Meat and Muscle Biology™

Hot Carcass Fabrication Intervention for Managing Top Round Quality in Heavy Weight Beef Carcasses

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Abstract: Chilling-related meat quality issues have been observed in the deep portion of the top round due to the increase of average beef carcass size. The current study examines the impact of an alternative fabrication method aimed at alleviating top round quality in heavy weight beef carcasses ($n = 11$; 510 kg average weight). Prior to rigor, the knuckle subprimal was partially fabricated to expose the femur on alternating sides of each carcass (TRT), and each adjacent intact side served as a control (CON). All sides were air chilled (2°C) for 48 h before further fabricating. Temperature loggers placed at approximately 2.54 cm below the top round surface was the superficial (SP) location while loggers for the deep (DP) location were inserted at the midline sagittal center of the round until in contact with the femur bone. Temperature and pH decline were monitored for 48 h. The top rounds were collected, aged under vacuum packaging until 14 d postmortem, and then cut into steaks (2.54 cm). Each steak was separated into SP and DP portions and subjected to Warner-Bratzler shear force (WBSF), consumer sensory panel, and a 3-d retail display analysis which included lipid oxidation and objective color evaluation. The TRT accelerated the rate of temperature decline at the DP location ($P < 0.001$) and increased the pH decline rate at the SP location ($P = 0.029$). Retail day and location were more impactful than TRT on objective color traits. SP steaks were more tender ($P = 0.001$) than DP steaks. Consumer taste panel indicated TRT improved overall acceptability ($P = 0.042$) and flavor ($P = 0.035$) of top round steaks regardless of locations. TRT accelerated top round DP chilling rate and elevated steak palatability attributes. Findings of the present study report an improvement of top round steaks due to the innovative fabrication treatment.

Keywords: beef, carcass size, top round, knuckle, alternative fabrication
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Introduction

Cattle size in the United States has been on an upward trend owing to increased production efficiency such as improved genetics, nutrition, and other managerial efforts (Capper, 2011; Lusk, 2013). There has been a 10% increase in average cattle dressed weight since 2000 (USDA ERS, n.d.). As beef carcasses continue to increase in size, the additional weight has been observed to cause issues during initial carcass chilling and has resulted in abnormalities regarding pH, temperature, and color (Lancaster et al., 2020). Variations in size and location among muscle groups can cause corresponding variations in chilling effect and chilling times. The beef round is a large primal that accounts for 22% of carcass weight (Campbell, n.d.). Within the round, the top round alone can account for roughly 6% of the entire carcass weight depending on the management system (Kellermeier et al., 2009). Delayed temperature decline in the deep portion of the top round has been observed compared to the superficial location of the top round muscle (Follett et al., 1974; Lancaster et al., 2020). Rapid pH drop accompanied by delayed temperature decline can lead to temperature-induced protein denaturation, creating ideal conditions for discoloration to occur (Seyfert et al., 2004; Kim et al., 2010) which leads to undesirable market outcomes.

Meat color is the first quality attribute that consumers observe and is often associated with "freshness" especially in fresh meat products (Troy & Kerry, 2010). Unfortunately, the color defect of "two toning" has commonly been observed in the top round. Prior research found that 2.55% of beef is discarded solely due to discoloration, which equates to 780,000 animals as well as their associated production resources cost being wasted, resulting in $3.73 billion annual monetary loss to the US beef industry (Ramanathan et al., 2022). The USDA reported that a total of 34.3 million head of commercial cattle were slaughtered in 2022 (USDA National Agricultural Statistics Service, 2023). With average cattle dressed weight around 408 kg (900 lb) (NW_LS410, July 2023), average top round steaks ranging from $4.99 to $9.99 per pound according to the August 2023 USDA National Retail Report - Beef (Northwest), and top round making up an average of 6% of the carcass weight, it is estimated that addressing top round discoloration alone could potentially save the US beef industry $19 million annually. Monetary value aside, preventing product loss would also improve industry sustainability and efficiency. The objective of this study is to assess the impact of an alternative fabrication method of the hot beef carcass round on pH and temperature decline, color, and tenderness of cuts from the top round and the knuckle, focusing on heavy weight beef carcasses. It is hypothesized that by performing the alternative fabrication method on the kill floor, more rapid chilling rate would be observed in the deep portion of the top round, thus alleviating temperature-induced meat quality issues.

Materials and Methods

Animal procurement

This project was reviewed and approved by the University of Idaho Institutional Animal Care and Use Committee (IACUC-2022-44). Eleven heavy weight *Bos taurus* steers with average live weights between 771 kg and 816 kg were randomly selected and obtained from a commercial beef finishing operation (Parma, ID). All steers were transported (460 km) to the University of Idaho Meat Laboratory (Moscow, ID).

Harvest & alternative fabrication

All steers were harvested at the Vandal Brand Meats USDA inspected facility at the University of Idaho (Moscow, ID). A captive bolt was used to render each steer unconscious prior to exsanguination during the slaughtering process. Hot carcass weight was measured post evisceration and carcass splitting. Carcasses were then washed, inspected, and sprayed with lactic acid (2% dilution of Birko Lactic Acid 88% F.G. L1905130328).

After lactic acid spray and prior to carcasses entering the hot carcass chiller (2°C), the alternative fabrication method (TRT) was performed. One side of each carcass had the knuckle subprimal peeled down, beginning from the patella, partially exposing the femur bone while the other side remained intact (CON). The knuckle subprimal was separated from the top round and the bottom round seams, loosened from the femur bone, but remained attached to the bottom sirloin. TRT was performed on alternating sides between carcasses to account for side-to-side variations.

Temperature and pH decline during initial chilling

Immediately following fabrication of the knuckle, temperature logger probes (Multistrip plastic handle probe logger, Temprecord International Limited, Auckland, New Zealand) were inserted into the top round at the deep (DP) and superficial (SP) locations on each side of the carcass. The probes for DP were inserted at the approximate midline sagittal center of the top round. Probes for the SP location were inserted approximately 2.54 cm below the surface of the top round. Temperature decline during initial chilling was recorded every 30 s for 48 h. Probes were intermittently removed for a few seconds to conduct pH measurements at the same location as the temperature recordings.

The pH for the initial chilling process was recorded at the DP and SP location every hour postmortem for the first 12 h and then every 6 h until h 48. A portable pH meter (APERA Instruments, Columbus, Ohio) equipped with a puncture-type probe plus blade was used. The probe was calibrated following a three-point calibration using the pH calibration Buffer Solution Kit with buffer solutions at pH 4.00, 7.00 and 10.01 (APERA Instruments, Columbus, Ohio). The pH probe was rinsed with deionized water and patted dry with Kimwipes (Kimtech, Roswell, GA) before each measurement. The probe was kept in 3M KCL soaking solution (APERA Instruments, Columbus, Ohio) when not in use. The same location was used throughout the measurement.

Carcass fabrication and steak preparation

At 48 h postmortem, both sides of each carcass were ribbed at the 12th–13th rib interface. Ultimate pH at the ribbed surface of the *longissimus thoracis* was measured with the same pH meter and probe used during chilling. Carcass characteristics such as marbling, backfat, ribeye area and kidney, pelvic, and heart fat (%) were recorded.

Primals and subprimals were fabricated from both sides of each carcass to obtain the top rounds and knuckles. The top rounds were denuded with the cap and side muscles removed (NAMI #169A). The knuckles were further fabricated to obtain rectus femoris (RF; NAMI #167E Sirloin Tip Center Roast) and vastus lateralis (VL; NAMI #167F Sirloin Tip Side Roast). Top rounds, RF and VL muscles were placed in vacuum sealed bags and aged until 14 d postmortem at 2°C.

Upon completion of aging, top rounds were cut proximal to distal and perpendicular to the muscle fibers into six 2.54 cm thick steaks. Each top round steak was then separated into "deep" and "superficial" portions 5.08 cm from the superficial edge before assigned to subsequent analyses. Labels for analyses were sequentially rotated based on steak cut order to account for location variations within each subprimal. This was done to ensure each analysis consisted of steaks from different locations within the top round. One 2.54 cm thick steak was cut from each RF and VL and were evaluated for objective color and ultimate pH, then packaged and frozen (−20°C) for WBSF analysis. Due to the size of the RF and VL subprimals, only one steak was obtained to examine the instrumental tenderness.

Six top round steaks (each separated into DP and SP portions) from each carcass side were evenly assigned to each of the following analyses in duplicate: 3-d shelf-life, Warner-Bratzler shear force (WBSF), and consumer taste panel. Shelf-life analyses included pH, lipid oxidation, and objective color evaluations at various stages of retail display. Objective color measurements were evaluated daily from d 0 to d 3. The pH and lipid oxidation measurements were examined on the first and last day (d 0 and d 3) of the shelf-life assessment. Steaks used for WBSF and consumer sensory panel were stored individually in vacuum packaging at −20°C until the respective analyses were performed.

Shelf-life—Retail color evaluation

Steaks subjected to the shelf-life experiment were placed in white Styrofoam meat trays (CKF Inc. #88134, Langley, BC, Canada) overwrapped with oxygen permeable polyvinyl chloride film (oxygen transmission: 1450 cc/645 cm^2 per 24 h, water vapor transmission rate: 17.0 g/645 cm^2 per 24 h, Koch Industries, Inc. #7500-3815, Wichita, KS) and laid under display lighting to simulate a retail environment. The steaks were put on stainless steel mobile shelves (H-9490, Uline, Pleasant Prairie, WI) under continuous 53 W 4,000 Lumen natural white lighting (Stonepoint 4000 Lumen Linkable LED Shop Light #SL4A-4000L, Stonepoint LED Lighting, Denver, CO). Steaks were displayed at 2°C and were rotated after each retail day among rows and columns to account for lighting variations in the display room. Two separated top round steaks (1 SP steak and 1 DP steak) from each side were used for objective color evaluation. Objective color (L^*, a^* and b^*) was measured each day with a Nix Pro2 Color Sensor with Illuminant A and Observer 10° (Nix Sensor LTD, Hamilton, Ontario, Canada). Two locations on each steak were scanned for objective color through the duration of the 3-d shelf-life experiment (d 0, 1, 2 and 3).

Shelf-life—Lipid oxidation

Lipid oxidation was measured using the thiobarbituric acid reactive substances (TBARS) assay. Assays were conducted on d 0 and d 3 of the retail display. TBARS protocol was outlined in AMSA Meat Color Measurement Guideline O. TBARS for Oxidative Rancidity–Rapid, Wet Method (King et al., 2023) with slight modification. One SP and one DP top round steak from each side were displayed alongside the color steaks. Samples from each steak were taken from the top half of the steak avoiding any edges as described in Colle et al. (2016). TBARS samples on d 0 were collected prior to the steak being packaged for retail display. The same procedures were performed on d 3 upon completion of the shelf-life experiment.

Shelf-life—Steak pH

Steak pH was measured on the first and last day of simulated retail display, d 0 and d 3, respectively. On d 0, steak pH was measured with a portable pH meter (APERA Instruments, Columbus, Ohio) prior to the overwrap packaging being applied as outlined in the *Shelf-life–Retail color evaluation* section for retail display. The same measuring process was conducted to obtain steak pH on d 3.

Warner-Bratzler shear force

Steaks used for WBSF were allowed to thaw at 2°C for 24 h prior to analysis. WBSF was performed on 2 consecutive days; each treatment and muscle were equally represented on both days. Top round steaks (1 SP and 1 DP), 1 RF and 1 VL steak from each side were analyzed. Individual steak weights were recorded before cooking (initial weight) and the steaks were weighed again when cooled to room temperature after cooking (cooked weight) to calculate cook loss (%). Cook loss was calculated as a percentage using the equation:

$$cook\ loss\,\% = \frac{(initial\ weight - cooked\ weight)}{initial\ weight}\, x\, 100\%.$$

The steaks were cooked using a clamshell-style electric grill (Cuisinart Griddler Deluxe Model GR-150) to an internal targeted temperature of 71°C. Temperature was monitored using a Type K thermocouple (Copper-Atkins 93230-K EconoTemp) and the peak internal temperature of each steak was recorded and analyzed as a covariate.

Steaks were allowed to passively cool to room temperature prior to coring. Six cores (1.27 cm diameter) were obtained from each steak parallel to the muscle fibers. A WBSF machine (G-R Manufacturing, Manhattan, KS) was used to shear each core once perpendicular to the muscle fibers to obtain a peak shear force value. Average peak shear force value calculated from the 6 cores was used to represent the tenderness measurement of each steak.

Consumer taste panels

Consumer sensory evaluation was conducted upon approval from the University of Idaho Institutional Review Board (IRB Protocol No. 22-158). A total of 90 panelists were recruited for the sensory panel. Superficial and deep top round steaks were cooked using the same grilling method outlined in the WBSF section. Clear sample cups with lids (20 oz clear plastic mini-cups, Great Value, Bentonville, AR) were prelabeled with random, non-repeating, 3-digit codes assigned to each location and treatment combinations. Samples were cut to 1.27 cm x 1.27 cm x cooked steak thickness cubes then placed into corresponding prelabeled cups in a warmer until served to panelists. Each panelist received 4 samples in individual cups, each with a unique 3-digit code. Muscle locations and fabrication methods of steaks were not revealed to panelists. Panelists were given verbal instructions on the process of the panel. Following the AMSA Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurement of Meat (AMSA, 2016), each panelist received a panel questionnaire with a demographics survey at the front, a plate with 4 samples, toothpicks, napkin, expectorant cup, bottled room temperature water and unsalted saltine crackers (Great Value, Bentonville, AR). A university food laboratory with a commercial kitchen set up was used for the consumer taste panel. The room was well-lit with natural light and had sufficient seating and table space. The kitchen hoods aided in removing cooking orders to minimize potential influence on panelists.

A unique ID of each sample was required as the first question on the questionnaire so the samples could be matched back to their respective treatments. Panelists were asked to rate steak characteristics including “overall acceptability,” “tenderness,” “juiciness,” and “flavor” on a 1 to 10 scale based on their preference with 1 being “dislike extremely” and 10 being “like extremely.” Participants were also asked if they detected any “off-flavor” (yes or no), as well as if they were satisfied with the sample (yes or no). To finish the questionnaire for each sample, panelists were asked to, if applicable, indicate their most and least liked trait about the sample. Traits included flavor, tenderness, juiciness, and texture/mouth feel. Space for overall commentary on each sample was provided on the questionnaire if panelists decided to leave any additional remarks.

Statistical analysis

The study used a complete randomized block design with individual carcass as blocks. Subsamples (sides) of each steer carcass were subjected to traditional and alternative fabrication methods. Data were acquired from deep and superficial locations of the top round, resulting in a 2-by-2 factorial with 2 levels of fabrication methods and 2 levels of muscle locations. Thus, each carcass is a replicate of all treatments.

Temperature preprocessing

The starting point to each curve was set as the highest observed temperature, and the final time point was measurements taken exactly 48 h after the starting point. Missing temperature data due to removal of and replacement of temperature probes for pH measurements occurred for all samples. Although precision was attempted, in some rare instances, the temperature probe was reinserted into a slightly different part of the muscle than the previous placement. Temperature data were inspected manually, and in most cases, smooth declining curves were observed for each sample. Mis-inserted probes resulting in erroneous data were identified by any increase in temperature during the decline period or large, out-of-pattern temperature decreases, both after removal and reinsertion of the probe. Those temperature samples with mis-inserted probes were removed in whole from the temperature analysis. Other missing data were imputed by fitting LOESS curves to each sample's temperature decay curve (span = 0.1) and imputing the LOESS prediction.

Nonlinear modelling of temperature and pH

A nonlinear exponential decay model was used for temperature and pH decline data during initial chilling:

$$y(t) = y_{Asym} + (y_{Initial} - y_{Asym})e^{(k1*TRT+k2*CON+u_i)t}$$

where:

y(t) = temperatures or pH at time t

t = time (seconds for temperature, hours for pH)

y_{Asym} = *lower asymptote,final temperature or pH where the curve was approaching*

$y_{Initial}$ = *initial sample temperature or pH*

e = Euler's constant

k = rate of decay ($k1$ = *TRT fabrication*;$k2$ = *CON fabrication*)

u_i = *rate of decay adjustment for each animal*

TRT and *CON* are indicator variables for the alternative (TRT) and traditional (CON) fabrication methods, respectively.

The model describes an exponential decline (k is negative) over time starting at $y_{Initial}$ and gradually flattens out at y_{Asym}. Smaller absolute values of k denotes slower rate of decay, whereas larger absolute values of k indicates more rapid temperature or pH decline. The parameters *k1* and *k2* were compared using a post hoc F-test.

Meat quality and consumer sensory panel variables

Distributions of all dependent variables were examined with histograms to identify outliers, errors, and assess appropriate distributions for downstream analysis. Analysis of variance using a linear mixed model with muscle location (SP and DP), fabrication method (CON and TRT) and their interaction as fixed effects, and animal as a random effect was conducted for the variables lipid oxidation, pH, WBSF, and all consumer taste panel variables. Peak internal temperature was also used as a covariate for WBSF in addition to the parameters mentioned.

The retail color variables were analyzed with a linear mixed model with muscle location, fabrication effect, retail day and all interactions between them as fixed effect and animal and sample as a random effect (where sample is nested in animal). To account for repeated measures of the samples over the retail days, an AR1 correlation structure was included for objective color variables, using a starting value of 0.25 for *rho*. The error terms of linear models were assumed to be independently and identically distributed. Distributions of residuals were examined for each model for evaluating model assumptions.

All data were analyzed with R Statistical Software (v4.3.1; R Core Team 2023) using the {nlme} package (Pinheiro and Bates, 2000; Pinheiro and Bates, 2023) for linear and nonlinear modelling and {emmeans} (Lenth, 2023) for estimating the marginal means for fixed effects from linear models and conducting post hoc comparisons. Tukey's adjustment was used for multiple comparison testing. *P* values less than 0.05 were the threshold used to declare statistical significance.

Results and Discussion

Temperature and pH decline during initial chilling

The 11 steers in this study yielded an average hot carcass weight of 510 kg. Observations for carcass traits are reported in Table 1. Temperature data were collected from 10 steers due to thermometer equipment failure on one of the carcasses. The initial starting temperature for DP was higher than SP (Figure 1), which was expected due to the physical characteristics of the

Table 1. Carcass trait means of steers ($N = 11$)

Carcass	Min	Max	Mean	SD
Hot carcass weight, kg	463.1	547.5	510.1	26.3
12th rib fat thickness, cm	0.5	2.8	1.9	0.7
Ribeye area, cm^2	77.4	112.3	95.0	10.5
Kidney, pelvic, and heart fat, %	1.5	2.5	1.8	0.3
Calculated yield grade	1.61	5.57	4.30	1.15
Marbling score[1]	430.0	780.0	565.5	100.5

[1]Marbling score; $Small^{00} = 400$; $Modest^{00} = 500$; $Moderate^{00} = 600$; Slightly $Abundant^{00} = 700$.

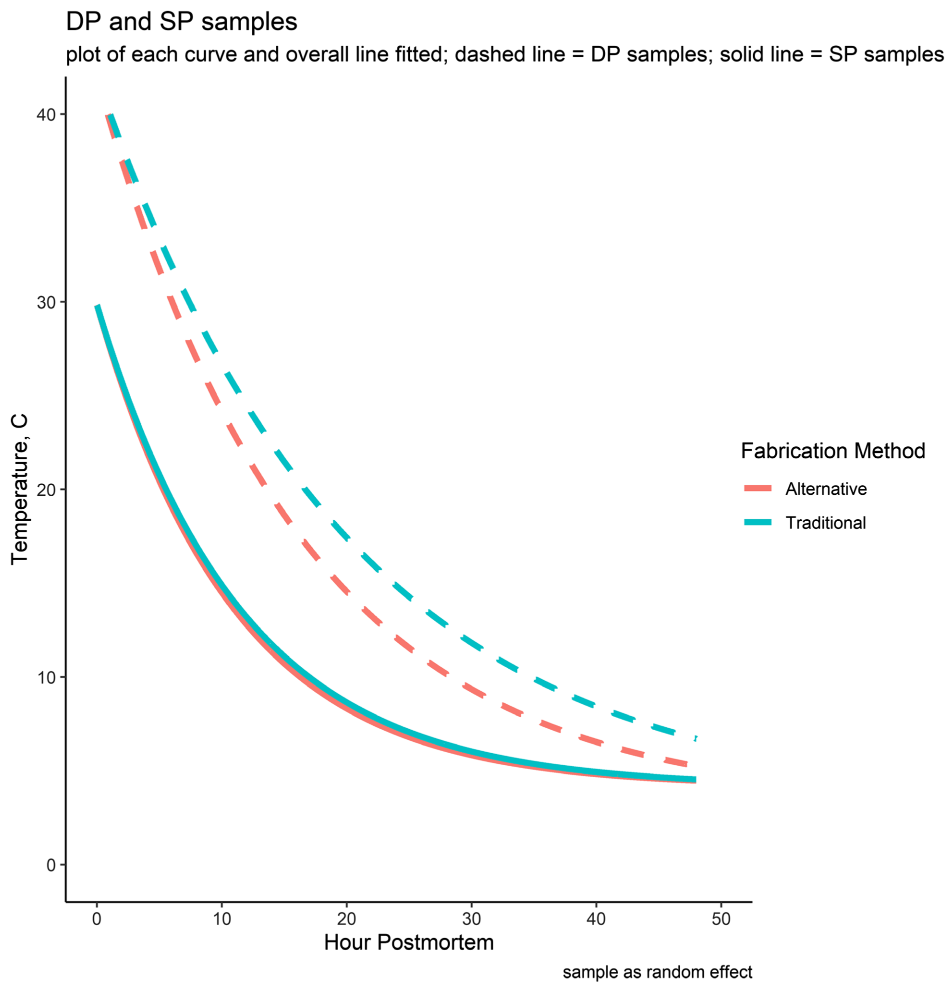

Figure 1. Estimated model of temperature (°C) decline of top round subprimals over 48 h initial chilling period of the deep and superficial locations using traditional and alternative hot carcass round fabrication methods. Plotted results of the deep (DP) and superficial (SP) locations were estimated separately.

locations and the distinct chilling behavior for DP and SP (Lancaster et al., 2020). During the initial 48-h chilling process, TRT had a more rapid rate of temperature decline than CON ($P < 0.001$) at the DP location (Figure 1). The current temperature rate decline observations are in agreement with a prior study which focused on hot-boning the knuckle prior to chilling (Seyfert et al., 2004). The rate of temperature decline for TRT and CON were not different at the SP location ($P = 0.618$). No differences in the rate of temperature decline between treatments at the SP location were expected because partially exposing the femur bone should not impact the chilling behavior in the SP portion. The curve of estimated rate of temperature change for the SP location showed similar behavior to what was reported in previous literature (Lancaster et al., 2020). It was postulated that accelerated chilling at the DP location is likely attributed to the increased surface area created by peeling down the knuckle.

Peeling down the knuckle resulted in accelerated pH decline at the SP location ($P = 0.029$; Figure 2). These results were unexpected as the researchers predicted no differences due to the location of the sample measurement in question. It was postulated that a difference in the rate of pH decline would have been seen in the DP locations due to the differences in temperature at that location during chilling. Temperature decline during hot carcass chilling affects pH decline due to its impacts on rates of glycolysis (Kim et al., 2014). Although differences in pH decline were observed at the SP location, the ultimate pH of the SP location was within what would be considered a normal range (pH 5.4–5.7). Furthermore, differences in the rate of pH decline at the SP location are so slight that they were unlikely to cause any additional interest or concern. No differences in pH decline at the DP location ($P = 0.360$) were observed between the fabrication method treatments (Figure 2). Similar findings were

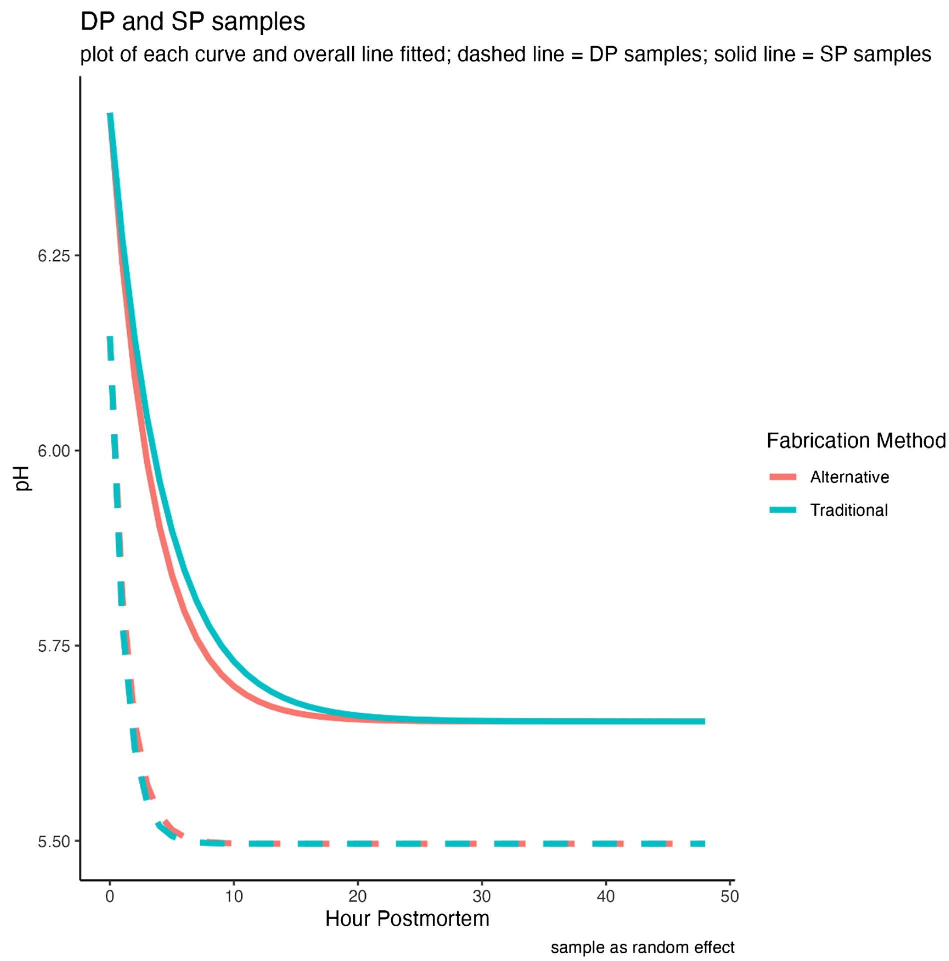

Figure 2. Estimated model of pH decline of top round subprimals over 48 h initial chilling period of the deep and superficial locations using traditional and alternative hot carcass round fabrication methods. Plotted results of the deep and superficial locations were estimated separately.

also indicated by prior research that the accelerated chilling rate was not sufficient to delay pH decline (Seyfert et al., 2004). Overall, DP had more rapid pH decline than SP (Figure 2), similar to results found in a prior study (Lancaster et al., 2020). At 48 h, DP and SP reached an ultimate mean pH of 5.55 and 5.58 respectively, and no differences in final pH were observed between fabrication method treatments (Figure 2). At 48 h postmortem, no significant differences in the ultimate pH measured at the 12^{th}–13^{th} rib interface in the *longissimus thoracis* were observed ($P = 0.806$). Ultimate pH at the 12^{th} and 13^{th} rib interface of the *longissimus thoracis* was observed to be within the normal range of 5.4 to 5.7 (Page et al., 2001) for both CON and TRT sides (mean aggregate ultimate pH = 5.54).

Shelf-life—Retail color evaluation

A retail day x location interaction was discovered for *a** ($P = 0.039$, Table 2). Analysis indicated no significant differences for mean *a** values between DP and SP steaks on each simulated retail day (Figure 3). For DP steaks, significant retail day effect was observed on each day. However, for the SP steaks, retail day effect was significant for d 0, 1, and 2 but diminished on d 3. Overall, both DP and SP steaks showed a decreasing mean *a** value over time, which suggested the steaks were progressively less red. Observed differences could be due to the decrease in the amount of oxymyoglobin present as retail time increased where similar trend was observed in Seyfert et al. (2004). No significant location ($P = 0.574$) or treatment ($P = 0.354$) effects were observed (Table 2) for *a**.

Retail display time impacted *L** ($P < 0.001$, Table 2). The current findings align with past color change observations which occur over time (Daniel et al., 2009). Regardless of location and fabrication method, top round steaks were the lightest on d 0 and no significant retail day effect was observed among d 1, 2, and 3 regarding mean *L** values. Fabrication

Table 2. Mean objective color values of simulated retail day, location, and treatment during retail display of top round steaks from beef carcasses where traditional and alternative hot carcass round fabrication methods were implemented

	L^{*1}	a^{*2}	b^{*3}
Significance of *P* Value			
Retail Day[4]	<0.001	<0.001	<0.001
Location[5]	<0.001	0.574	<0.001
Treatment[6]	0.542	0.354	0.356
Retail Day x Location	0.284	0.039	0.230
Retail Day x Treatment	0.982	0.992	0.673
Location x Treatment	0.645	0.923	0.521
Retail Day x Location x Treatment	0.664	0.859	0.187
Retail Day			
D0	36.0[a]	-	17.9[a]
D1	34.9[b]	-	15.8[b]
D2	34.3[b]	-	14.7[c]
D3	34.4[b]	-	14.7[c]
SEM	0.9	-	0.6
Location			
DP	37.7[x]	-	16.5[x]
SP	32.1[y]	-	15.1[y]
SEM	1.0	-	0.6
Treatment			
TRT	35.0	20.3	15.7
CON	34.7	20.6	15.9
SEM	1.0	0.9	0.6

[1]*L**: lightness; 0 = black; 100 = white.

[2]*a**: redness; −50 = green; 50 = red.

[3]*b**: yellowness; −50 = blue; 50 = yellow.

[4]Retail Day: days of simulated retail display.

[5]Location: DP – deep portion of the top round steak, SP – superficial portion of the top round steak.

[6]Treatment: fabrication methods, TRT – alternative fabrication method with the knuckle peeled down partially exposing the femur bone during slaughter, CON – traditional fabrication where the knuckle subprimal was left intact.

[a–c]Means lacking a common superscript within a column differ at ($P < 0.05$) due to retail display effect.

[x,y]Means lacking a common superscript within a column differ at ($P < 0.05$) due to location effect.

methods did not impact L^* ($P = 0.542$) while a significant location effect ($P < 0.001$) was observed. DP steaks were lighter than SP steaks, which is consistent with observations made in previously assessed simulated retail settings for top round steaks (Lancaster et al., 2020). The pale, soft and exudative (PSE) condition has been observed in muscles that experienced rapid pH decline at high temperature in various species (Kim et al., 2014). Results from the current study showed a more rapid pH decline, as well as slower temperature decline at the DP location of the top round during initial chilling compared to the SP location (Figure 1 and Figure 2). Poor thermal conductivity of muscles located in deep sections of the carcass during postmortem glycolysis occurring at higher-than-normal temperatures create a condition for temperature-induced muscle protein denaturation resulting in PSE-like meat (Kim et al., 2014) which may explain the lighter color observed in the DP steaks of the current study.

Retail day effect on b^* was observed ($P < 0.001$) on d 0, 1, and 2; the significant b^* differences due to time diminished on d 3. Location effect was observed for mean b^* values ($P < 0.001$) but not between fabrication methods ($P = 0.356$). As simulated retail time increased, mean b^* value gradually decreased, suggesting the color development towards a less-red shade over time, which could be due to myoglobin denaturation. DP steaks had higher average b^* values than SP steaks which indicated more yellowness at the DP location. These findings are in agreement with prior research that observed the deep portion of beef semimembranosus which had elevated mean b^* values in contrast to the superficial counterpart (Kim et al., 2010). In addition, hue angle, computed with $h_{ab} = arctangent(\frac{b^*}{a^*})$, is an indication of discoloration (Kim et al., 2010; King, 2023). Higher mean b^* values would contribute to greater hue angle based on the previously mentioned equation. This indicated DP steaks showed signs of discoloration even at the time of initial steak fabrication which could be attributed to temperature-induced muscle protein denaturation occurring during chilling in early-postmortem (Kim et al., 2014).

Objective color results of the RF observed no treatment effect for L^* ($P = 0.588$), a^* ($P = 0.407$) or b^* ($P = 0.160$) measurements (Table 3). A significant treatment effect was found among VL mean a^* ($P = 0.020$) measurements but not mean L^* ($P = 0.231$) or b^* ($P = 0.073$) (Table 3). CON had a higher observed average a^* score than TRT (22.9 and 20.9, respectively). Differences in average a^* values between CON and TRT suggested that by leaving the knuckle intact, steaks from the VL had greater redness. Observations of greater redness of the CON compared to the TRT treatments may be attributed to less environmental exposure during carcass chilling since the knuckle was left intact. On the contrary, the TRT side had the knuckle peeled down, which resulted in an increased surface area being exposed during chilling. Although the additional surface area exposed aided in heat dissipation, some oxidation could have occurred in the knuckles of the TRT sides resulting in a

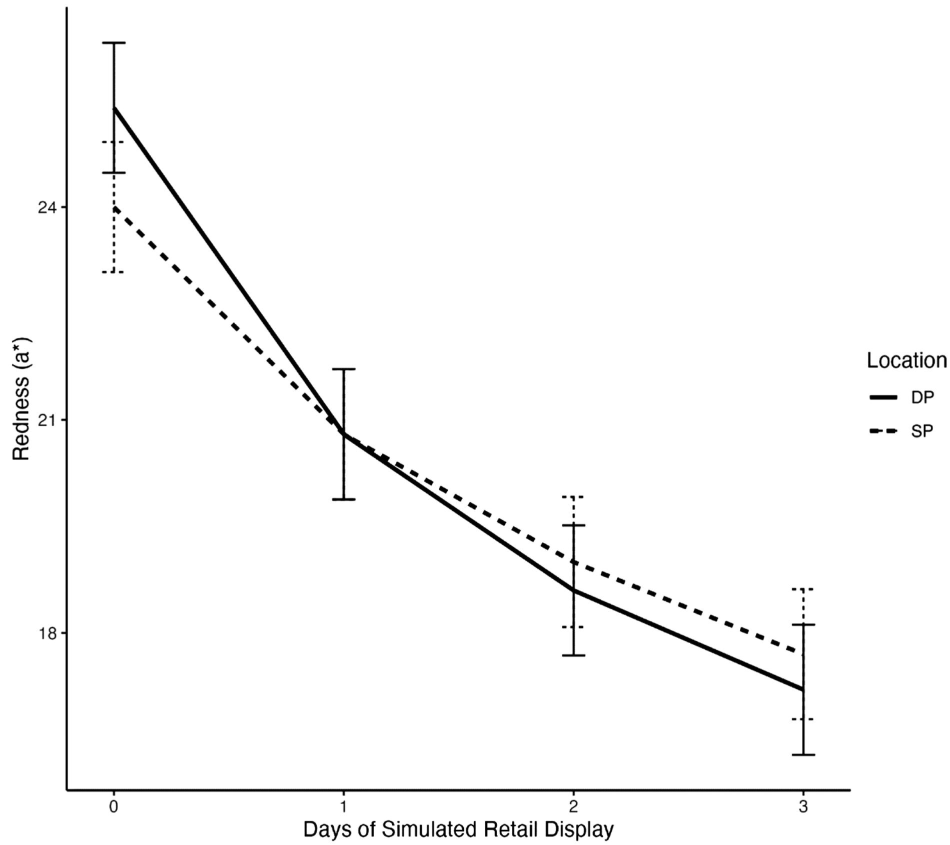

Figure 3. Effects of retail display day[1] x location[2] interaction on objective color a^{*3} mean score during simulated retail display for the beef top round ($P = 0.039$). [1]Retail display day: days of simulated retail display. [2]Location: DP – deep portion of the top round steak, SP – superficial portion of the top round steak. [3]a^*: redness; −50 = green; 50 = red.

Table 3. Effect of treatment of traditional and alternative hot beef carcass round fabrication techniques on the mean objective color L^{*1}, a^{*2}, and b^{*3} scores and Warner-Bratzler shear force (WBSF)[4] mean value (kgf) of the Rectus femoris and the Vastus lateralis muscles

	Treatment[5]			
	TRT	CON	SEM	*P*
Rectus femoris				
*L**	35.4	36.1	1.3	0.588
*a**	20.8	20.2	0.6	0.407
*b**	15.2	14.4	0.8	0.160
WBSF	4.45[a]	3.41[b]	0.30	0.003
Vastus lateralis				
*L**	32.6	33.7	1.0	0.231
*a**	20.9[b]	22.9[a]	0.7	0.020
*b**	14.3	15.7	0.8	0.073
WBSF	4.04	4.27	0.32	0.510

[1]L^*: lightness; 0 = black; 100 = white.

[2]a^*: redness; −50 = green; 50 = red.

[3]b^*: yellowness; −50 = blue; 50 = yellow.

[4]WBSF: Warner-Bratzler shear force, instrumental tenderness analysis.

[5]Treatment: fabrication methods, TRT – alternative fabrication method with the knuckle peeled down partially exposing the femur bone during slaughter, CON – traditional fabrication where the knuckle subprimal was left intact.

[a,b]Means without a common superscript within a row differ ($P < 0.05$) due to treatment effect.

decreased a^* value. Prior observations of oxidation of myoglobin to metmyoglobin over time have been used to explain negative impacts to a^* values (MacDougall, 2002).

Shelf-life lipid oxidation

Mean TBARS values increased ($P < 0.001$) from d 0 to d 3 (Table 4), which is consistent with previous research that observed lipid oxidation increase over time of retail display (Colle et al., 2016). Day 3 of retail display in the current study had the highest mean TBARS value regardless of location or treatment, however, the mean value was still below the detectable threshold regarding off-flavor of 1.0 mg malonaldehyde/kg of meat (McKenna et al., 2005). A trend was seen for location effect where SP showed numerically greater mean lipid oxidation than DP steaks ($P = 0.069$). Myoglobin oxidation has a negative impact on meat color and lipid oxidation contributes to off-flavor (Faustman et al., 2010; Corbin et al., 2015). Faustman et al. (2010) reported that there is a relationship between lipid and myoglobin oxidation and that the increase in the amount of one tends to lead to higher values of the other. Biochemical reactions for myoglobin and lipid oxidation produce products which can mutually accelerate the oxidation process (Faustman et al., 2010). No effect from fabrication method was observed for lipid oxidation ($P = 0.941$).

Table 4. Mean values of lipid oxidation (TBARS[1]) during retail display for top round steaks using traditional and alternatively hot carcass round fabrication techniques

	TBARS	pH
Significance of *P* Value		
Retail Day[2]	< 0.001	0.094
Location[3]	0.069	0.030
Treatment[4]	0.941	0.450
Retail Day x Location	0.353	0.047
Retail Day x Treatment	0.776	0.675
Location x Treatment	0.592	0.820
Retail Day x Location x Treatment	0.928	0.508
Retail Day		
D0	0.230[a]	–
D3	0.527[b]	–
SEM	0.07	–
Location		
DP	0.341	–
SP	0.416	–
SEM	0.06	–
Treatment		
TRT	0.376	5.60
CON	0.381	5.61
SEM	0.05	0.03

[1]TBARS; mg malondialdehyde/kg meat.

[2]Retail Day: days of simulated retail display.

[3]Location: DP – deep portion of the top round steak, SP – superficial portion of the top round steak.

[4]Treatment: fabrication methods, TRT – alternative fabrication method with the knuckle peeled down partially exposing the femur bone during slaughter, CON – traditional fabrication where the knuckle subprimal was left intact.

[a,b]Means lacking a common superscript within a column differ at ($P < 0.05$) due to retail display effect.

Steak pH and Warner-Bratzler shear force

WBSF analysis of the top round steaks indicated a location effect ($P = 0.001$). An average of 4.34 kgf and 5.29 kgf was observed for SP steaks and DP steaks, respectively (Table 5). The USDA tender threshold was determined at 4.4 kgf, suggesting the SP portion of top round steaks fits the description of "Certified Tender" based on the F295-11 Standard Specification for Tenderness (ASTM, 2007). No treatment effects ($P = 0.831$), or treatment x location interaction ($P = 0.278$) were observed for mean WBSF values.

Table 5. Mean values of Warner-Bratzler shear force (WBSF) (kgf) and cook loss (%) of top round steaks using traditional and alternative hot carcass beef fabrication techniques

	WBSF, kgf[1]	Cook Loss, %[2]
Significance of *P* Value		
Location[3]	0.001	0.050
Treatment[4]	0.831	0.947
Location x Treatment	0.278	0.150
Location		
DP	5.29[a]	30.4[b]
SP	4.34[b]	31.6[a]
SEM	0.33	0.47
Treatment		
TRT	4.79	31.0
CON	4.84	31.0
SEM	0.33	0.47

[1]WBSF: Warner-Bratzler shear force, instrumental tenderness analysis.

[2]Cook loss (%): calculated with (initial weight – cooked weight)/initial weight x 100%.

[3]Location: DP – deep portion of the top round steak, SP – superficial portion of the top round steak.

[4]Treatment: fabrication methods, TRT – alternative fabrication method with the knuckle peeled down partially exposing the femur bone during slaughter, CON – traditional fabrication where the knuckle subprimal was left intact.

[a,b]Means without a common superscript within a column differ ($P < 0.05$) due to location effect.

Peak internal temperature was analyzed as a covariate, and it did not impact the instrumental tenderness value ($P = 0.936$). Location effect had strong trend regarding cook loss ($P = 0.050$) with SP steaks having 1.2% more cook loss than DP steaks. A retail day x location interaction was observed in steak pH ($P = 0.047$); SP steaks had significantly lower mean pH than DP steaks on d 0 (5.55 and 5.63 respectively; Figure 4). The greater cook loss in SP steaks could be attributed to the lower mean pH, which has been associated with decreased water holding capacity in meat (Huff-Lonergan & Lonergan, 2005). Additionally, the effect of raw meat quality on cooked meat characteristics has been examined to show that reduced protein water holding capacity contributed to increased cook loss (Aaslyng et al., 2003). The fabrication method did not have an impact on the instrumental tenderness of VL ($P = 0.510$; Table 3), while a negative impact was observed in the RF ($P = 0.003$). Peeling down the knuckle prior to chilling increased the shear force value by 1.04 kgf compared to the traditional fabrication method; TRT and CON resulted in WBSF of 4.45 and 3.41, respectively. The authors suspect that the increased WBSF of the RF steaks is likely due to shortened sarcomere lengths as a result of how the knuckle subprimal was sitting in a "folded over–contracted state" after partially exposing the femur bone (Herring et al., 1967). This suspicion is also supported by prior reporting that considerable shortening in sarcomere length could occur as a result of hot-boning muscle prior to rigor (Locker, 1960; White et al., 2006). It is not anticipated that drastic differences in eating experiences would be observed due to the alternative fabrication method if the knuckle is cooked via smoking, braising or other cookery methods that employ the use of low heat for an extended time; however, if steaks were to be fabricated from the knuckle using the novel fabrication intervention being discussed in this study it is likely that a noticeable difference in tenderness would be observed. Previous research has indicated that consumers can detect differences in tenderness between steaks with a WBSF value equal to, or greater than, 0.50 kgf (Miller et al., 1995; ASTM, 2011).

Consumer taste panel

Consumer sensory analysis indicated that the fabrication method had an impact on overall acceptability

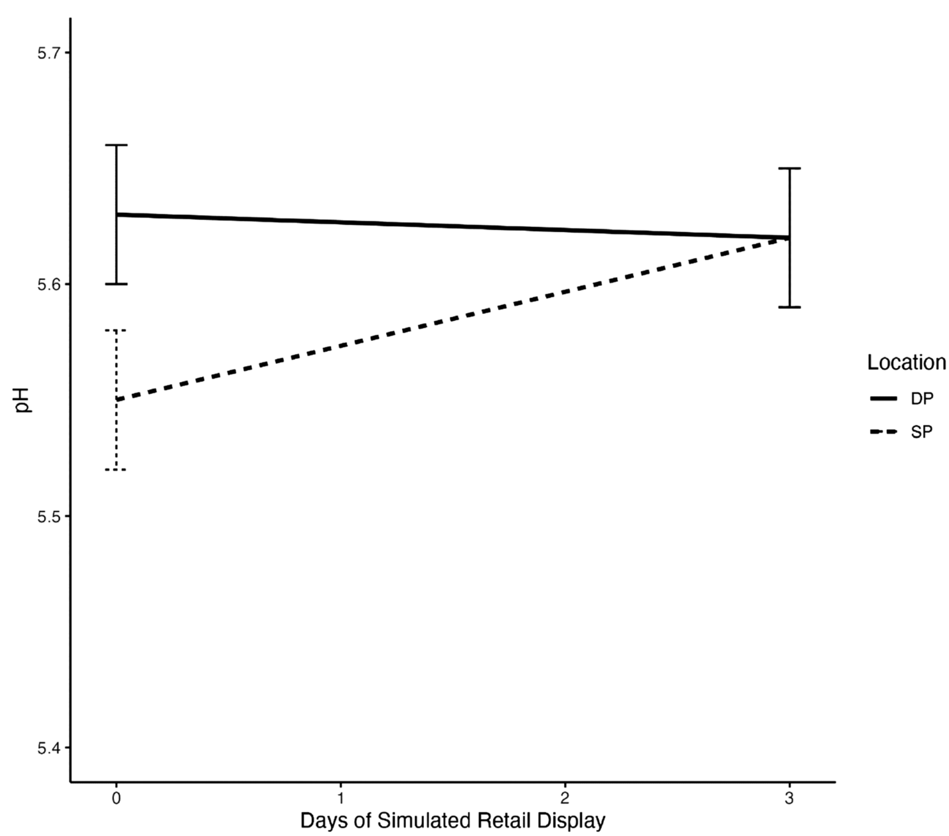

Figure 4. Effects of retail day[1] x location[2] interaction on pH mean value during simulated retail display for beef top round steaks ($P = 0.047$). [1]Retail day: days of simulated retail display. [2]Location; DP – deep portion of the top round steak, SP – superficial portion of the top round steak.

($P = 0.042$) and flavor ($P = 0.035$), but it did not affect tenderness ($P = 0.306$) and juiciness ($P = 0.290$; Table 6). The alternative fabrication method yielded higher mean ratings in overall acceptability and flavor. Panelists identified mean scores for overall acceptability and mean flavor scores suggesting panelists favored top round steaks from beef sides which had the knuckle subprimal peeled during chilling. Prior research had pointed out chilling rate impacts the profile of volatile and non-volatile compounds that are responsible for flavor in raw meat (Xiang et al., 2021). Xiang et al. (2021) also concluded that more rapid chilling positively influenced aromatic compounds in raw meat. Humans determine flavor using a complex process involving the gustatory sensory cells (taste), olfactory bulb (smell), and trigeminal nerves (feel), and a strong relationship has been identified between flavor and overall acceptability (Kerth & Miller, 2015). Since peeling down the knuckle resulted in an accelerated chilling rate of the top round; consequently, alterations in flavor compounds may have occurred. Thus, elevated ratings in both flavor and overall acceptability in the current study are unsurprising. Considering the change in temperature decline and consumer sensory findings from the current study, it is theorized that the accelerated chilling due to the alternative fabrication method proposed, the development of flavor compounds in the top round was altered, thus resulting in a more pleasurable eating experience. Future studies pertaining to volatile measurements could be of interest to further examine the impact of peeling down the knuckle from the aspect of flavor chemistry.

Table 6. Mean values of consumer sensory panel palatability acceptance characteristics of beef top round steaks using traditional and alternative beef hot carcass round fabrication techniques

	Overall Acceptability[1]	Tenderness[2]	Juiciness[3]	Flavor[4]
Significance of *P* Value				
Location[5]	0.232	0.856	0.090	0.138
Treatment[6]	0.042	0.306	0.290	0.035
Location x Treatment	0.107	0.654	0.544	0.168
Location				
DP	5.86	5.60	5.43	5.60
SP	6.07	5.64	5.80	5.90
SEM	0.20	0.26	0.23	0.20
Treatment				
TRT	6.15[a]	5.73	5.73	5.96[a]
CON	5.78[b]	5.51	5.50	5.53[b]
SEM	0.20	0.26	0.23	0.20

[1]Overall Acceptability: Score: 10 = extremely acceptable; 1 = extremely unacceptable.

[2]Tenderness: Score: 10 = extremely tender; 1 = extremely untender.

[3]Juiciness: Score: 10 = extremely juicy; 1 = extremely unjuicy.

[4]Flavor: Score: 10 = extremely flavorful; 1 = extremely unflavorful.

[5]Location: DP – deep portion of the top round steak, SP – superficial portion of the top round steak.

[6]Treatment: fabrication methods, TRT – alternative fabrication method with the knuckle peeled down partially exposing the femur bone during slaughter, CON – traditional fabrication where the knuckle subprimal was left intact.

[a,b]Means lacking a common superscript within a column differ at ($P < 0.05$) due to treatment effect.

No location effects were observed in overall acceptability ($P = 0.232$), tenderness ($P = 0.856$), or flavor ($P = 0.138$). Location effects showed a trend regarding juiciness ($P = 0.090$), with SP steaks being slightly juicier than DP steaks, numerically. These findings could be attributed to the "halo-effect" where consumers' perceptions of one trait is influenced by another (Corbin et al., 2015) since the instrumental tenderness test found that SP steaks were more tender than DP steaks. The "halo-effect" among other sensory attributes had also been reported in prior findings where appearance, indicative of steak degree of doneness, had impacted consumer perception of acceptability and other sensory characteristics (Prill et al., 2019). Corbin et al. (2015) also discussed the impact of the "halo-effect" and attempted to minimize the impact of such effect that tenderness might have on flavor ratings.

Conclusion

The proposed alternative fabrication method presented benefits in accelerating chilling in the deep portion of top round. Further explorations into the impact of peeling down the knuckle on top round flavor compound chemistry could be justified. Overall, retail time and location were more impactful on steak color than was the proposed alternative fabrication method. The superficial portion of the top round steaks exhibited more desirable color traits, met the USDA threshold of "certified tender" and was juicier, as indicated by the consumer panel. By separating the superficial portion of the top round, and merchandising it separate from the deep portion of those steaks, a more desirable consistent product offering may be made. Further examination into contamination, purge loss, microbial growth, and food safety-related issues should be explored using the innovative fabrication method of the hot beef carcass rounds.

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