



Aging Condition and Retail Display Lighting Impact Retail Display Life and Lipid Oxidation of Beef Biceps Femoris Steaks

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Abstract: The objective of this study was to determine the impact of aging method and retail display lighting type on the discoloration and oxidation of a beef muscle with low color stability. Beef biceps femoris (BF; $n = 38$) were fabricated 48 h postmortem and aged for 16 d post fabrication in either wet (vacuum packaged) or dry conditions. After aging steaks ($n = 9$) were cut from each BF and randomly assigned to 1 of 3 retail display lengths: 1, 3, or 5 d and 3 light treatments: light emitting diode (LED), high-UV fluorescent (HFLO), or low-UV fluorescent (FLO). Steaks were removed from retail display, and were subjected to instrumental color analysis (L^* , a^* , b^*), surface myoglobin redox forms, lipid oxidation, and metmyoglobin reducing activity. Dry aging resulted in greater ($P < 0.05$) redness, as determined by a^* , saturation index, and hue angle values of beef BF steaks, compared to wet aging. Significant interactions ($P < 0.05$) between aging method and retail display day were reported for a/b ratios, hue angle, deoxymyoglobin concentrations, and lipid oxidation values. Dry aging resulted in increased ($P < 0.05$) lipid oxidation over the duration of retail display, as determined by thiobarbituric acid reactive substances (TBARS), in comparison to wet aging. Light by day interactions ($P < 0.05$) occurred for b^* , metmyoglobin concentrations, oxymyoglobin concentrations, and saturation index values. Data indicate that utilization of fluorescent light sources promoted greater redness retention in a muscle with low color and oxidative stabilities over the duration of retail display in comparison to LED light sources.

Keywords: dry aging, myoglobin, oxidation, retail display, wet aging

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Introduction

Meat color is undoubtedly one of, if not, the most important factors in consumer perception of fresh meat quality (Mancini and Hunt, 2005; Brugiapaglia and Destefanis, 2009; Suman et al., 2014). Deviations from consumer color expectations can lead to potential product rejection and ultimately a substantial amount of revenue loss for the meat industry annually (Smith et al., 2000; Brugiapaglia and Destefanis, 2009).

Previous research from our lab evaluated the impact of different lighting technologies used during retail display on ground beef (Cooper et al., 2016), the triceps brachii, a color labile muscle (Cooper et

al., 2017), and the semimembranosus, a color stable muscle (Cooper et al., 2018). The utilization of light emitting diode (LED) lights over retail display of ground beef proved to have advantages for red color retention in comparison to fluorescent lights (Cooper et al., 2016). However, the use of LED lights resulted in increased lipid oxidation of ground beef patties over retail display. Data from whole muscle studies found that steaks produced from the triceps brachii (Cooper et al., 2017) and semimembranosus (Cooper et al., 2018) retained more redness, as indicated by oxymyoglobin and a^* values when displayed under high-UV fluorescent (HFLO) light sources in comparison to those displayed under LED bulbs. Additionally, steaks from the triceps brachii had less

lipid oxidation during retail display when HFLO lights were used in comparison to LED (Cooper et al., 2017).

Aging is a common industry practice that is known to impact many aspects of fresh meat quality (Kemp and Parr, 2012; Kim et al., 2016). Colle et al. (2016) found that aging between 14 and 21 d post fabrication optimizes consumer perception of bottom round tenderness. There are primarily 2 methods of meat aging: wet and dry. Wet aging is the process of vacuum packaging of meat cuts and cold storing them for a set period of time to maximize tenderness (Smith et al., 2008). Dry aging is less common in industry and involves placing carcasses or cuts in cold storage with well-regulated temperature, humidity, and air flow for extended periods of time (DeGeer et al., 2009). A key clear distinction between dry and wet aged beef products is the flavor profile. Dry aged beef is often associated with flavor descriptors like beefy or roasted (Warren and Kastner, 1992; Kim et al., 2016). It is also likely that these different aging environments impact the oxidation potential for the meat during retail display.

Colle et al. (2016) found that extended aging times have a negative impact on retail display life of fresh beef products. The biceps femoris (BF) is described as a “low” color stability muscle with moderate to high aging responses (McKenna et al., 2005; Gruber et al., 2006) and is much larger than the triceps brachii used in our previous research. Understanding aging, in combination with other environmental impacts on retail display life of fresh beef products is critical for both marketability and profitability of fresh beef. Previous studies from this lab indicate that utilization of different lighting technologies have a larger impact on numerous fresh meat quality parameters related to retail display in a color labile muscle in comparison to a color stable muscle (Cooper et al., 2017, 2018). Therefore, the objective of this study was to determine the impact of aging method (wet or dry) and retail display lighting (LED, HFLO, and low-UV fluorescent [FLO]) on surface color stability and lipid oxidation of beef steaks produced from the BF, a low color and oxidative stability muscle, over retail display.

Materials and Methods

Beef fabrication and retail display

Nineteen beef cattle were slaughtered at the University of Missouri red meats abattoir under USDA/FSIS inspection. Carcasses were chilled for 48 h and then fabricated according to Institutional Meat

Purchasing Specifications (IMPS). Ultimately, outside rounds (171B fat limitation option 6; USDA, 2014) were removed from each side of the carcass. Rounds from the right side of each carcass were subjected to wet aging, which consisted of vacuum packaging, boxing, and storing at $1.1 \pm 1^\circ\text{C}$ for 16 d. Over the same 16-d period, outside rounds from the left side of each carcass were subjected to dry aging, which consisted of placing it on a slatted metal rack which was exposed to open air, blacked out from any light and stored at $1.1 \pm 1^\circ\text{C}$ and a relative humidity of $82.1 \pm 3.80\%$.

Following the aging period, the BF ishiatic head (IMPS number 171E; USDA, 2014) was removed and discarded leaving the BF (IMPS number 171D; USDA, 2014). Biceps femoris was chosen for this study due to its low color stability (McKenna et al., 2005) and sufficient size to produce all steaks needed for analysis. After aging, crust was removed from dry aged BF before steaks were fabricated. Nine steaks (1.9-cm thick) were cut from each muscle, individually placed on Styrofoam trays, and overwrapped with oxygen permeable polyvinyl chloride ($15,500$ to $16,275 \text{ cm}^3 \text{ m}^{-2} \text{ 24 h}^{-1}$ period oxygen transmission rate at 23°C). The remainder of the BF muscle after removal of steaks was saved for pH, fat, and moisture determinations. Steaks from each BF were then randomly assigned to 1 of 9 lighting treatments (HFLO, FLO, and LED) \times d of retail display (1, 3, and 5) combinations, and subsequently placed into the deli case (TDBD-72-4, True Food Service Equipment, O’Fallon, MO). Each deli case was equipped with its assigned light source and all external light sources were blocked. Temperature and humidity were monitored in each case using EasyLog humidity/temperature datalogger (EL-USB-2, Lascar Electronics Inc., Erie, PA). Temperatures in HFLO, FLO, and LED were 3.9 ± 1.0 , 5.9 ± 1.1 , and $5.1 \pm 1.2^\circ\text{C}$, respectively, for the duration of retail display. Humidity levels in HFLO, FLO, and LED were 63.1 ± 4.0 , 63.9 ± 4.6 , and $63.7 \pm 5.1\%$, respectively, for the duration of retail display. Light characteristics were measured with a GS-1150 Spectrophotometer (Gamma Scientific, San Diego, CA) for all 3 cases. Readings were taken in each corner and the direct center of each deli case. Bulb lux values were 304.4, 184.2, and 707.6 for HFLO, FLO, and LED, respectively. Additionally, HFLO bulbs had a K value of 3,842.8 and a CRI of 66.4; FLO bulbs produced values of 3,407.0 K and 92.6 CRI; and values for K and CRI of LED bulbs were 3,899.0 and 85.4, respectively.

Moisture and fat analysis

On d 0 of display, determination of fat percentage was done in triplicate utilizing microwave drying and nuclear magnetic resonance as described in Dow et al. (2011) with a CEM SMART Trac rapid fat analysis system 5 (Matthews, NC). Briefly, 2 CEM sample pads were heated and dried before 3.75 to 4.5 g of sample from the remaining BF muscle after steak fabrication was hand minced using a knife and smeared across one pad and topped with the remaining pad. Samples were dried using the CEM Moisture/Solids Analyzer, and moisture was determined on a dry weight basis. Following determination of moisture, sample pads were wrapped in Trac paper, inserted into a CEM Trac tube and placed into the CEM Rapid Fat Analyzer. Fat percentage of samples was then determined on a dry weight basis using NMR and was ultimately converted to a wet weight basis. Triplicate values were averaged to determine overall fat percentages for each muscle.

pH

Muscle pH was determined according to American Meat Science Association (AMSA, 2012). On d 0 of display duplicate 3-g samples of each remaining BF muscle were briefly homogenized with 30 mL of distilled water. After homogenization, samples were filtered, and pH of the homogenate was measured using a benchtop probe (SevenCompact pH/ion meter S220, fitted with InLab Versatile Pro probe, Mettler-Toledo AG Analytical, Schwerzenbach, Switzerland). Duplicate values were averaged to determine overall pH for each muscle.

Instrumental color

On the assigned retail display day (1, 3, or 5 d), steaks were removed from display cases and packaging for analyses. The L* (lightness), a* (redness), and b* (yellowness) values were measured on 3 locations of the steak surface from end to end on the light-exposed steak surfaces using a HunterLab MiniScan 45/0 LAV (Hunter Associates Laboratory, Reston, VA) with a D65 light source, 25 mm aperture and 10° standard observer (AMSA, 2012). Average values were saved from triplicate readings to determine overall surface color of each steak. Physical standards were used for calibration of the HunterLab MiniScan each day prior to data collection. Instrumental color reading values were additionally utilized to calculate a/b ratio, saturation index (SI), and hue angle (HA) values (AMSA, 2012).

Myoglobin redox forms on the steak surface

After removal from retail display and packaging, percentage of total myoglobin redox forms (deoxymyoglobin [DMb], oxymyoglobin [OMb], and metmyoglobin [MMb]), were determined on each individual steak surface via methods of calculation involving specific wavelengths provided by AMSA (2012). Reflectance was measured at wavelengths of 470, 530, 570, and 700 nm on light-exposed steak surfaces employing a HunterLab MiniScan. Proportions of myoglobin redox forms were determined utilizing equations provided by AMSA (2012).

Metmyoglobin reducing activity

Metmyoglobin reducing activity was measured according to Sammel et al. (2002). After objective color determination, triplicate cubes (4 × 4 × 0.64 cm), from the center of each steaks surface were removed on each d of designated retail display for all light treatments. Once removed, samples were submerged in 0.3% sodium nitrite solution for 20 min to induce MMb formation. After the MMb formation period, samples were removed from the solution, blotted dry, and vacuum sealed (Multivac, Chamber Machine P200, Kansas City, MO) in individual packages. Triplicate readings of each sample were taken immediately after packaging utilizing a HunterLab MiniScan to obtain overall reflectance data. Samples were incubated at room temperature for 120 min to induce MMb reduction. After incubation, samples were rescanned in triplicate with a HunterLab MiniScan. Surface MMb values were calculated using K/S ratios and formulas provided in AMSA (2012). Metmyoglobin reducing activity was calculated using the equation below. The MRA values for each steak were averaged to determine overall reducing activity of each steak.

$$\%MRA = 100 \times \frac{\left(\frac{\text{Pre-incubation \% metmyoglobin} - \text{Post-incubation \% metmyoglobin}}{\text{Pre-incubation \% metmyoglobin}} \right)}$$

Lipid oxidation

Lipid oxidation was determined utilizing the distillation method to analyze thiobarbituric acid reactive substances (TBARS) described in Tarlagdis et al. (1960) with modifications found in Fernando et al. (2013). Duplicate 5 g surface steak samples were minced and homogenized (Polytron 10-35 GT, Kinematica, Bohemia, NY) with 25 mL of distilled water. Homogenate was poured into a 250 mL Kjeldahl

Table 1. Impact of aging method on muscle characterization of beef biceps femoris ($n = 38$)

Parameter	Aging method		SEM	<i>P</i> -value ¹
	Wet	Dry		
Moisture, %	76.05	76.34	0.25	0.1950
Fat, %	2.02 ^a	1.65 ^b	0.18	0.0177
pH	5.44	5.44	0.01	1.0000

^{a,b}Means within a row lacking common superscript differ ($P < 0.05$).

¹*P*-value for treatment comparisons within a row.

flask and blending tubes were immediately rinsed with an additional 25 mL of distilled water and added back to the homogenate along with 2 drops of antifoam solution (Antifoam B Silicone Emulsion, Thermo Fisher Scientific, Waltham, MA). Prior to distillation, 2.5 mL of 4N HCl was added to the flask to balance sample pH between 1.5 and 1.6. Flasks were placed into controlled heating elements (Fisher Scientific, Pittsburgh, PA) and samples were distilled through a water-cooled distillation apparatus until 25 mL of distilled sample was collected. Post distillation, 5 mL of sample was pipetted into a glass tube containing 5 mL of thiobarbituric acid reagent and vortexed individually. Following vortex, tubes were placed into a boiling water bath for 35 min. Tubes were submerged into an ice bath for 10 min immediately following the water bath. Color absorbance was measured at 538 nm using a Genesys 20 spectrophotometer (Thermo Fisher Scientific). Values for TBARS concentrations were obtained by calculating the average absorption of the duplicate sample readings and mg malonaldehyde (MDA)/kg was determined using the K value of 7.8 (Tarlagdis et al., 1960). Duplicate TBARS values were averaged to determine lipid oxidation for individual steaks.

Statistical analyses

The experimental design was a split-plot in space and time as outlined by Steel et al. (1996). Carcass served as a block, aging method (wet or dry) served as the main plot, and light source (HFLO, FLO, LED), and retail display d (1, 3, 5) served as sub plots. A model including fixed effects of aging method, light source, retail display length, and all possible interactions were analyzed using the PROC GLIMMIX function of SAS (SAS Version 9.4, SAS Inst. Inc., Cary, NC) to obtain LS means and standard error estimates. Significance was determined at $P < 0.05$. Highest order interactions are presented, if significant, for fixed effects; if no interaction occurred main effects are then presented.

Table 2. Effect of aging method on color traits of beef biceps femoris ($n = 38$) steaks ($n = 342$)

Parameter	Aging method		SEM	<i>P</i> -value ¹
	Wet	Dry		
L*	37.95 ^a	37.35 ^b	0.31	0.0029
a*	17.74 ^b	18.60 ^a	0.25	0.0021
b*	16.19	16.38	0.20	0.1825
MMb ²	40.33	40.08	0.18	0.0767
OMb ³	54.96 ^a	55.27 ^b	0.14	0.0069
MRA ⁴	31.72	31.56	2.46	0.8361
SI ⁵	24.09 ^b	24.84 ^a	0.29	0.0106

^{a,b}Means within a row lacking common superscript differ ($P < 0.05$).

¹*P*-value for treatment comparisons within a row.

²MMb = metmyoglobin (%).

³OMb = oxymyoglobin (%).

⁴MRA = metmyoglobin reducing activity (%).

⁵SI = saturation index.

Results

Moisture, fat, and pH analysis

In this study, all BF subjected to wet aging came from the right side of each carcass while those from the left side were dry aged. Aging method had no impact ($P > 0.05$) on pH values of BF muscles (Table 1). Aging method also did not impact overall moisture content ($P > 0.05$) of BF muscles (Table 1). Fat percentage was greater ($P < 0.05$) in BF muscles subjected to the wet aging method in comparison to those muscles which were dry aged.

Instrumental color

No interactions ($P > 0.05$) occurred between treatments for L* values. Utilization of the dry aging method resulted in a lower ($P < 0.05$) L* value compared to wet aged BF steaks (Table 2). Light source also impacted L* values of beef BF steaks with steaks displayed under HFLO and LED light sources having greater ($P < 0.05$) L* values than FLO treated steaks (Table 3). The L* values of beef steaks were greater ($P < 0.05$) on d 1 than d 3 and 5 of display (Table 4).

There were no interactions ($P > 0.05$) among treatments for a* values. Dry aged steaks had greater ($P < 0.05$) a* values than those produced from wet aged BF (Table 2). Use of HFLO and FLO light sources for the display of BF steaks resulted in greater ($P < 0.05$) a* values in comparison to steaks under LED display (Table 3). Values for a* decreased ($P < 0.05$) over the duration of retail display with d 1 > 3 > 5 (Table 4).

Table 3. Effect of light source on color traits and lipid oxidation (means \pm SE) of beef biceps femoris ($n = 38$) steaks ($n = 342$)

Parameter	Lighting treatment ¹			<i>P</i> -value ²
	FLO	HFLO	LED	
L*	37.19 ^b \pm 0.34	38.11 ^a \pm 0.34	37.65 ^a \pm 0.32	0.0065
a*	18.33 ^a \pm 0.25	18.64 ^a \pm 0.25	17.54 ^b \pm 0.24	< 0.0001
DMb ³	4.69 \pm 0.14	4.59 \pm 0.14	4.75 \pm 0.13	0.1277
MRA ⁴	38.61 ^a \pm 2.54	30.39 ^b \pm 2.55	29.50 ^c \pm 2.50	< 0.0001
a/b ⁵	1.12 ^a \pm 0.01	1.10 ^a \pm 0.01	1.08 ^b \pm 0.01	< 0.0001
HA ⁶	42.00 ^b \pm 0.32	42.54 ^b \pm 0.32	43.24 ^a \pm 0.30	< 0.0001
TBARS ⁷	2.74 ^b \pm 0.18	2.74 ^b \pm 0.18	2.97 ^a \pm 0.17	0.0239

^{a-c}Means within a row lacking common superscript differ ($P < 0.05$)

¹FLO = low-UV fluorescent; HFLO = high-UV fluorescent; LED = light emitting diode.

²*P*-value for treatment comparisons within a row.

³DMb = deoxymyoglobin (%).

⁴MRA = metmyoglobin reducing activity (%).

⁵a/b ratio.

⁶HA = hue angle.

⁷TBARS = thiobarbituric acid reactive substances (mg MDA/kg).

Aging method did not impact ($P > 0.05$) b* values for steaks produced from the BF (Table 2). As seen in Fig. 1, an interaction ($P < 0.05$) occurred between light source and duration of retail display for b* values. A decrease in b* value over time for steaks displayed under each light treatment d 1 > 3 > 5. Steaks displayed under HFLO light sources had greater ($P < 0.05$) b* values than those displayed under LED on d 1 and 3 of display (Fig. 1).

An aging method by day interaction ($P < 0.05$) occurred for a/b ratio values in steaks produced from BF (Fig. 2). By d 3 of retail display steaks subjected to dry aging had greater ($P < 0.05$) a/b ratio values than those subjected to wet aging methods (Fig. 2). Steaks displayed under HFLO and FLO bulbs had greater ($P < 0.05$) a/b ratio values than steaks displayed under LED bulbs (Table 3).

Steaks produced from BF muscles subjected to dry aging had greater ($P < 0.05$) SI values than steaks produced from wet aged BF muscles (Table 2). A light by day interaction ($P < 0.05$) occurred for SI values in steaks produced from the BF (Fig. 1). On d 1 of retail display, steaks displayed under HFLO and FLO lights had greater ($P < 0.05$) SI values in comparison to steaks displayed under LED lights (Fig. 2). By d 3 of display, steaks displayed under HFLO lights SI values were greater ($P < 0.05$) than those for FLO and LED displayed steaks (Fig. 2).

An interaction ($P < 0.05$) between aging method and retail display day occurred for HA values. Biceps

Table 4. Effect of retail display length on color traits of beef biceps femoris ($n = 38$) steaks ($n = 342$)

Parameter	Retail display day			SEM	<i>P</i> -value ¹
	1	3	5		
L*	38.42 ^a	37.39 ^b	37.14 ^b	0.33	< 0.0001
a*	22.86 ^a	17.87 ^b	13.79 ^c	0.35	< 0.0001
MRA ²	49.53 ^a	28.52 ^b	16.86 ^c	2.63	< 0.0001

^{a-c}Means within a row lacking common superscript differ ($P < 0.05$)

¹*P*-value for treatment comparisons within a row.

²MRA = metmyoglobin reducing activity (%).

femoris steaks exposed to wet aging had greater ($P < 0.05$) HA values by d 3 and continued into d 5 of retail display in comparison to dry aged BF steaks (Fig. 2). Light treatment impacted HA values with LED having greater ($P < 0.05$) HA values than both FLO and HFLO treated steaks (Table 3).

Myoglobin redox forms

An aging method by retail display day interaction ($P < 0.05$) occurred for DMb concentrations in steaks from the BF. Deoxymyoglobin concentrations decreased for each aging method over the duration of retail display (Fig. 2). On d 1 of retail display, steaks subjected to wet aging had greater ($P < 0.05$) DMb concentrations than dry aged steaks (Fig. 2). On d 3 of display, no differences in DMb concentrations between aging methods were found. By d 5 of display, DMb values were greater ($P < 0.05$) for steaks subjected to dry aging in comparison to wet aged steaks (Fig. 2). Light treatment did not ($P > 0.05$) impact DMb concentrations in steaks produced from the BF (Table 3).

Oxymyoglobin concentration for steaks produced from BF muscles subjected to dry aging method were greater ($P < 0.05$) than their wet aged counterparts (Table 2). A light by day interaction ($P < 0.05$) occurred for Omb values in steaks from the BF (Fig. 1). On d 1 of display, steaks displayed under FLO lights had greater ($P < 0.05$) Omb concentration values in comparison to both HFLO and LED (Fig. 1). By d 5 of display, steaks displayed with LED lights had less ($P < 0.05$) Omb than both HFLO and FLO displayed steaks (Fig. 1).

Ultimately, aging method did not impact ($P > 0.05$) MMb concentrations in steaks from the BF (Table 2). A light by day interaction occurred ($P < 0.05$) for MMb concentrations in steaks produced from the BF (Fig. 1). On d 1 of retail display, steaks displayed under FLO light treatments had less ($P < 0.05$) MMb than steaks displayed under HFLO light treatments. By days 3 and 5 of display, steaks displayed under

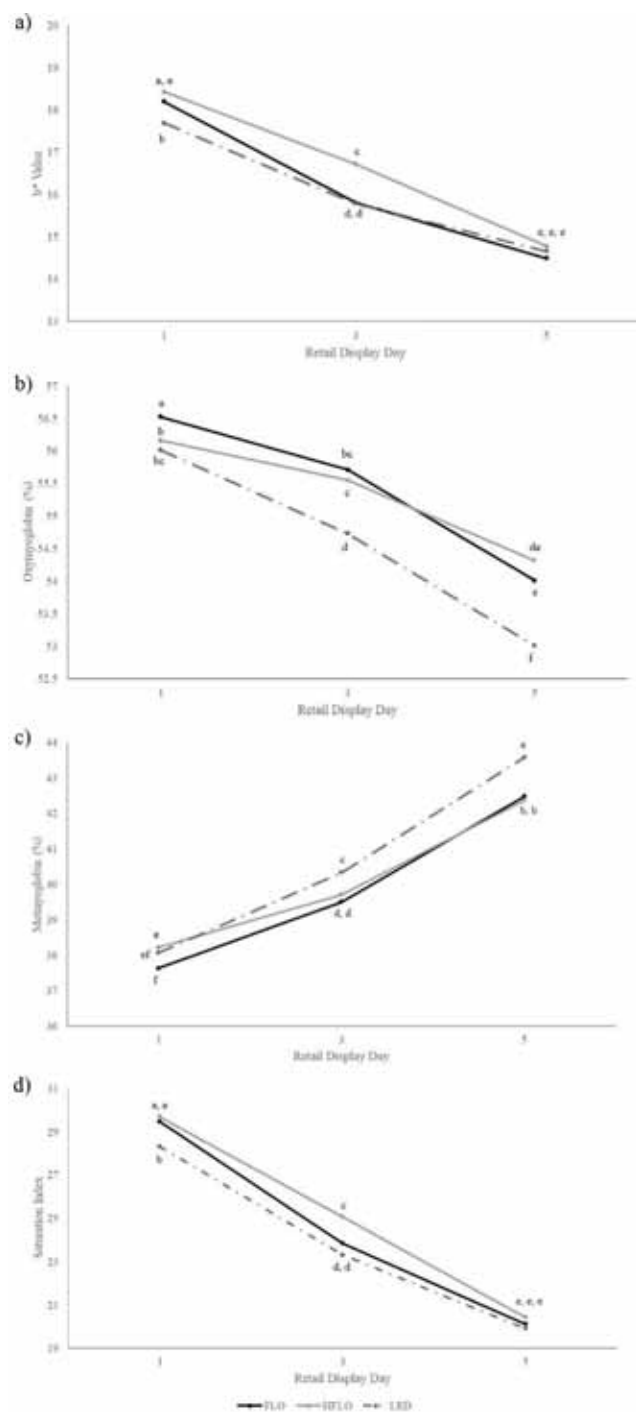


Figure 1. Effect of light source (FLO, HFLO, and LED) and retail display length on (a) b^* value, (b) oxymyoglobin (%), (c) metmyoglobin (%), and (d) saturation index of biceps femoris steaks. ^{a-c} Means lacking common superscript differ ($P < 0.05$).

LED light treatments had greater ($P < 0.05$) MMb concentrations than those displayed under both FLO and HFLO light sources (Fig. 1).

Metmyoglobin reducing activity

No interactions ($P > 0.05$) among treatments occurred for MRA values in this study. Aging method had no impact ($P > 0.05$) on MRA values for steaks produced from the BF (Table 2). Metmyoglobin reducing activity was greater ($P < 0.05$) for steaks displayed under FLO lighting than HFLO treated steaks, which in turn were higher ($P < 0.05$) than steaks subjected to LED light treatments (Table 3). Data indicates that values for MRA decreased ($P < 0.05$) over the duration of retail display with $d\ 1 > 3 > 5$ (Table 4).

Lipid oxidation

A retail display time by aging method interaction ($P < 0.05$) occurred for TBARS values of steaks from the BF (Fig. 2). In this study, steaks subjected to dry aging methods had greater ($P < 0.05$) TBARS values than those from wet aged BF on each d of retail display with $d\ 1 > 3 > 5$ indicating greater amounts of lipid oxidation (Fig. 2). Steaks displayed under LED lights had greater ($P < 0.05$) TBARS values than steaks displayed under both FLO and HFLO light treatments (Table 3).

Discussion

Muscle characterization

Results agreed with multiple studies which reported no differences in pH values for beef subjected to various aging methods and timeframes (Li et al., 2013; Kim et al., 2016, 2017; Hulánková et al., 2018). Data from this study agrees with that of Oreskovich et al. (1988) who reported no differences in moisture content of beef strip loins subjected to wet and dry aging methods. Alternatively, studies by Sitz et al. (2006) and Berger et al. (2018) reported that dry aging of fresh beef loins resulted in lower moisture content as opposed to their wet aged counterparts. Sitz et al. (2006) reported that wet aged USDA Prime steaks produced from the loin had greater fat content than USDA Prime steaks subjected to dry aging. Conversely, Dikeman et al. (2013) and DeGeer et al. (2009) reported higher fat percentages for dry aged beef loins in comparison to wet and special bag aged strip loins. In this study, a contributing factor to fat differences between aging methods could be muscle location and variation in fat content between muscles from each side of the carcass.

Instrumental color

Data agrees with findings in Kim et al. (2016) who reported lower L^* values for beef loins subjected to dry aging methods as opposed to wet aging methods. Indicating that dry aging can result in darker meat color in comparison to wet aged beef products. This may be explained by a greater reflectance associated with moisture (Bertram et al., 2004). Our results for instrumental lightness agree with findings in McKenna et al. (2005) who reported a decrease in L^* values of BF steaks after 1 d of retail display and King et al. (2011b) who reported decreases in L^* values of steaks from the triceps brachii over 6 d of retail display. In contrast, Colle et al. (2016) found that L^* values of BF steaks subjected to various lengths of wet aging, increased as retail display time increased.

Changes and variation in a^* values are normally indicative of changes and variation in red color of beef products, as a^* is a measurement of relative redness (CIE, 1978). Kim et al. (2016) conversely found that beef loins subjected to dry aging had lower a^* values than their wet aged counterparts. Colle et al. (2016) found that wet aged BF steaks aged 14 or more days had decreasing a^* values as retail display time increased. However, in this study, no aging by length of retail display interactions were observed for a^* values. Values for a^* indicate that the use of HFLO and FLO light sources promote greater redness retention than the use of LED lighting options. This data agrees with previous findings in the triceps brachii, a low color stability muscle (Cooper et al., 2017) as well as the semimembranosus, a high color stability muscle (Cooper et al., 2018). Steaks from both muscles showed benefits utilizing HFLO light sources over the duration of retail display. Contrary to these findings, Steele et al. (2016) reported no differences in a^* values in steaks from the semimembranosus when displayed under fluorescent or LED lights. Variations in retail display temperatures between studies could be a contributing factor to these differences. Again, in this study, steaks displayed under HFLO light sources had greater a^* values, steaks from all light treatments were above the a^* acceptability threshold defined by Holman et al. (2017) of 14.5. Data from this study agrees with multiple previous findings (King et al., 2011a; Mancini and Ramanathan, 2014; Colle et al., 2016; Cooper et al., 2016, 2017, 2018; Nair et al., 2016; Steele et al., 2016) that showed decreases ($P < 0.05$) in a^* values over the duration of retail display, as seen in Table 4. Findings indicate that over time, as expected, steaks from the BF lost red color as display time increased.

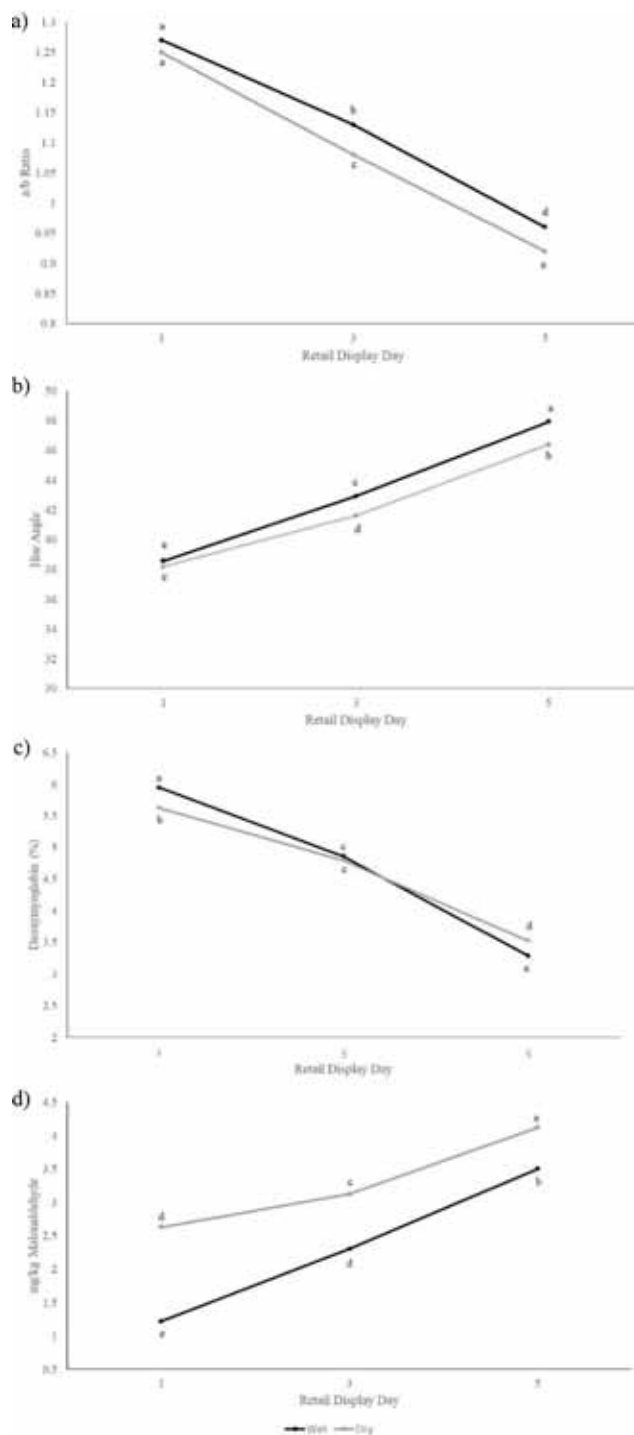


Figure 2. Effect of aging method (wet or dry) and retail display length on a) a/b ratio, b) hue angle, c) deoxymyoglobin (%) and d) lipid oxidation (mg MDA/kg) of biceps femoris steaks. ^{a-c} Means within a row lacking common superscript differ ($P < 0.05$).

Colle et al. (2016) reported decreases in b^* over retail display time for increasing wet aging periods (14 to 63 d). Previously, Cooper et al. (2017) reported higher b^* values for steaks produced from the triceps brachii displayed under HFLO light sources than

for those displayed under FLO or LED. Conversely, Cooper et al. (2018) found that light source had no impact on b^* values in the semimembranosus, a muscle with high color stability. This data agrees with multiple reports of decreasing b^* values during retail display of beef products (King et al., 2011a,b; Cooper et al., 2018). Previous studies from our lab reported lower a/b ratio values for steaks from the semimembranosus (Cooper et al., 2018) and the triceps brachii (Cooper et al., 2017) when displayed under LED light sources.

Saturation index, or chroma, refers to relative strength or intensity of color (AMSA, 2012). Similar findings for steaks produced from the triceps brachii, also a color labile muscle, were reported (Cooper et al., 2017). Data agrees with King et al. (2011b) who reported increases in HA values for steaks from the BF over 9 d of retail display, indicating a decrease in red hue as retail display increased (Trinderup and Kim, 2015), as well as findings in the semimembranosus (Steele et al., 2016; Cooper et al., 2018) and the triceps brachii (Cooper et al., 2017).

Myoglobin redox forms

Color of fresh meat is defined by the amount of 3 key derivatives of myoglobin: DMb, Omb, and MMb (Renerre, 1990). Deoxymyoglobin concentrations were higher ($P < 0.05$) for steaks exposed to wet aging on d 1 of retail display. This is expected as muscles were aged in vacuum packaging where oxygen was removed. As retail display time and the resulting oxygen exposure increased, the opportunity for DMb to oxygenate into Omb and further oxidize to MMb occurred (Faustman and Cassens, 1990). Light source had no impact on DMb concentrations in steaks from the BF in this study. This data agrees with the findings in Cooper et al. (2017) who also reported that light source did not impact DMb concentrations in another color labile muscle, triceps brachii.

Oxymyoglobin is the protein responsible for the bright, cherry red desirable color in fresh beef. A decrease in Omb is due to its oxidation and the simultaneous formation of MMb (Suman and Joseph, 2013; Mancini and Ramanathan, 2014). Steaks subjected to dry aging had greater amounts of Omb in comparison to wet aged mimicking the trend found in a^* values related to redness. Data from this study differs from previous findings in our lab. Steaks produced from the triceps brachii had greater concentrations of Omb when displayed under HFLO light sources (Cooper et al., 2017) in comparison to FLO lights in this study. These differences could be attributed to case tempera-

ture, light intensity, and muscle characteristic differences between the studies.

Metmyoglobin is the undesirable brown pigment resulting from the oxidation of Omb (Mitsumoto et al., 1998). Aging method did not impact MMb formation in steaks from the BF. In this study, steaks displayed under FLO lights had less metmyoglobin than steaks displayed under HFLO or LED lights, which is to be expected in relation to Omb concentrations. McKenna et al. (2005), reported large increases in MMb formation over retail display in beef steaks from the BF. A threshold value for surface MMb formation and its impact on consumer acceptance was established at 40% (Greene et al., 1971). Steaks in this study displayed under both HFLO and LED lights had MMb concentrations exceeding the 40% threshold previously mentioned. As expected, MMb concentrations increased as retail display time increased, indicating discoloration occurring over retail display. This is to be expected in relation to the decrease in a^* values, Omb concentrations, and agrees with multiple previous studies (Mitsumoto et al., 1998; Djenane et al., 2003; McKenna et al., 2005; Cooper et al., 2017, 2018).

Metmyoglobin reducing activity

Metmyoglobin reducing activity is an indication of ability to reduce ferric metmyoglobin to a ferrous redox form and its value regarding color stability is unclear (Reddy and Carpenter, 1991; Bekhit et al., 2001; Bekhit and Faustman, 2005; Nair et al., 2016). In steaks from the triceps brachii, Cooper et al. (2017) also found MRA values to be greater in steaks displayed under FLO lights than those displayed under HFLO or LED light sources. Alternatively, light source did not impact MRA in beef steaks produced from the semimembranosus (Cooper et al., 2018). Nair et al. (2016) and Cooper et al. (2018) reported similar findings in beef semimembranosus muscle with decreases in MRA values with increasing retail display time. Data from this study, as well as previous studies in our lab, indicate that variation in color and oxidative stabilities of muscles can attribute to variation in MRA values.

Lipid oxidation

As storage time increases post mortem, the muscle's ability and functionality of its antioxidant defense system decreases; which can ultimately result in increasing amounts of reactive oxygen species (Renerre et al., 1996). Lipid oxidation and its byproducts ulti-

mately lead to a deterioration of sensory qualities of meat products and the development of off flavors and rancidity (Moczkowska et al., 2017). Multiple thresholds have been identified for detectable rancidity in fresh beef products with values ranging from 1.0 mg MDA/kg (McKenna et al., 2005), 0.6 to 2.0 mg MDA/kg (Tarlagdis et al., 1960), 2.3 mg MDA/kg (Campo et al., 2006). Steaks from dry aged BF had TBARS values exceeding the threshold of 2.3 mg MDA/kg after 1 d of retail display while steaks from wet aged BF were under the threshold value until d 3 of retail display. These values were somewhat expected as McKenna et al. (2005) reported that steaks from the BF displayed greater susceptibility to autoxidation at earlier time-points in retail display. Previous work from our lab and others, has suggested the use of LED lights during retail display promoted greater amounts of lipid oxidation in fresh beef products (Cooper et al., 2016, 2017, 2018; Steele et al., 2016). Conversely, in this study light source showed no differences in impact on TBARS values for steaks produced from the BF.

A well-known relationship exists between lipid and myoglobin oxidation (Faustman and Cassens, 1990). Generally, muscles with known low color stabilities have higher TBARS values (McKenna et al., 2005). Radicals generated by lipid oxidation are known to promote oxidation of myoglobin (Faustman et al., 2010). Therefore, increasing lipid oxidation values are associated with MMB formation and ultimate discoloration of fresh meat surfaces.

Conclusion

Results indicate that dry aging of beef muscles from the biceps femoris, a muscle with low color and oxidative stabilities, produces steaks with a redder color, as indicated by both a^* and Omb concentration in comparison to steaks produced from wet aged muscle. However, dry aging did promote increased lipid oxidation over the duration of retail display. Steaks displayed under fluorescent light sources had increased redness retention over retail display as indicated by a^* and Omb concentration as well as less lipid oxidation in comparison to other retail light options. However, all light treatments were above a^* threshold for consumer acceptability over retail display. Utilization of fluorescent bulbs when displaying products from low color stability muscles may increase retail display life and consumer perception of product quality. Wet aging of steaks decreased lipid oxidation and could contribute to display life over retail display.

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