber et al. (2005) reported that in steaks from steers fed 0, 12.5, 25, or 50% dried distillers grains plus solubles or wet distillers grains (DM basis), steaks from steers fed the greatest amounts of dried distillers grains plus solubles and wet distillers grains were more likely to receive scores of moderately unacceptable when compared with steaks from steers fed a soybean meal-based diet.

Table 4. Least squares means for thaw loss, cook loss, and Warner-Bratzler shear force (WBSF) for longissimus lumborum steaks from steers fed dried corn gluten feed (CGF), dried distillers grains plus solubles (DDGS), or soybean meal with corn (SBM) as the main protein source

	7 d aging			14 d aging			21 d aging				*P*-value		
Item	CGF	DDGS	SBM	CGF	DDGS	SBM	CGF	DDGS	SBM	SEM	Diet	Day	Interaction
WBSF, kg	3.16^{c}	3.34^{bc}	3.86^{a}	3.46^{ab}	3.32^{bc}	3.70^{ab}	2.75^{d}	2.68^{d}	2.95^{cd}	0.18	0.08	<0.01	0.02
Thaw loss, %	3.42^{b}	3.69^{ab}	4.50^{a}	1.33^{cd}	1.26^{cd}	2.08^{c}	1.28^{cd}	0.97^{d}	1.11^{d}	0.29	0.20	<0.01	0.02
Cook loss, %	21.42	20.07	22.38	21.24	22.83	26.88	20.15	17.02	21.87	2.55	0.21	0.16	0.83

$^{a-d}$Within a row, means without a common superscript differ ($P < 0.05$).

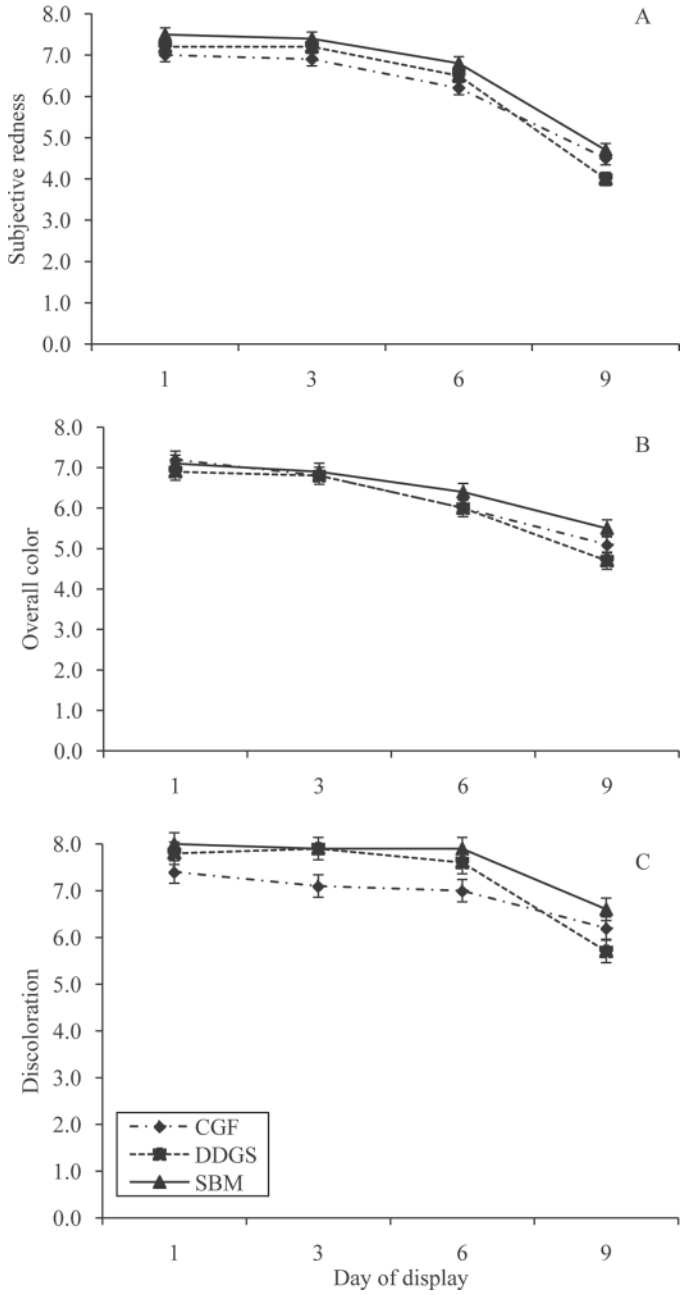

Figure 1. Subjective evaluation over a 9-d shelf life for beef strip steaks from steers fed dried corn gluten feed (CGF), dried distillers grains plus solubles (DDGS), or soybean meal with corn (SBM) as a protein source from weaning to slaughter. A) Subjective redness (1 = extremely dark red, 8 = extremely bright cherry red) showed a treatment × day interaction ($P = 0.04$); at d 9, steaks from steers fed DDGS became less red ($P < 0.01$) than SBM steaks. B) Overall color (1 = extremely unacceptable, 8 = extremely acceptable) had no treatment effect ($P = 0.17$) but decreased ($P < 0.05$) over time. C) Discoloration (1 = 95 to 100% discolored, 8 = 0 to 5% discolored) showed a treatment × day interaction ($P < 0.01$) in which CGF steaks were more ($P \leq 0.04$) discolored at d 3 and 6, but by d 9 DDGS steaks were more ($P < 0.01$) discolored than SBM steaks.

Dietary treatment and day of display both influenced LL steak L* values ($P = 0.04$ and $P = 0.01$, respectively; Figure 2). Steaks from steers fed CGF exhibited a lighter color reflectance over 9 d of display when compared with DDGS or SBM. Steak lightness decreased as time on display increased from d 3 to 9. Leupp et al. (2009) suggested that 30% inclusion of dried distillers grains plus solubles in feedlot diets tended to reduce L* values. However, this disagrees with Gunn et al. (2009) and Hutchison et al. (2006), who reported lighter L* values in top rounds and strip steaks from steers fed high-fat diets.

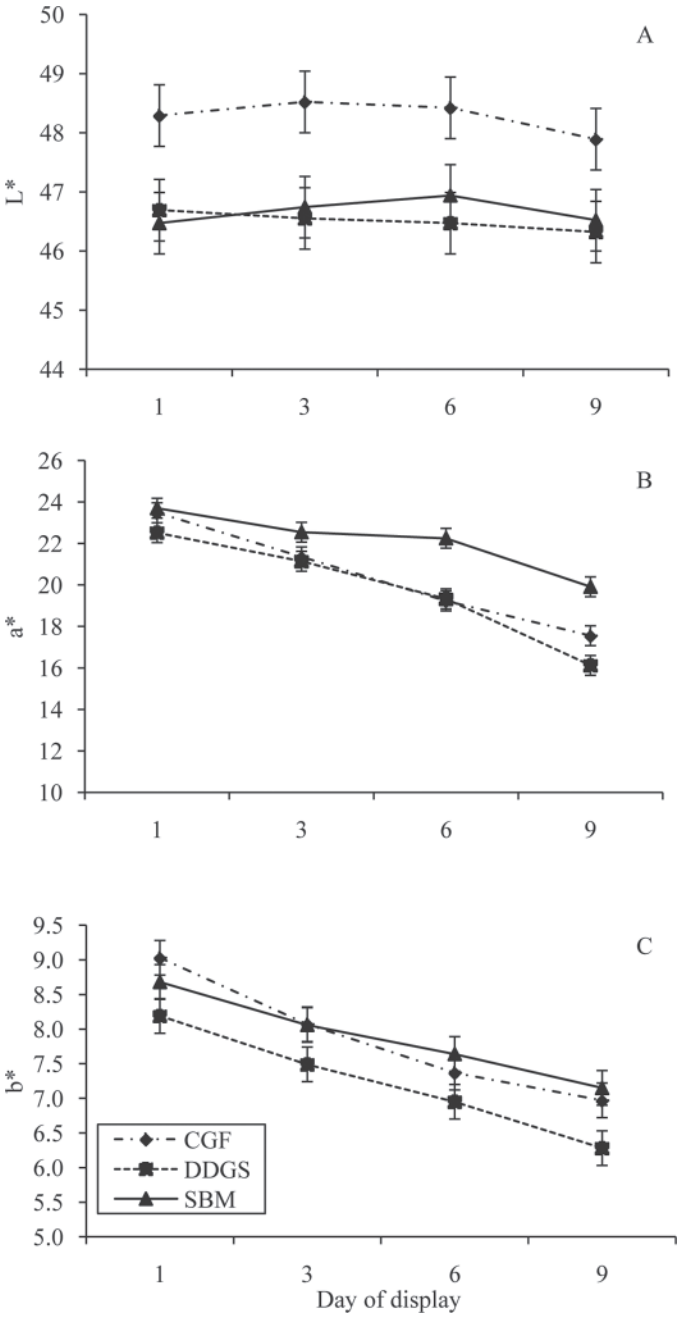

Figure 2. Objective color over a 9-d retail display for beef strip loin steaks from steers fed dried corn gluten feed (CGF), dried distillers grains plus solubles (DDGS), or soybean meal with corn (SBM) as a protein source from weaning to slaughter. A) The L* (0 = black, 100 = white) values were greatest ($P = 0.04$) in steaks from CGF steers. B) The a* (greater values indicate redness) values showed an interaction ($P < 0.01$) in which all steaks became less ($P < 0.01$) red over time. However, steaks from steers fed SBM retained more ($P < 0.05$) red color at d 6 and d 9. C) The b* (greater values indicate yellowness) steaks from steers fed DDGS tended to be less ($P = 0.08$) yellow (decreased b*) than steaks from CGF- or SBM-fed steers.

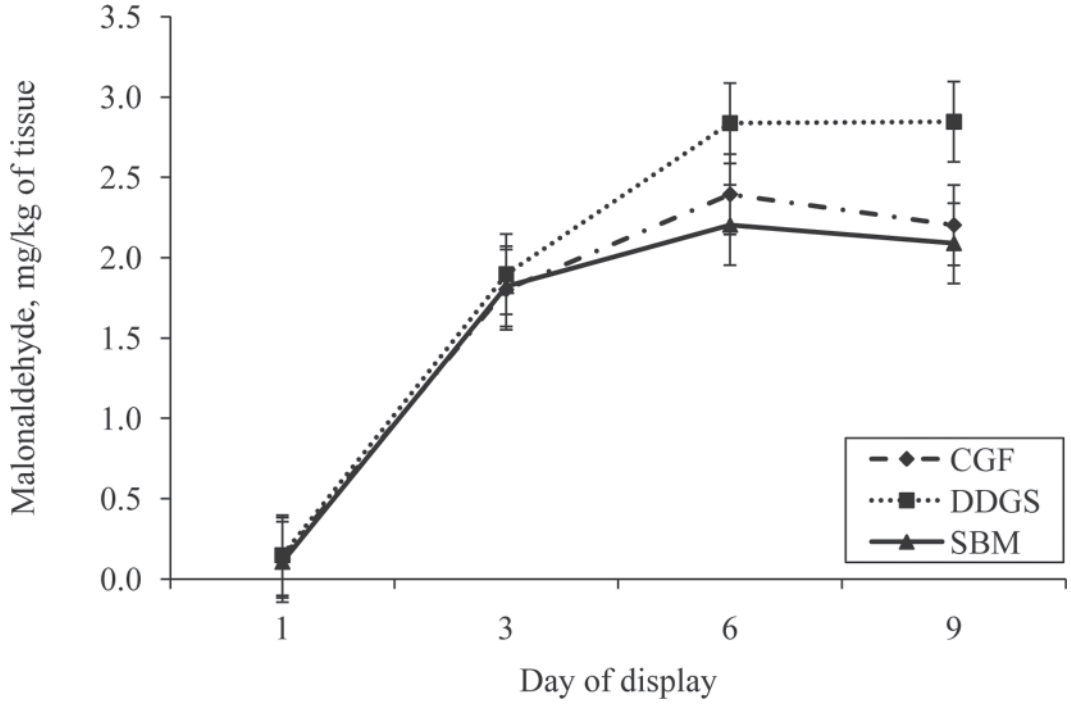

Figure 3. Lipid oxidation over a 9-d shelf life for beef strip steaks from steers fed dried corn gluten feed (CGF), dried distillers grains plus solubles (DDGS), or soybean meal with corn (SBM) as the protein source. Thiobarbituric acid reactive substance concentrations were not different ($P = 0.74$) among protein supplements, but did increase ($P < 0.01$) over time.

A treatment × day of display interaction ($P < 0.01$) occurred for a* values in which all steaks became less ($P < 0.01$) red over time. However, steaks from steers fed SBM retained more ($P < 0.01$) red color at d 6 and 9 than did steaks from DDGS- or CGF-fed steers. This is likely due to reduced rate of color deterioration in SBM steaks as was noted in subjective color evaluations. Steaks from steers fed DDGS and CGF became less ($P \leq 0.01$) red between each subsequent measurement over time, whereas SBM steaks were similar ($P = 0.50$) in redness at d 3 and 6. Gill et al. (2008) reported that steers fed no dried distillers grains plus solubles had redder steaks than those fed distillers grains. Conversely, Roeber et al. (2005) reported increased redness in steaks from steers fed dried distillers grains plus solubles and attributed it to increased xanthophylls, a concentrated pigment compound responsible for the color of corn. Steaks from steers fed DDGS tended to be less ($P = 0.08$) yellow (decreased b*) than steaks from CGF- or SBM-fed steers, and steaks from all treatments had decreased b* values as time on display increased ($P < 0.01$).

Lipid oxidation as indicated by TBARS concentrations increased ($P < 0.01$) over time as expected; however, no differences ($P = 0.74$) were found among steaks from different dietary treatments (Figure 3). Similarly, no differences were found among increasing dried distillers grains plus solubles for lipid oxidation compared with steam-flaked corn (Depenbusch et al., 2009). Oxidation can be controlled by the amount of antioxidant compounds found in the muscle tissue (Calkins and Hodgen, 2007). Gill et al. (2008) attributed increases in predisplay lipid oxidation to the increased PUFA concentrations from the lipid fraction of dried distillers grains plus solubles fed at 15% of the diet DM. Although LL steaks from steers fed DDGS exhibited greater concentrations of total PUFA ($P = 0.01$) than the other 2 treatments, CGF- and SBM-fed steers had greater concentrations of MUFA ($P = 0.02$; Table 5). It does not appear that the increased PUFA concentration of DDGS steaks had an important role in total lipid oxidation in the current study.

Fatty Acid Composition

Data for LL fatty acid composition are reported in Table 5. Steaks from steers fed DDGS had decreased concentrations of MUFA ($P = 0.02$) and increased PUFA ($P = 0.01$) compared with CGF and SBM steaks. This was expected due to the total n-6 fatty acids ($P = 0.01$) in steaks from DDGS fed steers. These differences are largely attributed to increased ($P = 0.01$) quantities of the C18:2 *trans*-10, *cis*-12 isomers by approximately 60%, as well as an approximate 70% increase in C18:2 *cis*-9, *cis*-12 ($P = 0.01$). As expected, steaks from DDGS fed steers had greater ($P = 0.01$) PUFA:SFA. This was likely due to the increased concentration of corn oil in the DDGS diet (NRC, 1996).

Steaks from CGF-fed steers tended to have the greatest ($P = 0.08$) concentrations of total SFA. This is likely due to the extrusion of fat during the wet milling process of corn gluten feed to produce corn oil (Hoffman, 1989) because this process removes the majority of the unsaturated fatty acids. It is important to note that in-

Table 5. Least squares means for fatty acid composition of longissimus lumborum steaks from steers fed dried corn gluten feed (CGF), dried distillers grains plus solubles (DDGS), or soybean meal with corn (SBM) as the main protein source

	Protein source				
Fatty acid, mg/100 mg	CGF	DDGS	SBM	SEM	*P*-value
SFA					
C10:0	0.02	0.00	0.01	0.01	0.32
C12:0	0.10	0.06	0.04	0.02	0.06
C14:0	3.38	3.06	3.03	0.15	0.20
C15:0	0.55[a]	0.47[b]	0.44[b]	0.20	<0.01
C16:0	28.30[a]	26.42[b]	26.72[b]	0.56	0.05
C17:0	1.40[a]	1.25[b]	1.24[b]	0.04	0.01
C18:0	13.32	13.90	12.72	0.50	0.24
C20:0	0.03	0.03	0.09	0.05	0.61
C21:0	0.46	0.39	0.48	0.07	0.60
C22:0	0.38	0.54	0.49	0.09	0.46
MUFA					
C14:1	0.86	0.70	0.80	0.70	0.26
C16:1	4.14[a]	3.57[b]	4.16[a]	0.20	0.03
C18:1 *trans*-9	0.04	0.09	0.09	0.03	0.44
C18:1 *trans*-10	0.22	0.26	0.22	0.30	0.50
C18:1 *trans*-11	1.54	2.09	1.79	0.24	0.24
C18:1 *cis*-9	39.11[a]	36.28[b]	39.40[a]	0.91	0.03
C18:1 *cis*-11	1.37	1.25	1.33	0.07	0.45
PUFA					
C18:2 *cis*-9, *cis*-12	3.37[b]	4.98[a]	3.55[b]	0.29	0.01
C18:3 *cis*-9, *cis*-12, *cis*-15	0.24	0.21	0.26	0.02	0.20
C18:2 *cis*-9, *trans*-11	0.34	0.32	0.38	0.03	0.51
C18:2 *cis*-11, *trans*-13	0.049	0.044	0.038	0.003	0.25
C18:2 *trans*-10, *cis*-12	0.016[b]	0.028[a]	0.018[b]	0.002	<0.01
C18:2 *cis*-11, *cis*-13	0.00	0.002	0.00	0.001	0.41
C18:2 *trans*-9, *trans*-11	0.01	0.01	0.03	0.02	0.51
C20:4 *cis*-5, 8, 11, 14	0.60	0.76	0.75	0.08	0.29
C20:5 *cis*-5, 8, 11, 14, 17	0.08	0.08	0.11	0.02	0.29
C22:5 *cis*-7, 10, 13, 16, 19	0.17	0.22	0.21	0.03	0.53
C22:6 *cis*-4, 7, 10, 13, 16, 19	0.01	0.03	0.02	0.01	0.35
Fatty acid sum					
SFA[1]	47.97	46.11	45.26	0.84	0.08
MUFA[2]	47.29[a]	44.24[b]	47.80[a]	0.96	0.02
PUFA[3]	4.93[b]	6.73[a]	5.42[b]	0.39	0.01
CLA[4]	3.83[b]	5.43[a]	4.07[b]	0.29	<0.01
n-3[5]	0.50	0.54	0.60	0.05	0.44
n-6[6]	4.43[b]	6.19[a]	4.82[b]	0.35	<0.01
Fatty acid ratio					
MUFA:SFA	0.99[b]	0.96[b]	1.06[a]	0.02	0.02
PUFA:SFA	0.10[b]	0.15[a]	0.12[b]	0.01	<0.01
UFA:SFA	1.09	1.11	1.18	0.03	0.07
n-6:n-3	9.15[b]	13.14[a]	9.13[b]	1.03	0.01

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Summation of SFA including C10:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0, C21:0, and C22:0.

[2]Summation of MUFA including C14:1, C16:1, C18:1 *trans*-9, C18:1 *trans*-10, C18:1 *trans*-11, C18:1 *cis*-9, and C18:1 *cis*-11.

[3]Summation of PUFA including C18:2 *cis*-9, 12, C18:3 *cis*-9, 12, 15, C18:2 *cis*-11, *trans*-13, C18:2 *trans*-10, *cis*-12, C18:2 *cis*-11, 13, C18:2 *trans*-9, 11, C20:4 *cis*-5, 8, 11, 14, C20:5 *cis*-5, 8, 11, 14, 17, C22:5 *cis*-7, 10, 13, 16, 19, and C22:6 *cis*-4, 7, 10, 13, 16, 19.

[4]Summation of CLA isomers including C18:2 *cis*-11, *trans*-13, C18:2 *trans*-10, *cis*-12, C18:2 *cis*-11, 13, and C18:2 *trans*-9, 11.

[5]Summation of n-3 fatty acids including C18:3 *cis*-9, 12, 15, C20:5 *cis*-5, 8, 11, 14, 17, C22:5 *cis*-7, 10, 13, 16, 19, and C22:6 *cis*-4, 7, 10, 13, 16, 19.

[6]Summation of n-6 fatty acids including C18:2 *cis*-9, 12, C18:2 *cis*-11, *trans*-13, C18:2 *trans*-10, *cis*-12, C18:2 *cis*-11, 13, C18:2 *trans*-9, 11, and C20:4 *cis*-5, 8, 11, 14.

creased concentrations of SFA are expected with high-starch diets. Steaks from steers fed CGF had greater ($P = 0.05$) amounts of palmitic acid (C16:0) and decreased ($P = 0.03$) oleic acid (C18:1 *cis*-9) compared with SBM and DDGS steaks. Cabezas et al. (1965) attributed decreased saturation in kidney and 12th-rib fat to a decreased ratio of C16:0 to C18:1 *cis*-9. Greater degrees of unstaturation resulted either when rumen fermentation

was altered via the acetate:propionate ratio to decrease the activity of hydrogenation enzymes, or when fewer H donor compounds exist in the diet (Cabezas et al., 1965). The SBM diet contained more ground corn than the CGF diets, and ground corn contains the corn oil component that has been extruded from corn gluten feed.

The increased ($P = 0.05$) C16:0 in CGF steaks is a point of concern. Hegsted et al. (1965) found that lauric (C12:0), myristic (C14:0), and palmitic (C16:0) acids are the primary fatty acids associated with increasing plasma low-density lipoprotein and total cholesterol concentrations in the human body. Steaks from DDGS steers had greater ($P = 0.003$) n-6 fatty acids and subsequently a greater ($P = 0.01$) n-6:n-3 fatty acid ratio. This was due to increased ($P < 0.01$) linoleic (C18:2 *cis*-9, *cis*-12) acid and the C18:2 *trans*-10, *cis*-12 ($P = 0.01$) CLA isomer given that α-linolenic acid (C18:3 *cis*-9, *cis*-12, *cis*-15), the major n-3 fatty acid in cattle diets (Gill et al., 2008), as well as total n-3 fatty acids, did not differ ($P > 0.05$). The n-6 and n-3 fatty acids are known for their effects on human health (Gill et al., 2008). Linoleic acid is used by the body to produce pro-inflammatory eicosanoids (Akoh and Min, 2002) and to moderate blood cholesterol concentrations (Zock and Katan, 1998). It is recommended that the n-6:n-3 ratio not exceed 4 (Wood et al., 2002). Although the health benefits of these fatty acids are well known, modern consumers enjoy a diet rich in n-6 fatty acids and yet deficient in n-3 fatty acids, a competitive inhibitor in the inflammatory process (Gill et al., 2008).

In conclusion, composition and tenderness of LL steaks were unaffected by protein supplement. Although a trained color panel observed differences in perceived color, overall color was similar among steaks from differing treatment groups. No differences were found in concentration of TBARS among treatment groups. However, steaks from steers fed DDGS became more discolored than SBM steaks after 9 d of retail display and contained greater PUFA, suggesting that a numerical increase in lipid oxidation may result in reduced shelf life for meat products from cattle fed dried distillers grains plus solubles long-term. This study suggests that dried distillers grains plus solubles and dried corn gluten feed can be substituted for soybean meal and a portion of corn in beef cattle diets from weaning to slaughter while maintaining meat quality. With the increasing economic instability of feed inputs, increasing alternative feedstuffs may provide producers with access to an opportunity to produce high-quality beef at reduced input costs compared with traditional protein supplements.

LITERATURE CITED

Ahn, D. U., D. G. Olson, J. I. Lee, C. Jo, C. Wu, and X. Chen. 1998. Packaging and irradiation effects of lipid oxidation on volatiles in pork patties. J. Food Sci. 63:15–19.

Akoh, C. C., and D. B. Min. 2002. Structured lipids. Pages 883–884 in Food Lipids: Chemistry, Nutrition, and Biotechnology. 2nd ed. Marcel Dekker Inc., New York, NY.

Aldai, N., J. L. Aalhus, M. E. R. Dugan, W. M. Robertson, T. A. McAllister, L. J. Walter, and J. J. McKinnon. 2010. Comparison of wheat- versus corn-based dried distillers' grains with solubles on meat quality of feedlot cattle. Meat Sci. 84:569–577.

AMSA. 1995. Research Guidelines for Cookery: Sensory Evaluation and Instrumental Tenderness Measurements of Fresh Meat. Am. Meat Sci. Assoc. and Natl. Livest. and Meat Board, Chicago, IL.

AOAC. 1990. Official Methods of Analysis of the Association of Official Analytical Chemists. 15th ed. Assoc. Off. Anal. Chem. Inc., Arlington, VA.

Cabezas, M. T., J. F. Hentges Jr., J. E. Moore, and J. A. Olson. 1965. Effect of diet on fatty acid composition of body fat in steers. J. Anim. Sci. 24:57–61.

Calkins, C. R., and J. M. Hodgen. 2007. A fresh look at meat flavor. Meat Sci. 77:63–80.

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

Duckett, S. K., J. G. Andrae, and F. N. Owens. 2002. Effect of high-oil corn or added corn oil on ruminal biohydrogenation of fatty acids and conjugated linoleic acid formation in beef steers fed finishing diets. J. Anim. Sci. 80:3353–3360.

Firkins, J. L., L. L. Berger, and G. C. Fahey Jr. 1985. Evaluation of wet and dry distillers grain and wet and dry corn gluten feeds for ruminants. J. Anim. Sci. 60:847–860.

Folch, J., M. Lees, and G. H. Sloane Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226:497–509.

Gill, R. K., D. L. VanOverbeke, B. Depenbusch, J. S. Droulliard, and A. DiCostanzo. 2008. Impact of beef cattle diets containing corn or sorghum distillers grains on beef color, fatty acid profiles, and sensory attributes. J. Anim. Sci. 86:923–935.

Gunn, P. J., A. D. Weaver, R. P. Lemenager, D. E. Gerrard, M. C. Claeys, and S. L. Lake. 2009. Effects of dietary fat and crude protein on feedlot performance, carcass characteristics, and meat quality in finishing steers fed differing levels of dried distillers grains with solubles. J. Anim. Sci. 87:2882–2890.

Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, and R. P. Huffman. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. 72:3246–3257.

Hegsted, D. M., R. B. McGrandy, M. L. Myers, and F. J. Stare. 1965. Quantitative effects of dietary fat on serum cholesterol in man. Am. J. Clin. Nutr. 17:281–295.

Hoffman, P. C. 1989. Corn Gluten Feed. Bulletin No. A3518. University of Wisconsin–Madison. Accessed May 17, 2010. http://learningstore.uwex.edu/assets/pdfs/a3518.pdf.

Hunt, M. C., J. C. Acton, R. C. Benedict, C. R. Calkins, D. P. Cornforth, L. E. Jeremiah, D. G. Olson, C. P. Salm, J. W. Savell, and S. D. Shivas. 1991. Pages 1–17 in Guidelines for meat color evaluation. Proceedings of 44th Recip. Meat Conf., Manhattan, KS.

Hutchison, S., E. B. Kegley, J. K. Apple, T. J. Wistuba, M. E. Dikeman, and D. C. Rule. 2006. Effects of adding poultry fat in the finishing diet of steers on performance, carcass characteristics, sensory traits, and fatty acid profiles. J. Anim. Sci. 84:2426–2435.

Jenschke, B. E., J. R. Benton, C. R. Calkins, T. P. Carr, K. M. Eskridge, T. J. Klopfestein, and G. E. Erickson. 2008. Chemical and sensory properties of beef of known source and finished on wet distillers grains diets containing varying types and levels of roughage. J. Anim. Sci. 86:949–959.

Kampman, K. A., and S. C. Loerch. 1989. Effects of dry corn gluten feed on feedlot cattle performance and fiber digestibility. J. Anim. Sci. 67:501–512.

Kim, C. J., and E. S. Lee. 2002. Effects of quality grade on chemical, physical, and sensory characteristics of Hanwoo (Korean native cattle) beef. Meat Sci. 63:397–405.

Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2007. BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86:1223–1231.

Koger, T. J., D. M. Wulf, K. E. Tjardes, K. S. Mateo, T. E. Engle, C. L. Wright, and R. J. Maddock. 2004. The influence of feeding various levels of wet distillers grains on carcass quality, carcass composition, and fatty acid profile of finishing steers. Proc. 57th Recip. Meats Conf. Accessed May 24, 2010. http://www.meatscience.org.

Leupp, J. L., G. P. Lardy, M. L. Bauer, K. K. Karges, M. L. Gibson, J. S. Caton, and R. J. Maddock. 2009. Effects of distillers dried grains with solubles on growing and finishing steer intake, performance, carcass characteristics, and steak color and sensory attributes. J. Anim. Sci. 87:4118–4124.

Loe, E. R., M. L. Bauer, and G. P. Lardy. 2006. Grain source and processing in diets containing varying concentrations of wet corn gluten feed for finishing cattle. J. Anim. Sci. 84:986–996.

Mancini, R. A., and M. C. Hunt. 2005. Current research in meat color. Meat Sci. 71:100–121.

Muchenje, V., K. Dzama, M. Chimonyo, P. E. Strydom, A. Hugo, and J. G. Raats. 2009. Some biochemical aspects pertaining to beef eating quality and consumer health: A review. Food Chem. 112:279–289.

Nelson, M. L., J. R. Busboom, J. D. Cronrath, L. Falen, and A. Blankenbaker. 2000. Effects of graded levels of potato by-products in barley-and corn-based beef feedlot diets: I Feedlot performance, carcass traits, meant composition, and appearance. J. Anim. Sci. 78:1829–1836.

NRC. 1996. Nutrient Requirement of Beef Cattle. 7th ed. Natl. Acad. Press, Washington, DC.

Park, P. W., and R. E. Goins. 1994. In situ preparation of FAME for analysis of fatty acid composition in food. J. Food Sci. 59:1262–1266.

Roberson, K. 2004. Corn dried distillers grains with solubles for laying hens—They're great. Proc. Midwest Poult. Fed. Conv., St. Paul, MN.

Roeber, D. L., R. K. Gill, and A. DiCostanzo. 2005. Meat quality responses to feeding distiller's grains to finishing Holstein steers. J. Anim. Sci. 83:2455–2460.

Segers, J. 2010. Effects of protein supplementation using corn byproducts in southeastern beef cattle production: A systems approach. MS Thesis. Univ. Georgia, Athens.

Shackelford, S. D., J. B. Morgan, H. R. Cross, and J. W. Savell. 1991. Identification of threshold levels for Warner-Bratzler shear force in beef top loin steaks. J. Muscle Foods 2:289–296.

Stephens, J. W., J. A. Unruh, M. E. Dikeman, M. C. Hunt, T. E. Lawrence, and T. M. Loughin. 2004. Mechanical probes can predict tenderness of cooked beef longissimus using uncooked measurements. J. Anim. Sci. 82:2077–2086.

Vander Pol, K. J., M. K. Luebbe, G. I. Crawford, G. E. Erickson, and T. J. Klopfenstein. 2009. Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts, or supplemental corn oil. J. Anim. Sci. 87:639–652.

Wood, J. D., R. I. Richardson, G. R. Nute, A. V. Fisher, M. M. Campo, E. Kasapidou, P. R. Sheard, and M. Esner. 2002. Effects of fatty acids on meat quality. Meat Sci. 66:21–32.

Zerby, H. N., K. E. Belk, J. N. Sofos, L. R. McDowell, and G. C. Smith. 1999. Case life of seven retail products from beef cattle supplemented with α-tocopheryl acetate. J. Anim. Sci. 77:2458–2463.

Zock, P. L., and M. B. Katan. 1998. Linoleic acid intake and cancer risk: A review and meta-analysis. Am. J. Clin. Nutr. 68:142–153.