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Beef Carcass Size and Aging Time Effects on Yield and Color Characteristics of Top Round Steaks

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Abstract: Variation in cut size and weight of fabricated subprimals is a challenge of increased beef carcass weights. Subsequently, variation in carcass size has resulted in consistency challenges during retail display. The objective of this study was to assess three aging periods of commercially available top rounds from varying carcass weights as it relates to yield and color characteristics. In the current study, 21 industry average weight (AW; 340 to 409 kg; no industry discount) beef carcasses and 21 oversized (OS; exceeding 454 kg; receive a discount) beef carcasses were evaluated. Carcasses were selected at a commercial beef packing plant, where the left and right (paired) top round subprimals of each carcass were procured. Paired top rounds were assigned to a short (8 d), average (23 d), or extended (42 d) postmortem aging period. After wet-aging, subprimals were fabricated into steaks for additional analysis. Steaks were evaluated as whole top round steaks or further fabricated into "superficial" and "deep" portions at 5.08 cm from the superficial edge of the *Semimembranosus* and the *Adductor* muscle. Top rounds and steaks from OS carcasses were larger ($P < 0.01$) than those from AW carcasses. Quantitative color of the anatomically deep locations of the OS steaks had the greatest mean L^* (lightness; $P < 0.01$), a^* (redness; $P < 0.01$) and b^* (yellowness; $P < 0.01$) values. Extending the aging timeline increased L^* (lightness; $P < 0.01$), decreased a^* (redness; $P < 0.01$), and decreased b^* (yellowness; $P < 0.01$). Alternative top round steak fabrication that separates the deep and superficial anatomical locations could be an effective means of providing more uniform steaks.

Key words: beef, carcass size, top round, aging, color
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Introduction

Grid-based marketing systems provide premiums and discounts to beef carcasses as a reflection of carcass merit and merchandising ability. In the case of oversize carcasses, discounts in the United States beef industry begin to be applied once carcasses reach the threshold of 408 kg (USDA-AMS, 2020). With the average finished beef carcass weight in the US continuing to rise (USDA-ERS, 2020), a greater percentage of carcasses are assigned weight-based discounts when marketed on a grid-based pricing system. Despite the discounts applied for carcass weight, the US beef industry continues to see an uptick in carcass weights, which could partially be attributed to the efficiencies gained by adding more weight per head.

The round is a high-volume beef primal that contains the *Semimembranosus* (SM) muscle. Due to its size, the SM has been observed to take additional time to cool compared to other muscles on the carcass (Klauer, 2019). The anatomically deep location of the SM, closest to the femur bone, cools at a slower rate than other parts of the carcass, while concomitantly the pH drops more rapidly than the anatomically superficial location (Lancaster et al., 2020). While the SM has been classified as "moderate" for color stability by McKenna et al. (2005), discoloration of

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top rounds at fabrication and during retail display has been observed (Sammel et al., 2002; Seyfert et al., 2006; Kim et al., 2010; Nair et al., 2016). Kim et al. (2010) attributed the discoloration due to myoglobin denaturation and noted potential tenderness challenges consequently. The anatomically deep location of steaks from oversized carcasses has been observed being lighter in color and more yellow in appearance compared to the anatomically superficial locations (Lancaster et al., 2020). The objective of this study was to assess three aging periods of commercially available top rounds from varying carcass weights as it relates to yield and color characteristics.

Materials and Methods

Product procurement

Carcasses were selected at Washington Beef (Toppenish, WA) in September 2019. Selected carcasses ($n = 42$) were commercially sourced from youthful (determined to be less than 30 months of age physiologically by United States Department of Agriculture [USDA] grading protocol), traditional, concentrate-fed, *Bos taurus*, beef cattle. Due to the opportunistic nature of the carcasses selected at a commercial beef processing facility, specific concentrate cattle rations, and other management practices were not known. Two-carcass weight groups were identified; average sized (AW) (340 to 409 kg; $n = 21$) and oversized (OS) (≥454 kg; $n = 21$) carcasses. Carcasses were included into the study if they met the requirements of USDA calculated Yield Grade 2 and 3. All carcasses selected were USDA Choice quality grade. During selection, carcass parameters were recorded (hot carcass weight, ribeye area, calculated yield grade, and quality grade) from a camera grading system (VGB2000, E+V Technology, Oranienburg, Germany). Carcasses were fabricated by plant personnel in the traditional commercial manner. The top rounds from both sides were collected and remained paired throughout the duration of the trial. Top rounds (NAMA #168) were vacuum packaged and transported under refrigerated conditions (4°C) to the University of Idaho Vandal Brand Meats Lab for further aging (1.6°C).

Product preparation

Seven carcasses from each carcass size treatment were randomly assigned to one aging treatment of 8 d, 23 d, or 42 d postmortem. Two aging times of the top rounds were identified as the minimum (8 d) and mean (23 d) aging time observed for top rounds at retail in the 2015 National Beef Tenderness survey (Martinez et al., 2017). The 42 d aging treatment time was observed in previous research as an optimal aging period for top rounds under extended aging conditions (Colle et al., 2016). Paired top rounds were assigned to an aging treatment and subsequent analyses were performed where carcass was considered the experimental unit thereby paired top round data were averaged to result in a final data point. Following the respective aging periods, top rounds were fabricated by removing the *Gracilis*, *Pectineus*, and *Sartorius* muscles at the natural seams to isolate the SM and *Adductor* muscle grouping to produce the equivalent of a NAMA #169A (NAMA, 2014). Subsequently, top rounds were denuded and trimmed to steak-ready level and then fabricated into steaks. Top rounds were faced perpendicular to the longitudinal axis of the cut at the distal edge from where the aitch bone was removed; subsequently, 2.54-cm-thick steaks were cut proximal to distal using a scalloped boneless bandsaw blade (Walton's Inc., Wichita, KS) on a bandsaw (Butcher Boy SAE20, Butcher Boy Machines International LLC, Selmer, TN). Steaks from the paired top rounds were fabricated and assigned for further analysis. One steak from each of the top rounds remained whole, while remaining steak samples from top round were fabricated to isolate the SM (from the *Adductor*) and were subsequently cut into an anatomically superficial and deep section (Figure 1). The outermost "superficial" steak was separated from the interior "deep" steak of the SM 5.08 cm from the anatomically superficial edge of the cut.

All steak samples were individually weighed (GFK 165a Bench Scale, Adam Equipment, Oxford, CT). The pH of each steak sample was measured with a portable pH meter (Apera Instruments SX811-SS, Columbus, OH) utilizing a puncture-type probe at 2.54 cm from

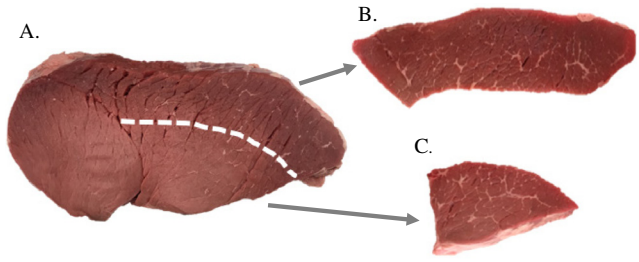

Figure 1. Image of traditionally fabricated top round steak (A) compared to alternatively fabricated steaks (B, C). The alternative fabrication method, excluding the adductor, is divided into superficial (B) and deep (C) portions based on anatomical locations from the *Semimembranosus*. The deep section of the *Semimembranosus* muscle is separated at 5.08 cm from the superficial edge of the steak.

the anatomically superficial and deep edge of the SM and the *Adductor* of each whole steak prior to further fabrication into "deep" and "superficial" sections. Cut steaks were identified by steak section treatment combination (SSTC) with respect to carcass weight (AW whole, AW deep, AW superficial, AW *Adductor*, OS whole, OS deep, OS superficial, OS *Adductor*). Steaks for retail display were overwrapped using oxygen permeable polyvinyl chloride film (oxygen transmission: 1,450 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 allowed to bloom for 1 h prior to the color evaluation.

Color evaluation

Objective steak color (L^*, a^*, b^*) was scanned using a Nix Pro2 Color Sensor (Nix Sensor Ltd., Hamilton, Ontario, Canada; D65 illuminant, 10° observer angle, 14 mm aperture). Objective color was assessed 30 min after top rounds were fabricated into steaks in order to allow for sufficient bloom time to occur. Each SSTC was measured at 2 locations and then those measurements were averaged for the final SSTC datapoint. Additionally, oxygen consumption rate (OC) and metmyoglobin reducing activity (MRA) was observed utilizing one representative steak from each SSTC. Both OC and MRA were conducted in accordance with the protocol described by Colle et al. (2019) and provided in Section XI, and analyzed using formulas provided in Section IX, of the Meat Color Measurement Guidelines (AMSA, 2012). Samples for OC followed the standard procedure using an incubator set at 25°C for 20 min. Samples for MRA assay were submerged in a 0.3% (w/w) sodium nitrite solution for 20 min at room temperature (18°C) to induce met myoglobin formation. Surface reflectance was measured using a portable handheld spectrometer (MiniScan EZ, HunterLab, Reston, VA) set to illuminant A using a 25 mm aperture with a 10° standard observer and was calibrated daily using a black and white calibration tile. The OC was calculated as a reflection of the percentage of oxymyoglobin (OMb) as $OC = \left(\frac{\text{Ititial\%OMb} - \text{Ending\%OMb}}{\text{Initial\%OMb}}\right) \times 100$. Metmyoglobin reducing activity was calculated using the percentage of metmyoglobin (MMb) as $MRA = \left(\frac{\text{Initial\%MMb} - \text{Final\%MMb}}{\text{Initial\%MMb}}\right) \times 100$.

Lipid oxidation

Following color evaluation, thiobarbituric acid reactive substances (TBARS) were used to measure secondary lipid oxidation products. Analysis was conducted following the protocol provided in Appendix O of the *Meat Color Measurement Guidelines* (AMSA, 2012). The samples for the *Adductor*, deep and superficial locations were obtained from the exposed (bloomed) side of the steak, avoiding the edge of the steak following the procedure as previously described by Colle et al. (2016). Briefly, samples were obtained by excluding the edge of the steak (approximately 1 cm), and subsamples were 0.5 cm wide, 2.0 cm long, and 2.54 cm thick were evaluated.

Statistical analysis

All analyses were carried out using SAS V 9.4 (SAS Institute, Inc., Cary, NC). All data were analyzed using linear mixed models in the GLIMMIX procedure. A randomized complete block design was assumed with SSTC and aging period as fixed effects and carcass as the block. Differences in the least squares means (LSM) were assessed using pairwise comparisons and a Tukey adjustment for multiple comparisons. Statistically significant differences were identified at $P < 0.05$.

Results and Discussion

Analysis of carcass traits are displayed in Table 1. Average hot carcass weights of carcasses in the OS group were heavier ($P < 0.01$) than carcasses in the AW group (480 vs. 376 kg, respectively). In addition, OS carcasses had a greater ($P < 0.01$) average yield grade than the AW carcasses (USDA YG 3.6 vs. 2.8, respectively). However, all carcasses fell within the

Table 1. Carcass trait means of AW[1] ($n = 21$) and OS[2] ($n = 21$) carcasses

	AW			OS			
	Min	Max	Average	Min	Max	Average	SEM
Carcass Weight (kg)	345	407	376[b]	456	509	480[a]	4
Calculated Yield Grade	2.0	3.9	2.8[b]	2.26	3.9	3.6[a]	0.13
Ribeye Area (cm^2)	80.0	112.3	94.8[b]	89.0	118.7	101.3[a]	1.7
Marbling Score[3]	418	691	501	407	610	509	14

[1]AW = average-weight carcass (340-409 kg).

[2]OS = oversized carcass (≥454 kg).

[3]Marbling score: 400 = small, 500 = modest, 600 = moderate.

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

parameters of USDA Yield Grade 2 or 3 as outlined in the carcass selection criteria. The average ribeye area in OS carcasses were larger ($P = 0.01$) than the AW carcasses (101.3 vs. 94.88 cm^2, respectively). Mean marbling scores were not different ($P = 0.71$) between the AW and OS carcass groups, with the average of both weight groups being USDA Choice (marbling score: 501 vs. 509, respectively). In agreement with previous research, ribeye area was larger for OS than AW carcasses (Fevold et al., 2019; Klauer, 2019; Lancaster et al., 2020). Due to the carcass data collection being derived from the online camera vision system, the 12th rib fat thickness was not reported as it was directly included in the USDA Yield Grade automatically formulated by the camera. However, it can be postulated that it is likely the OW carcasses had a greater 12th rib fat thickness measurement, which led to the higher calculated USDA Yield Grade reported for that carcass treatment group.

Top round characteristics

Characteristics of top round subprimal fabrication yields and dimensions are displayed in Table 2. Top rounds from OS carcasses had a greater ($P < 0.01$) untrimmed weight (13.75 vs. 10.95 kg, respectively), a greater ($P < 0.01$) trimmed weight (8.10 vs. 6.89 kg, respectively), and a greater ($P < 0.01$) amount of trim generated from the whole top round subprimal (4.06 vs. 5.65 kg, respectively) compared to AW carcasses. In addition, trimmed OS top rounds were 5.11 cm longer ($P < 0.01$), on average, and 3.76 cm wider ($P < 0.01$), on average, than AW top rounds. Weights of all whole steaks, prior to subsequent fabrication into smaller subsections, from OS top rounds were heavier ($P < 0.01$) than those from AW top rounds. Lancaster et al. (2020) previously reported a difference in untrimmed top round weight but did not see a difference in trimmed top round weight. The larger sample size in the current study likely contributes to the observed difference in the trimmed top rounds. Additionally, West et al. (2011) reported greater yields on boneless ribeye and strip loin subprimals fabricated from OS carcasses compared to AW carcasses.

Table 2. Mean top round subprimal characteristics of AW[1] and OS[2] carcasses

	AW ($n = 42$)	OS ($n = 42$)	SEM
Untrimmed Weight (kg)	10.95[b]	13.75[a]	0.20
Trimmed Weight[3] (kg)	6.89[b]	8.10[a]	0.10
Weight of Trimmings[4] (kg)	4.06[b]	5.65[a]	2.05
Length (cm)	55.88[b]	60.99[a]	0.38
Width (cm)	45.34[b]	49.10[a]	0.33
Steak Weight (kg)	0.78[b]	0.89[a]	0.01

[1]AW = average carcass (340-409 kg).

[2]OS = oversized carcass (≥454 kg).

[3]Trimmed weight was measured on denuded top rounds and contained *Semimembranosus* and *Adductor* muscles.

[4]Trim comprised of *Gracilis*, *Pectineus*, and *Sartorius* muscles and associated adipose tissue removed at the natural seams.

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

pH

Previous research has established differences of pH by location within top rounds (Sammel et al., 2002; Lee et al., 2007). Therefore, the current study chose to focus on the differences between the deep and superficial steaks fabricated from the isolated SM top round steaks among hot carcass weight treatments. There was an aging period by SSTC interaction ($P = 0.02$) for steak pH (Table 3). At day 8 of aging, no difference in pH was observed between SSTCs, while at days 23 and 42 of aging, differences became apparent. The AW deep and AW superficial sections of the SM had the greatest pH at day 23, and the AW deep section had the greatest pH at the day 42 aging period. The current data reports that the deep locations of the SM were consistently higher in pH than that of the superficial locations within carcass weight treatments. This finding aligns with previous research of the deeper portion having a higher mean pH than the superficial locations of the SM (Sammel et al., 2002; Lee et al., 2007). Lee et al. (2007) attributed variation in the pH of top round steaks to position in the subprimal (pH increased dorsal to ventral). In contrast, other research has indicated no difference in ultimate pH of the deep and superficial locations (Sawyer et al., 2007; Lancaster et al., 2020). Despite the positional differences, Colle et al. (2016) reported no difference in pH of steaks aged for varying lengths of time (day 2 to 63) measured at a consistent location on the exterior edge of the steak.

The authors of the current study expected the ultimate mean pH observations of the OS deep location to be lower than that of the superficial in both the AW and OS carcasses; however, this was not the case. Lancaster et al. (2020) observed a more rapid decline in pH of oversize carcass rounds compared to average weight carcass rounds; however, ultimate pH was not different between the carcass size treatments of that study. The more rapid decline of pH in oversized carcass rounds is likely due to the greater mass of the round primal and thus the ability of those rounds to retain heat and therefore speed the metabolism of postmortem acid products. Regardless of the aging treatment, the OS deep

Table 3. Mean pH of deep and superficial top round sections of the *Semimembranosus* by hot carcass weight treatment and aging period

	Steak Section Treatment Combination ($n = 7$)					
Aging Period	AW[1] Add[2]	AW[1] Deep[2]	AW[1] Sup[3]	OS[4] Add[2]	OS[4] Deep[2]	OS[4] Sup[3]
8 d	5.54 ± 0.02	5.55 ± 0.02	5.52 ± 0.02	5.56 ± 0.02	5.57 ± 0.02	5.50 ± 0.02
23 d	5.62 ± 0.02[a]	5.63 ± 0.02[a]	5.59 ± 0.02[ab]	5.54 ± 0.02[ab]	5.55 ± 0.02[ab]	5.50 ± 0.02[b]
42 d	5.56 ± 0.02	5.55 ± 0.02	5.47 ± 0.02	5.46 ± 0.02	5.52 ± 0.02	5.48 ± 0.02

[1]AW = steaks sourced from average carcass (340–409 kg).

[2]Add = sample from the *Adductor* muscle.

[3]Deep = sample from the deep section of the SM.

[4]Sup = sample from the superficial section SM.

[5]OS = steaks sourced from oversized carcass (≥454 kg).

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

location steaks of the current study had a numerically higher mean pH compared to the other steaks evaluated (Table 3). Indeed, the OS superficial section had a mean pH that was significantly lower ($P < 0.05$) than that of the AW *Adductor* and AW Deep sections of top round steaks observed in the 23 d aging treatment. Normal ultimate pH of beef muscle is expected to be between 5.40 and 5.79 (Lawrie, 1958; Tarrant and Mothersill, 1977; Zhang et al., 2005; Matarneh et al., 2017), of which all of the mean pH measurements in the current study were observed to be within this range.

Lipid oxidation

No interaction of lipid oxidation was observed between SSTC and aging period ($P = 0.47$). Concomitantly, no SSTC effects were observed ($P = 0.39$); however, there was an effect on aging with regard to lipid oxidation ($P < 0.01$). Lipid oxidation by aging period results were reported in Table 4. Lipid oxidation values were greater ($P < 0.01$) for the steaks aged 42 d compared to steaks aged for 8 d or 23 d (0.20 vs. 0.12 and 0.11 mg malondialdehyde/kg meat, respectively). Colle et al. (2016) observed increased TBARS means in round subprimals as aging progressed. All lipid oxidation values remained below 1 mg malondialdehyde per kg of meat regardless of aging period. The threshold of 1 mg malondialdehyde per kg of meat was suggested by McKenna et al. (2005) for the detection of off-flavors linked to lipid oxidation and is one of several studies that have attributed elevated TBARS values to off-flavors (Tarladgis et al., 1960; Campo et al., 2006). Additionally, Colle et al. (2016) reported extended aging of top round steaks also resulted in TBARS values below the threshold of off-flavors. Lipid oxidation has been linked in the past with myoglobin oxidation (Faustman and Cassens, 1990) and as a result may decrease color stability in fresh beef subprimals as aging time progresses.

Objective color

No interaction with regard to objective color (L^*, a^*, and b^*) was observed between SSTC and aging time ($P = 0.38$, 0.74, and 0.06, respectively); however, the main effects of SSTC and aging were significant ($P < 0.01$). Mean objective color values for SSTC are shown in Table 5. The OS deep portion steaks were the lightest in color while the superficial

Table 4. Objective color L^* (0 = black; 100 = white), a^* (−50 = green; 50 = red), and b^* (−50 = blue; 50 = yellow) means of *Adductor*, deep and superficial top round sections of the *Semimembranosus* (SM) and whole top round steak by aging period. Metmyoglobin reducing activity and lipid oxidation values (thiobarbituric acid reactive substances [TBARS][1]) means of *Adductor*, deep and superficial top round sections of the *Semimembranosus* by aging period ($n = 7$)

Aging Treatment	L^*	a^*	b^*	Metmyoglobin Reducing Activity	TBARS
8 d	34.78 ± 0.46[c]	27.02 ± 0.31[a]	20.07 ± 0.23[a]	24.75 ± 1.06[a]	0.12 ± 0.01[b]
23 d	36.58 ± 0.47[b]	25.01 ± 0.32[b]	17.97 ± 0.24[b]	15.81 ± 1.11[b]	0.11 ± 0.01[b]
42 d	38.60 ± 0.45[a]	25.66 ± 0.30[b]	17.78 ± 0.23[b]	14.39 ± 1.12[b]	0.20 ± 0.01[a]

[1]Milligrams malondialdehyde/kilograms meat.

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

Table 5. Objective color L^* (0 = black; 100 = white), a^* (−50 = green; 50 = red), and b^* (−50 = blue; 50 = yellow) means of *Adductor*, deep and superficial top round sections of the *Semimembranosus* (SM), and whole top round steak by hot carcass weight treatment. Metmyoglobin reducing activity means of *Adductor*, deep and superficial top round sections of the *Semimembranosus* by hot carcass weight treatment ($n = 7$)

Top Round Treatment Location	L^*	a^*	b^*	Metmyoglobin Reducing Activity
AW[1] Add[3]	36.19 ± 0.55^{cd}	25.15 ± 0.37^{cd}	17.58 ± 0.31^{d}	13.16 ± 1.83^{c}
AW[1] Deep[4]	38.46 ± 0.47^{b}	26.14 ± 0.31^{bc}	19.40 ± 0.26^{c}	16.09 ± 1.35^{c}
AW[1] Sup[5]	32.28 ± 0.46^{e}	24.75 ± 0.31^{de}	19.99 ± 0.25^{b}	27.47 ± 1.26^{a}
AW[1] Whole[6]	35.73 ± 0.53^{d}	24.31 ± 0.35^{e}	17.41 ± 0.30^{d}	–
OS[2] Add[3]	38.10 ± 0.52^{b}	26.42 ± 0.35^{b}	18.85 ± 0.29^{c}	15.53 ± 1.99^{c}
OS[2] Deep[4]	41.51 ± 0.46^{a}	27.66 ± 0.31^{a}	21.43 ± 0.25^{a}	14.18 ± 1.35^{c}
OS[2] Sup[5]	33.37 ± 0.47^{e}	26.25 ± 0.31^{b}	17.92 ± 0.26^{d}	23.45 ± 1.35^{b}
OS[2] Whole[6]	37.58 ± 0.53^{bc}	26.58 ± 0.36^{b}	19.28 ± 0.30^{c}	–

[1]AW = steaks sourced from average carcass (340–409 kg).

[2]Add = sample from the *Adductor* muscle.

[3]Deep = sample from the deep section of the SM.

[4]Sup = sample from the superficial section SM.

[5]OS = steaks sourced from oversized carcass (≥454 kg).

[6]Whole intact top round steak including the SM and *Adductor* muscles.

[a–d]Within a color parameter (column), means without a common superscript differ ($P < 0.05$).

portion from OS and AW carcasses were the darkest ($P < 0.01$) in color (L^* values of 41.51 vs. 33.37 and 32.28, respectively). Additionally, the OS deep location steaks were the most red (a^*; $P < 0.01$) of the SSTC and nearly all SSTC derived from OS carcasses were more red than those from AW carcasses. The OS deep portion steaks were the most yellow (b^*) in color ($P < 0.01$) while the AW whole, OS superficial, and AW *Adductor* had the lowest b* values. The objective color means by aging period are shown in Table 4. As the aging periods progressed the L^* values increased ($P < 0.01$) with the lightest color being observed at the 42 d aging period. Steaks from the 8 d aging period were more red ($P < 0.01$) than steaks from the 23 d and 42 d aging periods (27.02 vs. 25.01 and 25.66, respectively). Additionally, steaks had greater b^* values ($P < 0.01$) at the 8 d aging period compared to the longer aging periods. Top round steaks have been noted for having variation in color (Sammel et al., 2002; Seyfert et al., 2004; Lee et al., 2007; Fevold et al., 2019). Additionally, the SM muscle is often lighter (higher L^*) than other muscles in the carcass (McKenna et al., 2005). In past research, delayed temperature reduction, and more rapid pH decline, of the deep SM location negatively impacted steak color (Lancaster et al., 2020). Previous research indicates more rapid pH declines increases protein denaturation, which is partially attributed to the lighter colored muscle (Hector et al., 1992; Lancaster et al., 2020). Lawrie and Ledward (2006) suggested denatured proteins have a more open structure, which results in greater light scattering and negatively impacts meat color. Furthermore, the increased rate of glycolysis of the deep SM location can result in negative color consequences and have similar appearance to pale, soft, and exudative pork in the beef muscle (Nair et al., 2016). Moreover, the OS deep section was the lightest and most yellow of all SSTC sections. The deep section of the top round has been attributed with being lighter in color, redder in appearance, and more yellow than the superficial section (Lee et al., 2007). Lancaster et al. (2020) found oversized beef carcasses (>432 kg) amplified the lightness and yellowness of the deep portion of the SM. Mancini and Ramanathan (2014) reported that beef aged for a longer time (45 d) has greater color intensity post bloom due to decreased OC, but also decreased color stability over the shelf life of the product.

Metmyoglobin reducing activity

The AW superficial SSTC location had the greatest metmyoglobin reducing activity ($P < 0.01$) while the *Adductor* and deep SM locations from both the AW and OS carcasses had the lowest MRA (Table 5). The MRA by aging period ($P < 0.01$) was displayed in Table 4. Metmyoglobin reducing activity was greatest for the short (8 d) aging period and was greatly decreased for the longer aging periods (23 d and 42 d). The advantage of the superficial anatomical locations

of the SM in MRA suggests benefits in terms of retail color stability. The SM has been previously identified as a muscle of intermediate color stability, with low MRA (McKenna et al., 2005). Furthermore, the superficial location within the SM has been reported to have greater MRA than the deep location (Seyfert et al., 2006; Nair et al., 2017). Nair et al. (2017) reported the superficial portion of the top round had greater mitochondrial functionality. These findings are partially attributed to the mitochondria's role in the reduction of metmyoglobin formation.

Oxygen consumption rate

All SSTC OC rates were measured on the day steaks were fabricated. No significant interaction between SSTC and days of aging was observed for OC rate ($P = 0.19$); concomitantly, no significant days of aging OC effects were observed ($P = 0.16$). The SSTC with regard to OC rate served as a significant source of variation ($P = 0.02$). The OS deep SM section had the lowest OC rate ($P < 0.01$) while consumption rate of the AW deep section were similar to that of the AW and OS superficial sections (Figure 2). Nair et al. (2017) reported lower OC rates, a reflection of decreased mitochondrial functionality, in the deep portion of the top round. Sammel et al. (2002) found the superficial location of the top round had greater OC rates and total aerobic reducing activity.

Bendall (1972) reported an increase in the OC rate in fresh beef muscle postmortem at higher temperatures compared to lower temperatures. Based on previous research, Lancaster et al. (2020) clearly demonstrated a higher maintained postmortem temperature of the deep location of beef rounds compared to beef rounds of average size carcasses. This is likely the explanation for the observed difference with the OC rate of the deep location in the oversized beef carcass top rounds of the current study.

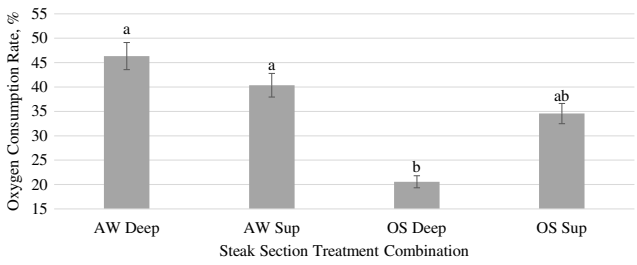

Figure 2. Oxygen consumption rate of beef top round steaks. Samples from average weight (AW; 340-408 kg; $n = 21$) and oversized (OS; ≥ 454 kg; $n = 21$) carcasses were analyzed by deep or superficial sections within the *Semimembranosus* muscle of steaks. Superficial sections were separated from the deep portion at 5.08 cm from the superficial edge of the steak. Rates are means ± SEM from analyses evaluated in triplicate. [a,b]Steak section treatment combinations with different superscripts differ ($P < 0.05$).

Conclusions

Carcasses in the OS category (≥454 kg hot carcass weight) of the current study can receive heavyweight discounts on a grid-based marketing system. Oversized carcasses result in larger subprimals and, ultimately, larger steaks. Results suggest that there are meaningful differences among the anatomical sections within a top round steak among carcasses of different weights. The OS carcasses present a challenge in greater color variation for lightness and redness between superficial and deep sections of the steak. The altered color of steaks sourced from OS carcasses of varying aging times may lead to greater color variation at retail. Few adjustments are currently being made in processing and merchandising products from larger carcasses compared to average sized carcasses. This study suggests a lack of uniformity in steaks sourced from average and oversized beef carcasses. The current research provides empirical data to help packers provide greater premiums for those cattle that fall within the more "ideal" range of hot carcass weight or increase the emphasis of alternative merchandising of carcasses exceeding 454 kg. Additionally, the research demonstrated that oversized cattle may pose a greater challenge in producing top round steaks that are consistent throughout the entire steak.

Conflict of Interest Statement

The authors declare that they have no conflict of interest with any organization regarding this manuscript.

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