Published May 3, 2018

Meat and Muscle Biology™

Impact of Light Source on Color and Lipid Oxidative Stabilities from a Moderately Color-Stable Beef Muscle during Retail Display

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Abstract: Consumers' purchasing decisions are heavily impacted by fresh meat color, which they consider an indicator of quality in a retail setting. The objectives of this study were to evaluate the impact of light source on surface color and lipid oxidation during retail display of fresh steaks from *semimembranosus* (SM), a beef muscle with moderate oxidative and color stabilities. Steaks ($n = 240$) from the SM ($n = 20$) were packaged on Styrofoam trays and overwrapped with oxygen-permeable polyvinyl chloride. Steaks were then assigned to 1 of 3 lighting treatments, high UV fluorescent (HFLO), low UV fluorescent (FLO), and light emitting diode (LED) to mimic current storage conditions with a variety of industry available fluorescent bulbs, and evaluate emerging lighting conditions with LED. Steaks were removed on retail display d 1, 3, 5, and 7 for evaluation of instrumental color (L^*, a^*, and b^* values), surface myoglobin redox forms, metmyoglobin reducing activity, and lipid oxidation. Light source influenced ($P < 0.05$) redness (a^* values), with HFLO-displayed steaks having greatest ($P < 0.05$) a^* values and LED-displayed steaks exhibiting lowest ($P < 0.05$) a^* values. Surface redness decreased ($P < 0.05$) over retail display day. Steaks displayed in HFLO and FLO had greater ($P < 0.05$) oxymyoglobin percentages than those displayed under LED, indicating that LED accelerated surface discoloration compared to HFLO and FLO lights. Metmyoglobin (MMb) percentages increased over retail display, with LED-exposed steaks having greater ($P < 0.05$) percentages of MMb than those displayed in HFLO and FLO. By d 7 of retail display, HFLO-exposed steaks had lower ($P < 0.05$) MMb percentages than the steaks displayed in both FLO and LED. Lighting type did not influence ($P > 0.05$) lipid oxidation in SM steaks, however, lipid oxidation increased ($P < 0.05$) over retail display. The findings indicated that light source influenced the color stability in SM steaks during retail display and that HFLO light can minimize surface discoloration in moderate color stability beef muscles.

Keywords: beef color, lighting, myoglobin, oxidation, semimembranosus
Meat and Muscle Biology 2:102–110 (2018) **doi:10.22175/mmb2017.07.0040**
Submitted 27 Jul. 2017 Accepted 18 Mar. 2018

Introduction

Consumer perception of fresh meat quality relies heavily on color during retail display (Faustman and Cassens 1990; Bekhit et al., 2001; Suman et al., 2014; Holman et al., 2017). Numerous factors impact color stability and oxidation in retail fresh meat; temperature (Jeremiah and Gibson, 2001), retail display length (Martin et al., 2013), and light source (Cooper et al., 2016; Steele et al., 2016). Therefore, the evaluation of fresh meat color in various retail settings is necessary to ensure continued consumer satisfaction as new lighting technologies are developed.

Color and oxidative stabilities vary greatly between muscles in a beef carcass (McKenna et al., 2005; Von Seggern et al., 2005; Seyfert et al., 2006; Canto et al., 2016). McKenna et al. (2005) reported that the beef *semimembranosus* (SM), a muscle iso-

This work was funded by the Missouri Beef Industry Council.

lated from the top round, is a muscle with moderate color and oxidative stabilities based on objective color, myoglobin concentrations, metmyoglobin reducing activity, lipid oxidation, and other biochemical factors. Cooper et al. (2016) documented that ground beef patties produced from the top round retained more redness (*a** values) over retail display under light emitting diode (LED) lights in comparison to the patties displayed under fluorescent light sources.

The United States Department of Energy (US DOE, 2016) reported that by 2035, over 85% of lighting technologies will be LED compared to the 5% today. While retail display conditions influence the consumer quality perception of meat color (American Meat Science Association, 2012), monitoring the impacts of the changes in retail display conditions on meat color is of importance or to meat industry. Although Cooper et al. (2016) reported that patties prepared from beef SM retained redness longer under LED lights than under fluorescent lights, scientific information is limited on the impact of lighting technologies on beef whole-muscle cuts with moderate color and oxidative stabilities. We hypothesized that the use of LED lights would decrease oxidation of meat products in comparison to fluorescent light sources. Additionally, we assumed that low-UV fluorescent and high-UV fluorescent lights would impact oxidation differently from one another. Therefore, the objectives of this study were to evaluate the impact of LED, high-UV fluorescent (HFLO), and low-UV fluorescent (FLO) light sources on surface color and lipid oxidation of steaks from beef SM during the duration retail display.

Materials and Methods

Beef muscle fabrication and retail display

Beef top rounds (n = 20; USDA Select, Institutional Meat Purchase Specification 168; USDA, 2014) were purchased from a local vendor and delivered to the University of Missouri meat laboratory in vacuum packaging. Top rounds were aged for 20 d post-packaging date at 1.1 ± 1°C to match industry averages reported by Guelker et al. (2013), and the SM muscles were removed to produce individual steaks (n = 240). Twelve steaks (2.5 cm thick) were cut from each SM muscle. Steaks were manually packaged on individual Styrofoam® trays and overwrapped with oxygen-permeable polyvinyl chloride (15,500 - 16,275 cm^3/m^2/24 h oxygen transmission rate at 23°C).

Packaged steaks from various locations within the SM muscle were then randomly assigned to 1 of 3 lighting treatments (HFLO, FLO, and LED) × retail display d (1, 3, 5, or 7) combination, and were placed into 1 of 3 sliding door deli cases (TDBD-72–4, True Food Service Equipment, O'Fallon, MO) equipped with its exclusive light source (HFLO, FLO, or LED). Additionally, all windows in each case were blacked out to avoid external light influence. Each deli case contained one shelf, steaks were randomly placed within their assigned case. Average light intensities for HFLO, FLO, and LED bulbs were 289.97, 168.44, and 757.44 lux, respectively. Light intensity was measured in 5 different locations within each deli case by a GS-1150 Spectrophotometer (Gamma Scientific, San Diego, CA). Temperature within each case was monitored by factory-supplied thermometers, and all 3 deli cases had temperature of 2 ± 1°C.

Proximate composition

Determination of fat percentage was done in triplicate utilizing microwave drying and nuclear magnetic resonance (NMR) 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 minced sample from the remaining beef top round muscle (after steak fabrication) was smeared across 1 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 was placed into the CEM Rapid Fat Analyzer. Fat percentage of samples was then determined on a dry basis using NMR and was ultimately converted to a wet basis. Triplicate values were averaged to determine overall fat percentages for each muscle.

Meat pH

Meat pH was determined according to American Meat Science Association (2012). Briefly, duplicate, 10-g sample of each remaining beef top round muscle (after steak fabrication) was homogenized with 100 mL of distilled water. After homogenization, 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).

Instrumental color

One steak from each SM and assigned light source was removed from its package on the assigned retail

display d (1, 3, 5, or 7). *L** (lightness), *a** (redness), and *b** (yellowness) values were measured on 3 random locations on the light-exposed steak surface using a HunterLab MiniScan 45/0 LAV (Hunter Associates Laboratory, VA) equipped with a D65 light source, 2.5 cm aperture, and 10° standard observer (American Meat Science Association, 2012). Physical standards were used to calibrate the HunterLab MiniScan each day before the readings were taken. Instrumental color readings were also utilized to calculate *a*/*b* ratio, saturation index (SI), and hue angle (HA) values (American Meat Science Association, 2012).

Myoglobin redox forms on the steak surface

Percentages of myoglobin (Mb) redox forms, i.e., deoxymyoglobin (DMb), oxymyoglobin (OMb), and metmyoglobin (MMb), on steak surfaces were determined at each retail display time point (American Meat Science Association, 2012). Reflectance was measured at wavelengths of 470, 530, 570, and 700 nm on the light-exposed steak surfaces employing a HunterLab MiniScan 45/0 LAV (Hunter Associates Laboratory, VA), and the percentage of Mb redox forms were determined utilizing the equations according to American Meat Science Association (2012).

Myoglobin content

Duplicate 2.5 g minced steak surface samples (0.64-cm deep) were homogenized for 60 s using a Polytron homogenizer (Polytron 10–35 GT, Kinematica, Bohemia, NY) in 22.5 mL of ice-cold sodium phosphate buffer, pH 6.8, for 90 s. Homogenate was then filtered through filter paper with particle retention of 4 to 8 μm and a flow rate of 25 mL/min (Fisherbrand P4 Grade, Fisher Scientific, Suwanee, GA) into clean tubes. Filtrate absorbance was read at 525 nm on a Genesys 20 spectrophotometer (Thermo Fisher Scientific, Waltham, MA). Myoglobin concentrations were calculated utilizing the equation provided in American Meat Science Association (2012).

Metmyoglobin reducing ability

Metmyoglobin reducing ability was measured using a method described by Sammel et al. (2002). Triplicate cubes, 4-cm × 4-cm × 0.64-cm deep, from the center of each steaks surface were removed on each day of designated retail display for all light treatments. Upon removal, samples were submerged in 0.3% sodium nitrite solution for 20 min to induce MMb formation. After 20 min, samples were removed from the solution, blotted dry, and vacuum sealed (Multivac, Chamber Machine P200, Kansas City, MO) in individual packages. Readings of each sample were taken immediately after packaging utilizing a HunterLab MiniScan in triplicate to obtain 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 American Meat Science Association (2012). Metmyoglobin reducing ability was calculated using the equation below.

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

Lipid oxidation

Lipid oxidation was determined utilizing the distillation method to analyze thiobarbituric acid reactive substances (TBARS) as described in Tarladgis et al. (1960) with modifications found in Fernando et al. (2013). Duplicate 5 g steak samples were minced and homogenized (Polytron 10–35 GT, Kinematica) with 25 mL of distilled water. Homogenate was then poured into a 250 mL Kjeldahl flask and blending tubes were rinsed with an additional 25 mL distilled water and transferred into the same flask. Two drops of antifoam solution (Antifoam BTM Silicone Emulsion, Thermo Fisher Scientific) along with 2.5 mL 4 N HCl to balance sample pH between 1.5 to 1.6 were added to the flask immediately before distillation. Flasks were placed into controlled heating elements (Fisher Scientific, Pittsburg, PA) and 25 mL of sample was distilled through a water-cooled distillation apparatus. After distillation, 5 mL of sample was pipetted into a glass tube containing 5 mL thiobarbituric acid reagent and vortexed individually. Tubes were then placed into a boiling water bath for 35 min. Immediately following removal from the water bath, tubes were submerged into an ice bath for 10 min. Color absorbance was measured at 538 nm using a Genesys 20 spectrophotometer (Thermo Fisher Scientific). Values for TBARS concentrations were determined by obtaining the average absorption of the duplicate sample readings and mg/kg of malonaldehyde was determined using the K value of 7.8 (Tarladgis et al., 1960; American Meat Science Association, 2012).

Statistical analyses

The experimental design was a randomized complete block design with twenty replicates. Data were analyzed with the model including fixed effects of light (HFLO,

FLO, or LED), length of retail display (1, 3, 5, or 7 d), and all possible interactions. Analyses of instrumental color, myoglobin redox forms, myoglobin content, metmyoglobin reducing activity, and lipid oxidation were done using the 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 $P < 0.05$ level. The PROC CORR procedure of SAS was then used to generate correlations.

Results and Discussion

Meat ph and proximate composition

Average pH values of SM steaks (Table 1) were similar to those reported by Von Seggern et al. (2005) and King et al. (2011a). Fat content of SM steaks were lower than those reported by Von Seggern et al. (2005). Variations in fat and moisture concentrations of fresh beef can impact objective color measurements as increased fat content can increase *L** values (Raines et al., 2009; Martin et al., 2013; Garner et al., 2014).

Instrumental color

The *L** values in SM steaks displayed under various light sources demonstrated differences ($P < 0.05$), with LED-displayed steaks having the greatest *L** value (greater lightness; Table 2). Steele et al. (2016) reported no differences in *L** values for SM steaks under FLO and LED light sources. Additionally, Cooper et al. (2017) found no differences in L* values for steaks from the *Triceps brachii,* a muscle with low oxidative and color stability, displayed under fluorescent and LED lights during retail display. Retail display time also played a role in *L** values in steaks from the SM; *L** values decreased ($P < 0.05$) over retail display (Table 3). This finding agrees with those of King et al. (2011a), who observed a decrease in *L** values of beef SM steaks from d 0 to 6 of retail display. Khliji et al. (2010) found that an L* value of 35 and higher contributed to an acceptable meat color according to consumers.

Table 1. Proximate composition and pH values of beef *semimembranosus* ($n = 20$) steaks ($n = 240$)

Parameter	Average	Minimum	Maximum	SD[1]
pH	5.41	5.02	6.24	0.33
Fat, %	2.10	0.43	5.53	1.33
Moisture, %	74.86	70.04	79.00	2.30

[1]Standard deviations of mean values.

Table 2. Effect of display light source on color traits of beef *semimembranosus* ($n = 20$) steaks ($n = 240$)

	Light source[1]				
Parameter	HFLO	FLO	LED	SEM	*P*-value[2]
*L**	41.83^{ab}	41.14^{b}	42.36^{a}	0.46	0.0335
*a**	20.85^{a}	20.11^{ab}	19.37^{b}	0.43	0.0031
*b**	19.59	19.37	19.20	0.35	0.5434
a/b[3]	1.07^{a}	1.04^{a}	1.00^{b}	0.02	0.0006
SI[4]	28.68^{a}	28.02^{ab}	27.37^{b}	0.51	0.0400
HA[5]	43.48^{b}	44.43^{a}	45.30^{a}	0.45	0.0004
DMb[6]	4.68^{a}	4.20^{b}	4.53^{ab}	0.18	0.0229
OMb[7]	56.59^{a}	56.45^{a}	55.95^{b}	0.16	0.0002
Mb[8]	4.39	4.29	4.24	0.11	0.3981
MRA[9]	18.64	19.04	15.53	2.11	0.1928
TBARS[10]	1.23	1.19	1.31	0.08	0.3197

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

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

[2]*P*-value of LS Means.

[3]a/b = a/b ratio.

[4]SI = Saturation Index.

[5]HA = Hue Angle.

[6]DMb = Deoxymyoglobin (%).

[7]OMb = Oxymyoglobin (%).

[8]Mb = Myoglobin concentration (mg/g).

[9]MRA = Metmyoglobin reducing ability (%).

[10]TBARS = Thiobarbituric acid reactive substances (mg/kg).

Table 3. Effect of retail display day on color traits of beef *semimembranosus* ($n = 20$) steaks ($n = 240$)

	Retail display day					
Parameter	1	3	5	7	SEM	*P*-value[1]
*L**	42.91^{a}	42.18^{ab}	41.49^{bc}	40.52^{c}	0.57	0.0001
*a**	24.52^{a}	20.34^{b}	19.35^{c}	16.25^{d}	0.50	< 0.0001
*b**	21.02^{a}	19.73^{b}	19.24^{b}	17.57^{c}	0.41	< 0.0001
a/b[2]	1.18^{a}	1.06^{b}	0.98^{c}	0.92^{d}	0.02	< 0.0001
SI[3]	32.33^{a}	28.05^{b}	27.68^{b}	24.03^{c}	0.60	< 0.0001
HA[4]	40.55^{d}	43.46^{c}	45.85^{b}	47.75^{a}	0.52	< 0.0001
DMb[5]	5.82^{a}	4.85^{b}	3.82^{c}	3.39^{d}	0.20	< 0.0001
OMb[6]	56.70^{a}	56.58^{a}	56.46^{a}	55.59^{b}	0.19	< 0.0001
Mb[7]	4.40	4.34	4.25	4.23	0.13	0.5078
MRA[8]	27.11^{a}	15.39^{b}	16.06^{b}	12.38^{b}	2.43	< 0.0001
TBARS[9]	0.47^{d}	1.06^{c}	1.49^{b}	1.95^{a}	0.09	< 0.0001

[a-d]Means without a common superscript differ ($P < 0.05$).

[1]*P*-value of LS Means.

[2]a/b = a/b ratio.

[3]SI = Saturation Index.

[4]HA = Hue Angle.

[5]DMb = Deoxymyoglobin (%).

[6]OMb = Oxymyoglobin (%).

[7]Mb = Myoglobin concentration (mg/g).

[8]MRA = Metmyoglobin reducing ability (%).

[9]TBARS = Thiobarbituric acid reactive substances (mg/kg).

All L* values in this study were above the threshold for meat color acceptability based on L* values.

Surface redness (*a** values) differed ($P < 0.05$) between light sources (Table 2). Greater *a** values indicate a more red, consumer-desirable product. High UV fluorescent -displayed steaks demonstrated greater ($P < 0.05$) redness than the LED-exposed steaks. This finding indicated that the use of a HFLO light source promoted greater redness retention than LED light sources. These findings agree with those found in Cooper et al. (2017) who reported higher a* values in steaks produced from the *Triceps brachii* displayed under HFLO lights in comparison to those kept under LED light sources during retail display. Steele et al. (2016) reported that on d 0 of retail display, *a** values were greater for SM steaks displayed under LED lights than under fluorescent lights. However, for the duration of retail display, Steele et al. (2016) reported no differences in a* values between steaks from the SM displayed under fluorescent and LED light sources. Display case temperatures in Steele et al. (2016) were slightly lower (LED display case 0.84°C; fluorescent display case 1.53°C) than those in the present study, which could have impacted the rate of discoloration. Decreases in *a** values are indicative of discoloration of fresh meat products by a loss of redness on the surface of the product (Rogers et al., 2014). Values for a* decreased ($P < 0.05$) with increasing retail display time (Table 3). This finding is supported by the previous studies (McKenna et al., 2005; King et al., 2011a; Colle et al., 2016; Cooper et al., 2016; Steele et al., 2016; Cooper et al., 2017) that observed decreases in *a** values over retail display time for fresh beef products under fluorescent light sources. Holman et al. (2017) reported that an *a** value of 14.5 is considered the acceptable threshold for consumer acceptability of fresh beef. Accordingly, SM steaks in the present study were acceptable to consumers under all light treatments and for the entire duration of retail display.

No differences ($P > 0.05$) in *b** values were found between steaks displayed in all 3 light sources (Table 2). However, *b** values decreased ($P < 0.05$) throughout the duration of retail display (Table 3). King et al. (2011a) also reported a similar trend in *b** values for SM steaks during retail display. Similarly, Cooper et al. (2017) found that b* values decreased over the duration of 7 d of retail display in steaks produced from the *Triceps brachii*. Previous research has also reported a decrease in *b** values over 9 d of retail storage in steaks from the *Longissimus lumborum,* a color stable muscle (Joseph et al., 2012; Canto et al., 2016).

The *a*/*b* ratios were lower ($P < 0.05$) for SM steaks displayed under LED lights compared to those displayed with HFLO and FLO lights (Table 2). Decreases in *a*/*b* ratio values indicate a loss of redness (American Meat Science Association, 2012). This finding indicated greater discoloration in steaks displayed with LED lights than those displayed under HFLO and FLO. Additionally, the *a*/*b* ratios decreased ($P < 0.05$) over 7 d of retail display (Table 3).

Mimicking trends in a* values, SI differed ($P < 0.05$) between light sources, with HFLO steaks having greater SI values ($P < 0.05$) than steaks displayed with both FLO and LED light sources (Table 2). This indicated greater amounts of redness retention in SM steaks displayed under HFLO lights than in SM steaks under FLO and LED lights. Steele et al. (2016) reported greater SI for SM steaks displayed under LED light than those displayed under fluorescent light on d 0 of retail display, whereas for the remainder of the 4-d retail display no differences were observed between the LED and fluorescent light sources. The SI decreased ($P < 0.05$) over retail display (Table 3), agreeing with multiple previous reports (King et al., 2011a; Steele et al., 2016; Cooper et al., 2016) indicating a decrease in surface color intensity over time.

Hue angle increases as discoloration increases (Trinderup and Kim, 2015). The SM steaks displayed with HFLO lights exhibited lower ($P < 0.05$) HA than their counterparts under FLO and LED (Table 2), indicating that the use of HFLO bulbs minimizes discoloration in retail display. Length of retail display also impacted ($P < 0.05$) HA values, with HA increasing over retail display (Table 3). These results agree with previous investigations (King et al., 2011a; Cooper et al., 2016; Steele et al., 2016).

Instrumental color data suggested that the use of HFLO light in retail display promoted a greater amount of surface red color retention in comparison to FLO or LED lights in beef SM steaks, as indicated by *a** value, *a*/*b* ratios, SI, and HA. Cooper et al. (2017) found that the use of HFLO light sources promoted greater redness retention in beef steaks from the *Triceps brachii* compared to steaks under LED and FLO retail display. Steele et al. (2016) reported higher a* and SI values for SM steaks on d 0 of retail display but reported no differences between light sources for the duration of display.

Surface myoglobin redox forms

Light source influenced ($P < 0.05$) the DMb percentage in SM steaks, with the steaks displayed under HFLO demonstrating greater ($P < 0.05$) DMb levels than those under LED (Table 2). During retail display, DMb percentage decreased ($P < 0.05$) in steaks (Table 3); this finding was expected as oxygen exposure during retail display allows for the oxygenation of DMb to OMb (Faustman and

Cassens, 1990). The OMb is the bright cherry-red redox form that provides the consumer-desirable color to fresh beef products. As oxidation progresses, OMb percentage decreases with a concomitant increase in surface discoloration due to the formation of MMb (Suman and Joseph, 2013; Mancini and Ramanathan, 2014). Oxymyoglobin percentage of SM steaks differed ($P < 0.05$) between light sources (Table 2); steaks displayed under HFLO and FLO had greater ($P < 0.05$) OMb percentages than those displayed in LED. As previously stated, a* values for steaks displayed under LED light sources were lower than those displayed under HFLO and FLO light sources (Table 2). These findings indicate that the use of LED light sources in retail display promotes discoloration via loss of redness in SM steaks at greater degree than both high and low UV-fluorescent light. Oxymyoglobin percentage was not affected ($P > 0.05$) through d 5 of display, but decreased ($P < 0.05$) on d 7 (Table 3), indicating that SM steaks retained redness through d 5 of retail display.

As expected with the decrease in OMb percentage, the MMb percentage increased ($P < 0.05$) in SM steaks under all light treatments over retail display (Fig. 1). Decreasing a* values reported over the duration of retail display for steaks from the SM is an indicator of the discoloration brought on by MMb formation (Table 3). By d 5, LED-displayed steaks had greater ($P < 0.05$) MMb percentages than both HFLO and FLO displayed steaks, indicating more severe discoloration occurring in steaks displayed with LED lights compared to both fluorescent light sources. On d 7 of retail display, both LED and FLO displayed steaks had greater ($P < 0.05$) MMb percentages than those displayed with HFLO lights. Greene et al. (1971) established a threshold of 40% surface MMb formation to illicit consumer discrimination against beef due to discoloration. These findings indicate that the use of HFLO light minimizes Mb oxidation and surface discoloration in SM steaks during retail display. Cooper et al. (2017) reported that the use of HFLO light sources promoted greater amounts of redness retention in comparison to LED light sources in steaks produced from the *Triceps brachii.*

Myoglobin content

Concentration of myoglobin in a muscle can be used as an indicator of oxidative metabolism (King et al., 2011a). As expected, no differences ($P > 0.05$) were observed in Mb concentrations of steaks displayed in different lighting (Table 2). Retail display time also did not impact ($P > 0.05$) Mb concentrations (Table 3). Myoglobin concentrations in this study were similar to those previously reported (McKenna et al., 2005; King et al., 2011a).

Metmyoglobin reducing activity

Metmyoglobin reducing activity attributes to the color stability of individual muscles by the reduction of metmyoglobin to its ferrous redox forms (McKenna et al., 2005; Nair et al., 2016). Light source did not impact ($P > 0.05$) metmyoglobin reducing activity of SM steaks (Table 2). However, retail display time influenced ($P < 0.05$) metmyoglobin reducing activity, and metmyoglobin reducing activity values were greater ($P < 0.05$) on d 1 than values over the remaining days of retail display (Table 3). Moderate oxidative and color stabilities of

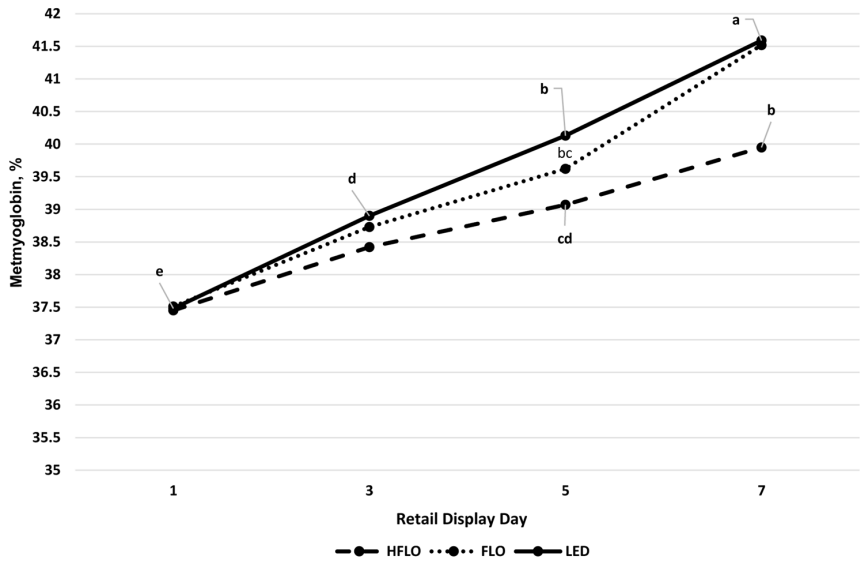

Figure 1. Effect of light source[1] and retail display on metmyoglobin contents in beef *semimembranosus* ($n = 20$) steaks ($n = 240$). 1HFLO = high UV fluorescent; FLO = low UV fluorescent; LED = light emitting diode. [a-d]Data without a common superscript differ ($P < 0.05$).

beef SM (McKenna et al., 2005) may be attributed to the lack of variation of metmyoglobin reducing activity values between d 3 and 7 of retail display. Wu et al. (2015) reported that metmyoglobin reducing activity exhibited no changes in beef *semitendinosus* steaks during retail display over 5 d. Whereas, Kim et al. (2006) reported decreasing metmyoglobin reducing activity values over 7 d of retail display in steaks from the *Longissimus lumborum* and SM. These variations in reducing ability could be attributed to the rate of depletion of NADH pools within each muscle (Bekhit and Faustman, 2005; Kim et al., 2006; King et al., 2011b; Wu et al., 2015).

Lipid oxidation

Light treatment did not influence ($P > 0.05$) lipid oxidation in SM steaks (Table 2). The TBARS values for all light treatments were below the detectable rancidity threshold value of 2.0 (Campo et al., 2006). Since beef SM has moderate color and oxidative stability (McKenna et al., 2005), these results were expected. Cooper et al. (2016) found no differences in lipid oxidation in ground patties from beef SM displayed under LED and fluorescent lighting. In contrast, Steele et al. (2016) observed that SM steaks displayed under LED lights demonstrated greater lipid oxidation than those under fluorescent light sources throughout retail display. Cooper et al. (2017) reported higher TBARS values in steaks from the *Triceps brachii* displayed under LED lights as opposed to HFLO light sources. In the present study, lipid oxidation increased ($P < 0.05$) with the retail display time (Table 3), and these results agree with the previous studies (Martin et al., 2013; Colle et al., 2016; Cooper et al., 2016; Steele et al., 2016; Cooper et al., 2017) in fresh beef products. The results of the present study indicate that retail display time had a greater impact than light source on lipid oxidation in beef SM steaks.

Relationship between color traits and lipid oxidation

Strong negative correlations were observed between TBARS and *a** values indicating that increases in lipid oxidation results in product discoloration (Table 4). Moderate negative correlations occurred between TBARS and *b** values and DMb contents. Conversely, a strong positive correlation was noted between TBARS and MMb levels. These trends indicate that an increase in TBARS values correlate with a decrease in redness. Strong relationships between lipid oxidation and discoloration in fresh meat products have been documented (Faustman and Cassens, 1990; Lynch et al., 1999; Renerre, 2000; Faustman et al., 2010). As expected, the increases in TBARS values positively correlated with MMb percentage; indi-

Table 4. Correlation among various color characteristics and biochemical attributes in beef *semimembranosus* ($n = 20$) steaks ($n = 240$)

Parameter	*L**	*a**	*b**	DMb	OMb	MMb	TBARS	Mb	MRA	pH
*L**	1.00									
*a**	-0.28***	1.00								
*b**	0.08	0.73***	1.00							
DMb[1]	-0.03	0.58	0.17	1.00						
OMb[2]	-0.13*	0.44	-0.45	-0.23**	1.00					
MMb[3]	0.12	-0.83	-0.45	-0.56***	-0.31	1.00				
TBARS[4]	0.15*	-0.72***	-0.45***	-0.56***	-0.31	0.72***	1.00			
Mb[5]	-0.13*	0.01	-0.08	-0.11	0.14*	0.01	0.05	1.00		
MRA[6]	-0.50***	0.51***	0.24***	0.31***	0.09	-0.34***	-0.26***	-0.001	1.00	
pH	-0.54***	0.20*	-0.11	0.27***	-0.10	-0.18*	-0.08	0.06	0.40***	1.00

*$P < 0.05$.

**$P < 0.001$.

***$P < 0.0001$.

[1]DMb = Deoxymyoglobin (%).

[2]OMb = Oxymyoglobin (%).

[3]MMb = Metmyoglobin (%).

[4]TBARS = Thiobarbituric acid reactive substances (mg/kg).

[5]Mb = Myoglobin concentration (mg/g).

[6]MRA = Metmyoglobin reducing ability (%).

cating that lipid oxidation and discoloration progress simultaneously in fresh beef products.

Metmyoglobin reducing activity demonstrated moderate negative correlations with *L** and weak negative correlations with both MMb content and TBARS values. Results indicate that increases in metmyoglobin reducing activity correlate with decrease in TBARS and MMb concentrations. These results are in agreement with multiple findings of increased metmyoglobin reducing activity levels in muscles with greater color and oxidative stabilities (Joseph et al., 2012; Canto et al., 2016). Moderate positive correlations occurred between metmyoglobin reducing activity and *a** values. McKenna et al. (2005) also found a positive correlation between metmyoglobin reducing activity and a* values in numerous bovine muscles. As metmyoglobin reducing activity is an indirect measurement of color stability, positive correlations with *a** are expected as an increase in redness would be an indicator of color retention (King et al., 2011b; Joseph et al., 2012).

Conclusions

Light source impacted surface redness retention, discoloration and Mb oxidation of steaks produced from the SM during retail display. Data indicated that while the use of HFLO lights promoted a greater amount of surface redness retention in comparison to LED lights, all steaks were above the determined threshold for a* acceptability within each light treatment. However, SM steaks displayed under LED reached the threshold of consumers to detect brown color as indicated by percent surface MMb on retail display d 5 compared to HFLO and FLO lighting sources which did not reach the threshold until retail display d 7. Light sources used in retail display may not have an impact on consumer purchase preference in steaks produced from muscles with moderate color stability.

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