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Color stability and tenderness variations within the *gluteus medius* from beef top sirloin butts

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ABSTRACT

Beef top sirloin butts (n = 48) from USDA quality grade (QG; upper 2/3 US Choice vs. US Select) and yield grade categories (YG; 1 and 2 vs. 4 and 5) were aged 14 days, GM steaks were cut, with 2 steaks removed from the anterior (ANT), middle (MID) and posterior (POST) sections of the GM. One steak from each section was cut into lateral (LAT), central (CENT) and medial (MED) portions, packaged aerobically, and displayed for 7 days, whereas the second steaks were cooked to 71 °C for WBSF. Top Choice-steaks were redder and more yellow ($P < 0.05$) than Select steaks during display. Cooking losses were greatest ($P < 0.05$) in the MED, and least ($P < 0.05$) in the CENT, portions of GM steaks. Neither QG nor YG category affected WBSF, but differences within the GM were found for ($P < 0.05$) WBSF. Results of this experiment indicate tenderness and color stability gradients exist within the GM.

1. Introduction

Beef top sirloin steaks are one of the most popular steaks served in restaurants (Harris, Miller, Savell, Cross, & Ringer, 1992), as well as purchased at retail outlets (National Cattlemen's Beef Association, 2005), across the United States. Beef top sirloin steaks are typically marketed at lower prices compared to the other steaks from the loin and rib primals (Harris et al., 1992) because of palatability inconsistencies, especially in cooked beef tenderness. Even though the variation in tenderness for top sirloin steaks has been reduced (Brooks, Belew, Griffin, Gwartney, Hale, Henning, Johnson, Morgan, Parrish, Reagan and Savell, 2000; Morgan, Savell, Hale, Miller, Griffin, Cross and Shackelford, 1991), research has reported similar (Belew, Brooks, McKenna, & Savell, 2003; McKeith, DeVol, Miles, Bechtel, & Carr, 1985; Shackelford, Wheeler, & Koohmaraie, 1995; Voges, Mason, Brooks, Delmore, Griffin, Hale, Henning, Johnson, Lorenzen, Maddock, Miller, Morgan, Baird, Gwartney and Savell, 2007) or greater shear force values (Harris et al., 1992; Rhee, Wheeler, Shackelford, & Koohmaraie, 2004), along with lower tenderness ratings (Carmack, Kastner, Dikeman, Schwenke, & Garcia Zepeda, 1995; Harris et al., 1992; McKeith et al., 1985; Neely, Lorenzen, Miller, Tatum, Wise, Taylor, Buyck, Reagan and Savell, 1998; Rhee et al., 2004; Shackelford et al., 1995), when compared to beef top loin and/or ribeye steaks. Even though Rhee et al. (2004) reported that shear force values from the *gluteus medius* muscle (GM) did not differ between steaks removed from the anterior and posterior of top sirloin steaks, little is known about the tenderness gradient, if any, within the GM.

A number of studies have shown that the beef GM also has color stability issues (Hood, 1980; O'Keefe & Hood, 1982). Based on metmyoglobin formation and discoloration rates over five days of simulated retail display, McKenna, Mies, Baird, Pfeiffer, Ellebracht and Savell (2005) classified the GM as an "intermediate" color-stable muscle when compared to other muscles. Research on the beef *semimembranosus* – also classified as an "intermediate" color stable muscle – demonstrated considerable within-muscle variation in fresh color measured within 30 min of steak fabrication (Lee, Yancey, Apple, Sawyer, & Baublits, 2008) and across seven days of simulated retail display (Sawyer, Baublits, Apple, Meullenet, Johnson and Alpers, 2007). Yet, the limited work on color development and stability on the GM has not examined the existence of lateral and/or longitudinal color variations. Therefore, objectives of this study were to investigate the interactive effect of USDA quality and yield grades on instrumental color and shear force variations within the GM.

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2. Materials and methods

2.1. Top sirloin butt selection and fabrication

Beef top sirloin butts (IMPS #184) were selected at a large commercial slaughter facility based on USDA quality grade (upper 2/3, or top, USDA Choice ["modest" and "moderate" degrees of marbling] or USDA Select ["slight" degree of marbling]) and USDA yield grade (yield grades 1 and 2 or 4 and 5). Individually-identified top sirloin butts (n = 48) from left carcass sides were captured during fabrication, vacuum-packaged, and transported under refrigeration to the University of Arkansas Red-Meat Abattoir for further processing.

Top sirloin butts were allowed to age at 2 °C for 14 days from the box date before removal from vacuum-sealed packages. Depth of the subcutaneous fat opposite the center of the *biceps femoris* (rump fat) was measured with a metal ruler prior to removal of the *biceps femoris* and all overlying subcutaneous fat, as well as the *gluteus intermedius* and *gluteus profundus*. Then, beginning at the posterior end of the resulting *gluteus medius* (GM), eight 2.54-cm-thick steaks were hand-cut: 1) first and second steaks designated as posterior (POST) steaks; 2) third steak was discarded; 3) fourth and fifth steaks designated at middle (MID) steaks; 4) sixth steak was discarded; and 5) seventh and eighth steaks were designated as anterior (ANT) steaks (Fig. 1A). One steak from each location pair was randomly chosen, identified, vacuum-packaged in a 3 mil standard barrier nylon/polyethylene pouch, and frozen approximately 6 weeks at −20 °C for Warner–Bratzler shear force (WBSF) determination.

The remaining steak from each location pair was further divided into three equal length intra-steak portions, designated as lateral (LAT), central (CENT) and medial (MED) portions (Fig. 1B). An approximately 2-g sample of GM was removed from each portion for pH measurement before steak portions were placed onto polystyrene foam trays (with absorbent pads) and over-wrapped with an oxygen-permeable, PVC film (OTR = 14,000 cc O_2/m^2/24 h/atm; Koch Supplies Inc., Kansas City, MO, USA). Subsequently, individually-packaged steak portions were placed in open-topped, coffin-chest display cases (model LMG12; Tyler Refrigeration Corp., Niles, MI, USA) maintained at an average temperature of 2.5 °C, and displayed under continuous lighting (1,600 lx of deluxe, warm-white fluorescent lighting [bulb type F40T12, 40-W; Philips Inc., Somerset, NJ, USA]) for seven days. Temperature was monitored with an EV_2 temperature logger (Comark Instruments, Inc., Beaverton, OR), and steaks were rotated daily.

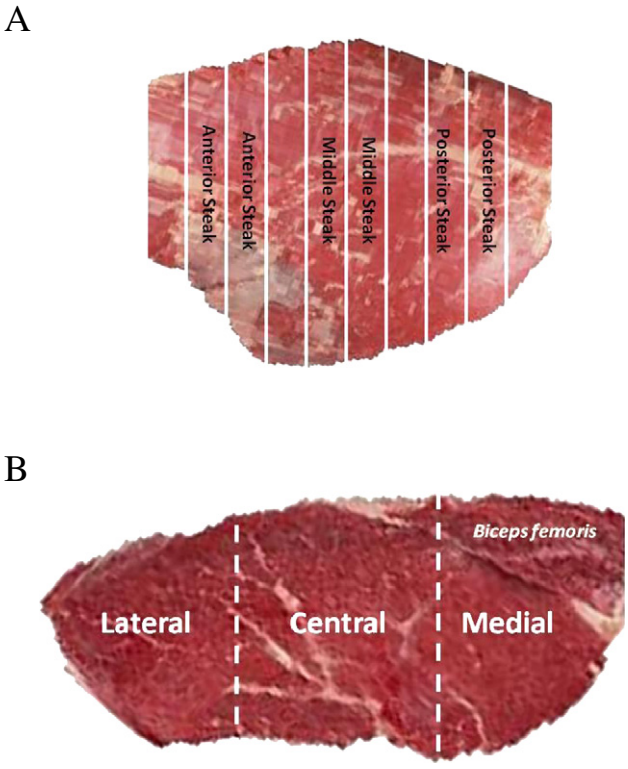

Fig. 1. Diagram of (A) *gluteus medius* steak fabrication and (B) within-steak positions.

2.2. Muscle pH

The 2 g of GM removed from each steak prior to packaging were homogenized in 20 ml of distilled, deionized water, and pH of the homogenate was measured with a pH meter (UP-10; Denver Instruments, Denver, CO, USA) equipped with a temperature-compensating, combination pH electrode. The pH meter was calibrated to both pH 4.0 and 7.0 before measuring GM pH.

2.3. Instrumental color measurement

Instrumental color readings of steak portions (n = 432) were measured daily during the seven-day simulated retail display period using a Hunter MiniScan XE (45/0-L; Hunter Associates Laboratory, Inc., Reston, VA, USA) calibrated against a standard white tile and black glass each day immediately before data collection. The L*, a* and b* values of each steak portion in display were determined from the average of three readings on the cut surface using illuminant A, a 2.54-cm aperture, and a 10° standard observer. Chroma (C*), or saturation index, $\left(\sqrt{a*^2 + b*^2}\right)$ and hue angle ($\tan^{-1}[b^* / a^*]$) were also calculated for each steak portion daily (AMSA, 1991). In addition, reflectance values were simultaneously measured at 10-nm intervals from 400 to 700 nm.

2.4. Warner–Bratzler shear force determinations

Steaks from the ANT, MID, and POST of each GM were allowed to thaw for 16 h in a 4 °C commercial refrigerator before removal from vacuum-packages, and identified with heat-resistant tags. Then, steaks were cut into LAT, CENT, and MED within-steak sections, weighed and oriented on the belt of a gas-fired, air-impingement oven (Lincoln Impinger; Food Service Products, Inc., Ft. Wayne, IN, USA). The oven was preheated to 165 °C, with the belt speed set at 25 min to produce the desired endpoint temperature of 71 °C. Endpoint temperature of each cooked steak was confirmed at the completion of cooking with a digital, hand-held thermometer (KM28; Comark Instruments, Inc., Beaverton, OR, USA). Cooked steaks were allowed to cool to room temperature before weighing, and the difference between the pre-cooked and cooked steak weights was used to calculate cooking loss percentages. Subsequently, cooked steaks were wrapped in an oxygen-permeable, PVC film and chilled overnight in a 4 °C commercial refrigerator before six 1.27-cm-diameter cores were removed parallel to the muscle fiber orientation from each steak. Each core was then sheared once through the center with a V-shaped WBSF device attached to an Instron Universal Testing Machine (Instron Corp., Canton, MA, USA) equipped with a 50-kg load cell and set at a crosshead speed of 200 mm/min. The peak WBSF of the six cores within each steak location was averaged before statistical analyses.

2.5. Statistical analyses

Carcass data from which the top sirloin butts (BUTT) originated were analyzed using the mixed models procedure of SAS (SAS Inst., Inc., Cary, NC, USA), with quality grade (QG) and yield grade (YG) categories, as well as the QG × YG interaction, included in the model as fixed effects. The experiment was conducted as a split–split plot design, with QG and YG as the whole plot, steak location within the

GM (POST, MID, or ANT) as the sub-plot, and the within-steak position (LAT, CENT, and MED) as the sub-sub-plot. Analysis of variance for the instrumental color and cooked steak data was generated with PROC MIXED, and the fixed effects included in the statistical model included QG, YG, steak location (LOC), within-steak position (WSP), and display day (instrumental color data only), whereas the random effects were QG × YG × BUTT and QG × YG × LOC × WSP × BUTT. Display day (DAY) was the repeated variable in the analysis of the color data and subject of the repeated measure was LOC × WSP × BUTT. Least squares means were calculated for all significant ($P \leq 0.05$) main and interactive effects, and statistically separated with pair-wise *t*-tests (PDIFF option). It should be noted that there were no significant interactions for:

QG × YG × WSP ($P \geq 0.364$)
YG × LOC × WSP ($P \geq 0.119$)
YG × DAY ($P \geq 0.263$)
QG × YG × DAY ($P \geq 0.228$)
LOC × DAY ($P \geq 0.118$)
QG × LOC × DAY ($P \geq 0.995$)
YG × LOC × DAY ($P \geq 0.954$)
QG × YG × LOC × DAY ($P \geq 0.871$)
WSP × DAY ($P \geq 0.836$)
QG × WSP × DAY ($P \geq 0.947$)
YG × WSP × DAY ($P \geq 0.995$)
QG × YG × WSP × DAY ($P \geq 0.922$)
LOC × WSP × DAY ($P \geq 0.845$)
QG × WSP × DAY ($P \geq 0.708$)
YG × LOC × WSP × DAY ($P \geq 0.997$)
QG × YG × LOC × WSP × DAY ($P = 0.999$).

3. Results and discussion

3.1. Beef carcass characteristics

There were no QG × YG interactions ($P \geq 0.11$) for any carcass characteristics (Table 1). Even though Select-grade (SEL) carcasses were heavier ($P = 0.05$) than top (upper ⅔) Choice-grade (CHO) carcasses, it was not surprising that both marbling scores and actual quality grades were greater ($P < 0.001$) in CHO- than SEL-carcasses. On the other hand, YG 4 and 5 (YG45) carcasses were heavier ($P = 0.03$) than YG 1 and 2 (YG12) carcasses, and, as expected, YG45-carcasses had greater ($P < 0.001$) fat depths opposite the *longissimus* muscle and over the rump when compared to YG12-carcasses. Interestingly, YG12-carcasses had greater marbling scores ($P = 0.05$), a higher actual quality grade ($P = 0.09$), and larger *longissimus* muscle areas ($P < 0.001$) than YG45-carcasses.

According to the National Beef Quality Audit (2012), among cattle grading YG12, more graded USDA Choice (26.4%) than Select (22.6%); however, among YG 45 cattle, many more graded USDA Choice (7.6%) than Select (1.5%). The muscles used in the present study were from top USDA Choice carcasses with marbling scores of "moderate" and "modest." Although the National Beef Quality Audit does not segregate top Choice carcasses into YG categories, the percentage of cattle qualifying for Certified Angus Beef (CAB) or other Top Choice programs was 13.4%. Furthermore, in the National Beef Quality Audit (2012), YG for USDA Prime carcasses were greater than that of USDA Choice, which was greater than Select, but there was only a 1.1 YG unit spread in the mean YG from Prime to Select carcasses, suggesting that YG 45 are a much smaller segment of the US cattle population than YG 12.

3.2. Ultimate pH of gluteus medius steaks

The pH of the GM was not affected by USDA QG category ($P = 0.51$), but tended to be lower ($P = 0.07$) in the GM from YG45-carcasses than YG12-carcasses (Table 2). It is possible that the lack of fat cover in the YG12 muscles allowed for faster chilling during rigor and that the glycolytic enzymes became inactive sooner in the muscles from the trimmer carcasses. Lee et al. (2008) found lower pH values in *semimembranosus* (SM) steaks from USDA Prime carcasses than Choice and Select, but did not compare YG in the SM. However, Von Seggern, Calkins, Johnson, Brickler, and Gwartney (2005) compared several muscles from the beef round and chuck and reported that the effects of QG on pH were inconsistent and varied between muscles.

Although no research has been published on within-muscle variation of pH in the GM, McKenna et al. (2005) reported that the GM had similar pH values to the *biceps femoris* (BF), *psoas major* (PM), SM, and *semitendonosus* (ST), and the GM had a lower pH than the *longissimus lumborum* and *thoracis* (LD). In the present study, GM steaks removed from the POST had lower ($P = 0.001$) ultimate pH values than steaks cut from the ANT and MID locations within the GM (Table 3). In the SM, Lee et al. (2008) found higher pH values in the ventral end of the muscle, with lower values in the dorsal end. The SM is a very large muscle and ventral end is insulated on the inside portion of the carcass by the *gracilis*; however, in the present study, the posterior end of the GM is insulated by the BF and the pelvic bone and has a lower muscle pH. The SM is much larger than the GM and has a more anaerobic metabolism than the GM (Hunt & Hedrick, 1977; Kirchofer, Calkins, & Gwartney, 2002), and the insulation of the other muscles may have had a lesser effect on the final pH of that portion of the muscle.

Lastly, pH from the MED-position within GM steaks was greater ($P = 0.002$) than the pH from either the LAT- or CENT-positions of the steaks. Lee et al. (2008) found that the most interior section of the SM had the greatest pH, similarly, in the GM, the most interior position within the steak (MED) had the greatest pH.

3.3. Effect of QG and YG on fresh beef color

The GM from SEL-carcasses was lighter (higher L* values; $P < 0.001$), and less red (lower a* values; $P < 0.001$), than the GM from CHO-carcasses, whereas L* and a* values were greater

Table 1
Effects of USDA quality grade (QG) and yield grade (YG) categories on carcass characteristics from which top sirloin butts originated.

	Top U.S. Choice		U. S. Select			$P > F$[a]		
Characteristic	1 & 2	4 & 5	1 & 2	4 & 5	SE	QG	YG	QG × YG
Hot carcass weight (kg)	367	377	376	397	7.2	0.05	0.03	0.46
Fat thickness (cm)	1.06	2.24	1.07	2.02	0.098	0.61	<0.001	0.27
Longissimus muscle area (cm^2)	87.8	73.9	87.9	76.0	2.73	0.96	<0.001	0.67
Rump fat depth (cm)[b]	2.52	4.24	3.17	3.98	0.280	0.47	<0.001	0.11
Actual YG	2.6	4.6	2.7	4.4	0.16	0.69	<0.001	0.39
Marbling score	Moderate[43]	Modest[70]	Slight[90]	Slight[83]	20.2	<0.001	0.05	0.11
Actual QG	Choice[81]	Choice[56]	Select[82]	Select[73]	9.9	<0.001	0.09	0.46

[a] Probability value of the main and interactive effects included in the statistical model.
[b] Rump fat depth was subcutaneous fat measured at the center of the *biceps femoris*.

Table 2
Effects of USDA quality grade (QG) and yield grade (YG) categories on pH, instrumental color, and cooking characteristics of *gluteus medius* steaks.

	Top USDA Choice[a]		USDA Select		$P > F$[b]		
Variable	1 & 2	4 & 5	1 & 2	4 & 5	QG	YG	QG × YG
Muscle pH	5.43 ± 0.016	5.41 ± 0.016	5.43 ± 0.016	5.39 ± 0.016	0.51	0.07	0.31
Lightness (L*)[c]	36.8 ± 0.25	41.0 ± 0.52	38.4 ± 0.26	42.3 ± 0.25	<0.001	<0.001	0.65
Redness (a*)[c]	14.8 ± 0.21	16.8 ± 0.43	12.1 ± 0.21	13.5 ± 0.20	<0.001	<0.001	0.20
Yellowness (b*)[c]	16.3^{z} ± 0.12	18.9^{x} ± 0.24	16.4^{z} ± 0.12	17.0^{y} ± 0.11	<0.001	<0.001	<0.001
Hue angle (°)[d]	48.5^{z} ± 0.31	48.9^{z} ± 0.64	53.6^{x} ± 0.32	52.1^{y} ± 0.31	<0.001	0.19	0.03
Chroma (C*)[e]	22.2^{y} ± 0.20	25.5^{x} ± 0.42	20.5^{z} ± 0.21	21.8^{y} ± 0.20	<0.001	<0.001	<0.001
Cooking loss (%)	29.5 ± 0.65	30.1 ± 0.65	31.8 ± 0.68	32.1 ± 0.65	0.003	0.53	0.50
Shear force (N)	34.0 ± 2.57	34.4 ± 2.56	40.2 ± 2.70	36.2 ± 2.55	0.13	0.48	0.40

[x,y,z] Within a row, interactive least squares means lacking common superscript letters differ ($P < 0.05$).
[a] Means ± standard error.
[b] Probability value of the main and interactive effects included in the statistical model.
[c] L* = a measure of darkness to lightness (a greater L* value indicates a lighter color); a* = a measure of redness (a greater a* value indicates a redder color); and b* = a measure of yellowness (a greater b* value indicates a more yellow color).
[d] Hue angle represents the change from the true red axis (a larger hue angle indicates a greater shift from red to yellow).
[e] Chroma, or saturation index, is a measure of the total color/vividness of color (a greater chroma value indicates greater total color/a more vivid color).

($P < 0.001$) for GM steaks from YG45- than YG12-carcasses (Table 2). Even though calculated hue angles were greater ($P < 0.05$) in YG12- than YG45-carcasses within the QG category of SEL, the GM steaks from CHO-carcasses were redder (lower hue angle; $P < 0.05$) than that of SEL-carcasses, regardless of YG category (QG × YG interaction, $P = 0.03$). Steaks from CHO, YG45-carcasses were more yellow (greater b* values; $P < 0.05$) than GM steaks from SEL, YG45-carcasses, which had higher ($P < 0.05$) b* values than GM steaks from YG12-carcasses, regardless of QG category (QG × YG interaction, $P < 0.001$). In addition, CHO GM steaks from YG45 carcasses had a more ($P < 0.05$) vivid color (greater C* values) than all other GM steaks, whereas CH, YG12- and SEL, YG45-steaks had a more ($P < 0.05$) vivid color than GM steaks from SEL, YG12-carcasses (QG × YG interaction, $P < 0.001$).

The GM steaks from SEL-carcasses had greater ($P < 0.05$) reflectance values from 400 to 590 nm, indicating a greater total reflection of light, which was consistent with the greater L* values. Reflectance values did not ($P \geq 0.28$) differ between QG categories in the spectral range of 600 to 660 nm (Fig. 2A). Yet, from 670 to 700 nm, GM steaks from CHO-carcasses had greater ($P < 0.05$) reflectance values than those from SEL-carcasses. This difference in the long wavelengths in the red portion of the spectrum is consistent with the differences in a* values. Conversely, GM steaks from YG45-carcasses had greater ($P < 0.05$) reflectance values across the entire spectral range (400 to 700 nm) than GM steaks from YG12-carcasses (Fig. 2B), which is consistent with the other instrumental color measures.

Meat color is affected by a myriad of events and characteristics of the live animal and the carcass. These may include, but are not limited to, pH, fiber type, chilling and countless immeasurable traits that may have been imposed on the live animal. Although quality grade did not affect pH, YG 45 muscles tended to have lower pH values than YG12, which would be the expected relationship with lighter, redder, more yellow fresh meat color. Furthermore, in carcasses from YG45, a substantial amount of fat accumulates over the sirloin, and this fat will affect the chilling of the muscle. The inner portion of the SM chills more slowly than the outer portion and is also known to have a lighter, more diluted color (Lee et al., 2008; Sawyer et al., 2007). It is possible that the combination of slow chilling and pH decline during rigor creates an environment of low pH and high temperature and somewhat denatures the muscle proteins in the YG45 GM muscles.

According to Kirchofer et al. (2002) and Hunt and Hedrick (1977), the GM is largely made up of α-white muscle fibers (>59% of muscle area), which is similar to the percentage of white fiber area found in the LM (Hunt & Hedrick, 1977). Calkins, Dutson, Smith, Carpenter, and Davis (1981) reported that the percentage of α-white muscle fibers was significantly and negatively correlated with marbling score in beef striploins, meaning that as marbling score increased, the percentage of α-white fibers decreased. In the present study, GM muscles

Table 3
Main effects of steak location and within-steak position on pH, instrumental color, and cooking characteristics of *gluteus medius* steaks.

	Steak location (S)[a]				Within-steak position (P)[b]				$P > F$[c]		
Variable	ANT	MID	POST	SE	LAT	CENT	MED	SE	S	P	S × P
Muscle pH	5.43^{x}	5.42^{x}	5.40^{y}	0.009	5.40^{y}	5.41^{y}	5.43^{x}	0.009	0.001	0.002	0.17
Lightness (L*)[d]	38.5^{y}	40.1^{x}	40.2^{x}	0.25	39.8^{x}	40.3^{x}	38.7^{y}	0.25	<0.001	<0.001	0.16
Redness (a*)[d]	14.5	14.3	14.2	0.19	14.4	14.2	14.4	0.19	0.36	0.78	0.40
Yellowness (b*)[d]	16.9^{y}	17.3^{x}	17.2^{xy}	0.12	17.2	17.1	17.1	0.12	0.05	0.92	0.008
Hue angle (°)[e]	50.3^{y}	51.1^{x}	51.0^{x}	0.28	50.6	51.0	50.7	0.28	0.02	0.56	0.87
Chroma (C*)[f]	22.4	22.6	22.4	0.20	22.5	22.4	22.5	0.20	0.61	0.90	0.06
Cooking loss (%)	31.2	30.8	30.6	0.44	32.0^{x}	29.5^{z}	31.1^{y}	0.40	0.54	<0.001	0.42
Shear force (N)	34.6^{y}	38.3^{x}	35.6^{y}	1.52	37.5	34.8	36.4	1.45	0.02	0.06	<0.001

[x,y,z] Within a row and main effect, least squares means lacking common superscript letters differ ($P < 0.05$).
[a] Steak location: ANT = anterior; MID = middle; and POST = posterior.
[b] Within steak position: LAT = lateral; CENT = central; and MED = medial.
[c] Probability value of the main and interactive effects included in the statistical model.
[d] L* = a measure of darkness to lightness (a greater L* value indicates a lighter color); a* = a measure of redness (a greater a* value indicates a redder color); and b* = a measure of yellowness (a greater b* value indicates a more yellow color).
[e] Hue angle (reported in degrees) represents the change from the true red axis (a larger hue angle indicates a greater shift from red to yellow).
[f] Chroma, or saturation index, is a measure of the total color/vividness of color (a greater chroma value indicates greater total color/a more vivid color).

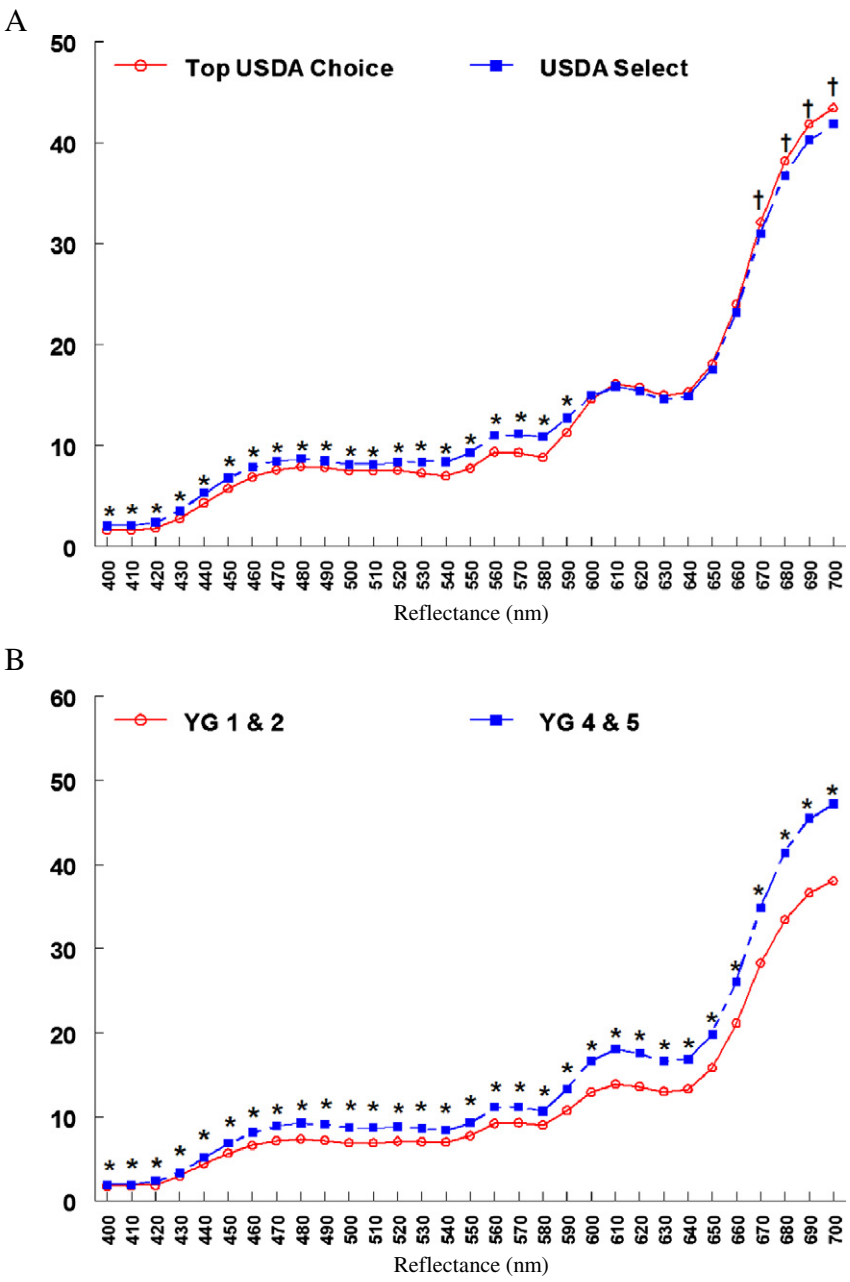

Fig. 2. Main effects of (A) USDA quality grade category and (B) USDA yield grade (YG) category on the reflectance spectra of *gluteus medius* steaks. In panel A, an asterisk (*) indicates U.S. Select greater ($P < 0.05$) than top U.S. Choice steaks, whereas a cross (†) indicates top U.S. Choice greater ($P < 0.05$) than U.S. Select steaks. In panel B, an asterisk (*) indicates that YG 4 and 5 were greater ($P < 0.05$) YG 1 and 2.

from CHO carcasses were darker and more red than SEL, indicative of fewer α-white fibers.

3.4. Effect of steak location and within-steak position on fresh beef color

Steaks cut from the ANT portion of the GM were darker (lower L* values; $P < 0.05$) than steaks cut from the MID and POST portions, and L* values were lower ($P < 0.05$) in the MED position than in either the LAT or CENT positions within GM steaks (Table 3). Even though there was no ($P = 0.83$) QG × steak location interaction on L* values of GM steaks, steaks cut from the MID and POST locations of GM from YG45-carcasses were lighter ($P < 0.05$) than steaks cut from the ANT portion of the GM from YG45-carcasses, as well as steaks cut from YG12-carcasses, regardless of location (YG × steak location, $P = 0.003$; Fig. 3A). Moreover, ANT steaks were darker (lower L* value; $P < 0.05$) than POST steaks within the GM from YG12-carcasses. Conversely, there was no ($P = 0.144$) YG × within-steaks position interaction for L* values; however, the MED position within CHO-steaks was darkest (lowest L* values; $P < 0.05$), and the LAT position of CHO-steaks was darker ($P < 0.05$) than the CENT position within CHO-steaks, as well as all three positions within SEL-steaks (Fig. 3B).

Redness (a*) values did not differ among steak locations ($P = 0.36$) or within steak positions ($P = 0.78$), but hue angles were lower ($P < 0.05$) in ANT GM steaks than either the MID or POST steaks; hue angles were similar ($P = 0.56$) within GM steaks (Table 3). Chroma values were not affected by steak location ($P = 0.61$) or within-steak position ($P = 0.90$). Also, there was a steak location × within-steak position interaction for yellowness (b*; $P = 0.008$), but the difference were so small it was of little importance (data not presented).

Steaks cut from the MID of the GM had greater ($P < 0.05$) reflectance values at 400 nm than GM steaks cut from the ANT portion of the GM; however, between 410 and 700 nm, steaks cut from the

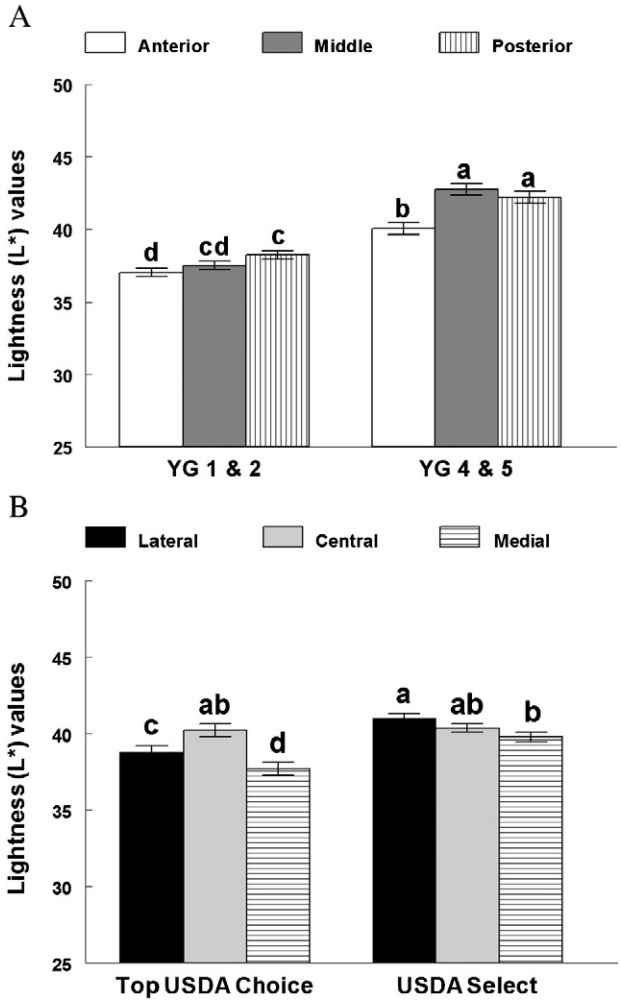

Fig. 3. Interactive effects of (A) USDA yield grade and steak location ($P = 0.003$) and (B) quality grade and within-steak position ($P = 0.002$) on lightness (L*) values of *gluteus medius* steaks. [a,b,c,d]Bars lacking common letters differ ($P < 0.05$).

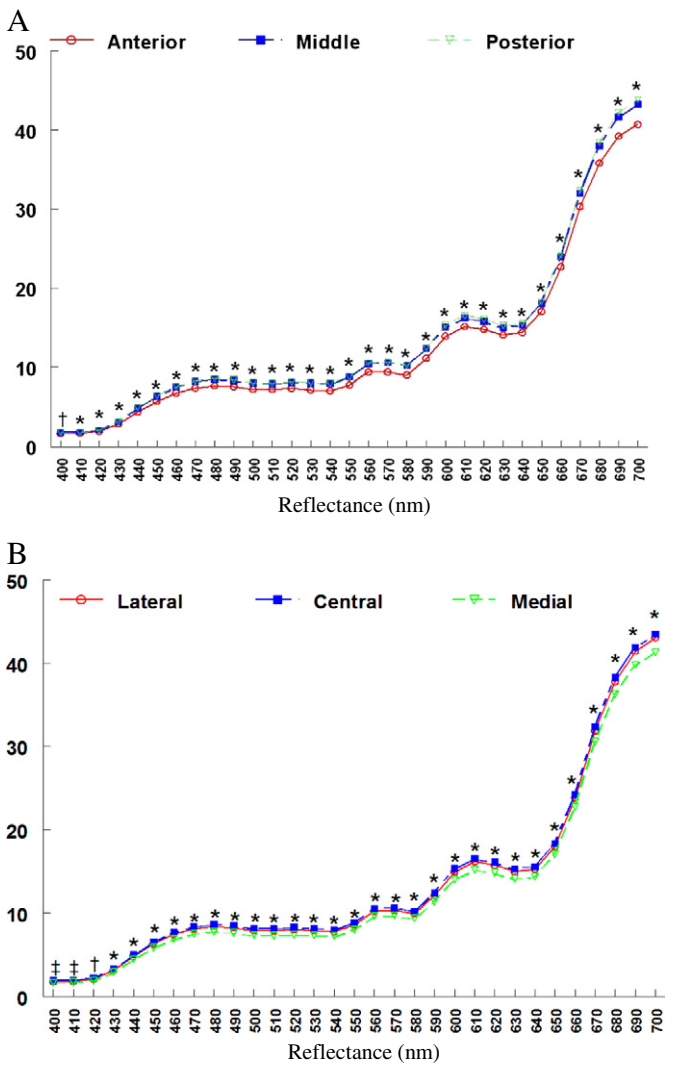

Fig. 4. Main effects of (A) steak location and (B) within-steak position on the reflectance spectra of *gluteus medius* steaks. In panel A, a cross (†) indicates steaks cut from the middle were greater ($P < 0.05$) than steaks cut from the anterior, whereas an asterisk (*) indicates steaks cut from the middle and posterior were greater ($P < 0.05$) than steaks cut from the anterior. In panel B, a double cross (‡) indicates the central position was greater ($P < 0.05$) than the medial position within steaks; a cross (†) indicates the central position was greater ($P < 0.05$) than the medial and lateral positions within steaks; and an asterisk (*) indicates that the central and lateral positions were greater ($P < 0.05$) than the medial position within steaks.

MID and POST portions of the GM had greater ($P < 0.05$) reflectance values than steaks cut from the ANT portion (Fig. 4A), indicating a greater amount of total reflected light, which corresponds with the greater L* values seen in the MID and POST steaks. Within GM steaks, the CENT position had greater ($P < 0.05$) reflectance values at 400 and 410 nm than the MED position, whereas reflectance values at 420 nm were greater ($P < 0.05$) in the CENT than either the MED or LAT positions within steaks (Fig. 4B). Furthermore, between 430 and 700 nm of the spectra, the CENT and LAT positions within GM steaks had greater ($P < 0.05$) reflectance values than the MED within-steak position, greater light reflectance in such a large area of the visual spectrum would be indicative of greater L* values seen in the CENT and LAT positions.

Again, several events affect meat color changes within muscles, but no research has been conducted on within-muscle differences in fresh color of the GM. The SM is similar to the GM in pH value (McKenna et al., 2005) and in that it is largely made up of α-white fibers (Kirchofer et al., 2002) In fact, Hunt and Hedrick (1977) found the GM to have similar α-white fiber percentages compared to the outer portion of the SM. The inner portion of the SM has long been studied due to its variation in color from the remainder of the muscle (Hunt & Hedrick, 1977; Sammel et al., 2002; Sawyer et al., 2007). Lee et al. (2008) reported that the cranial, distal quadrant of SM steaks (inner portion) was lighter than the remaining quadrants and this was especially true in steaks from the middle of the muscle, compared to those from the dorsal or ventral steaks, but the difference in redness was less defined. In the GM, the anterior portion was the darkest with the lowest hue angle and least reflectance in the visual spectrum (Table 3), which is not surprising because the ANT steaks would have chilled more quickly than steaks from the MID and POST portions. The more insulated portions were lighter. This was especially evident in the interaction of YG and steak position in that steaks from the fatter, more insulated YG45 carcasses, the difference between ANT from MID and POST were more defined that in YG12 where ANT only differed from POST. Within the GM steaks, the MED portion (closest to the backbone) was the darkest and had the least percentage of reflectance in the visual spectra. This portion also had the greatest pH, which is indicative of a darker fresh beef color.

3.5. Effect of display day on fresh beef color

There were no ($P \geq 0.893$) interactive effects between display day and QG, YG, steak location or within-steak position for L* values. However, steaks had the highest ($P < 0.05$) L* values on day one of

display, and L* values were still higher ($P < 0.05$) on day two than days three through seven of display (Table 4). And, through the last five days of display, GM steaks on day seven were only darker (lower L* value; $P < 0.05$) than GM steaks on day four of display. McKenna et al. (2005) reported that L* values played a minimal role in color stability.

Redness (a*) values decreased ($P < 0.05$) across the seven days of simulated retail display, and GM steaks from CHO-carcasses were redder (higher a* values; $P < 0.05$) than steaks from SEL-carcasses each day of display (QG × display day, $P < 0.001$; Fig. 5A). Conversely, hue angles increased ($P < 0.05$) as the duration of retail display was extended from day one to seven; yet, similarly, hue angles were lower ($P < 0.05$) – indicative of a redder color – for GM steaks from CHO- than SEL-carcasses (QG × display day, $P = 0.03$; Fig. 5B). In addition, steaks from CHO-carcasses were more ($P < 0.05$) yellow (greater b* values) than GM steaks from SEL-carcasses, but b* values were similar ($P > 0.05$) between the second and sixth day of display in SEL-steaks, whereas b* values of CHO-steaks differed ($P < 0.05$) between the second and fourth, as well as between the fourth and seventh, days of display (QG × display day, $P < 0.001$; Fig. 6A). Even though C* values also decreased ($P < 0.05$) as display time was extended, GM steaks from CHO-carcasses had a more ($P < 0.05$) vivid color (greater C* values) each day of display than did steaks from SEL-carcasses (QG × display day, $P < 0.001$; Fig. 6B). In the GM, steaks from CHO carcasses were consistently redder than those from SEL carcasses throughout display. However, when the interaction of QG and days of display was evaluated in the SM, muscles from CHO and SEL carcasses were similar at day zero and three of display, and only differed at day six (Sawyer et al., 2007).

King, Shackelford, and Wheeler (2011) compared animal and muscle attributes and their contribution to the variance in display color scores, and reported that QG did not contribute an appreciable degree of variance to the color traits of fresh beef in display. However, when that same lab compared the display attributes of the LM from different breeds of cattle, differences between breeds in color stability were inversely related to differences between breeds in marbling score, indicating that breeds with less marbling had greater color stability in the LM (King et al., 2010).

The lack of display color differences between steak positions (a* and C*) and within-steak locations (a*, b*, hue angle and C*) should be noted. Although within-muscle differences in display color values in the GM have not been reported previously, within-muscle differences in the SM were quite evident (Sawyer et al., 2007). Hood (1980) reported that rigor temperature accounted for 32.5% of the variation in muscle discoloration, and likely contributed to the variation in display found in the SM (Sawyer et al., 2007). However, within the GM, differences in insulation during rigor development were not enough to elicit display discoloration differences.

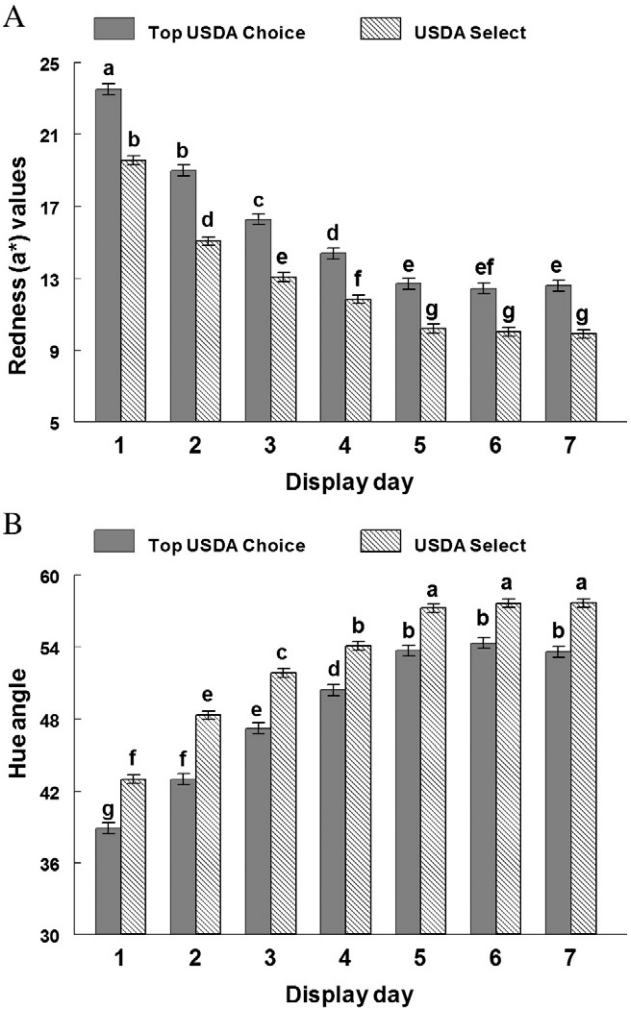

Fig. 5. Interactive effect of USDA quality grade and display day on (A) redness (a*) values ($P < 0.001$) and (B) hue angles ($P = 0.03$) of *gluteus medius* steaks. [a, b, c, d, e, f, g] Bars lacking common letters differ ($P < 0.05$).

3.6. Cooking losses and shear force values of gluteus medius steaks

Steaks from SEL-carcasses had greater ($P = 0.003$) cooking losses than GM steaks from CHO-carcasses, but cooking loss percentages were similar ($P = 0.53$) between YG categories (Table 2). Luchak et al. (1998) and George-Evins, Unruh, Waylan, and Marsden (2004) compared top sirloin steaks from different QG and did not

Table 4
Effects of display duration on instrumental color of *gluteus medius* steaks.

	Display day								$P > F$[a]		
Variable	1	2	3	4	5	6	7	SE	D	Q × D	Y × D
Lightness (L*)[b]	40.8^{v}	40.3^{w}	39.2^{xy}	39.6^{x}	39.3^{xy}	39.2^{xy}	39.0^{y}	0.24	<0.001	0.89	1.00
Redness (a*)[b]	21.6^{v}	17.0^{w}	14.7^{x}	13.1^{y}	11.5^{z}	11.2^{z}	11.2^{z}	0.19	<0.001	<0.001	0.29
Yellowness (b*)[b]	18.5^{v}	17.2^{w}	17.1^{wx}	16.9^{xy}	16.8^{yz}	16.8^{yz}	16.6^{z}	0.11	<0.001	<0.001	0.48
Hue angle (°)[c]	40.9^{z}	45.6^{y}	49.5^{x}	52.2^{w}	55.5^{v}	56.0^{v}	55.6^{v}	0.29	<0.001	0.03	0.96
Chroma (C*)[d]	28.4^{v}	24.3^{w}	22.5^{x}	21.4^{y}	20.3^{z}	20.2^{z}	20.1^{z}	0.19	<0.001	<0.001	0.26

[v,w,x,y,z] Within a row, least squares means lacking common superscript letter differ ($P < 0.05$).

[a] Probability value of the main effect of display day (D) and the interactive effects with quality grade (Q) and yield grade (Y) categories.

[b] L* = a measure of darkness to lightness (a greater L* values indicates a lighter color); a* = a measure of redness (a greater a* value indicates a redder color); and b* = a measure a yellowness (a greater b* values indicates a more yellow color).

[c] Hue angle (reported in degrees) represents the change from the true red axis (a larger hue angle indicates a greater shift from red to yellow).

[d] Chroma, or saturation index, is a measure of the total color/vividness of color (a greater chroma value indicates greater total color/a more vivid color).

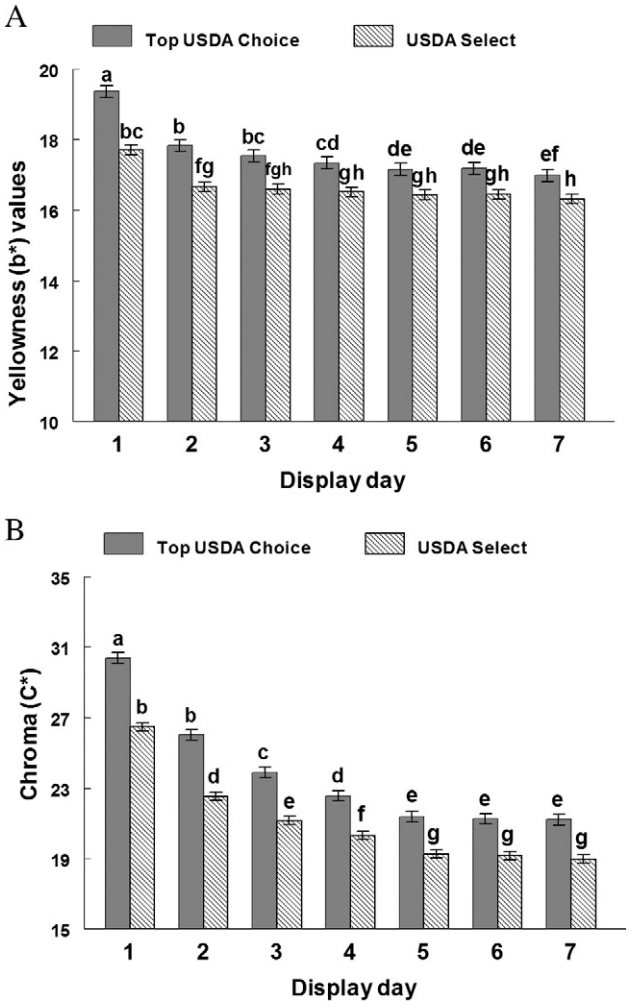

Fig. 6. Interactive effect of USDA quality grade and display day on (A) yellowness (b*) values ($P < 0.001$) and (B) chroma (C*) values ($P < 0.001$) of *gluteus medius* steaks. [a,b,c,d,e,f,g,h] Bars lacking common letters differ ($P < 0.05$).

find differences in cooking loss. Even though cooking losses did not ($P = 0.54$) differ among steak locations, the LAT position within GM steaks had the greatest ($P < 0.05$) cooking loss percentages, and the MED position within GM steaks had greater ($P < 0.05$) cooking losses than the CENT position (Table 3). Unlike the present study, Rhee et al. (2004) found steaks from the POST end of the GM to have less cooking loss than those from the ANT end. However, within-steak differences have not been previously studied. It is possible that the surface area to mass ratio of the different GM steak sections affected cooking loss. Pre-cooking weights of steaks from the CENT position were heaviest, and steaks from the MED were heavier than those from LAT positions ($P < 0.012$; data not presented). Heavier steaks would have a lower surface area to mass ratio, thus the least area to lose moisture and lower cooking losses.

Warner–Bratzler shear force values were not affected by either YG ($P = 0.48$) or QG ($P = 0.13$) category (Table 2). Similarly, Luchak et al. (1998) found no differences in GM shear force or sensory panel tenderness due to QG. However, King, Wheeler, Shackelford, and Koohmaraie (2009) compared USDA low Choice and SEL GM and TB muscles, and found that steaks from low Choice carcasses had a minor, but significant, advantage in overall tenderness over SEL as judged by a sensory panel; yet, GM steaks from SEL carcasses had decreased slice shear force values compared to those from low Choice. Furthermore, George-Evins et al. (2004) found GM steaks from SEL carcasses to have greater WBSF values than those from low Choice and CAB carcasses when cooked to 71.1 °C.

However, the MED position of steaks cut from the MID of the GM had greater ($P < 0.05$) WBSF values than the LAT position of MID-cut steaks, as well as the CENT and MED positions of steaks cut from both the ANT and POST portions of the GM (location × within-steak position, $P < 0.001$; Fig. 7). Conversely, the CENT position of steaks cut from the ANT GM had lower ($P < 0.05$) WBSF values than the LAT position of ANT steaks and steaks cut from the MID and POST portions of the GM, regardless of the within-steak position.

Like color, muscle tenderness differences within and between muscles can be attributed to several factors, including sarcomere length and cold shortening, collagen content and solubility, and the extent of postmortem proteolysis. Rhee et al. (2004) compared steaks from the POST and ANT ends of the GM and found no difference in WBSF, sarcomere length, or collagen content. However they reported more desmin degraded in steaks from the ANT end. Previous research has not extensively studied within-steak differences in GM tenderness. However, several other large muscles have been tenderness-mapped laterally and longitudinally, including the SM (Reuter, Wulf, & Maddock, 2002; Sawyer et al., 2007; Senaratne, Calkins, de Mello, Pokharel, & Hinkle, 2010), the BF (Reuter et al., 2002; Senaratne et al., 2010), the TB (Searls, Maddock, & Wulf, 2005), the infraspinatis (IF; Searls et al., 2005), and, of course, the LM (Janz, Aalhus, Dugan, & Price, 2006; Jeremiah & Murray, 1984). Searls et al. (2005) attributed several of the differences in tenderness within muscles to the proximity and attachment of the muscle to the bone and the action of the muscle in the live animal. According to the Bovine Myology website (bovine.unl.edu), the action of the GM is to extend the hip joint and abduct the rear limb. It is attached on the medial side to the pelvic bone and on the posterior end to the femur. The origin and insertion portions of the GM muscle were not evaluated in this study as only top sirloin butts (IMPS 184) were selected rather than the entire muscle dissected from the carcass.

Rhee et al. (2004) reported that the GM had the shortest sarcomere length among 11 muscles studied, including the ST and SM. They also reported a high degree of variation in sarcomere length, both within and among GM steaks. Interestingly, the GM was also among the muscles with the least amount of collagen, greater only than the PM and similar to the LM. Consistently tender muscles, such as the IF, have less within-muscle variation than tougher muscles such as the TB (Searls et al., 2005). The GM is among the tougher muscles as evaluated by Von Seggern et al. (2005) and Sullivan and Calkins (2011). However, the GM was among the more tender muscles as evaluated by a sensory panel and a medium-tenderness muscle as evaluated by WBSF (Schönfeldt & Strydom, 2011). Rhee et al. (2004) also found the GM to be midrange in sensory tenderness

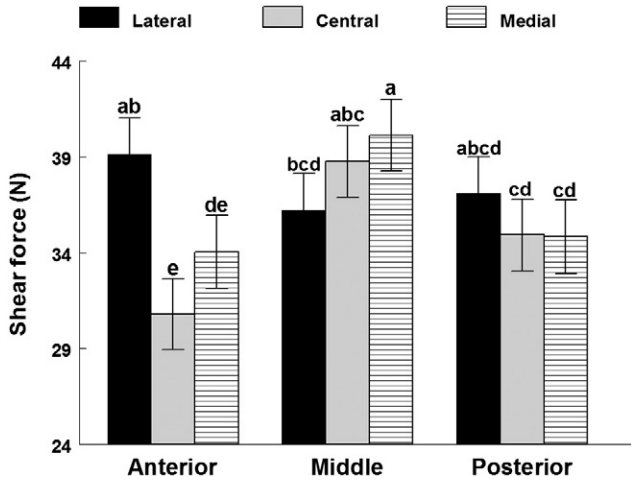

Fig. 7. Interactive effect of steak location and within-steak position ($P < 0.001$) on Warner–Bratzler shear force values of *gluteus medius* steaks. [a, b, c, d, e]Bars lacking common letters differ ($P < 0.05$).

and WBSF among 11 muscles. The spread in WBSF means within the GM in the present study was less than 10 N, whereas spread of within-muscle means in WBSF in the SM was greater than 24 N (Sawyer et al., 2007).

In the GM, the anterior end, especially the lateral portion, is attached to the illium of the pelvic bone, and Searls et al. (2005) hypothysized that areas of muscles attached to the bone likely contained a greater amount of connective tissue due to that attachment. Furthermore, in the anterior end, the more lateral portion is tapering in for attachment, thus concentrating the connective tissue. Consequently, Rhee et al. (2004) did not find a difference in collagen concentration between POST and ANT steaks in the GM. However, they did not analyze the most anterior steak in the muscle as was done in the present study. Furthermore, the ANT, LAT portion of the GM could be most susceptible to toughening due to cold shortening due to its proximity to the surface of the carcass. The CENT and MED portions of the ANT steaks are likely used mostly for support of the remainder of the muscle, which may explain that more tender portion of the muscle.

In the CENT steaks, the MED portion would likely be closely associated with the pelvic bone (bovine mycology website), and its toughening could be attributed to the connective tissue associated with that attachment (Searls et al., 2005). Within the top butt, the posterior steaks would mostly provide support for the remaining portions of the muscle, as the extreme posterior portion of the muscle is in the round. This supportive section of the GM was found to be more consistent within the steaks and among the more tender portions.

4. Conclusions

Variation in fresh beef color and discoloration within the GM was minimal and likely not economically important. However, tenderness variation within the GM may have some potential for economic advantage. Large muscles, such as the GM, are often cut into smaller, more appropriately-portioned steaks for food service establishments and retail sale. The present study indicated that these steaks could be further segregated according to tenderness to optimize the eating experience of consumers. Tougher sections of the GM may need further processing with a tenderizing marinade or a more tenderizing cookery method. Further research would be needed to determine how these variations in tenderness can be overcome with further processing steps, such as moist vs. dry cookery, end-point temperature optimization, or ingredient addition.

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