**RAPID COMMUNICATION:**

Impact of contemporary light sources on oxidation of fresh ground beef

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**ABSTRACT:** Meat color is considered one of the driving factors in consumer purchasing decisions. The objective of this study was to determine the impact of 2 different lighting sources on color and lipid oxidation of ground beef patties in a controlled environment. USDA Select top rounds (n = 20) were processed to produce ground beef at 2 different fat levels (5 and 25%) and made into patties (113.4 g). Patties were packaged with oxygen permeable polyvinyl chloride, assigned to one of three lighting treatments (low UV fluorescent [FLO], light emitting diode [LED], and no light [DRK, negative control]), and placed within deli cases at 5°C. Patty removal for evaluation occurred on retail display d 1, 3, 5, and 7. Objective color measurements were obtained using a HunterLab MiniScan 45/0 LAV. These values were utilized to determine myoglobin redox forms as a measure of myoglobin oxidation. Additionally, thiobarbituric acid reactive substances (TBARS) were measured to indicate lipid oxidation. Objective color measurement for a* (redness), decreased for all light treatments by retail display day (P < 0.0001). Oxymyoglobin values for all light treatments decreased daily but showed no differences between treatments until d 5 (P < 0.0001) where DRK > LED > FLO. Conversely, metmyoglobin values increased daily (P < 0.0001), but showed no differences between treatments until d 5 where FLO > LED > DRK. TBARS values increased by day for each fat percentage (P < 0.0001) with 5% fat patties having higher TBARS values indicating great oxidation occurring in the phospholipids than adipose tissues. Results indicate that light treatment affected discoloration and metmyoglobin formation in ground beef patties; LED lighting may lead to increased meat quality shelf life in a retail setting.

**Key words:** color, ground beef, lighting, myoglobin, oxidation


**INTRODUCTION**

Color is one of the driving factors in consumer purchasing decisions regarding meat products in a retail setting (Djenane et al., 2001). As oxymyoglobin (MbO₂) transitions to metmyoglobin (MMb), meat color subsequently changes from a desirable bright cherry red to an undesirable brown color. This color change often results in a decreased willingness of consumers to purchase meat products; leading to discolored meat products being sold at discounted rates. Smith et al. (2000) reported that 15% of total retail sales of meat products were discounted due to product discoloration; resulting in a loss of $1 billion of revenue annually. Oxygen tension, temperature, surface microbial growth, and lighting conditions are the major factors that play a role in the alteration of meat color shelf life (Renerre, 1990). Fluorescent bulbs are the most common light source utilized within meat cases in retail settings today. However, Paul et al. (2014) reported that light emitting diodes (LED) are evolving quickly within retail settings. LED bulbs have the advantage of a longer life span, and an increased energy efficiency (Lee et al., 2011).

A pilot study, conducted at the University of Missouri meat lab, evaluated the effect of no light, high ultraviolet (UV) fluorescent light, and LED lights on ground beef patties in a simulated retail setting. Data showed fading of redness over time as indicated by a decrease in a* values (Cooper et al., 2015). The surface temperature of patties within the fluorescent chamber were continu-
ally higher than LED treated patties (Cooper et al., 2015). With temperature having an impact on oxidation in fresh products, controlling that variation would allow for the impact of the light source on discoloration to be studied independently. Therefore, the objective of this study was to determine the impact of low UV fluorescent and LED light sources on color and lipid oxidation of ground beef patties in a controlled temperature environment.

**MATERIALS AND METHODS**

**Deli Case Preparation**

Three deli cases (TDBD-72-4, True Food Service Equipment, O'Fallon, MO) were installed at the University of Missouri meat lab. All windows were blacked out to eliminate exposure to outside light sources. One deli case was equipped with factory installed low UV fluorescent bulbs (F25T8 TL741, Philips, Amsterdam, the Netherlands) with an average light intensity of 244 lux, color temperature of 4,100 K, and a CRI of 78, a second case was equipped with LED bulbs (L36/40/15W Market Lite LED, Interlectric Corporation, Warren, PA) with an average light intensity of 732 lux, color temperature of 4,000 K, and CRI of 85, and bulbs were removed from the final case (negative control). Light intensities were measured with a TES 1335 Digital Light Meter (TES Instrument, Shanghai, China). Lights in the deli cases were on continually for the duration of retail display. Deli cases were set to a constant temperature of 3 ± 1°C. Temperature and humidity were monitored within each individual case with data loggers placed in the center of each case (EL-USB-W-LCD, Dataq Instruments, Akron, OH) recording values every 15 min.

**Ground Beef Patty Manufacture**

USDA Select top rounds (n = 20) with remaining subcutaneous fat were purchased. Rounds were then trimmed and processed to remove all visible external fat from the surface. Lean was ground through a 10-mm grinding plate, blended and divided in half. One-half of the lean was ground through a 4.5-mm grinding plate (#8 Meat Grinder .35 HP, LEM Products, West Chester, OH) before being formed into 113.4-g patties of a 5% fat premium ground beef. The remaining one-half was supplemented with a portion of the trimmed subcutaneous fat, blended, ground through a 4.5-mm grinding plate, and formed into 113.4-g patties containing 25% fat. Patties were placed in Styrofoam trays, overwrapped with oxygen permeable polyvinyl chloride (UltraWrap Stretch Product #7021860 PVC #3, Anchor Packaging, St. Louis, MO), and assigned to 1 of 3 light treatments (low-UV fluorescent [FLO], LED, no light [DRK]).

**Fat and Moisture Percentage Determination**

This method was done as described by Dow et al. (2011). Using the CEM SMART Trac rapid fat analysis system, 2 sample pads were dried and a 3.75- to 4.5-g sample was spread across the first pad. The second pad was placed on top of the first and the sample was sandwiched between both pads. Moisture percentages of samples were determined on a weight basis using the CEM Moisture/Solids Analyzer. Following moisture determination, dried sample pads were then wrapped in TRAC paper and inserted into a CEM TRAC tube. The tube was placed into the CEM Rapid Fat Analyzer and fat percentage was then determined on a dry basis using NMR and converted to wet basis. To increase accuracy of fat and moisture determinations, samples were analyzed in triplicate. Values of these readings were averaged to determine an overall fat percentage for each sample batch.

**Objective Color Determination**

Instrumental measurements of color were preformed to assess color change in relation to overall acceptability within treatments. A HunterLab MiniScan 45/0 LAV (Hunter Associates Laboratory, Reston, VA) with a 25-mm aperture, D65 light source and physical standard was utilized to measure color (L*, a*, b*) on each patty on their assigned display removal day of d 1, 3, 5, or 7. Hue angle (HA), saturation index (SI), and a/b ratios were determined according to AMSA (2012). Color measurements were taken on patties immediately after removal from their respective cases. To obtain greater accuracy of patty surface color, samples were evaluated in triplicate and averaged as an indicator of total patty surface color.

**Myoglobin Concentrations**

Myoglobin concentrations were determined using selected wavelengths described by AMSA (2012). Reflectance was measured at the isobestic wavelengths 470, 530, 570, and 700 nm. Wavelength values were obtained in triplicate on retail display d 1, 3, 5, and 7 of the study. Deoxymyoglobin (DMb), MbO2, and MMb values are calculated using the equations provided in AMSA (2012). Oxymyoglobin values were determined after both M Mb and DMb values were calculated.

**Lipid Oxidation**

Lipid oxidation was measured using the method described by Tarladgis et al. (1960) with modifications from Fernando et al. (2013). Duplicate 5-g samples of each patty were obtained from both the surface and interior portion of each patty and blended for 2 min with 25 mL of distilled water with a hand blender. Following
homogenization, the cup was rinsed with an additional 25 mL of distilled water and poured into a Kjeldahl flask. 2.5 mL of HCl was added to the flask to balance the pH between 1.5 and 1.6 along with 2 drops of antifoam solution. 25 mL of each sample was distilled through a water-cooled distillation apparatus. Following distillation, 5 mL of each sample was pipetted into a glass tube followed by 5 mL of thiobarbituric acid (TBA) reagent. Samples were then placed in a boiling water bath for 35 min; once pulled samples were immediately placed into an ice bath for 10 min. Color absorbance was measured at 538 nm using a Spectronic 20 (Bausch & Lomb, Rochester, NY) spectrophotometer. Values of each reading were recorded and averaged for further use. Concentrations were calculated using the recorded averages, and the standard curve equation, thiobarbituric acid reactive substances (TBARS) values are expressed in mg of malonaldehyde/kg of product.

### Statistical Analysis

All experiments were replicated 20 times for each fat percentage. Data was analyzed as a randomized complete block design, the model included the fixed effects of light (DRK, LED, FLO), fat percentage (5 and 25%), length of retail display time (1, 3, 5, or 7 d), and all possible interactions. Statistical analysis for objective color, myoglobin concentrations, and TBARS values were analyzed using the GLIMMIX function of SAS (SAS Inst. Inc., Cary, NC) to obtain LS means and SE estimates. Significance was determined at $P < 0.05$.

### RESULTS AND DISCUSSION

#### Deli Case Environments and Patty Characteristics

Light intensity measurements taken for each light treatment resulted in means of 0, 244, and 732 lux for DRK, FLO, and LED, respectively. Mean deli case temperatures for DRK, FLO, and LED lighting treatments were 3.41, 3.65, and 3.37°C, respectively. Data indicates that although LED bulbs had a higher light intensity than FLO bulbs, they produced less heat within the case which agrees with the previous studies results (Cooper et al., 2015). Differences in temperature due to lighting treatment in the current study were smaller than the differences in our previous study (Cooper et al., 2015), which was expected as the deli cases were a controlled environment. Steele et al. (2016) also reported cases equipped with LED lights produced lower overall mean temperatures than those equipped with FLO lights. Decrease in storage temperature can reduce the rate of product discoloration and oxidation, in turn prolonging retail shelf life. Mean fat contents were 5.7 and 18.74% for the low and high fat patties. These values did not match the desired fat percentages of 5 and 25%, but are accurate representations for examining a low and high fat content ground beef patties. Values for mean moisture content for low and high percent fat patties were 61.64 and 71.09%, respectively (data not presented in tabular form). These values are expected as protein contains 3 to 4 times more water than fat. Therefore, patties with a higher protein content would in turn have a higher moisture content than patties with low fat percentages.

### Objective Color

$L^*$ values for all light treatments showed no differences ($P > 0.05$) over the duration of retail display as seen in Table 1. These findings agree with those reported in Steele et al. (2016) which reported no differences in mean $L^*$ values for ground beef displayed in FLO or LED lights. Values for $a^*$ decreased over time for all treatments where $d1 > d3 > d5 > d7$, indicating a decrease in the amount of redness over display time in agreement with previous findings (Jeremiah and Gibson, 2001). As seen in Table 1, each day of the study, patties with no light exposure had higher $a^*$ values than both lighting treatments, indicating that light exposure contributes to discoloration. It is important to note that on $d5$, LED and FLO treated patties differed from one another ($P < 0.05$) with mean $a^*$ values of 15.48 and 14.01, respectively. Values indicate that LED treated patties retained more redness on $d5$ of retail display life than FLO treated patties. Steele et al. (2016) reported a decrease in visual color score for ground beef displayed under LED lights in comparison to ground beef displayed under FLO lights indicating more red color. Values for $b^*$ mimicked $a^*$ values in the decrease over retail display time with $d1 > d3 > d5 > d7$ as seen in Table 1. These decreases in $b^*$ values over retail display time support data found in Raines et al. (2009) and Rogers et al. (2014) indicating an increase in discoloration over retail display time. However, Jeremiah and Gibson (2001) found that decreases in $b^*$ values had no relation to display time on whole muscle steaks in vacuum or CO$_2$ packaging, possibly indicating that grinding and packaging types impact changes in $b^*$ values over retail display time.

Differences ($P < 0.05$) in $L^*$ values were found between low and high fat patties over retail display time. As seen in Table 2, patties composed of 25% fat had higher $L^*$ values ($P < 0.05$) than patties containing 5% fat. Additionally, $L^*$ values were higher ($P < 0.05$) for patties containing 25% fat on each retail display day. These values were expected as $L^*$ is measuring darkness to lightness. Fat within the patties was white, therefore a higher fat content would contribute to an increase in lightness compared to a lower fat content. Differences
Table 1. Means of light source and retail display day on objective color, myoglobin concentration percentages, and TBARS values in ground beef

<table>
<thead>
<tr>
<th>Item</th>
<th>DRK</th>
<th>FLO</th>
<th>LED</th>
<th>DRK</th>
<th>FLO</th>
<th>LED</th>
<th>DRK</th>
<th>FLO</th>
<th>LED</th>
<th>SEM</th>
<th>( P )-value</th>
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<tbody>
<tr>
<td>L*</td>
<td>46.54</td>
<td>46.59</td>
<td>46.43</td>
<td>47.05</td>
<td>45.82</td>
<td>46.59</td>
<td>46.11</td>
<td>45.49</td>
<td>45.73</td>
<td>46.35</td>
<td>45.65</td>
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<tr>
<td>a*</td>
<td>24.57</td>
<td>23.67</td>
<td>23.39</td>
<td>20.32</td>
<td>19.74</td>
<td>19.63</td>
<td>18.95</td>
<td>17.47</td>
<td>17.89</td>
<td>17.69</td>
<td>16.41</td>
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<tr>
<td>b*</td>
<td>22.37</td>
<td>21.97</td>
<td>21.94</td>
<td>20.32</td>
<td>19.74</td>
<td>19.63</td>
<td>18.95</td>
<td>17.47</td>
<td>17.89</td>
<td>17.69</td>
<td>16.41</td>
</tr>
<tr>
<td>DMb</td>
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<td>4.43</td>
<td>4.71</td>
<td>4.40</td>
<td>3.73</td>
<td>4.35</td>
<td>3.52</td>
<td>2.37</td>
<td>3.14</td>
<td>2.42</td>
<td>2.15</td>
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<tr>
<td>MBO2</td>
<td>58.08</td>
<td>58.14</td>
<td>57.84</td>
<td>57.60</td>
<td>57.84</td>
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<td>37.43</td>
<td>37.42</td>
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<td>38.32</td>
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<td>40.10</td>
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<tr>
<td>a/b</td>
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<td>1.07</td>
<td>1.00</td>
<td>0.96</td>
<td>0.97</td>
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<td>51.78</td>
<td>49.27</td>
<td>52.34</td>
<td>57.83</td>
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</table>

a–h Means within a row lacking a common superscript differ \( P < 0.05 \).

1 Item: DMb = deoxymyoglobin (%), MBO2 = oxymyoglobin (%), MMb = metmyoglobin (%); TBARS = thiobarbituric acid reactive substances (mg/kg); a/b = a*/b*; SI = saturation index; HA = hue angle.

2 \( P \)-value light treatment × retail display day interaction.

were found in \( a^* \) values with fat percentage by day changes \( P < 0.05 \). Values for \( a^* \) decreased by retail display day for both fat percentages with d 1 > 3 > 5 > 7, respectively. Patties with 25% fat had lower \( P < 0.05 \) \( a^* \) values than patties containing 5% fat, with the exception of d 5 which had no difference \( P > 0.05 \). These results were expected due to patties with lower fat content containing more lean, therefore a greater amount of redness to be detected. Fat percentage also played a role in \( b^* \) values as patties containing 25% fat had higher \( P < 0.05 \) \( b^* \) values than 5% fat patties. These values are to be expected as an increase in fat content would cause an increase in detectable yellowness within the patties.

Decreases in \( a^* \) and \( b^* \) values over time indicate the loss of redness that occurs during the oxidation of bright red \( MbO_2 \) and its transition to brown M Mb. Data indicates that oxidation and discoloration of ground beef are impacted by light treatment and fat percent over retail display time. Steele et al. (2016) reported no differences in L*, \( a^* \), \( b^* \) values between FLO and LED lights, but their reported case temperature on d 3 of the study, with LED showing no differences between either treatment \( P < 0.05 \). By d 5 of the study, differences \( P < 0.05 \) in a/b ratios occurred between all light treatments with DRK > LED > FLO. Indicating that by d 5 of retail display, LED treated patties retained more redness than FLO treated patties.

Saturation index (SI) values decreased over time for patties within all light treatments. Patties treated with no light had higher SI values \( P < 0.05 \) for all retail display days. Patties treated with FLO and LED lights showed no differences \( P > 0.05 \) in SI values until d 5 where LED treated patties had a higher \( P < 0.05 \) SI value than patties treated with FLO lights. Higher saturation indices along with higher \( a^* \) values for LED treated patties on d 5 further indicate a greater amount of retained redness within LED treated patties over a longer retail display period. Five percent fat patties had a higher \( P < 0.05 \) SI value than their 25% counterparts on retail display d 1. However, for the remaining retail display days there were no significant differences in SI values for both fat percentages as seen in Table 2.

Hue angle (HA) values for patties within all light treatments increased with an increase in retail display time. As seen in Table 1, there were no differences \( P > 0.05 \) in hue angle values for all light treatments for retail display d 1 and 3. On d 5 differences were seen between light treatments \( P < 0.05 \) where FLO > LED > DRK, respectively. Larger HA values indicate greater discoloration and loss of redness within the patties. Further indicating that light treatment plays a role in discoloration of ground patties within retail display. Values in Table 2 show that HA values increased for both 5 and 25% fat patties over time as would be expected, however there were no differences found for fat percentage HA values over retail display time \( P > 0.05 \). Steele et al. (2016) found no differences in SI or HA values due to lighting source which support the findings in this study.
Impact of LED lights on ground beef oxidation

Myoglobin Concentrations

Deoxymyoglobin percentage values decreased over time with retail display d 1 > 3 > 5 > 7. These values were to be expected due to increased oxidation because of oxygen exposure over time. On retail display d 3 and 5, average DMb values were higher (P < 0.05) for LED treated patties. Oxymyoglobin values decreased over time for patties within all light treatments as seen in Table 1. For retail display d 1 and 3, there were no differences in MbO2 percentages within all light treatments (P > 0.05). Oxymyoglobin values for patties with no light treatment were superior to both LED and FLO treated patties on retail display d 5 and 7. Higher MbO2 values over time indicate the retention of the bright cherry red desirable meat color.

Metmyoglobin concentrations increased over time for patties within each light treatment. As seen in Table 1, MMB concentrations were not different (P > 0.05) between treatments until retail display d 5. Retail display d 5 and 7 MMB percentage values were lower and superior for patties not exposed to light compared to LED and FLO treated patties. Metmyoglobin concentrations were lower (P < 0.05) for LED treated patties than MMB concentration values for FLO treated patties on d 5 with means of 40.10 and 41.70, respectively. Data indicates that patty discoloration changes, as indicated by MMB concentrations, was greater for FLO treated patties than those treated with LED lights. McMillin (2008) reported that ground beef patties packaged in oxygen permeable over wrap had an overall display life of 2 to 7 d. Greater retention of redness by patties treated with LED lights through d 5 indicates that the use of LED lights can contribute to a longer display life for ground product. Patties treated with no light source had the lowest amount of MMB formation, further indicating that light exposure does have an effect on MMB formation and discoloration of ground beef.

Fat percentage impacted myoglobin concentration percentages over time. Table 2 shows that patties with 5% fat had higher MMB concentrations on retail display d 1 through 5 of the study when compared to patties with 25% fat. Oxymyoglobin concentrations decreased over display time for both fat percentages with differences (P < 0.05) on retail display d 7, where patties containing 5% fat had greater MbO2 concentrations than patties containing 25% fat with means of 53.71 and 52.43, respectively. These findings were to be expected as patties with lower fat content have a greater amount of lean available for discoloration.

Lipid Oxidation

Table 2 shows that TBARS values increased over time for each fat treatment. Patties with 5% fat content had greater TBARS values (P < 0.05) over retail display d 3 through 7, where d 3 < 5 < 7 than patties with 25% fat content. Polyunsaturated fatty acids found in membrane phospholipids have greater susceptibility to oxidation than saturated fatty acids (Wood et al., 2003, Aberle et al., 2012; Jiang and Xiong, 2016). An increase in red muscle fibers increases the susceptibility of lipid oxidation due to increased iron and phospholipids (Wood et al., 2004; Faustman et al., 2010). Due to a greater amount of red muscle fibers in patties containing 5% fat compared to those of 25% fat, which contain a greater proportion of added adipose tissue to muscle fibers; the 5% fat patties

Table 2. Means of fat percentage and retail display day on objective color, myoglobin concentration percentages, and TBARS values in ground beef

<table>
<thead>
<tr>
<th>Item</th>
<th>1</th>
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<th>5</th>
<th>7</th>
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<td>L*</td>
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<td>a*</td>
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<td>b*</td>
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<td>DMb</td>
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<td>MbO2</td>
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<td>a/b</td>
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<td>HA</td>
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</table>

Notes:
- a–hMeans within a row lacking a common superscript differ (P < 0.05).
- 1 Item: DMb = deoxymyoglobin (%), MbO2 = oxymyoglobin (%), MMB = metmyoglobin (%); TBARS = thiobarbituric acid reactive substances (mg/kg); a/b = a*/b*; SI = saturation index; HA = hue angle.
- 2P-value light treatment × retail display day interaction.
have an increased opportunity for a greater amount of oxidation to occur within cell phospholipid membranes. Previous research has indicated a concurrent increase in the discoloration of meat and lipid oxidation (Greene et al., 1971, Renerre, 2000). Min et al. (2010) reported that metmyoglobin induced lipid oxidation and increased TBARS values linearly in a phospholipid liposome system. Polyunsaturated fatty acids are almost exclusively restricted to the phospholipid fraction of muscle and adipose tissue in ruminants (Wood et al., 2003). This supports our findings of 5% fat patties having higher TBARS values than their 25% counterparts. While all TBARS values increased over retail display period for all light treatments, there were no differences (P > 0.05) between treatments for TBARS values. Steele et al. (2016) reported similar findings for TBARS values in ground beef under LED and FLO retail display with no differences being found between light treatments.

**Conclusion**

Light treatment had an impact on the formation of MMb in fresh ground beef patties. Patties exposed to no light were superior in all aspects of the study compared to those treated with both LED and FLO lights. Data indicates that introducing controlled temperature environments and the use of LED lighting changed the rate of discoloration as indicated by decreases in a* values and formation of MMb in ground beef patties over extended retail display. TBARS values were higher for patties containing 5% fat as compared to those containing 25% fat; indicating that lipids in the cell membrane play a larger role in lipid oxidation than added fat.

**LITERATURE CITED**


