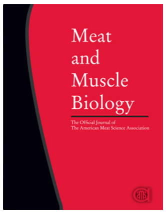
Meat and Muscle Biology™


Meat
and
Muscle
Biology

Palatability and Biochemical Factors of Beef from Mature Cattle Finished on a Concentrate Diet Prior to Harvest

Devin A. Gredell[1], Travis G. O'Quinn[2]*, Jerrad F. Legako[1],
J. Chance Brooks[1], and Markus F. Miller[1]

[1]Department of Animal and Food Sciences, Texas Tech University, Lubbock, TX 79409, USA
[2]Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS 66506, USA
*Corresponding author. Email: travisoquinn@ksu.edu (T. G. O'Quinn)

Abstract: The objective of this study was to investigate the influence of grain-finishing on mature beef palatability. Beef strip loins ($n = 15$ per treatment) from 2 marbling score groups [Slight (SL) and Traces/Practically Devoid (TR/PD)] and 3 carcass types [young fed (YF), mature fed (MF), and mature unfed (MU)] were collected. Young fed and MF cattle were grain-finished prior to harvest, whereas, beef from MU cattle were not identified as being grain-finished prior to harvest. Consumer and trained sensory panels evaluated steaks for palatability characteristics. Additionally, Warner-Bratzler shear force (WBSF), collagen solubility, sarcomere length, and volatile compounds were evaluated. Consumer ratings were not influenced ($P > 0.05$) by an interaction of main effects. Slight samples were greater ($P < 0.05$) than TR/PD samples for tenderness, juiciness, flavor, and overall like. Trained panelists rated SL samples more tender ($P < 0.01$) than TR/PD samples. Additionally, YF and MU steaks were the most and least tender ($P < 0.01$), respectively. No differences ($P > 0.05$) were observed among SL samples for beef flavor, beef flavor intensity, or off-flavor intensity due to carcass type. However, TR/PD-MF and MU steaks had more intense ($P < 0.01$) off-flavors. Steaks from YF and MF carcasses had lower ($P < 0.01$) WBSF values than steaks from MU carcasses. Percentage of heat soluble collagen was greatest ($P < 0.01$) in YF carcasses. Among SL treatments, sarcomere length was not affected ($P > 0.05$) by carcass type; however, MF and MU carcasses with TR/PD marbling scores had shorter ($P < 0.05$) sarcomeres than YF carcasses. Various volatile compounds were influenced ($P < 0.05$) by treatment and showed relationships with sensory ratings. Improvements in palatability were observed due to grain-finishing mature cattle, suggesting an adequate degree of marbling could offset negative palatability traits typically associated with beef from mature cattle.

Keywords: collagen solubility, flavor, sarcomere length, sensory, tenderness, volatile compounds
Meat and Muscle Biology 2:111–126 (2018) **doi:10.22175/mmb2017.09.0046**
Submitted 26 Sep. 2017 Accepted 19 Jan. 2018

Introduction

The majority of beef produced in the US comes from fed steers and heifers less than 30 mo of age; however, beef cows accounted for 8.6% of all cattle slaughtered in the United States in 2016 (USDA National Agriculture Statistics Service, 2017). Although the majority of a cow-calf producer's annual profit comes from selling calves, the sale of cull cows can account for up to 25% of their annual income (Woerner, 2010). Therefore, it can be beneficial for producers to manage cull cows in a way that maximizes profitability. Beef cows are often culled after weaning. With the seasonality of weaning, this leaves many cull cows being sold in the fall directly after weaning when market prices are the least favorable (Amadou et al., 2014). Placing cull cows on a high-energy, corn-based diet prior to harvest not only increases carcass weights and improves palatability, but also allows producers to refrain from selling their cull cows until market prices are more favorable (Little et al., 2002). Although numerous factors can affect the profitability of holding cull cows on feed, profitability can especially be maximized if cull cows begin the feeding period with a lower BCS (Amadou et al., 2014). Feeding cull cows a high-energy diet is an effective way to add pounds to beef carcasses, allowing for greater availability of red meat without increasing cattle numbers. Previous studies have shown that placing cull cows on a high-energy diet have increased hot carcass weights, dressing percentages, and subprimal weights (Schnell et al., 1997; Allen et al., 2009; Neill et al., 2009).

It has been well documented that as physiological carcass maturity increases, consumers find beef to be less tender and have more intense off-flavors (Hilton et al., 1998; Stelzleni et al., 2007). A high-energy finishing diet can improve sensory ratings for tenderness and flavor attributes, and lessen the occurrence of off-flavors (Cranwell et al., 1996; Schnell et al., 1997). Several studies have investigated improving mature beef quality through grain-finishing, and some have even compared grain-finished mature beef to young beef. However, little to no work has been done to compare unfed cow beef, grain-finished cow beef, and grain-finished young beef, while keeping marbling score constant among carcass types. It is well known that marbling score has a large influence on sensory attributes (Tatum et al., 1982; O'Quinn et al., 2012); therefore, it was the objective of this study to evaluate the influence of grain-finishing and degree of marbling on sensory and biochemical characteristics of mature beef strip steaks.

Materials and Methods

Product selection

Beef strip loins (Institutional Meat Purchase Specifications, 180; *n* = 15 per treatment) were collected to represent 2 marbling score groups [Slight (SL) and Traces/Practically Devoid (TR/PD)] across three carcass types [young fed (YF), mature fed (MF), and mature unfed (MU)] from commercial processing facilities. Carcass quality and yield grade attributes were collected by trained personnel from Texas Tech University. Marbling score groups were chosen to represent those that would be necessary for USDA Select and USDA Standard beef quality grades. Because marbling score was being held constant across all carcass types, the described marbling score groups were chosen because of difficulties in procuring mature unfed carcasses with greater than Slight marbling scores. Young carcasses were selected to be within A maturity as evaluated by skeletal ossification and lean color and mature beef was selected from carcasses that exhibited C maturity or greater as evaluated by skeletal ossification and lean color. Fed carcasses (both YF and MF) were selected from a processing facility that identified all cattle as being commercially finished on a conventional grain-based diet, whereas, unfed carcasses were collected from a cull-cow harvest facility that did not identify cattle as being finished on grain. For all carcass types, collection from dairy type carcasses was avoided to only include beef from *Bos taurus* beef breeds. Additionally, selected carcasses had a hump height of less than 5 cm to minimize the influence of *Bos indicus* genetics. Neither collection facility utilized electrical stimulation technology at the time samples were collected for the current study. Subprimals were shipped to Texas Tech University and stored under vacuum at 0 to 4°C prior to steak fabrication.

Steak fabrication

Subprimals were fabricated into 2.54-cm thick steaks from anterior to posterior, vacuum packaged, and aged for 21 d postmortem at 4°C. One steak from each subprimal was assigned to be used for the following analyses: proximate analysis/collagen solubility, consumer taste panels, trained taste panels, volatile flavor compounds, Warner-Bratzler shear force (WBSF), and sarcomere length. For each striploin, steak location was randomly assigned for each analysis. Following the 21-d aging period, steaks were frozen and stored at -20°C in the absence of light until being used for their respective analysis.

Proximate analysis

Proximate analysis was performed to determine percentage of the fat, moisture, and protein. All subcutaneous fat, intermuscular fat, and connective tissue was removed from each sample so that only the *M. longissimus dorsi* was evaluated. Each sample was ground through a commercial food grinder (Krups 150 Watt Grinder item #402–70, Krups, Sheldon, CT). Samples were analyzed using an AOAC-approved (Anderson, 2007) near infrared spectrophotometer (FoodScan, FOSS NIRsystems, Inc., Laurel, MD). After being analyzed, each ground sample was frozen in liquid nitrogen, homogenized, and stored at –80°C until analysis for collagen solubility.

Warner-Bratzler Shear Force

Tenderness of each steak was determined using a WBSF analyzer (G-R Elec. Mfg,., Manhattan, KS). Frozen steaks were thawed at 2 to 4°C for 24 h prior to analysis. Raw steak weights and temperatures were recorded by use of a digital thermometer (Digi-Sense Type J, Cole-Parmer Instrument Company, Vernon Hills, IL) in the geometric center of each sample prior to cooking. Steaks were cooked to a peak internal temperature of 71°C using a commercial gas grill (Model

IRB-36, Imperial Commercial Cooking Equipment, Corona, CA). After a 3-min rest period, final cooked temperatures and weights were recorded. Steaks were allowed to chill at 2 to 4°C for 18 to 24 h prior to shear force analysis. Six 1.3-cm cores were removed parallel to the muscle fiber from each steak and sheared perpendicular to the muscle fiber orientation. The values from the 6 cores were averaged to determine the overall shear force value for each steak for statistical analyses (American Meat Science Association, 2015).

Collagen solubility

An aliquot from the powdered proximate analysis sample was used for the determination of collagen solubility. A modified procedure of Hill (1966) was used to isolate heat soluble collagen. Four grams of sample were heated in 12 mL of distilled water for 63 min at 77°C. Following 2 centrifugation steps, approximately 20 mL of supernatant was reserved for analysis of heat soluble collagen. The remaining pellets were placed into aluminum pans and dried for 16 h at 100 to 103°C. Dried pellets were hydrolyzed in 5 mL of 6 N hydrochloric acid (HCl) at 110°C for 16 h and 3 mL of supernatant were hydrolyzed in 3 mL of concentrated HCl at 110°C for 16 h. After hydrolysis, samples were filtered and neutralized using sodium hydroxide (NaOH). The pellet and supernatant of each sample was then diluted with distilled water to 100 mL and 15 mL, respectively. Hydroxyproline content of each fraction was determined in duplicate by a modified procedure of Bergman and Loxley (1963). Hydroxyproline concentration was determined at 558 nm using a Genesys 20 spectrophotometer (Thermo Fisher Scientific; Waltham, MA). If absorbencies of duplicates for insoluble collagen had a SEM > 10 or heat soluble collagen had a SEM > 3.5, samples were re-evaluated. Average absorbency was calculated for each sample and the resulting number was used to calculate mg of hydroxyproline/g of muscle. Conversion factors of 7.25 and 7.52 were used to calculate the amount of insoluble and heat soluble collagen, respectively (Cross et al., 1973). Total collagen was calculated as the sum of heat soluble and insoluble collagen.

Sarcomere length

Sarcomere length was measured using neon laser diffraction as described by Cross et al. (1981). A 3.0 × 3.0 × 2.0 cm^2 sample was removed parallel to the muscle fiber orientation and fixed in glass vials with a 5% glutaraldehyde solution (Thermo Fisher Scientific) for 4 h at 4°C. After fixing, glutaraldehyde solution was replaced with 0.2 M sucrose solution for overnight storage at 4°C. Muscle fibers were excised from each sample using forceps and spread onto glass slides. Fibers were moistened with the 0.2 M sucrose solution before application of a cover slip. A neon laser (Model 117A; SpectraPhysics Inc., Irvine, CA) operated at a wavelength of 632.8 nm was used to measure 6 different diffraction patterns per sample. Sarcomere length for each sample was calculated from the average of these 6 measurements.

Volatile flavor compounds

Steaks used for volatile flavor analysis were cooked to 71°C using a propane gas grill (Commercial Quantum Infrared 4-Burner, Char-Broil, LLC, Columbus, GA). Five 1.3-cm cores were removed perpendicular to the cut steak surface within 3 min of cooking. Cores were then homogenized in a coffee bean grinder (KRUPS, Medford, MA; Type #F203). Five grams of homogenized sample was weighed into a 20 mL GC vial and secured with a polytetrafluoroethylene septa and screw cap. Ten µL of an internal standard (1, 2-dichlorobenzene; 1.306 mg/ml) was added to the vial and the vial was loaded by an automated sampler (MultiPurpose Sampler; Gerstel; Linthicum, MD) for a 5 min incubation period at 65°C in the Gerstel agitator (500 rotations per minute) followed by a 20 min extraction period where volatile compounds were collected from the headspace of cooked samples by solid phase microextraction using an 85-mm film thickness carboxen polydimethylsiloxane fiber (Supleco, Bellefonte, PA). Extracted volatile compounds were injected on a VF-5 ms capillary column (30 m × 0.25 mm × 1.00 mm; Agilent J&W GC Columns, Santa Clara, CA). The electron impact mode was set at 70 eV in the mass spectrometry which detected the ions within the range of 50 to 500 m/z. Selective ion monitoring/scan mode was used to collect the data. External standard comparison was used to validate the volatile compound identity of ion fragmentation patterns. Quantitation was performed by an internal standard calibration with authentic standards.

Consumer sensory panels

The Texas Tech University Institutional Review Board approved procedures for use of human subjects for consumer panel evaluation of sensory attributes (#504547).

Consumer panelists were used to determine palatability of cooked steaks. Five panels of 24 panelists were conducted at the Texas Tech University Animal and Food Sciences Building for a total of 120 consumers. Participants were pre-screened to ensure that they were regular beef eaters and preferred a medium degree of doneness (71°C). Additionally, each consumer was monetarily compensated for his or her time and participation in the study. The study was arranged as a completely random design in which each consumer evaluated 1 sample from each of the carcass type × marbling group combination.

Before cooking, steaks were thawed for 24 h at 2 to 4°C. Steaks were cooked to an internal temperature of 71°C using a commercial gas grill (Model IRB-36, Imperial Commercial Cooking Equipment) to simulate cooking practices used in the food service industry. End point temperatures were monitored by use of a digital thermometer (Digi-Sense Type J, Cole-Parmer Instrument Company) in the geometric center of each sample prior to cooking. After a 3 min rest period, final cooked temperatures and weights were recorded. Each steak was cut into 8 equal parts relative (approximately 2 cm^2) to the size of the steak and served to the panelists. Panelists evaluated each sample for tenderness, juiciness, flavor identity, flavor liking, overall liking, and off flavor intensity on 100 cm verbally anchored line-scales (0 = dislike extremely, extremely tough, extremely dry, dislike extremely, extremely bland; 100 = like extremely, extremely tender, extremely juicy, like extremely, extremely intense). Acceptability (yes/no) of tenderness, juiciness, flavor liking, and overall liking were also rated for each sample.

Trained sensory panels

The Texas Tech University Institutional Review Board approved procedures for use of human subjects for trained panel evaluation of sensory attributes (#504547).

Trained panels were conducted and trained according to the AMSA sensory guidelines (American Meat Science Association, 2015). Seven trained panelists participated in 15 panels, each lasting approximately 30 min. Panelists were trained during 3 separate training sessions where they were fed beef of varying marbling scores, maturities, and muscles to evaluate tenderness, juiciness, and flavor according to the methods as described by Lucherk et al. (2016). Before cooking, steaks were thawed for 24 h at 2 to 4°C. Steaks were cooked using the procedures previously described for consumer panels. Two samples measuring 1 cm^3 from each steak were served to each panelist. Panels were conducted in a dark room under red lights to eliminate bias from the visual appearance of the sample. Trained panelists evaluated each sample for initial juiciness, sustained juiciness, initial tenderness, sustained tenderness, beef flavor, flavor intensity, and off-flavor intensity on 100 mm verbally anchored line-scales (0 = extremely dry, extremely tough, extremely unbeef-like, extremely bland; 100 = extremely juicy, extremely tender, extremely beef-like, extremely intense).

Statistical analysis

Data were analyzed using the procedures of SAS (Version 9.4; SAS Inst. Inc., Cary, NC). The experiment was designed as a 2 × 3 factorial with marbling score and carcass type as the fixed effects. Main effect and interaction comparisons were tested for significance using PROC GLIMMIX with $\alpha = 0.05$ and the denominator degree of freedom were calculated using the Kenward-Roger method. For both trained and consumer sensory data, ratings for each sample were averaged across panelist before analysis and panel number was included in the model as a random effect. Acceptability data for consumer sensory ratings were analyzed with a model that included a binomial error distribution. Consumer demographic information was summarized using PROC FREQ. Relationships between PROC CORR was used for calculating and determining significance ($P < 0.05$) of all correlation coefficients between volatile compounds and sensory ratings.

Results and Discussion

Carcass characteristics

Carcass characteristics are presented in Table 1. It should be noted that carcasses chosen for this project were selected to show clear differences in carcass maturity and marbling scores. Thus, these data do not represent a random selection of samples from these USDA maturity and marbling scores and are reported to aide in the discussion of sensory and chemical analyses. Skeletal maturity scores for YF carcasses were less ($P < 0.01$) than both MF and MU carcasses. Lean maturity scores for YF and MF carcasses were more youthful ($P < 0.01$) than MU carcasses. Additionally, TR/PD-MU carcasses had darker ($P < 0.01$) lean than SL-MU carcasses, although means for both treatments were still well within B maturity. These results agree with Kerth et al. (2007) who reported decreased lean maturity scores from finishing cattle on grain alone. Overall maturity scores were more youthful ($P < 0.01$) for YF carcasses (A maturity) than for both MF and MU carcasses (D maturity). During sample collection, YF groups were specifically chosen to represent A maturity, while MF and MU groups were chosen to represent C and greater maturity.

Within TR/PD carcasses, marbling scores of MF carcasses were greater ($P < 0.01$) than those for YF and MU carcasses. Although there was a difference in marbling scores of TR/PD carcasses, means for all carcass types were within the “Traces” marbling score group. These marbling scores met our objective to select car-

Table 1. Carcass characteristics of mature cattle commercially identified as fed or unfed and young fed carcasses of varying marbling scores

Treatment	Hot carcass weight, kg	Fat thickness, cm	Ribeye area, cm^2	Marbling score[1]	Lean maturity[2]	Skeletal maturity[2]	Overall maturity[2]
Slight							
Young Fed	399.94^{am}	1.01^{am}	90.58^{wx}	354.67^{w}	184.00^{y}	158.67^{n}	169.33^{n}
Mature Fed	430.09^{am}	1.29^{am}	91.80^{w}	353.33^{w}	178.00^{y}	548.00^{m}	448.00^{m}
Mature Unfed	326.07^{an}	0.76^{an}	84.38^{xy}	351.33^{w}	242.67^{x}	550.00^{m}	454.67^{m}
Traces/Practically Devoid							
Young Fed	353.34^{bm}	0.55^{bm}	93.22^{w}	226.00^{y}	168.00^{y}	142.67^{n}	152.67^{n}
Mature Fed	354.76^{bm}	0.96^{bm}	72.32^{z}	266.67^{x}	182.00^{y}	544.67^{m}	446.67^{m}
Mature Unfed	263.44^{bn}	0.02^{bn}	82.83^{y}	210.67^{y}	284.67^{w}	552.67^{m}	458.67^{m}
SEM[3]	11.96	0.10	2.58	9.40	7.21	15.12	13.04
P-value[4]							
Marbling Score	<0.01	<0.01	<0.01	<0.01	0.09	0.65	0.66
Carcass Type	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Interaction	0.48	0.09	<0.01	0.01	<0.01	0.82	0.71

[a,b] Least squares means in the same column without a common superscript differ ($P < 0.05$) because of marbling score.

[m,n] Least squares means in the same column without a common superscript differ ($P < 0.05$) because of carcass type.

[w–z] Least squares means in the same column without a common superscript differ ($P < 0.05$) because of the marbling score × carcass type interaction.

[1] 200 = traces^{00}; 300 = slight^{00}.

[2] 100 = A^{00}; 200 = B^{00}; 300 = C^{00}; 400 = D^{00}; 500 = E^{00}.

[3] Pooled SE of least squares means.

[4] Observed significance levels for main effects of marbling score, carcass type, and the marbling score × carcass type interaction.

casses from each carcass type to fall within marbling score groups that would be representative of those similar to USDA Select and USDA Standard requirements. Hot carcass weights were affected ($P < 0.01$) by both marbling score and carcass type. Carcasses with SL marbling scores were heavier ($P < 0.01$) than carcasses with TR/PD marbling scores. Additionally, YF and MF carcasses were heavier ($P < 0.01$) than MU carcasses from both marbling score groups. Fat thickness followed the same trends as HCW. Carcasses with SL marbling scores had greater fat thickness ($P < 0.01$) than TR/PD carcasses. Additionally, YF and MF carcasses had greater fat thickness ($P < 0.01$) than MU carcasses. These results comply with findings from numerous studies which reported increases in HCW and fat thickness as a result of grain-finishing when compared to forage-finishing (May et al., 1992; Realini et al., 2004; Duckett et al., 2013). Ribeye area was influenced ($P < 0.01$) by a marbling score × carcass type interaction. Within SL treatments, YF and MF carcasses had greater ($P < 0.01$) ribeye area than MU carcasses. However, among TR/PD carcasses, YF samples had greater ($P < 0.01$) ribeye area than MF and MU. Additionally, MU carcasses had greater ($P < 0.01$) ribeye area than MF carcasses. The results for ribeye area of SL carcasses agree with those published by Stelzleni et al. (2007) showing that feeding cull beef cows a high-energy diet prior to harvest leads to similar ribeye areas as young grain-finished cattle.

Proximate analysis

The proximate composition of samples is shown in Table 2. The samples chosen for this project were intended to show clear differences in the chemical fat content of the *M. longissimus dorsi* muscle between marbling scores. Therefore, these data do not represent a random selection of samples from these USDA marbling scores and are merely reported to help explain sensory analyses. Fat percentages increased ($P < 0.01$) with increasing marbling score. This information reinforces the accuracy of our trained personnel to call carcass marbling scores, since marbling scores are a direct reflection of intramuscular fat percent of the *M. longissimus dorsi* muscle between the 12th and 13th ribs. Percent moisture was also influenced ($P \leq 0.03$) by marbling score and was inversely related to percent fat. Fat and moisture were also influenced ($P < 0.01$) by carcass type, as shown by MF steaks having greater ($P < 0.01$) percent fat and lesser ($P < 0.01$) percent moisture than all other carcass types. The higher marbling scores given to MF carcasses, as previously discussed, can explain this difference in fat and moisture content. Percentage of fat and moisture are inversely related, therefore, as fat content increases, moisture will decrease (Minchin et al., 2009; O'Quinn et al., 2012; Garmyn et al., 2014). Finally, MU steaks had a lower ($P < 0.01$) percentage of protein than YF and MF steaks.

Table 2. Least squares means for percentage chemical fat, moisture, and protein for beef strip steaks from mature beef carcasses commercially identified as fed or unfed and young fed carcasses of varying marbling scores determined by proximate analysis

Treatment	Fat, %	Moisture, %	Protein, %	Collagen, %
Slight				
Young Fed	4.33^{an}	71.14^{bn}	23.44^{m}	1.73^{an}
Mature Fed	4.41^{am}	70.38^{bn}	23.56^{m}	1.81^{am}
Mature Unfed	4.16^{an}	72.26^{bm}	22.54^{n}	1.57^{ao}
Traces/Practically Devoid				
Young Fed	2.40^{bn}	72.38^{an}	24.10^{m}	1.46^{bn}
Mature Fed	3.80^{bm}	71.85^{an}	23.41^{m}	1.66^{bm}
Mature Unfed	2.15^{bn}	74.00^{am}	22.79^{n}	1.36^{bo}
SEM[1]	0.37	0.35	0.20	0.05
P-value[2]				
Marbling Score	<0.01	<0.01	0.13	<0.01
Carcass Type	0.03	<0.01	<0.01	<0.01
Interaction	0.11	0.77	0.14	0.50

^{a,b}Least squares means in the same column without a common superscript differ (P < 0.05) because of marbling score.

$^{m-o}$Least squares means in the same column without a common superscript differ (P < 0.05) because of carcass type.

[1] Pooled SE of least squares means.

[2] Observed significance levels for main effects of marbling score, carcass type, and the marbling score × carcass type interaction.

Table 3. Concentration of total, heat soluble, and insoluble collagen from beef strip steaks of mature carcasses commercially identified as fed or unfed and young fed carcasses of varying marbling scores

Treatment	Heat soluble, mg/g	Insoluble, mg/g	Total, mg/g	Heat soluble, %
Slight				
Young Fed	0.54^{a}	1.47	1.98^{a}	27.28^{x}
Mature Fed	0.20^{b}	1.38	1.58^{ab}	13.53^{y}
Mature Unfed	0.14^{b}	1.54	1.67^{b}	8.10^{z}
Traces/Practically Devoid				
Young Fed	0.71^{a}	1.39	2.10^{a}	32.46^{x}
Mature Fed	0.15^{b}	1.81	1.95^{ab}	8.02^{z}
Mature Unfed	0.09^{b}	1.51	1.60^{b}	6.13^{z}
SEM[1]	0.06	0.13	0.15	1.77
P-value[2]				
Marbling Score	0.57	0.34	0.29	0.59
Carcass Type	<0.01	0.50	0.04	<0.01
Interaction	0.13	0.13	0.37	0.01

^{a,b}Least squares means in the same column without a common superscript differ ($P < 0.05$) because of carcass type.

$^{x-z}$Least squares means in the same column without a common superscript differ ($P < 0.05$) because of the marbling score × carcass type interaction.

[1] SEM is the pooled standard error (largest) of least square means.

[2] Observed significance levels for main effects of marbling score, carcass type, and the marbling score × carcass type interaction.

Collagen solubility

Collagen characteristics are presented in Table 3. Marbling score had no influence ($P > 0.05$) on collagen characteristics. Neither collagen content nor solubility is known to be influenced by marbling score, but rather, it is predominantly influenced by animal age and muscle type (Purslow, 2005). In the current study, collagen characteristics were affected ($P < 0.05$) by carcass type. Concentrations of heat insoluble collagen were similar ($P = 0.50$) among all carcass types; however, samples from YF carcasses had significantly greater ($P < 0.01$) concentrations of heat soluble collagen compared to both groups of mature carcasses. Thus, total collagen concentrations were greater ($P < 0.05$) in YF samples than in MU samples. Within TR/PD carcasses, MF and MU samples had similar ($P > 0.05$) percentages of heat soluble collagen; however, SL-MF samples showed a greater ($P < 0.01$) percent of heat soluble collagen than SL-MU samples. Grain feeding SL-MF cattle showed to improve collagen solubility; however, it was still not to the same extent as beef from more youthful carcasses. A study performed on rats found muscle collagen to have a relatively long turnover rate at 90 d (Rucklidge et al., 1992), thus, it may be possible that MF cattle may have not consumed high levels of dietary energy long enough to resynthesize new, heat soluble collagen to a greater extent.

The results of our study agree with the idea that as an animal matures, collagen crosslinks also mature and produce a greater amount of heat stable crosslinks between adjacent collagen fibers (Bailey, 1985; McCormick, 1994; Lepetit, 2007). Total collagen concentrations vary a little within the same muscle, regardless of animal age, so the percent of heat soluble collagen will decrease as animal age increases, without changing total collagen concentrations (Hill, 1966). Although it is well documented that collagen solubility decreases with increasing animal age, placing mature animals on a high-energy diet prior to slaughter can stimulate protein turnover and the synthesis of new, heat soluble collagen (Cranwell et al., 1996). In our study, grain-finished mature animals had numerically greater concentrations of heat soluble collagen; however, this difference was not statistically significant ($P > 0.05$). Nevertheless, when comparing the concentration of heat soluble collagen to total collagen, grain finishing only improved the percent of heat soluble collagen of SL-MF cattle ($P < 0.01$). Among steaks from TR/PD carcasses, no improvement ($P > 0.05$) was seen between MF and MU samples as a result of grain feeding. In previous literature, when collagen solubility has been increased in mature cows through a high-energy diet, an improvement in WBSF values and sensory tenderness have also been observed in the same samples (Miller et al., 1987; Cranwell et al., 1996). In the current study, collagen solubility did not seem to influence WBSF values, however, it did seem to relate with an improvement in sensory tenderness ratings.

Sarcomere length

Among SL samples, carcass type had no influence ($P > 0.05$) on sarcomere length (Table 4). On the contrary, YF samples had significantly longer ($P < 0.05$) sarcomeres than both MF and MU carcasses with TR/PD marbling scores. Little data directly comparing sarcomere length with time on feed in mature cattle exists, however, our results are similar to those reported for young carcasses (Bowling et al., 1977). The shorter sarcomeres from TR/PD-MU steaks appear to be linked to fat thickness, or lack thereof. As presented in Table 1, TR/PD-MU carcasses averaged 0.02 cm of fat thickness, providing little to no insulation during post-mortem chilling. Compared to the remaining treatments, the treatment (TR/PD-YF) with the least fat still had 0.55 cm of fat thickness, which appeared to be sufficient insulation to prevent shortening as evidenced by these samples having the longest sarcomeres of all treatments. The association between fat thickness and sarcomere length is due to carcass chilling rate post-mortem and can be controlled when sufficient fat cover insulates muscle and regulates chilling rates (Savell et al., 2005). The application of electrical stimulation can help prevent cold shortening by increasing the rate of glycolysis just after harvest (Hwang et al., 2003); however, in the current study, neither facility that samples were collected from were utilizing electrical stimulation at the time of collection. Therefore, it seems that feeding cull cows grain prior to harvest may improve beef tenderness simply by increasing fat thickness and adding insulation to carcasses during chilling, resulting in longer sarcomeres.

Warner-Bratzler Shear Force

Warner-Bratzler shear force values were influenced ($P < 0.05$) by carcass type (Table 4). The greatest ($P < 0.01$) WBSF values were recorded for MU steaks, while YF and MF steaks had similar ($P > 0.05$) values. In agreement with Cranwell et al. (1996), WBSF values improved due to grain finishing cull cows. It is also significant to note that no difference ($P > 0.05$) was observed in shear values between steaks from YF and MF carcasses. Stelzleni et al. (2007) compared steaks from grain-finished beef cows, unfed beef cows, and USDA Select carcasses, in which improvements in WBSF values of grain-finished beef cows made them similar to USDA Select beef. In both studies, grain finishing offset the negative age-related effects on WBSF values typically associated with beef from mature animals. The USDA has determined *M. longissimus dorsi* must have WBSF values ≥ 3.9 kg to be guaranteed very tender for marketing purposes (ASTM, 2011). Within both marbling score groups, MU samples did not meet this threshold; however, MF WBSF values were well below this threshold.

Table 4. Least squares means for sarcomere length and Warner-Bratzler Shear Force (WBSF) values of beef strip steaks from mature carcasses commercially identified as fed or unfed and young fed carcasses of varying marbling scores

Treatment	Sarcomere length, µm	WBSF, kg
Slight		
Young Fed	1.81^{xy}	3.25^{a}
Mature Fed	1.88^{xy}	3.24^{a}
Mature Unfed	1.76^{yz}	4.34^{b}
Traces/Practically Devoid		
Young Fed	1.98^{x}	3.96^{a}
Mature Fed	1.73^{yz}	3.47^{a}
Mature Unfed	1.62^{z}	4.59^{b}
SEM[1]	0.09	0.36
P-value[2]		
Marbling Score	0.42	0.05
Carcass Type	0.01	<0.01
Interaction	0.02	0.57

[a,b] Least squares means in the same column without a common superscript differ ($P < 0.05$) because of carcass type.

[x-z] Least squares means in the same column without a common superscript differ ($P < 0.05$) because of the marbling score × carcass type interaction.

[1] Pooled SE of least squares means.

[2] Observed significance levels for main effects of marbling score, carcass type, and the marbling score × carcass type interaction.

Volatile compounds

Of the 39 volatile compounds quantified in the current study, 15 were influenced ($P < 0.05$) by either marbling score or carcass type (Table 5). No compounds were influenced ($P > 0.05$) by a marbling score × carcass type interaction. There was no clear pattern for the concentrations of aldehydes extracted from the headspace of cooked steaks. Hexanal was extracted in the greatest abundance of all aldehydes and was the only aldehyde that was influenced by carcass type. Young fed steaks contained greater ($P < 0.01$) concentrations of hexanal than both MF and MU carcasses, which was present at concentrations roughly twice as high as both other carcass types. Hexanal is derived from the degradation of linoleic acid and has been associated with cat-

Table 5. Concentrations of identified volatile compounds isolated from beef strip steaks from mature carcasses commercially identified as fed or unfed and young fed carcasses of varying marbling scores cooked on a propane gas grill

	Marbling Score				Carcass Type					Interaction
Compound (ng/g)	Slight	Traces/practically devoid	SEM[1]	*P*-value	Young fed	Mature fed	Mature unfed	SEM[1]	*P*-value	*P*-value
n-aldehydes										
Acetaldehyde	11.81	11.67	0.96	0.92	10.18	12.2	12.84	1.16	0.25	0.54
2-Methyl Propanol	0.63^{a}	0.50^{b}	0.04	0.03	0.50	0.56	0.63	0.05	0.29	0.70
Hexanal	27.36	22.42	2.83	0.21	36.61^{x}	19.77^{y}	18.29^{y}	3.49	< 0.01	0.80
Heptanal	3.59	3.55	0.47	0.95	2.89	3.48	4.35	0.58	0.19	0.83
Octanal	4.98	4.56	0.69	0.66	4.07	4.53	5.71	0.85	0.36	0.70
Nonanal	2.38	2.57	0.26	0.59	2.17	2.77	2.48	0.32	0.41	0.52
Decanal	0.43^{b}	0.52^{a}	0.03	0.04	0.53	0.48	0.42	0.03	0.12	0.91
Strecker Aldehydes										
3-Methyl Butanal	29.36^{a}	23.56^{b}	1.97	0.03	24.10	26.38	28.9	2.42	0.37	0.87
2-Methyl Butanal	2.65^{a}	1.97^{b}	0.19	0.01	2.22	2.12	2.59	0.24	0.33	0.90
Benzaldehyde	8.20	8.90	1.02	0.63	7.72	8.88	9.05	1.27	0.71	0.43
Benzeneacetaldehyde	0.72	0.61	0.06	0.22	0.59	0.78	0.61	0.07	0.19	0.75
Ketones										
Acetoin	227.30	177.71	25.58	0.17	336.61^{x}	88.53^{z}	182.37^{y}	31.33	< 0.01	0.48
2-Propanone	13.84	15.59	1.53	0.41	12.44	13.59	18.11	1.88	0.08	0.54
2,3-Butanedione	12.46	11.09	1.09	0.37	17.14^{x}	7.34^{z}	10.84^{y}	1.35	< 0.01	0.22
2-Butanone	12.82	14.12	1.22	0.45	10.98	14.1	15.32	1.51	0.11	0.58
2-pentanone	1.15	1.11	0.06	0.66	1.07	1.07	1.24		0.25	0.17
2-Heptanone	4.07	2.97	0.41	0.06	3.77	3.12	3.67	0.51	0.63	0.54
Sulfides										
Dimethyl Sulfide	0.65	0.59	0.03	0.25	0.60	0.66	0.60	0.66	0.59	0.86
Dimethyl Disulfide	0.48	0.57	0.06	0.33	0.43	0.59	0.56	0.08	0.33	0.56
Carbon Disulfide	0.19	0.2	0.01	0.49	0.20	0.19	0.20	0.01	0.82	0.45
Thiols										
Methional	1.78	1.70	0.16	0.72	1.50	1.89	1.83	0.20	0.34	0.54
Furans										
2-Pentyl Furan	1.49	1.32	0.11	0.29	1.36	1.50	1.35	0.13	0.67	0.67
Carboxylic Acids										
Butanoic Acid	7.68	6.45	0.70	0.21	9.99^{x}	5.78^{y}	5.41^{y}	0.87	< 0.01	0.8
Pentanoic Acid	0.91^{b}	0.94^{a}	0.01	0.03	0.94	0.91	0.92	0.01	0.28	0.38
Hexanoic Acid	1.71	1.57	0.12	0.42	1.83	1.73	1.37	0.15	0.08	0.74
Octanoic Acid	0.47	0.47	0.01	0.75	0.45	0.51	0.45	0.03	0.14	0.67
Alkanes										
Octane	2.19	2.53	0.31	0.42	2.22	2.21	2.65	0.38	0.64	0.15
Pyrazines										
Methyl Pyrazine	1.49^{a}	1.00^{b}	0.10	< 0.01	1.24	1.18	1.30	0.12	0.77	0.67
2,5-Dimethyl Pyrazine	4.01^{a}	2.50^{b}	0.31	< 0.01	3.26	3.00	3.51	0.38	0.64	0.69
Trimethyl Pyrazine	2.56^{a}	1.64^{b}	0.20	< 0.01	2.18	1.84	2.28	0.24	0.41	0.81
2-Ethyl-3,5-Dimethyl Pyrazine	0.003^{a}	0.002^{b}	< 0.01	< 0.01	0.002	0.002	0.003	< 0.01	0.28	0.82
Esters										
Acetic Acid, Methyl Ester	0.21	0.19	0.01	0.21	0.18	0.21	0.2	0.01	0.31	0.07
Butanoic Acid, Methyl Ester	1.43	1.48	0.06	0.59	1.38	1.53	1.45	0.08	0.41	0.52
Octanoic Acid, Methyl Ester	0.50^{b}	0.60^{a}	0.03	0.03	0.56	0.54	0.54	0.04	0.93	0.90
Alcohols										
1-Hexanol	0.63	0.57	0.04	0.32	0.57	0.61	0.62	0.06	0.84	0.97
1-Heptanol	0.81	0.76	0.03	0.28	0.77	0.78	0.82	0.03	0.54	0.67
1-Octen-3-Ol	0.75	0.81	0.06	0.49	0.79	0.74	0.82	0.07	0.76	0.92
Alkene										
2-Methyl 1-Pentene	7.71	6.52	0.77	0.27	9.95^{x}	4.13^{z}	7.25^{y}	0.93	< 0.01	0.09

[a,b] Least squares means in the same column without a common superscript differ ($P < 0.05$) because of marbling score.

[x-z] Least squares means in the same column without a common superscript differ ($P < 0.05$) because of carcass type.

[1] SEM is the pooled standard error (largest) of least square means.

[2] Observed significance levels for main effects of marbling score, carcass type, and the marbling score × carcass type interaction.

tle finished on concentrate diets (Elmore et al., 2004). Calkins and Hodgen (2007) reported hexanal as having fatty-green, grassy, strong green, tallow, and fat like aromas. Decanal and 2-methyl propanol were the only aldehydes affected by marbling score. Concentrations of 2-methyl propanol were greater ($P < 0.05$) in SL steaks than in TR/PD steaks. Machiels et al. (2004) extracted this compound from cooked beef steaks and described the aroma as burnt, nutty, and oily. Unlike 2-methyl propanol, concentrations of decanal decreased ($P < 0.05$) as marbling score increased. Resembling hints of citrus aromas (Calkins and Hodgen, 2007), Resconi et al. (2012) found no differences in concentrations of decanal isolated from cooked beef from cattle fed diets varying in forage and concentrate amounts. Although not significant in the current study, there was a numerical decrease in concentration of heptanal seen in MU, MF, and YF steaks, respectively. This agrees with previous studies that have associated higher concentrations of heptanal in forage finished beef over grain finished beef and positively related its concentration to grassy flavors of cooked steaks (Larick et al., 1987).

Among the Strecker aldehydes, both 3-methylbutanal and 2-methylbutanal were isolated from the headspace of cooked steaks in greater ($P \leq 0.03$) concentrations from SL samples than TR/PD samples. Additionally, 3-methylbutanal was found in the greatest concentrations of all Strecker aldehydes evaluated. Both of these compounds are formed during the Strecker degradation of amino acids, with 3-methylbutanal originating from leucine and 2-methylbutanal from isoleucine (Resconi et al., 2013). These types of carbonyl compounds are believed to contribute to the roasted flavor of beef (Liebich et al., 1972).

Ketones are included in the classification of lipid-oxidized products (Van Ba et al., 2012). Acetoin was isolated in the greatest concentrations of all ketones and was affected ($P < 0.01$) by carcass type. Young fed carcasses had significantly more ($P < 0.01$) acetoin than both MF and MU carcasses. Furthermore, MU samples possessed more ($P < 0.01$) acetoin than MF samples. O'Quinn et al. (2016) produced similar results by reporting greater concentrations of acetoin in beef samples that had been finished on grain than from samples finished on grass. Additionally, O'Quinn et al. (2016) found acetoin to be negatively correlated with off-flavors such as grassy and gamey, but positively associated with overall flavor desirability. These results conflict those of Melton (1990), which noted a decrease in acetoin as days on feed increased. There was a decrease in the concentration of acetoin when mature carcasses were placed on feed before harvest; however, when comparing YF to MU samples, YF samples had nearly twice the amount of acetoin as MU samples. Concentrations of 2,3-butanedione followed similar trends to those of acetoin, as carcass type played a significant ($P < 0.01$) role in influencing the amount extracted from cooked steaks. Young fed carcasses showed the greatest ($P < 0.01$) and MF carcasses the least ($P < 0.01$) amounts of 2,3-butanedione. Specht and Baltes (1994) reported buttery aromas associated with this compound. Furthermore, O'Quinn et al. (2016) found 2,3-butanedione to be highly correlated with overall flavor desirability and browned/grilled flavor in addition to buttery flavor. While not significant ($P > 0.05$), numerical differences were seen in the amounts of 2-propanone and 2-butanone extracted from samples. For both compounds, concentrations were least in YF samples and greatest in MU samples. O'Quinn et al. (2016) found both compounds to be positively associated with sour flavors.

The most consistent trends of all the groups of compounds evaluated in our study were those seen in pyrazines. All 4 pyrazine compounds were isolated in greater ($P < 0.05$) concentrations from the headspace of cooked steaks with SL marbling scores. Pyrazines are formed through the interaction of amino acids of the Maillard reaction and are associated with cooked, roasted, burnt, meaty aromas (van Boekel, 2006; Van Ba et al., 2012). Dashdorj et al. (2015) outlined an interaction of Maillard reaction and lipid products as a potential source of pyrazine formation, which could explain the higher concentrations in the higher fat samples. The concentration of pyrazines is dependent on cookery method and temperature, which is particularly increased by grilling (Mottram, 1985). Therefore, the high heat used to cook steaks in the current study would be expected to facilitate pyrazine formation.

Consumer demographics and questionnaire

Table 6 contains demographic results from 120 consumers in Lubbock, Texas. The majority of participating consumers were Caucasian/White (58.62%) and/or female (57.76%). Hispanics were the second most common ethnicity (38.79%) of consumers represented in the survey. A majority (63.03%) of consumers were also married. More than half (> 50%) of participants had an annual household of at least $50,000 (62.39%) and had, at minimum, some college/technical school education (83.05%). Furthermore, 70.09% of consumers preferred the flavor of beef over other species such as chicken, pork, lamb, and fish. Flavor was reported the most frequently (46.22%) as the most important palatability trait that consumers look for when consuming beef, followed by tenderness (36.97%) and juiciness (16.81%).

Table 6. Demographic characteristics and meat consumption responses of consumers (n = 120) who participated in consumer sensory panels

Characteristic	Response	% of consumers
Sex	Male	42.24
	Female	57.76
Household size	1 person	12.50
	2 people	30.00
	3 people	13.33
	4 people	23.33
	5 people	11.67
	6 people	6.67
	> 6 people	2.50
Marital status	Single	36.13
	Married	63.03
Age	< 20	5.83
	20-29	19.17
	30-39	19.17
	40-49	20.00
	50-59	14.17
	> 60	21.67
Ethnic origin	African-American	2.59
	Caucasian/White	58.62
	Hispanic	38.79
Annual household income, US $	< 25,000	12.82
	25,000-34,999	6.84
	35,000-49,999	17.95
	50,000-74,999	22.22
	75,000-100,000	17.09
	> 100,000	23.08
Education level	Non-high school graduate	3.39
	High school graduate	13.56
	Some college/technical school	43.22
	College graduate	28.81
	Post Graduate	11.02
Weekly beef consumption	None	1.67
	1 to 3 times	46.67
	4 to 6 times	40.00
	7 or more times	11.67
Most important palatability trait when consuming beef	Flavor	46.22
	Juiciness	16.81
	Tenderness	36.97
Flavor preference	Beef	70.09
	Chicken	15.38
	Fish	3.42
	Lamb	0.85
	Mutton	0.85
	Pork	6.84
	Turkey	1.71
	Venison	0.85

Consumer palatability scores

Carcass type had no effect ($P > 0.05$) on consumer sensory scores of beef strip steaks (Table 7). However, marbling score did play a significant ($P < 0.05$) role in determining consumer ratings for tenderness, juiciness, flavor liking, and overall liking. Consumers rated steaks from SL carcasses greater ($P < 0.05$) for each palatability traits than steaks from TR/PD carcasses. The fact that consumer ratings for palatability traits increases as marbling score increases in A maturity cattle has been well documented in previously published literature (Smith et al., 1987; O'Quinn et al., 2012; Hunt et al., 2014). Additionally, Miller et al. (1983) reported that carcass maturity had no effect on trained panel scores for tenderness and flavor desirability when marbling score was held constant in carcasses from cattle 2 to 5 yr old. However, it would be expected that maturity, regardless of finishing diet, would have an influence on consumer ratings. Stelzleni et al. (2007) compared consumer ratings of unfed beef cows, grain-finished beef cows, and USDA Select beef. In this study, panelists scored grain-finished beef cows greater for tenderness and lesser for the presence of off-flavors than unfed cow beef. However, the observed improvements in palatability were not enough to be similar to consumer scores for USDA Select beef. Furthermore, no differences ($P > 0.05$) in off-flavor intensity were noted in our study by consumers. In terms

Table 7. Least squares means of consumer (n = 120) sensory scores[1] for palatability traits of beef strip steaks from mature beef carcasses commercially identified as fed or unfed and young fed carcasses of varying marbling scores

Treatment	Tenderness	Juiciness	Flavor liking	Overall liking	Off flavor intensity
Slight					
Young Fed	58.91^{a}	57.47^{a}	52.90^{a}	54.29^{a}	11.55
Mature Fed	56.20^{a}	53.50^{a}	53.93^{a}	54.62^{a}	11.29
Mature Unfed	52.93^{a}	62.29^{a}	56.42^{a}	56.27^{a}	11.86
Traces/Practically Devoid					
Young Fed	53.82^{b}	47.55^{b}	51.20^{b}	54.29^{b}	6.48
Mature Fed	46.28^{b}	41.27^{b}	46.74^{b}	46.70^{b}	14.99
Mature Unfed	44.22^{b}	48.24^{b}	45.40^{b}	44.52^{b}	12.38
SEM[2]	3.60	4.02	2.93	2.91	2.55
P-value[3]					
Marbling Score	< 0.01	< 0.01	< 0.01	< 0.01	0.87
Carcass Type	0.10	0.14	0.82	0.25	0.14
Interaction	0.78	0.88	0.24	0.08	0.12

[a,b] Least squares means in the same column without a common superscript differ ($P < 0.05$) because of marbling score.

[1] Sensory scores: 0 = extremely tough, extremely dry, dislike extremely, extremely bland; 100 = extremely tender, extremely juicy, like extremely, extremely intense.

[2] Pooled SE of least squares means.

[3] Observed significance levels for main effects of marbling score, carcass type, and the marbling score × carcass type interaction.

of finishing diet, previous studies have often found grass-finished samples to be less desirable for palatability traits (Hedrick et al., 1983; May et al., 1992; Kerth et al., 2007). However, similar eating experiences can be obtained when grass and grain-fed cattle are finished to similar parameters, such as weight or fat thickness (Muir et al., 1998). The amount of intramuscular fat is known to play a significant role in palatability (O'Quinn et al., 2012; Tatum et al., 1982; Smith et al., 1987), thus, keeping marbling score consistent among cattle types in our study may have eliminated some of the variation that would have been expected among carcass types.

The percentage of samples rated as acceptable by consumers for tenderness, juiciness, flavor liking, and overall liking is presented in Table 8. Consumer acceptance for tenderness and juiciness were influenced ($P \leq 0.03$) by both marbling score and carcass type. Tenderness and juiciness acceptability was greater ($P \leq 0.03$) in steaks with SL marbling. Samples from YF carcasses were rated acceptable for tenderness more often ($P < 0.01$) than both MF and MU carcass groups. Although carcass type did not influence tenderness scores of consumers, steaks from mature carcasses were more frequently below the threshold for consumer acceptance. Consumer acceptance for juiciness was greater ($P = 0.03$) for MU steaks than for MF steaks. Furthermore, YF steaks were similar ($P > 0.05$) to both MF and MU steaks. A marbling score × carcass type interaction was observed for flavor liking and overall liking acceptance scores ($P < 0.05$). Among SL marbling scores, no differences in flavor liking or overall liking acceptability were observed; however, within TR/PD marbling score samples, steaks from YF carcasses were rated more acceptable ($P < 0.05$) than both MF and MU groups.

Although consumer palatability scores only differed due to marbling score, the acceptance of each palatability trait showed either a carcass type effect or an interaction of both main effects. Therefore, while many consumer scores only showed insignificant numerical differences, these differences appear to be large enough to affect acceptability. It is evident that marbling score played a role in the palatability of steaks from mature carcasses. For samples with SL marbling scores, neither consumer scores nor acceptance was affected by carcass type, as all traits were rated similarly. This suggests that at a slight degree of marbling, enough intramuscular fat was present to offset any negative maturity-related palatability problems. However, there was a much greater separation of TR/PD acceptance due to maturity, suggesting that the degree of marbling was not sufficient to offset maturity related palatability differences, regardless of finishing diet.

Table 8. Percentage of samples for tenderness, juiciness, flavor, and overall liking rated as acceptable by consumers (n = 120) of beef strip steaks from mature beef carcasses commercially identified as fed or unfed and young fed carcasses of varying marbling scores

Treatment	Tenderness	Juiciness	Flavor liking	Overall liking
Slight				
Young Fed	79.59^{am}	71.91^{amn}	70.23^{xy}	68.68^{xyz}
Mature Fed	77.09^{an}	69.73^{an}	77.83^{x}	79.40^{x}
Mature Unfed	69.80^{an}	79.21^{am}	73.32^{x}	70.36^{xy}
Traces/Practically Devoid				
Young Fed	75.99^{bm}	57.60^{bmn}	72.75^{x}	76.23^{x}
Mature Fed	58.18^{bn}	44.45^{bn}	59.46^{y}	60.03^{yz}
Mature Unfed	54.67^{bn}	59.29^{bm}	58.40^{y}	57.26^{z}
SEM[1]	0.05	0.05	0.05	0.05
P-value[2]				
Marbling Score	< 0.01	< 0.01	< 0.01	0.03
Carcass Type	< 0.01	0.03	0.48	0.12
Interaction	0.28	0.53	0.04	< 0.01

[a,b]Least squares means in the same column without a common superscript differ ($P < 0.05$) because of marbling score.

[m,n]Least squares means in the same column without a common superscript differ ($P < 0.05$) because of carcass type.

[x-z]Least squares means in the same column without a common superscript differ ($P < 0.05$) because of the marbling score × carcass type interaction.

[1]SEM is the pooled standard error (largest) of least square means.

[2]Observed significance levels for main effects of marbling score, carcass type, and the marbling score × carcass type interaction.

Trained panel palatability scores

Table 9 shows trained panel sensory scores. Initial juiciness of all treatments was similar ($P > 0.05$), regardless of marbling score or carcass type. Scores for sustained juiciness, though, were greater ($P < 0.01$) for samples from SL strip loins. As evidenced by Corbin et al. (2015), juiciness ratings increase as marbling score and percent fat also increase. Panelist ratings for both initial tenderness and sustained tenderness followed similar trends and were influenced ($P < 0.01$) by both marbling score and carcass type. Initial and sustained tenderness were greater ($P < 0.01$) for steaks from SL samples, agreeing with previous literature on the positive correlation between tenderness and fat content (O'Quinn et al., 2012; Garmyn et al., 2014). Additionally, initial and sustained tenderness scores were greatest ($P < 0.01$) for YF samples and least ($P < 0.01$) for MU samples. Unlike consumer ratings, there is a clear separation between each of the 3 carcass types for trained panel tenderness scores. Hilton et al. (1998) demonstrated a decrease in trained panel tenderness ratings as overall beef maturity increased from A to E, without differentiating between finishing diet. Although the link between carcass maturity and tenderness is very evident, many studies

Table 9. Least squares means of trained panel sensory scores[1] for palatability traits of beef strip steaks from mature beef carcasses commercially identified as fed or unfed and young fed carcasses of varying marbling scores

Treatment	Initial juiciness	Sustained juiciness	Initial tenderness	Sustained tenderness	Beef flavor	Beef flavor intensity	Off flavor intensity
Slight							
Young Fed	65.91	63.56^{a}	77.04^{am}	75.27^{am}	75.31^{xy}	68.77^{a}	14.52^{yz}
Mature Fed	68.30	65.38^{a}	67.52^{an}	65.58^{an}	79.38^{x}	73.63^{a}	11.52^{z}
Mature Unfed	69.41	67.41^{a}	58.66^{ao}	53.76^{ao}	76.61^{x}	70.35^{a}	11.74^{z}
Traces/Practically Devoid							
Young Fed	62.81	57.64^{b}	66.45^{bm}	63.03^{bm}	75.72^{xy}	67.20^{b}	8.32^{z}
Mature Fed	62.55	58.98^{b}	61.24^{bn}	58.24^{bn}	70.49^{yz}	64.24^{b}	21.25^{xy}
Mature Unfed	66.36	63.33^{b}	56.01^{bo}	51.76^{bo}	67.92^{z}	61.04^{b}	25.26^{x}
SEM[2]	2.45	3.77	3.03	3.45	2.08	2.22	3.18
P-value[3]							
Marbling Score	0.05	0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.03
Carcass Type	0.34	0.20	< 0.01	< 0.01	0.22	0.27	0.06
Interaction	0.82	0.90	0.34	0.24	0.03	0.09	< 0.01

^{a,b}Least squares means in the same column without a common superscript differ ($P < 0.05$) because of marbling score.

$^{m-o}$Least squares means in the same column without a common superscript differ ($P < 0.05$) because of carcass type.

$^{x-z}$Least squares means in the same column without a common superscript differ ($P < 0.05$) because of the marbling score × carcass type interaction.

[1] Sensory scores: 0 = extremely dry, extremely tough, extremely unbeef-like, extremely bland; 100 = extremely juicy, extremely tender, extremely beef-like, extremely intense.

[2] Pooled SE of least squares means.

[3] Observed significance levels for main effects of marbling score, carcass type, and the marbling score × carcass type interaction.

have found that placing mature cows on a high-energy diet prior to harvest can reverse some of the tenderness loss as a result of maturation (Cranwell et al., 1996; Schnell et al., 1997), as is shown in the trained panel results of our study. Even though grain finishing improved trained tenderness scores between MU and MF steaks, MF steaks were still not rated as tender as YF steaks.

For beef flavor scores, panelists responded differently to carcass type between SL and TR/PD steaks. Among SL steaks, beef flavor was similar ($P > 0.05$) between all carcass types. However, when steaks had TR/PD marbling scores, beef flavor scores were greater ($P = 0.03$) from YF than MU carcasses, while MF carcasses were similar to both treatments. Furthermore, panelists scored SL steaks greater ($P < 0.01$) for beef flavor intensity than TR/PD steaks. Differences in off-flavor intensity were not detected among carcass types of SL samples ($P > 0.05$); however, within TR/PD marbling score groups, YF samples were rated lesser ($P < 0.01$) than MF and MU for off-flavor intensity. It has been previously reported that off-flavors are more frequent in beef from mature and grass-finished carcasses (Hedrick et al., 1983; Hilton et al., 1998). Unlike consumer sensory panel ratings, trained panelists were trained to detect the presence of off-flavors in samples, which is evident in the results of the current study. Again, trained panelists proved to be more discerning of differences in beef palatability. As previously reported (Tatum et al., 1982; O'Quinn et al., 2016), our study showed positive flavor attributes increased as marbling score and fat content increased.

Relationships among volatile compounds and flavor

Correlation coefficients showing relationships between sensory panel ratings and volatile compounds are presented in Table 10. Flavor is a perception of multiple factors (taste, aroma, mouthfeel, etc.) and can be difficult to predict using chemical methods (Dikeman, 1978). Although concentrations of 2,3-butanedione, pentanoic acid, and octanoic acid, methyl ester were influenced by either the marbling score or carcass type main effects, none of these 3 compounds were related ($P > 0.05$) to sensory panel ratings for flavor attributes. From this, it can be inferred that these significant differences did not have large contributions to flavor differences.

Of the n-aldehydes, 2-methylpropanal was the only compound correlated ($P < 0.05$) to trained panel ratings for beef flavor ($r = 0.29$) and beef flavor intensity ($r = 0.34$). Found in greater concentrations in SL samples was 2-methylpropanal, which were the same samples rated higher for flavor attributes by trained panelists, although it was not related to percent fat. Hexanal was weakly correlated ($r = 0.21$; $P < 0.01$) to

Table 10. Pearson correlation coefficients quantifying the relationship between volatile compounds and consumer and trained sensory panel ratings mature beef carcasses commercially identified as fed or unfed and young fed carcasses of varying marbling scores

Compound	% Fat	Consumer overall like	Consumer flavor like	Consumer off-flavor intensity	Trained beef flavor	Trained beef flavor intensity	Trained off-flavor intensity
n-Aldehydes							
2-Methylpropanol	0.17	0.13	0.15	-0.09	0.29*	0.34**	-0.14
Hexanal	0.14	0.21**	0.12	-0.19	0.17	0.13	-0.16
Decanal	-0.18	-0.02	-0.08	-0.22*	0.05	0.08	-0.20*
Strecker Aldehydes							
3-Methylbutanal	0.17	0.13	0.16	-0.13	0.25*	0.29**	-0.14
2-Methylbutanal	0.09	0.21*	0.25*	-0.07	0.28**	0.34**	-0.14
Benzeneacetaldehyde	0.18	0.12	0.14	-0.04	0.20	0.21*	-0.10
Ketones							
Acetoin	0.04	0.15	0.15	-0.11	0.13	0.12	-0.21*
2,3-Butandedione	0.00	0.14	0.12	-0.17	0.18	0.15	-0.18
Thiols							
Methional	0.04	0.03	0.04	-0.01	0.14	0.22**	-0.11
Carboxylic Acids							
Butanoic Acid	0.14	0.21**	0.12	-0.19	0.17	0.13	-0.16
Pentanoic Acid	-0.18	0.13	0.12	-0.03	0.07	0.04	-0.02
Hexanoic Acid	0.15	0.10	0.01	-0.13	0.21*	0.20*	-0.10
Alkanes							
Octane	-0.14	-0.22*	-0.24*	-0.12	0.05	0.07	0.06
Pyrazines							
Methylpyrazine	0.31**	0.24*	0.25*	-0.10	0.38**	0.36**	-0.24*
2,5-Dimethylpyrazine	0.30**	0.26*	0.27**	-0.09	0.39**	0.37**	-0.27**
Trimethylpyrazine	0.29**	0.25*	0.25*	-0.08	0.37**	0.34**	-0.26**
2-Ethyl-3,5-Dimethylpyrazine	0.24*	0.24*	0.24*	-0.05	0.37**	0.34**	-0.24*
Esters							
Octanoic Acid, methyl ester	-0.15	-0.05	-0.04	-0.15	-0.04	-0.02	0.02
Alkene							
2-Methyl-1-Pentene	-0.07	0.04	0.03	-0.13	0.16	0.12	-0.27*

*Correlation coefficient differs from 0 ($P < 0.05$).

**Correlation coefficient differs from 0 ($P < 0.01$).

consumer overall like ratings. Hexanal has been associated with concentrate feeding (Elmore et al., 2004) and "fatty" aromas (Elmore et al., 1999), both which are known to increase consumer palatability ratings. Decanal also contributed ($P < 0.05$) to positive flavor attributes, as it was negatively correlated to both consumer ($r = –0.22$) and trained ($r = –0.20$) off-flavor intensity. Thus, it seems that higher concentrations of decanal helped over power the potency of off-flavors.

Of the Strecker aldehydes, both 3-methylbutanal and 2-methylbutanal were positively related ($P < 0.05$) to trained beef flavor ($r = 0.25$, 3-methylbutanal; $r = 0.28$, 2-methylbutanal) and beef flavor intensity ($r = 0.29$, 3-methylbutanal; $r = 0.34$, 2-methylbutanal). Both 2-methylbutanal and 3-methylbutantl have been previously reported as being positively associated with desirable beef flavor attributes (O'Quinn et al., 2016). Additionally, increases in 2-methylbutanal concentrations in the current study were correlated ($P < 0.05$) with consumer scores for overall liking ($r = 0.21$) and flavor liking ($r = 0.25$). Furthermore, benzeneacetaldehyde was related ($r = 0.21$; $P < 0.05$) to trained beef flavor intensity. Many of the aldehydes (both n-aldehydes and Strecker aldehydes) compared in our study were correlated to positive sensory panel ratings for beef flavor attributes, emphasizing the important role this group of compounds play in flavor development. Aldehydes in general release meaty, tallow-like aromas that contribute positively to flavor perception (Brewer, 2007).

Two of the isolated carboxylic acids, which are related to lipid oxidation (Van Ba et al., 2012), showed weak relationships with sensory panel ratings. Butanoic acid was weakly correlated ($P < 0.01$) to consumer overall liking ($r = 0.21$). Butanoic acid can have a strong, unpleasant odor, however, at lower concentrations it can be desirable (Kerth, 2016). Hexanoic acid was weakly associated ($P < 0.05$) with trained beef flavor ($r = 0.21$) and beef flavor intensity ($r = 0.20$). Stetzer et al. (2008) reported that butanoic acid and hexanoic acid both increased with aging and enhancement of various beef muscles.

Pyrazines were the most consistently correlated group of volatile compounds associated with positive flavor attributes, for both consumer and trained sensory ratings. All 4 pyrazines measured showed the greatest relationships ($P < 0.05$) with trained scores for beef flavor ($0.37 < r < 0.39$) and beef flavor intensity ($0.34 < r < 0.37$). Pyrazines also had some of the strongest correlations ($P < 0.05$) to consumer overall like ($0.24 < r < 0.26$) and flavor like ($0.25 < r < 0.27$). Heterocyclic compounds, including pyrazines, are associated with roasted flavors of meat (Mottram, 1998). More specifically, pyrazines have been described as nutty, cracker-like, bell pepper, burnt, and meaty (Brewer, 2007; Van Ba et al., 2012). Furthermore, pyrazines were the only compounds that were positively related ($0.24 < r < 0.31$; $P < 0.05$) to percent fat. Dashdorj et al. (2015) described the interaction of Maillard reaction and lipid degradation products as one potential route for pyrazine formation during cooking.

Other compounds related ($P < 0.05$) to trained sensory flavor ratings were methional, 3-hydroxy-2-butanone, and 2-methyl-1-pentene. Methional correlated ($r = 0.22$) with trained beef flavor intensity. Whereas, 2-methyl-1-pentene ($r = -0.27$) and 3-hydroxy-2-butanone ($r = -0.21$) were negatively correlated with trained off-flavor intensity ratings. O'Quinn et al. (2016) found acetoin to be one of the compounds most highly correlated ($r = 0.57$) with overall flavor desirability. However, in our study, it seems that the compound played a small role in masking off-flavor. Octane was the only compound that was negatively correlated ($P < 0.05$) to consumer sensory ratings for both overall like ($r = -0.22$) and flavor like ($r = -0.24$), making it the only compound in our study that was negatively related to flavor. Elmore et al. (2004) found concentrations of octane to increase as concentrations of PUFAs increased in muscle lipid of cattle. Additionally, Larick et al. (1987) reported that octane numerically decreased as days on feed increased, further suggesting a relationship between octane and grass finishing. In our study, unfed samples also had greater concentrations of octane, however, this difference was not significant.

Conclusions

Consumer sensory ratings only differed due to marbling score and not due to carcass type; however, carcass type affected consumer acceptance of sensory attributes including overall acceptability. Although sensory ratings were not necessarily significant, it is evident that numerical differences were large enough to break consumer thresholds for acceptability. Grain finishing cull cows improved several objective indicators of tenderness including WBSF. Multiple factors evaluated including sarcomere length, collagen solubility, and pyrazine concentrations showed greater improvement in samples with increased marbling levels, despite differences in carcass type. Overall, these data suggest that there is the potential for the utilization of adequately marbled cull cow beef in the current beef market, while minimally affecting eating quality.

Literature Cited

Allen, J. D., J. K. Ahola, M. Chahine, J. I. Szasz, C. W. Hunt, C. S. Schneider, G. K. Murdoch, and R. A. Hill. 2009. Effect of preslaughter feeding and ractopamine hydrochloride supplementation on growth performance, carcass characteristics, and end product quality in market dairy cows. J. Anim. Sci. 87:2400–2408. doi:10.2527/jas.2008-1630

Amadou, Z., K. C. Raper, J. T. Biermacher, B. Cook, and C. E. Ward. 2014. Net Returns from Feeding Cull Beef Cows: The Influence of Initial Body Condition Score. J Ag. Appl. Econ. 46:139–155. doi:10.1017/S1074070800000687

American Meat Science Association. 2015. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. Version 1.0. Am. Meat Sci. Assoc., Champaign, IL.

Anderson, S. 2007. Determination of fat, moisture, and protein in meat and meat products using the FOSS FoodScan near-infrared spectrophotometer with FOSS Artificial Neural Network Calibration Model and Associated Database: Collaborative Study. J. AOAC Int. 90:1073–1083.

ASTM. 2011. Standard F2925-11: Standard specification for tenderness marketing claims associated with meat cuts derived from beef. ATSM Int., West Conshohocken, PA.

Bailey, A. J. 1985. The Role of Collagen in the Development of Muscle and its Relationship to Eating Quality. J. Anim. Sci. 60:1580–1587. doi:10.2527/jas1985.6061580x

Bergman, I., and R. Loxley. 1963. Two Improved and Simplified Methods for the Spectrophotometric Determination of Hydroxyproline. Anal. Chem. 35:1961–1965. doi:10.1021/ac60205a053

Bowling, R. A., G. C. Smith, Z. L. Carpenter, T. R. Dutson, and W. M. Oliver. 1977. Comparison of Forage-Finished and Grain-Finished Beef Carcasses. J. Anim. Sci. 45:209–215. doi:10.2527/jas1977.452209x

Brewer, S. 2007. The Chemistry of Beef Flavor. National Cattlemen's Beef Association. http://beefresearch.org/CMDocs/BeefResearch/The%20Chemistry%20of%20Beef%20Flavor.pdf. (accessed 26 September 2017).

Calkins, C. R., and J. M. Hodgen. 2007. A fresh look at meat flavor. Meat Sci. 77:63–80. doi:10.1016/j.meatsci.2007.04.016

Cranwell, C. D., J. A. Unruh, J. R. Brethour, and D. D. Simms. 1996. Influence of steroid implants and concentrate feeding on carcass and longissimus muscle sensory and collagen characteristics of cull beef cows. J. Anim. Sci. 74:1777–1783. doi:10.2527/1996.7481777x

Corbin, C. H., T. G. O'Quinn, A. J. Garmyn, J. F. Legako, M. R. Hunt, T. T. N. Dinh, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2015. Sensory evaluation of tender beef strip loin steaks of varying marbling levels and quality treatments. Meat Sci. 100:24–31. doi:10.1016/j.meatsci.2014.09.009

Cross, H. R., Z. L. Carpenter, and G. C. Smith. 1973. Effect of Intramuscular Collagen and Elastin on Bovine Muscle Tenderness. J. Food Sci. 38:998–1003. doi:10.1111/j.1365-2621.1973.tb02133.x

Cross, H. R., R. L. West, and T. R. Dutson. 1981. Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. Meat Sci. 5:261–266. doi:10.1016/0309-1740(81)90016-4

Dashdorj, D., T. Amna, and I. Hwang. 2015. Influence of specific taste-active components on meat flavor as affected by intrinsic and extrinsic factors: An overview. Eur. Food Res. Technol. 241:157–171. doi:10.1007/s00217-015-2449-3

Dikeman, M. E. 1978. Are We Married to Sensory and Shear Tests? American Meat Science Association. http://www.meatscience.org/docs/default-source/publications-resources/rmc/1977/are-we-married-to-sensory-panels-and-shear-tests.pdf?sfvrsn = 2. (Accessed 26 September 2017.).

Duckett, S. K., J. P. S. Neel, R. M. Lewis, J. P. Fontenot, and W. M. Clapham. 2013. Effects of forage species or concentrate finishing on animal performance, carcass and meat quality. J. Anim. Sci. 91:1454–1467. doi:10.2527/jas.2012-5914

Elmore, J. S., D. S. Mottram, M. Enser, and J. D. Wood. 1999. Effect of the polyunsaturated fatty acid composition of beef muscle on the profile of aroma volatiles. J. Agric. Food Chem. 47:1619–1625. doi:10.1021/jf980718m

Elmore, J. S., H. E. Warren, D. S. Mottram, N. D. Scollan, M. Enser, R. I. Richardson, and J. D. Wood. 2004. A comparison of the aroma volatiles and fatty acid compositions of grilled beef muscle from Aberdeen Angus and Holstein-Friesian steers fed diets based on silage or concentrates. Meat Sci. 68:27–33. doi:10.1016/j.meatsci.2004.01.010

Garmyn, A. J., J. C. Brooks, J. M. Hodgen, W. T. Nichols, J. P. Hutcheson, R. J. Rathmann, and M. F. Miller. 2014. Comparative effects of supplementing beef steers with zilpaterol hydrochloride, ractopamine hydrochloride, or no beta agonist on strip loin composition, raw and cooked color properties, shear force, and consumer assessment of steaks aged for fourteen or twenty-one days postmortem. J. Anim. Sci. 92:3670–3684. doi:10.2527/jas.2014-7840

Hedrick, H. B., J. A. Paterson, A. G. Matches, J. D. Thomas, R. E. Morrow, W. C. Stringer, and R. J. Lipsey. 1983. Carcass and Palatability Produced on Pasture, Corn Silage and Corn Grain. J. Anim. Sci. 54(4):791–801.

Hill, F. 1966. The solubility of intramuscular collagen in meat animals of various ages. J. Food Sci. 31:161–166. doi:10.1111/j.1365-2621.1966.tb00472.x

Hilton, G. G., J. D. Tatum, S. E. Williams, K. E. Belk, F. L. Williams, J. W. Wise, and G. C. Smith. 1998. An Evaluation of Current and Alternative Systems for Quality Grading Carcasses of Mature Slaughter Cows. J. Anim. Sci. 76:2094–2103. doi:10.2527/1998.7682094x

Hunt, M. R., A. J. Garmyn, T. G. O'Quinn, C. H. Corbin, J. F. Legako, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2014. Consumer assessment of beef palatability from four beef muscles from USDA Choice and Select graded carcasses. Meat Sci. 98:1–8. doi:10.1016/j.meatsci.2014.04.004

Hwang, I. H., C. E. Devine, and D. L. Hopkins. 2003. The biochemical and physical effects of electrical stimulation on beef and sheep meat tenderness. Meat Sci. 65:677–691. doi:10.1016/S0309-1740(02)00271-1

Kerth, C. 2016. Determination of volatile aroma compounds in beef using differences in steak thickness and cook surface temperature. Meat Sci. 117:27–35. doi:10.1016/j.meatsci.2016.02.026

Kerth, C. R., K. W. Braden, R. Cox, L. K. Kerth, and D. L. Rankins. 2007. Carcass, sensory, fat color, and consumer acceptance characteristics of Angus-cross steers finished on ryegrass (Lolium multiflorum) forage or on a high-concentrate diet. Meat Sci. 75:324–331. doi:10.1016/j.meatsci.2006.07.019

Larick, D. K., H. B. Hedrick, M. E. Bailey, J. E. William, D. L. Hancock, G. B. Garner, and R. E. Morrow. 1987. Flavor constituents as influenced by forage- and grain feeding. J. Food Sci. 52:245–251. doi:10.1111/j.1365-2621.1987.tb06585.x

Lepetit, J. 2007. A theoretical approach of the relationships between collagen content, collagen cross-links and meat tenderness. Meat Sci. 76:147–159. doi:10.1016/j.meatsci.2006.10.027

Liebich, H. M., D. R. Douglas, A. Zlatkis, F. Mueggler-Chavan, and A. Donzel. 1972. Volatile components in roast beef. J. Agric. Food Chem. 20:96–99. doi:10.1021/jf60179a009

Little, R. D., A. R. Williams, R. C. Lacy, and C. S. Forrest. 2002. Cull cow management and its implications for cow-calf profitability. J. Range Manage. 55:112–116. doi:10.2307/4003345

Lucherk, L. W., T. G. O'Quinn, J. F. Legako, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2016. Consumer and trained panel evaluation of beef strip steaks of varying marbling and enhancement levels cooked to three degrees of doneness. Meat Sci. 122:145–154. doi:10.1016/j.meatsci.2016.08.005

Machiels, D., L. Istasse, and S. M. Van Ruth. 2004. Gas chromatography-olfactometry analysis of beef meat originating from differently fed Belgian Blue, Limousin and Aberdeen Angus bulls. Food Chem. 86:377–383. doi:10.1016/j.foodchem.2003.09.011

May, S. G., H. G. Dolezal, D. R. Gill, F. K. Ray, and D. S. Buchanan. 1992. Effect of days fed, carcass grade traits, and subcutaneous fat removal on postmortem muscle characteristics and beef palatability. J. Anim. Sci. 70:444–453. doi:10.2527/1992.702444x

McCormick, R. J. 1994. The flexibility of the collagen compartment of muscle. Meat Sci. 36:79–91. doi:10.1016/0309-1740(94)90035-3

Melton, S. L. 1990. Effects of feeds on flavor of red meat: A review. J. Anim. Sci. 68:4421–4435. doi:10.2527/1990.68124421x

Miller, M. F., H. R. Cross, J. D. Crouse, and T. G. Jenkins. 1987. Effect of feed energy intake on collagen characteristics and muscle quality of mature cows. Meat Sci. 21:287–294. doi:10.1016/0309-1740(87)90065-9

Miller, R. K., J. D. Tatum, H. R. Cross, R. A. Bowling, and R. P. Clayton. 1983. Effects of Carcass Maturity on Collagen Solubility and Palatability of Beef from Grain-Finished Steers. J. Food Sci. 48:484–486. doi:10.1111/j.1365-2621.1983.tb10772.x

Minchin, W., F. Buckley, D. A. Kenny, F. J. Monahan, L. Shalloo, and M. O'Donovan. 2009. Effect of grass silage and concentrate based finishing strategies on cull dairy cow performance, carcass and meat quality characteristics. Meat Sci. 81:93–101. doi:10.1016/j.meatsci.2008.07.001

Mottram, D. S. 1985. The Effect of Cooking Conditions on the Formation of Volatile Heterocyclic Compounds in Pork. J. Sci. Food Agric. 36:377–382. doi:10.1002/jsfa.2740360510

Mottram, D. S. 1998. Flavour formation in meat and meat products: A review. Food Chem. 62:415–424. doi:10.1016/S0308-8146(98)00076-4

Muir, P. D., J. M. Deaker, and M. D. Bown. 1998. Effects of forage- and grain-based feeding systems on beef quality: A review. N. Z. J. Agric. Res. 41:623–635. doi:10.1080/00288233.1998.9513346

Neill, S., J. A. Unruh, T. T. Marston, J. R. Jaeger, M. C. Hunt, and J. J. Higginst. 2009. Effects of implanting and feeding zilpaterol hydrochloride on performance, carcass characteristics, and subprimal beef yields of fed cows. J. Anim. Sci. 87:704–710. doi:10.2527/jas.2008-1254

O'Quinn, T. G., J. C. Brooks, R. J. Polkinghorne, A. J. Garmyn, B. J. Johnson, J. D. Starkey, R. J. Rathmann, and M. F. Miller. 2012. Consumer assessment of beef strip loin steaks of varying fat levels. J. Anim. Sci. 90:626–634. doi:10.2527/jas.2011-4282

O'Quinn, T. G., D. R. Woerner, T. E. Engle, P. L. Chapman, J. F. Legako, J. C. Brooks, K. E. Belk, and J. D. Tatum. 2016. Identifying consumer preferences for specific beef flavor characteristics in relation to cattle production and postmortem processing parameters. Meat Sci. 112:90–102. doi:10.1016/j.meatsci.2015.11.001

Purslow, P. P. 2005. Intramuscular connective tissue and its role in meat quality. Meat Sci. 70:435–447. doi:10.1016/j.meatsci.2004.06.028

Realini, C. E., S. K. Duckett, G. W. Brito, M. Dalla Rizza, and D. De Mattos. 2004. Effect of pasture vs. concentrate feeding with or without antioxidants on carcass characteristics, fatty acid composition, and quality of Uruguayan beef. Meat Sci. 66:567–577. doi:10.1016/S0309-1740(03)00160-8

Resconi, V. C., M. del Mar Campo, F. Montossi, V. Ferreira, C. Sañudo, and A. Escudero. 2012. Gas Chromatographic-Olfactometric Aroma Profile and Quantitative Analysis of Volatile Carbonyls of Grilled Beef from Different Finishing Feed Systems. J. Food Sci. 77(6):S240–S246.

Resconi, V. C., A. Escudero, and M. M. Campo. 2013. The development of aromas in ruminant meat. Molecules 18:6748–6781. doi:10.3390/molecules18066748

Rucklidge, G. J., G. Milne, B. A. McGaw, E. Milne, and S. P. Robins. 1992. Turnover rates of different collagen types measured by isotope ratio mass spectrometry. BBA- Gen Subjects. 1156:57–61. doi:10.1016/0304-4165(92)90095-C

Savell, J. W., S. L. Mueller, and B. E. Baird. 2005. The chilling of carcasses. Meat Sci. 70:449–459. doi:10.1016/j.meatsci.2004.06.027

Schnell, T. D., K. E. Belk, J. D. Tatum, R. K. Miller, and G. C. Smith. 1997. Performance, carcass, and palatability traits for cull cows fed high-energy concentrate diets for 0, 14, 28, 42 or 56 days. J. Anim. Sci. 75:1195–1202. doi:10.2527/1997.7551195x

Smith, G. C., J. W. Savell, H. R. Cross, Z. L. Carpenter, C. E. Murphey, G. W. Davis, H. C. Abraham, F. C. Parrish, and B. W. Berry. 1987. Relationship of USDA Quality Grades to Palatability of Cooked Beef. J. Food Qual. 10:269–286.

Specht, K., and W. Baltes. 1994. Identification of Volatile Flavor Compounds with High Aroma Values from Shallow-Fried Beef. J. Agric. Food Chem. 42:2246–2253.

Stelzleni, A. M., L. E. Patten, D. D. Johnson, C. R. Calkins, and B. L. Gwartney. 2007. Benchmarking carcass characteristics and muscles from commercially identified beef and dairy cull cow carcasses for Warner-Bratzler shear force and sensory attributes. J. Anim. Sci. 85:2631–2638.

Stetzer, A. J., K. Cadwallader, T. K. Singh, F. K. McKeith, and M. S. Brewer. 2008. Effect of enhancement and ageing on flavor and volatile compounds in various beef muscles. Meat Sci. 79:13–19. doi:10.1016/j.meatsci.2007.07.025

Tatum, J. D., G. C. Smith, and Z. L. Carpenter. 1982. Interrelationships Between Marbling, Subcutaneous Fat Thickness and Cooked Beef Palatability. J. Anim. Sci. 54:777–784. doi:10.2527/jas1982.544777x

USDA National Agriculture Statistics Service. 2017. Livestock Slaughter 2016 Summary. National Agriculture Statistics Service. Washington, DC

Van Ba, H., I. Hwang, D. Jeong, and A. Touseef. 2012. Principle of Meat Aroma Flavors and Future Prospect. In: Latest Research into Quality Control. p. 145–176. doi:10.5772/51110

van Boekel, M. A. J. S. 2006. Formation of flavour compounds in the Maillard reaction. Biotechnol. Adv. 24:230–233. doi:10.1016/j.biotechadv.2005.11.004

Woerner, D. R. 2010. Beef from Market Cows. National Cattlemen's Beef Assocation. http://www.beefissuesquarterly.com/CMDocs/BeefResearch/PE_White_%20Papers/Beef_from_Market_Cows.pdf. (accessed 26 September 2017).