EVALUATION OF THE RETAIL DISPLAY LIFE OF GROUND BEEF STORED IN MODIFIED ATMOSPHERE PACKAGING AND MODERN LIGHTING CONDITIONS

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

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presented by Danielle Reynolds,

a candidate for the degree of master of science,

and hereby certify that, in their opinion, it is worthy of acceptance.

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ABSTRACT

Color is the most important factor in decision making for the consumer in the retail setting. The objective of this study was to determine the color stability of ground beef patties packaged in modified atmosphere packaging (MAP) under three different retail lighting conditions. USDA Choice chuck rolls were first ground through a coarse 10 mm plate and then reground through a fine 4.5 mm plate and then formed into 27 patties (113.4 g). Patties were then assigned into one of three packaging treatments: HO_2-MAP (80% O_2: 20% CO_2), LO_2-MAP (20% O_2: 20% CO_2: 60% N_2), or overwrap with polyvinyl chloride (PVC). Then each packaging type was then assigned to one of three retail lighting conditions: low-UV fluorescent bulbs (FLO), light emitting diode (LED), and no light (DRK). Patties were removed on storage days 1, 3, 7, 10, and 14 for analysis of L*a*b*, lipid oxidation by thiobarbituric acid reactive substances (TBARS), and percentage of myoglobin states. The entire experiment was replicated three times. There was an interaction between package type and storage day for L* ($P < 0.0001$). Patties packaged in HO_2-MAP had an increase ($P < 0.05$) in L* through storage day but were

similar to each subsequent day. L* increased (P < 0.05) on storage days 3, 7, and 10 for patties packaged in LO_2-MAP. PVC patties had increase (P < 0.05) in L* from storage day 7 to 10. Patties packaged in HO_2-MAP and LO_2-MAP had higher (P < 0.05) L* values on storage days 3, 7, 10, and 14 than PVC. Package type had an effect (P < 0.0001) on a* where HO_2-MAP > LO_2-MAP > PVC, with averages on 15.88, 14.34, and 12.63, respectively. Lighting type also had an effect (P = 0.0005) on a* where DRK = FLO > LED, with averages of 15.32, 14.31, and 13.22, respectively. There was a decrease (P < 0.0001) in a* throughout storage day, 1 > 3 > 7 > 10 > 14, with averages of 23.56, 19.56, 12.98, 8.70, and 6.70, respectively. Lighting type did not have an effect on (P = 0.1045) TBARS. TBARS decreased (P < 0.0001) throughout storage day where 1 < 3 < 7 < 10 < 14, with averages of 0.58, 0.98, 1.67, 2.60, and 4.07, respectively. Packaging had an effect on oxymyoglobin (OMb) (P = 0.0012) where HO_2-MAP = PVC > LO_2-MAP (51.61, 50.84, and 49.45, respectively) and metmyoglobin (MMb) (P = 0.0025) where LO_2-MAP > HO_2-MAP = PVC (47.21, 43.92, and 45.16, respectively). Oxymyoglobin values were impacted by storage day where 1 = 3 > 7 > 10 = 14, with averages of 55.68, 54.6, 50.45, 46.48, and 45.95, respectively. Deoxymyoglobin (DMb) followed the same trend with storage day 1 = 3 > 7 > 10 = 14, with averages of 6.45, 6.33, 3.87, 1.63, and 1.42, respectively. Inversely, MMb increased over time with storage day 1 = 3 < 7 < 10 = 14, with averages of 37.87, 39.07, 45.68, 51.89, and 52.65, respectively. There were no differences between lighting type on OMb (P = 0.2410), DMb (P = 0.5229), or MMb (P = 0.2736) percentages. The use of HO_2-MAP in retail settings will increase redness in ground beef patties regardless of lighting source,

indicating that a movement towards LED lights in the retail setting will not be detrimental to discoloration in products packaged in HO_2-MAP.

Chapter 1

INTRODUCTION

Visual appearance is the first sensory experience for a consumer and color is the sole indicator of wholesomeness and quality at the time of purchase. Nearly 15% of retail beef is discounted during display for discoloration resulting in $1 billion in revenue loss annually (Smith, Belk, Sofos, Tatum, & Williams, 2000). Therefore, a large emphasis has been placed on strategies to improve fresh meat color and shelf life during retail display to increase profitability. Meat discoloration is inevitable during retail display and there is evidence that muscle with high myoglobin concentrations can be subject to oxidation during retail display (Raines, Hunt, &, Unruh, 2010). Autoxidation of oxymyoglobin and deoxymyoglobin to metmyoglobin results in undesirable brown discoloration (Suman & Joseph, 2013). Many different factors can effect meat color both in the live animal and post mortem. There are two different factors that can influence meat color in retail display the packaging type and the retail lighting source. Modified atmosphere packaging (MAP) removes or changes the environment inside a sealed package (McMillin, 2008). This new environment can contain varying levels of oxygen, carbon dioxide, nitrogen and in some cases carbon monoxide. MAP can be described as high (70-80%) or ultra-low (0%) oxygen content. Various combinations of gases such as oxygen, carbon dioxide, nitrogen and carbon dioxide can be used to extend color life by saturating the surface of meat and binging to myoglobin. Research has shown high oxygen MAP can extend shelf life of

ground beef up to at least 10 days (John, Cornforth, Carpenter, Sørheim, Pette, & Whittier, 2004). Low oxygen MAP with CO can extend shelf life up to 21 days (John et al., 2004), however, consumers discriminate against the use of CO (Cornforth & Hunt, 2008). The dark purple color of deoxymyoglobin associated with low O_2 MAP is also less desirable to consumers when compared the bright cherry red color produced by oxymyoglobin or carboxymyoglobin (Carpenter, Cornforth, & Whittier, 2001). Recent work in the University of Missouri Meat Science Laboratory indicates that light source effects color fading of overwrapped ground beef patties (Cooper, Wiegand, Koc, Schumacher, & Lorenzen , 2015; Cooper, Reynolds, Wiegand, Callahan, Koc, Schumacher, & Lorenzen, 2016). Therefore, the use of modified atmosphere packaging and new lighting sources such as light emitting diode could be used to extend color life in ground beef. The objective of this study was to determine the color stability of ground beef patties packaged in MAP under three different retail lighting conditions.

Chapter 2

LITERATURE REVIEW

2.1 The Influence of Appearance on Purchasing Decisions

Visual appearance and palatability of meat products are the two factors that impact consumers' preference for a particular meat product (Naumann, McBee, Jr., & Brady, 1957). Factors that influence palatability, such as flavor, tenderness and juiciness cannot be determined at the point of sale due to packaging and display constraints. Therefore, color and visual appearance are the most important factors influencing consumers' decisions at time of purchase (Carpenter et al., 2001; Djenane, Sánchez-Escalante, Beltrán, & Roncalés, 2001). These factors give an expectation for the product to have a high-quality eating experience and a long shelf-life; in reality there is not a well-established correlation between fresh meat color and palatability (Troy & Kerry, 2010). Nevertheless, consumers prefer to purchase meat displayed in the bright-red oxymyoglobin (OMb) state over meat displayed in the purple deoxymyoglobin (DMb) state or the brown metmyoglobin (MMb) state (Carpenter et al., 2001). It should be noted that fresh meat color at the time of purchase will not influence taste scores (Carpenter et al., 2001). This indicates that purchasing decisions do not influence eating satisfaction; however, consumers are still hesitant to purchases discolored meat products. Discrimination of discolored meat products during refrigerated display has resulted in the revenue loss of $1 billion dollars annually for the meat industry (Smith et al., 2000). This

can be contributed to consumers relating discoloration to microbial growth and spoilage (Seideman, Cross, Smith, & Durland, 1984). When meat appears bright cherry-red consumers will perceive the product to be safe, fresh and wholesome.

2.2 Myoglobin

2.2.1 Contributors to Meat Pigment.
Myoglobin is responsible for binding and delivering oxygen to the mitochondria in living muscle, thus allowing for the mitochondria to carry out functions of the cell (Wittenberg & Wittenberg, 2003). Myoglobin is the primary protein responsible for pigment in muscle, contributing 80-90% of total pigment in meat (Aberle, Forrest, Garrard, & Mills, 2012). Two other heme proteins contribute to pigment in muscle, but to a lesser extent. Hemoglobin is responsible for oxygen transport in red blood cells, but as exsanguination occurs the majority of blood is lost from the carcass leaving little hemoglobin to contribute to pigment (Aberle et al., 2012). Cytochrome c is another heme protein that contributes to meat pigment and in living cells functions as part of the electron transport chain in living cells (Aberle et al., 2012). Cytochrome c is more predominate in poultry than in red meat. Being more heat stable than myoglobin, cytochrome c contributes to the pink color found in cooked turkey (Suman & Joseph, 2014).

2.2.2. Myoglobin Structure.
Myoglobin is composed of a globular protein moiety consisting of 8 alpha-helices that form a coiled structure that surrounds a monomeric heme prosthetic group which has a centrally located iron atom with six coordination

binding sites. The iron atom can exist in the reduced ferrous (Fe^{2+}) state or the oxidized ferric (Fe^{3+}) state. Four of those sites are bound to nitrogen, the fifth site is bound to histidine-93 which connects the heme to the globin chain, leaving the sixth binding site available to bind to ligands. The ligand bound at the sixth binding site will determine meat pigment. In fresh meat, four chemical states of myoglobin can exist: deoxymyoglobin (DMb), oxymyoglobin (OMb), metmyoglobin (MMb) and carboxymyoglobin (COMb).

2.2.3 Myoglobin Chemistry. When the heme iron is reduced and no ligand is bound to the sixth coordination site, myoglobin is in the DMb state, resulting in the meat appearing purplish-red or purplish-pink (Mancini & Hunt, 2005). As myoglobin is exposed to oxygen the meat will "bloom" to a bright cherry-red color associated with the OMb state that results when oxygen is bound to the sixth coordination site (Mancini & Hunt, 2005). The brown pigmented, MMb state occurs as the ferrous iron (Fe^{2+}) is oxidized to the ferric (Fe^{3+}) state (Mancini & Hunt, 2005) and water occupies the sixth coordination position (Faustman & Cassens, 1990). As packaging technologies have advanced, it has been shown that the addition of carbon monoxide (CO) to the packaging atmosphere will result in a very bright cherry-red pigment in meat (Suman & Joseph, 2013). Myoglobin has a greater binding affinity for CO than it does for oxygen which will create a stable pigment when CO is bound to the sixth coordination site (Suman & Joseph, 2013).

In a meat product, myoglobin will usually exist in two or more of the chemical states. The state that is in the majority in a particular area will give the product its visual

appearance (Seideman et al., 1984). If 60% of the pigments are in the MMb state in an area of product the meat will appear to be brown (Seideman et al., 1984). In fresh cut meat products, the primary myoglobin state on the surface, after the products have had time to bloom, is the red pigmented OMb state. A layer of DMb will exist deep within the muscle and a thin layer of MMb will lay in between them (Møller & Skibsted, 2006). The depth of the outside OMb layer is determined by the partial pressure of oxygen (Møller & Skibsted, 2006). To reduce MMb formation in fresh meat, oxygen must be completely excluded from the environment or present at high levels (Faustman & Cassens, 1990). Oxygen partial pressures, above that of air, have been shown to slow MMb formation (Jeremiah & Gibson, 2001).

2.3 Factors Affecting Beef Color

Many factors effect and contribute to meat color stability from the live animal to post-mortem. It is important to understand how each factor contributes to the stability of meat color to be able to maximize color-life in beef.

2.3.1 pH. The rate of pH decline postmortem and the ultimate pH in post-rigor muscle both effect meat color stability. Ultimate pH in post rigor muscle of normal meat is approximately 5.4-5.8. It has been shown that lower pH values favor oxidation of myoglobin (Faustman & Cassens, 1990; Seideman et al., 1984). Low pH will accelerate the conversion of the heme iron from its ferrous state to the ferric state (Ahn & Maurer, 1989). At low pH, the heme protein is exposed as the globin tertiary structure goes

through a conformation change allowing the oxygen to disassociate from the heme (Seideman et al., 1984; Yin & Faustman, 1993). Beef with an ultimate pH greater than 5.8 is more color stable than product with a pH of 5.6 (Ledward, Dickinson, Powell & Shorthose, 1986) due to the heme iron staying predominantly in the ferrous state (Ahn & Maurer, 1989) resulting in the meat appearing to be dark red in color. However, as the pH nears 6.0, meat has a shorter shelf-life due to the increase in hydrogen sulfide-production bacteria which can cause greening on the surface of meat (Cole, Jr., 1986).

The rate of pH decline can be a result of pre-slaughter stress and lead to one of two color defects. Animals that are susceptible to stress usually result in an increase in body temperature and a rapid glycolysis (Aberle et al., 2012). When the rate of post-mortem decline is accelerated, but temperature still remains high, water-binding myofibrillar proteins are denatured and therefore will bind less water (Faustman & Cassens, 1990). Lighter surface color will result when the moisture from the unbound water increases the reflectance on the surface of meat (Swatland, 1984). This is commonly referred to as pale, soft, and exudative (PSE) meat which occurs mainly in pork, but can also occur in other species such as beef, lamb, and poultry (Aberle et al., 2012). Myoglobin from PSE muscle is less stable than myoglobin from normal muscle in pork (Bembers & Satterlee, 1975).

When an animal has a glycogen deficiency due to stress, such as fatigue, exercise, fasting, excitement or electrical shock, and is slaughtered before the animal has sufficient time to replenish its glycogen stores, limited glycolysis will occur resulting in a higher-than-normal ultimate pH due to the decrease in lactic acid production (Aberle et al., 2012). Muscle will absorb less total light and the pigments will reflect a dark-red or

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purplish color (Aberle et al., 2012). This will result in a product that is dark, firm and dry (DFD) and occurs mainly in beef and lamb (Aberle et al., 2012).

   2.3.2. Temperature.   Temperature is another factor that influences meat color. As temperature increases, the rate of myoglobin oxidation is increased (Seideman et al., 1984; Yin & Faustman, 1993) due to an increase in the rate of pro-oxidant reactions in the muscle (Faustman & Cassens, 1990). One reaction that occurs as temperature increases, is that the residual respiratory enzymes have a greater oxygen scavenging ability resulting in low oxygen tension which will facilitate the autoxidation of myoglobin (Renerre, 1990). Another pro-oxidant reaction as temperatures increase results in the loss of the globin moiety's function of protecting the heme (Seideman et al., 1984) resulting in the dissociation of oxygen from myoglobin producing the less stable DMb state which has a tendency for oxidation to the MMb state (Faustman & Cassens, 1990). As temperature increases there is an increase in oxygen consumption, microbial growth, and lipid oxidation rate, all of which effect discoloration in meat. Inversely, temperature decreases will result in the delayed onset of discoloration; therefore, slowing the oxygenation of myoglobin (Seideman et al., 1984). This occurs because the low temperature will promote the penetration of oxygen into the meat's surface and will increase the oxygen solubility, helping to maintain the OMb state (Renerre & Labadie, 1993). Hood (1993) reported that discoloration in beef was 2-5 times higher when stored in 10°C than when stored in 0°C after four days of storage.

2.3.3. Myoglobin Concentration. Differences in color intensity between species are generally caused by differences in myoglobin concentration (Seideman et al., 1984). Of the red meats, beef has the highest concentration of myoglobin, followed by lamb, then pork (Seideman et al., 1984). As an animal ages, myoglobin concentration increases resulting in the muscle appearing darker (Aberle et al., 2012). Sex also has an influence in myoglobin concentration, with intact males having higher concentrations of myoglobin than that of their castrated or female counterparts (Aberle et al., 2012).

2.3.4. Muscle Location and Fiber Type. There are muscle to muscle differences within the same animal that are due to the muscle fiber type present (Aberle et al., 2012). Muscles used in locomotion generally have a higher myoglobin concentration than support muscles due to the high oxygen requirement for energy in the muscle (Seideman et al., 1984). Muscles that have a high proportion of red fibers will appear to be dark red (Aberle et al., 2012). This is due to the fact that red muscle fibers predominantly use aerobic metabolism in which the oxygen is transported by myoglobin, leading to a higher concentration of myoglobin in these fibers than in white muscle fibers which function more on anaerobic metabolism (Seideman et al., 1984). Color stable muscles generally have greater depth of penetration by oxygen into the muscle aided by a lower oxygen consumption rate (McKenna, Mies, Baird, Pfeiffer, Ellebracht, & Savell, 2005).

2.3.5. Bacteria. Bacterial contamination has been shown to influence the discoloration of meat. Consumers often relate discoloration of meat to bacterial growth. It

has been noted that as MMb formation increases due to a reduction in oxygen tension happens as the logarithmic growth phase of aerobic bacteria (Renerre & Labadie, 1993). The reduction in oxygen tension is most likely due to the oxygen requirement of aerobic bacteria during the logarithmic growth phase (Seideman et al., 1984). However, previous research in the University of Missouri Meat Science Laboratory by Callahan, Lorenzen, Shircliff, Reynolds, Mustapha, and Wiegand (2016) suggests that myoglobin and lipid oxidation play a larger role in discoloration of ground beef than bacterial growth. In addition to the possible formation of MMb due to bacteria growth, some bacteria produce by-products that bind to myoglobin to produce a green pigment (Seideman et al., 1984). Most notably, the production of H_2S and H_2O_2 will react with myoglobin to produce sulfmyoglobin and choleglobin, respectively (Seideman et al., 1984). Packaging and storage temperature can be utilized to control bacteria growth in meat. Higher temperatures and oxygen permeable film will lead to an increase in bacterial growth on meat products (Seideman et al., 1984).

2.3.6. Lipid Oxidation. Lipid oxidation occurs as pro-oxidants are introduced in a cascade known as autoxidation that occurs in a three step process consisting of initiation, propagation, and termination (Aberle et al., 2012). Initiation occurs when oxygen is exposed to the product and cleaves the fatty acid double bonds to form free radicals (Aberle et al., 2012). As initiation occurs oxygen is produced or introduced from the surrounding atmosphere and will continue to attack unsaturated fatty acids, producing more free radicals (Aberle et al., 2012). This process is known as the propagation step which will continue as long as oxygen is available to cleave the double bonds (Aberle et

al., 2012). Termination will occur naturally as non-reactive products are formed and the propagation can no longer occur (Aberle et al., 2012). Autoxidation of the lipid is catalyzed by pro-oxidants such as metal ions, heat, low pH, and ultraviolet (UV) light (Aberle et al., 2012). Lipid oxidation is often analyzed by measuring the amount of malonaldehyde produced as a secondary bi-product of the propagation step. There is a strong positive correlation between the accumulation of malonaldehyde and MMb buildup (Hutchins, Lui, & Watts, 1967). The degree of lipid oxidation in meat is dependent on the composition of the phospholipids, the amount of polyunsaturated fatty acids, and the concentration of pro-oxidants (Calkins & Hodgen, 2007). Lipid oxidation can be related to many different meat quality factors including loss of color, development of off-flavor, odors and loss of nutritional value.

There are two different thoughts about the relationship between lipid and pigment oxidation. One is that heme pigments are catalyst of the propagation step in lipid oxidation (Faustman & Cassens, 1990). As stated previously, heme proteins are comprised of iron which is a metal ion and a known pro-oxidant of lipid oxidation. Ferrous myoglobin plays a part in the propagation stage of lipid oxidation by cleaving lipid hydroperoxides (Møller & Skibsted, 2006). However, heme pigments in the ferric state might be a more active catalyst than when heme-iron is in the ferrous state (Greene & Price, 1975). The other possible reason for the strong relationship between pigment and lipid oxidation is that the production of radical species from autoxidation will result in pigment oxidation (Faustman & Cassens, 1990).

2.3.7. Packaging

2.3.7.1. History of packaging technologies. At the turn of the 20th century through the early 1940's butchers would cut meat to order, wrap the product in paper and then tie it with string (Brody, 2002). In the late 1940's, DuPoint developed cellophane which allowed for backroom cutting and packaging of meat products in molded pulp trays with cellophane wrap in supermarkets (Brody, 2002). Cellophane is moisture resistant and oxygen-permeable. The use of cellophane wrap expanded throughout the 1950's, but issues with short shelf-life, color deterioration, and leakage led to new advancements in packaging (Brody, 2002). The 1960's saw many advancements in packaging. The introduction of overwrap with polyvinyl-chloride (PVC) and new polystyrene trays provided a package that was transparent, oxygen-permeable, and served as a moisture barrier (Brody, 2002). As the use of PVC became more popular, cellophane as a packaging device for meat became obsolete. The 1960's also saw the beginning of vacuum packaging (VP) for cured meats and primal cuts. This lead to the transition from whole beef carcass shipments to the concept of "boxed beef", where fabrication could happen prior to distribution to the retailer (Cole, Jr., 1986). Centralized packaging for red meats was developed in the late 1960's with the use of chubs for ground beef and barrier bags for wholesale cuts (Brody, 2002).

Since that time, three major trends have continued to influence meat packaging. The first is the movement towards increased hours of the retail store and the need to reduce labor cost by reducing the number of butchers. The second is the consumer's need for a convenient, fresh and high quality meat product. The last trend to influence meat packaging is the ability to provide a safe and wholesome product to the

consumer (Bechler, 2006). This has led to the increase of case ready packing in the retail store. The 2010 National Meat Case Study showed that 66% of total meat was packaged in case ready packaging (Cryovac, 2010). Ground beef had the highest percentage packaged in case-ready packaging at 71%. From that time case ready packaging has increased as the 2015 National Meat Case Study showed that total meat packaged in case ready packaging increased to 76% (Cryovac, 2015). Modified atmosphere packaging (MAP) is incorporated into many of the case ready systems (Zhao, Wells, & McMillin, 1994). Currently, there are two main formats to present meat in: one is placement of meat on trays with an oxygen permeable overwrap and the other is place in a gaseous modified atmosphere with high oxygen barrier tray and lidding or film system (Troy & Kerry, 2010).

2.3.7.2. Current Packaging Technologies

2.3.7.2.1. Overwrap. In retail settings that still utilize butchers, the use of trays and overwrap is a common packaging technique for fresh meat products. As primal and sub-primals are fabricated in to retail cuts, they are typically placed in a polystyrene tray and overwrapped with an oxygen-permeable film. Most commonly meat is overwrapped with a stretch PVC film. Consumers prefer this type of packaging over vacuum packaging and MAP (Carpenter et al., 2001). The typical retail display life for fresh meat is from 3 to 5 days when packaged in oxygen-permeable overwrap (Cole, Jr., 1986).

2.3.7.2.2. Vacuum Packaging. Vacuum packaging is the process of the complete removal of air surrounding the product and then sealing it in a barrier material. With VP being void of O_2, the product is displayed in the purplish-red DMb

state. Consumers are less likely to purchase meat that is displayed as purple when compared to meat that is bright cherry red (Carpenter et al., 2001). Although it appears that there is no residual air space in a vacuum package, a small amount of oxygen will still be present causing the formation of MMb on the surface of meat due to the low oxygen tension. As oxygen is consumed by the meat and microorganisms, the oxygen partial pressure will decrease further resulting in the reduction of MMb to the purple DMb state (Cole, Jr., 1986; Seideman et al., 1984). Another disadvantage to VP is the visible purge in the package, which is unattractive to consumers (Lagerstedt, Ahnström, & Lundstöm, 2011). The main advantage to VP is a long shelf life of up to 90 days for whole muscle cuts and up to 60 days for ground product (McMillin, 2008). Meats packaged in VP have minimal oxidative deterioration due to lack of O_2 (McMillin, 2008) and are easy for consumers to handle and store (Resurreccion, 2003). A newer VP technology is referred to as vacuum skin packaging (VSP). Meat is placed in a tray and the upper layer of film is heated then shrunk tightly around the product and adheres to the tray when the vacuum is drawn (Lagerstedt et al., 2011).

   2.3.7.2.3. Modified Atmosphere Packaging. Modified atmosphere packaging is defined as the removal and/or replacement of the surrounding atmosphere around a product which is then sealed in an oxygen-barrier package (McMillin, 2008). This type of packaging is convenient for the retailer as it can be pre-priced and pre-labeled at the packing plant (Belcher, 2006). Modified atmosphere packaging can include VP or the use of replacement gas flushes in the headspace with mixtures of O_2, CO_2, N_2, and CO (McMillin, 2008). The O_2 will react with surface myoglobin and work to extend color life of the product by extending the OMb state (Belcher, 2006). The CO_2 works to

inhibit aerobic spoilage bacteria (McMillin, 2008). The uses of CO_2 at 20% in MAP will prevent growth of spoilage bacteria; however, in concentrations over 20%, CO_2 has been shown to decrease the pH in the muscle and therefore increase the rate of MMb formation (Cole Jr., 1986). Nitrogen is primarily used as a headspace filler to displace oxygen and maintain the package integrity (Cole, Jr., 1986).

2.3.7.2.2.1. Ultra-Low Oxygen MAP Options

2.3.7.2.2.1.1. Ultra-Low Oxygen MAP. Ultra-low O_2 MAP usually has a head space containing 80% N_2 and 20% CO_2 (Belcher, 2006). Like VP, ultra-low O_2 MAP displays in the purplish-red DMb state (McMillin, 2008). An alternative to prevent an ultra-low O_2 package from displaying in this state is to use a barrier tray and a peelable lid. This will allow for the product to be distributed in the DMb state, then a peelable lid will be removed to expose an oxygen permeable film which will allow the product to bloom to the red OMb state (Belcher, 2006). This will allow for an increase in storage life of 5-10 days (Belcher, 2006) and due to the reduction of O_2, a decrease in oxidation, discoloration and microbial spoilage (Skandamis & Nychas, 2002).

2.3.7.2.2.1.2. Ultra-Low Oxygen with Carbon Monoxide MAP. An alternative to the ultra-low O_2 MAP is the addition of CO with a peelable lid. The use of 0.4% CO in MAP was approved by the United States Food and Drug Administration (FDA) for masterpacks in 2002 (FDA, 2002) and in primary packages in 2004 (FDA, 2004); however, due to consumer perception, many companies withdrew products packaged in CO-MAP (Grebitus, Jensen, & Roosen, 2013). Seyfert, Mancini, Hunt, Tang, & Faustman (2007) showed that 0.4% CO might be too low to

include in packaging containing 20% or 80% oxygen to promote color stability. Therefore, headspaces in these packages are usually comprised of 79.6% N_2, 20% CO_2, and 0.4% CO (McMillin, 2008). As previously discussed, CO has a high binding affinity to myoglobin. Therefore, the product will display in the stable, bright cherry-red COMb state. Brooks, Alvarado, Stephens, Kellermeier, Tittor, Miller, & Brashears (2008) showed the bright cherry-red of COMb can be stable for up to a year. The main concern with this type of package is that the color-life will mask spoilage (Belcher, 2006, Grebitus et al., 2013). However, Hunt, Mancini, Hachmeister, Kropf, Merriman, DelDuca, & Milliken (2004) showed that the addition of CO to MAP will not mask product spoilage in extended storage of 35 days.

2.3.7.2.2.2. High Oxygen MAP. The most common form of MAP is a high O_2 atmosphere with a barrier tray and lid (Belcher, 2006). This type of package typically has 80% O_2 and 20% CO_2 (Belcher, 2006), but can have headspaces with anywhere from 25-90% O_2 and 15-80% CO_2 (McMillin, 2008). The addition of oxygen into modified atmospheres will maintain the muscle in the cherry-red OMb state for a period of 8 to 14 days (Cole Jr., 1986). It is well documented that packaging in high O_2 MAP will result in a more desirable red initially and through early display but will then have a rapid decrease in surface redness when compared to meat packaged in ultra-low O_2 MAP or vacuum (Grobbel, Dikeman, Hunt, & Milliken, 2008; Jayasignh, Cornforth, Brennand, Carpenter, & Whittier, 2002; John, Cornforth, Carpenter, Sørheim, Pettee, & Whittier, 2005; Kim, Huff-Lonergan, Sebranek, & Lonergan, 2010). Initial color stability is seen in result of the formation of a thick layer of OMb at the meat surface, which will mask the underlying MMb layer (Jeremiah & Gibson, 2001). This

increase in the depth of surface OMb and therefore increase in distance of the MMb layer

from the meat's surface is one of the reasons why high O_2 MAP is more widely used in

the retail setting than that of ultra-low O_2 MAP (Hunt et al. 2004). However, it has been

shown that meat packaged in high O_2 MAP is less color stable than meat packaged in

ultra-low O_2 MAP, VP or MAP with CO (Grobbel et al., 2008; John et al., 2005). It is

important to note that the meat packaged in ultra-low O_2 MAP and VP will display in the

purple DMb state and although myoglobin has a higher affinity for CO, higher

concentrations of O_2 (50-80%) are effective of stabilizing redness in ground beef (Esmer,

Irkin, Degirmencioglu, & Degirmencioglu, 2011). Jayasingh and others (2002) showed

that ground beef packaged in 80% O_2 and 20% CO_2 maintained a bright red color through

10 days of storage. As oxygen amount in a package is decreased, the onset of

discoloration will increase (Esmer et al., 2011).

Esmer and others (2011) showed that varying gas compositions has no effect on

lipid oxidation. However, it is more accepted that the main disadvantage to this type of

packaging is an increase in lipid oxidation (Clausen, Jakobsen, Ertbjerg, & Madsen,

2009; Esmer et al., 2011; Jayasingh et al., 2002; Kim et al., 2010) due to the large

amount of O_2 in the package and therefore the development of off-flavors and odors

(Jayasingh et al., 2002). In addition to an increase in lipid oxidation, packaging in high

O_2 atmospheres can lead to deterioration of other quality aspects including; a decrease in

juiciness, tenderness, and an increase in protein oxidation (Clausen et al., 2009). Ground

beef stored in 80% O_2 and 20% CO_2 MAP had an undesirable flavor described as rancid

at six days of storage (Jayasingh et al., 2002).

2.3.8 Light Exposure. Light source in retail display can play an important role in discoloration of meat products. With new advancements in light sources it is important to continue to investigate the impact of these lights on display life of meat products. Not only is it important to investigate the impact of light sources on meat quality, but as new technologies are developed it is important to also evaluate these sources as they relate to economic and environmental concerns. Supermarkets allot half of their annual electricity cost to operate refrigerated display cases (EPA, 2006). Lighting contributes to about 15% of the total electricity that is used in refrigerated display cases (DOE, 2007). Display lighting can effect meat by an increase in temperature at the meat surface, photochemical effects, or differences in color rendition (Kropf, 1980).

2.3.8.1. Types of Light Sources

2.3.8.1.1. Incandescent. The common household light bulb is an incandescent (INC) bulb in which an electric current is used to heat a filament to produce light (Hunt & Mancini, 2009). Meat color is preferred under INC lighting when compared to fluorescent and metal halide light sources (Barburt, 2001). Under INC lighting meat will appear to be the familiar red color consumers prefer. This could be attributed to the relative luminance curve obtained for INC in this study demonstrated that the reflection was mainly in the red region. In a later study conducted by Barburt (2002) showed that consumers are more likely to buy ground meat under INC lighting than when displayed under fluorescent and metal halide. However, these bulbs often emit heat and do not provide a uniform illumination (Hunt & Mancini., 2009).

2.3.8.1.2. Fluorescent. Light is produced from a layer of fluorescent material and comes in a wide variety of tubular bulbs (Hunt & Mancini,

2009). Fluorescent (FLO) lights are the most common light source used in refrigerated display cases (DOE, 2008). However, FLO lights can cause some issues in the meat cases. There is a lack of luminance within the red region (Barbut, 2001). Fluorescent lights become less efficient at refrigeration and freezing temperatures. However, FLO bulbs are more efficient when compared to INC bulbs (Barbut, 2001). Due to the geometry of the FLO lights and lack of additional optics, only about 60% of the light generated illuminates the food on display and the other is lost outside of the case (DOE, 2008). Fluorescent bulbs do emit extra heat (DOE, 2008) but to a lesser extent than INC bulbs. Fluorescent bulbs emit about one-fifth the heat as INC bulbs (Kropf, 1980). White FLO lights generally do not cause discoloration of meat that is detrimental; however, some studies have shown some detrimental effect on the stability of color (Renerre & Labadie, 1993). This can be partial contributes to FLO bulbs with high UV-light which induces harmful effects on fresh red color in meat (Djenane et al., 2001). However, low UV-fluorescent bulbs showed no difference in a* and TBA values up to 5 days of retail display (Djenane et al., 2001). Therefore, when storing under FLO bulbs it is important to use a low-UV bulb.

   2.3.8.1. Light Emitting Diode. Light emitting diode (LED) provides a new alternative for illuminating display cases. LED bulbs operate more efficiently than FLO bulbs at colder temperatures (DOE, 2008). Light produced from LED bulbs can be directed toward the food that is on display (DOE, 2008). Brightness levels, measured in lux, are similar to that of FLO due to a more uniform light distribution (DOE, 2008). This type of lighting could be beneficial when used in a retail

meat case because LED bulbs produces less heat than FLO bulbs (DOE, 2008). However, less than 1% of refrigerated display cases utilize LED lighting systems (DOE, 2008).

2.3.8.2. Effects of Light on Discoloration. There is greater pigment oxidation in meat stored under light than storage with no light (Faustman & Cassens, 1990). An increase in temperature will lead to an increase in the rate of deteriorative reactions such as oxidation and microbial metabolism (Kropf, 1998). Deluxe FLO bulbs radiate about one-fifth as much heat as INC bulbs (Kropf, 1980). Incandescent lights will lead to an increase in surface temperature of meat of around 7°C when compared to meat stored in the dark and Deluxe Cool White FLO will increase the surface temperature about 6°C (Kropf, 1980). For every 10 foot candles of INC lighting for cases with 70 cubic feet per minute air velocity, meat surface temperature will increase approximately 1°F (Kropf, 1980). Surface temperature rises can also occur from radiant energy from the walls, ceiling and floor around the product even in the absence of light (Kropf, 1980).

Varying wavelength energies will react with the meat differently and be either absorbed or reflected. Those that are absorbed cause photochemical effects which will initiate or catalyze reactions that lead to changes in myoglobin leading to discoloration by destruction of the heme pigments (Kropf, 1998). Renerre and Labadie (1993) showed that light plays a critical role in pigment photooxidation due to light serving as a catalyst for the formation of MMb. However, they also showed that there is no particular wavelength in the visual spectrum that will enhance MMb formation over the others.

Color rendition is how close of a match the meat color is to the spectral energy distribution of the light (Kropf, 1998). Light sources should have a reasonable amount of wavelengths in the red portion of the spectrum to give a desirable red appearance of the

product (Kropf, 1980). Deluxe cool white FLO have more power in the red and green areas of the spectrum and less in the violet, blue, and yellow region and therefore are preferred over Standard Cool Light for red meat lighting (Kropf, 1980). Barbut (2001) showed that beef color was a more preferred red under INC light over FLO and metal halide lights (MH); 85% of panelist reported those products in INC lighting as brown/dark red and 90% described the meat under MH lights as dark red/brown. This could be contributed to the low amount of luminesce in the red region. The great amount of wavelengths produced in the red region by INC lighting could possibly lead to the increase in meat surface temperature seeing with this type of lighting (Kropf, 1980).

There are some reports that light does not affect meat color (Rambottom, Goeser, & Schultz, 1951; Kraft & Aryes, 1954). Kropf (1980) contributes this to the possibility that the eye might not be sensitive enough to detect pigment changes in early display.

EVALUATION OF THE RETAIL DISPLAY LIFE OF GROUND BEEF STORED IN MODIFIED ATMOSPHERE PACKAGING AND MODERN LIGHTING CONDITIONS

Abstract

Ground beef patties were packaged in modified atmosphere packaging (MAP) and displayed in retail deli cases (5°C) under no light (DRK), low UV-fluorescent (FLO), or light emitting diode (LED). Packaging treatments consisted of HO_2-MAP (80% O_2: 20% CO_2), LO_2-MAP (20% O_2: 20% CO_2: 60% N_2), or overwrap with polyvinyl chloride (PVC). Evaluation of L*a*b*, myoglobin state concentration and thiobarbituric acid reactive substances (TBARS) on storage days 1, 3, 7, 10, and 14. Patties packages in HO_2-MAP had greater (P < 0.05) surface redness than LO_2-MAP and PVC. Patties packaged in LO_2-MAP had greater (P < 0.05) metmyoglobin formation. Redness decreased (P < 0.05) over time and TBARS increased (P < 0.05) over time regardless of package type and light source. There were no differences between light sources on myoglobin state percentage (P > 0.05) and TBARS (P > 0.05). This could indicated that a movement towards LED lighting in the retail setting will not be detrimental to discoloration in products packaged in HO_2-MAP.

3.1 Introduction

Visual appearance is the first sensory experience for a consumer and color is the sole indicator of wholesomeness and quality at the time of purchase. Nearly 15% of retail beef is discounted during display for discoloration resulting in $1 billion in revenue loss annually (Smith, Belk, Sofos, Tatum, & Williams, 2000). Therefore, a large emphasis has been placed on strategies to improve fresh meat color and shelf life during retail display to increase profitability. Autoxidation of oxymyoglobin and deoxymyoglobin to metmyoglobin results in undesirable brown discoloration (Suman & Joseph, 2013).

A common strategy to improve color in meat is packaging type and technique. Modified atmosphere packaging (MAP) removes or changes the environment inside a sealed package (McMillin, 2008). Research has shown high oxygen MAP (80% O_2 and 20% CO_2) can extend shelf life of ground beef up to at least 10 days (John, Cornforth, Carpenter, Sørheim, Pettee, & Whittier, 2004). The 2015 National Meat Case Study showed that total meat packaged in case ready packaging increased to 76% (Cryovac, 2015) and MAP is incorporated into many of the case ready systems (Zhao, Wells, & McMillin, 1994).

Light source in retail display can play an important role in discoloration of meat products. There is greater pigment oxidation in meat stored under light than storage with no light (Faustman & Cassens, 1990). With new advancements in light sources, such as light emitting diode, it is important to continue to investigate the impact of these lights on display life of meat products. Not only is it important to investigate the impact of light sources on meat quality, but as new technologies are developed it is important to also

evaluate these sources as they relate to economic and environmental concerns. Supermarkets allot half of their annual electricity cost to operate refrigerated display cases (EPA, 2006). Therefore, the objective of this study was to determine the color stability of ground beef patties under three different retail lighting conditions in three different packaging types.

3.2 Materials and Methods

3.2.1 Sample Preparation and Packaging

USDA Choice chuck rolls (n = 3) were first ground through a 10 mm, coarse ground plate, then reground through at 4.5 mm, fine grind plate. Ground chuck was then portioned by use of a Frey F-Line F223 (Heinrich Frey Maschinenbau GmbH, Herbrechtingen, Germany) vacuum stuffer and then formed into twenty-seven patties (113.4 g). Patties were assigned to one of three packaging systems: a high-oxygen MAP (80% O_2, 20% CO2; HO2-MAP), a low-oxygen MAP (20% O_2, 20% CO_2, 60% N_2; LO2-MAP), or overwrap with oxygen-permeable polyvinyl chloride (PVC). Modified atmosphere packages were placed in black, #3 polypropylene tray and sealed with high barrier film with the use of a Rhino4 (UltraSource, Kansas City, MO, USA) tray sealer. Percentage of O_2 was measured at random by a gas analyzer to determine if gas compositions. Patties packaged in PVC were placed in black, #2S Styrofoam® trays and overwrapped with PVC. Packages were then assigned to one of three deli cases (TDBD-72-4, True Food Service Equipment, O'Fallon, MO, USA) each equipped with a different lighting source. One case had factory installed low-UV fluorescent bulbs (FLO) with an

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average lux of 244, another had light emitting diode (LED) bulbs with an average lux of 732, and bulbs were removed from the final case (DRK). Light intensities were measures with a TES 1335 Digital Light Meter (TES Instrument, Shanghai, China). Deli cases were set to a constant temperature of 5°C and all windows were blacked out to eliminate exposure to outside light sources. Patties were removed on retail storage days 1, 3, 7, 10, and 14 for analysis.

3.2.2. Fat and Moisture Determination

Fat and moisture percentage determination was performed in triplicate for each meat block according to methods described by Dow, Wiegand, Ellersieck, & Lorenzen (2011) by a CEM Moisture/Solids Analyzer and Smart Trac Rapid Analysis system (CEM Corp., Matthews, NC, USA). Briefly, a 3.75 – 4.5 g meat sample was spread in-between two sample pads and placed in the CEM Moisture/Solids Analyzer to determine moisture percentages on a weight basis. Following moisture determination, the dried sample pads were then wrapped in TRAC paper and inserted into a CEM TRAC tube. The tube was then placed into the CEM Rapid Fat Analyzer to determine fat percentage on a dry basis using NMP and converted to wet basis. Means for fat content for each group were as follows: 9.39, 9.05, and 13.60. Moisture content for each group was determined at 69.76, 69.11, and 66.75.

3.2.3. Objective Color Determination

Instrumental color of L*a*b* was determined using a HunterLab MiniScan 45/0 LAV (Hunter Associates Laboratory., Virginia, USA) with a D65 light source and a physical standard on retail storage days 1, 3, 7, 10 and 14. Color measurements were

taken on each patty directly after removal from their respective cases. Measurements were taken in triplicate on each patty and averaged to obtain a more accurate measurement of total patty surface color.

3.2.4. Myoglobin Concentration

Myoglobin concentrations were determined using selected wavelengths described in the AMSA Meat Color Measurements Guidelines (AMSA, 2012). Reflectance was measured at the isobestic wavelengths 470, 530, 570, and 700 nm which were reported by a HunterLab MiniScan 45/0 LAV (Hunter Associates Laboratory., Virginia, USA). On storage days 1, 3, 7, 10 and 14, wavelength values were obtained in triplicate. The reflectance (R) was converted to reflex attenuance (A) using Equation 1. The A values obtained were then inserted into Equations 2 and 3 to calculate metmyoglobin (MMb) and deoxymyoglobin (DMb), respectably. Metmyoglobin and DMb values were used in Equation 4 to determine the percentage of oxymyoglobin (OMb):

Equation 1: $A = \log(1/R)$

Equation 2: $\%MMb = \{1.395 - [(A570 - A700)/(A530 - A700)]\} \times 100$

Equation 3: $\%DMb = \{2.375x - [1 - (A470 - A700)/(A525 - A700)]\} \times 100$

Equation 4: $\%OMb = 100 - (\%MMb + \%DMb)$

3.2.5. Lipid Oxidation

Lipid oxidation was measured on storage days 1, 3, 7, 10 and 14 using the distillation method for determining malonaldehyde levels described by Tarladgis, Watts, Younathan, & Dugan (1960) with modifications from Fernando, Berg, & Grün (2003).

Duplicate 5 g samples of each patty were homogenized with 25 mL of distilled water for 2 minutes using a Hamilton Beach 2-speed handheld blender (Model #56760, Southern Pines, NC, USA). Following homogenization, the cup was rinsed with an additional 22.5 mL of distilled water and poured into a Kjeldahl flask. Then, 2.5 mL of 4N HCl was added to balance the pH between 1.5-1.6, along with, two drops of antifoam solution. 25 mL of each sample was distilled through a water-cooled distillation apparatus. 5 ml of distillate was pipetted into a glass tube followed by 5 mL of thiobarbituric acid reactive substances (TBARS) reagent. Samples were placed in a boiling water bath for 35 minutes. Tubes were pulled and placed directly in an ice bath for 10 minutes to stop the reaction. Sample was transferred into an acrylic cuvette with a visible spectral range of 340-750 nm. Color absorbance was measured by a spectrophotometer (Thermo spectronic Genesys 20 4001-04, Thermo Electron Corporation, Madison, WI, USA) at 538 nm. Values of each reading were recorded and averaged.

3.2.6. Statistical Analysis

Statistical analysis for objective color, myoglobin concentrations, and TBA values were analyzed using the GLIMMIX function of SAS (SAS Institute, Inc., Cary, NC, U.S.A.) to obtain LS means and SE estimates. The experimental unit was the patty and the model included the random effects of group and fixed effects of package type (HO_2-MAP, LO_2-MAP, PVC), light source (DRK, LED, FLO), and length of retail storage time (1, 3, 5, or 7 days) and all possible interactions. Means for fat and moisture on each group were determined using the GLM function of SAS. Significance was determined at $P < 0.05$.

3.3. Results and Discussion

3.3.1. Objective color

An interaction occurred (P < 0.0001) between package type and retail storage day for L* (Table 1). On day 1 HO_2-MAP had a higher (P < 0.05) L* values than PVC. Patties packaged in HO_2-MAP where similar (P > 0.05) in L* to those packaged in LO_2-MAP and both had higher (P < 0.05) L* values than PVC on days 3, 7, 10, and 14. Similar results have been noted by Seyfert, Mancini, Hunt, Tang, & Faustman (2007) who showed that beef packaged in HO_2-MAP, regardless of muscle, were lighter than that of beef packaged in atmospheric conditions. Similarly, ground beef packaged in HO_2-MAP have higher L* values than when stored anaerobic conditions (Jayasingh, Cornforth, Brennand, Carpenter, & Whittier, 2002). However, Esmer, Irkin, Degirmencioglu, & Degirmencioglu (2011) showed that varying gas compositions of O_2, CO_2 and N_2 had no effect on lightness in ground beef.

Patties packaged in HO_2-MAP increased (P < 0.05) in L* throughout 14 days of retail storage but each day was similar to the subsequent day. There was an increase (P < 0.05) in L* for patties packaged in LO_2-MAP on days 3, 7, and 10, where 3 < 7 < 10. Also, an increase (P < 0.05) was seen through days 7, 10 and 14 for PVC. Rogers, Brooks, Martin, Tittor, Miller, & Brashears (2014) showed that L* increased during storage for ground beef stored in HO_2-MAP, ultra-low O_2 MAP and overwrap with PVC. Light source did not have an impact (P = 0.1263) on L*, in a study by Steele, Weber, Boyle, Hunt, Lobaton-Sulabo, Cundith, Hiebert, Abrolat, Attey, Clark, Johnson, & Roenbaugh (2016) no differences where seen in L* for ground beef packaged in PVC overwrap stored under FLO lights or LED.

An interaction (P = 0.0332) was seen for b* between package type and retail storage day (Table 1). HO_2-MAP had a higher (P < 0.05) b* than LO_2-MAP on days 1 and 7. On day 3, HO_2-MAP was greater (P < 0.05) than PVC which was similar (P > 0.05) to patties packaged in LO_2-MAP. HO_2-MAP was similar (P > 0.05) to PVC on day 10 as both were higher (P < 0.05) than LO_2-MAP. Patties packaged in PVC were more yellow (P < 0.05) than both LO_2-MAP and HO_2-MAP on day 14. Ground beef in aerobic packaging is more yellow compared to when packaged in anaerobic atmosphere (Jayasingh et al., 2002; Rogers et al., 2014).

Patties packaged in HO_2-MAP decreased (P < 0.05) in b* though each retail storage day. There was also a decrease (P < 0.05) in b* for patties packaged in LO_2-MAP through day 10. PVC packaged patties decreased (P < 0.05) in yellow color through day 7. As display time increases, there was a decline in overall yellow color for ground beef in HO_2-MAP and overwrap in PVC (Rogers et al., 2014). Light source had an effect (P = 0.0021) on b* where DRK = FLO > LED. No differences were reported for b* in ground beef in PVC overwrap between storage under FLO lighting and LED (Steele et al., 2016).

The effects of package type, light source, and retail storage day on a* are presented in Table 2. Differences (P < 0.05) were seen between package type on a*, where HO_2-MAP > PVC > LO_2-MAP. This is expected due to the high amount of oxygen in the HO_2-MAP treatment saturating the surface of the patty, binding to myoglobin and producing the cherry-red OMb state. It is well documented that packaging in HO_2-MAP will result in a more desirable red initially and through early display but will then have a rapid decrease in surface redness when compared to meat packaged in ultra-low O_2 MAP or vacuum (Grobbel, Dikeman, Hunt, & Milliken, 2008; Jayasignh et al., 2002; John,

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Cornforth, Carpenter, Sørheim, Pettee, & Whittier, 2005; Kim, Huff-Lonergan, Sebranek, & Lonergan, 2010). Three cuts of beef steaks, *m. longissimus lumborum*, *semimembranosus*, and *adductor*, had more surface redness when stored in HO_2-MAP than steaks stored in vacuum package (Kim et al., 2010). Trained sensory panels showed that ground beef stored in HO_2-MAP and overwrap in PVC where similar and brighter red than ground beef packaged in vacuum package or ultra-low O_2 MAP (Rogers et al., 2014). This is expected as meat stored in a package lacking oxygen will display in the purple DMb state. Ground beef in HO_2-MAP will have high initial a* values but after 20 days of storage a* values will decrease to lower than all other package types (Rogers et al., 2014). One explanation for a greater a* in patties in PVC over patties packaged in LO_2-MAP, is that as oxygen in consumed CO_2 is released and can be removed from the packaged and at the same time more oxygen can be exposed to bind to myoglobin. The high barrier film used in LO_2-MAP will not allow for the transfer of oxygen back into the package, and oxygen concentrations will decrease over time in the package.

In ground beef, a* will decrease over time regardless of light treatment (Cooper, Reynolds, Wiegand, Callahan, Koc, Schumacher, & Lorenzen, 2016; Steele et al., 2016). Results from the current study supported this as a* decreased ($P < 0.05$) over retail storage day, where day 1 > 3 > 7 > 10 > 14, indicating a decrease in redness overtime. This is expected as the autoxidation of myoglobin will proceed in the presence of oxygen.

Patties displayed in DRK were similar ($P > 0.05$) in a* to patties in FLO lighting conditions. Both DRK and FLO had higher ($P < 0.05$) a* values than patties displayed under LED bulbs. This contradicts previous work that evaluated the effects of LED lighting conditions on a* in ground beef. Steele et al. (2016) showed no differences

between ground beef stored under FLO or LED for a* of ground beef. However, even though instrumental color did not indicate any differences, consumer panelist indicated that ground beef was less discolored under LED than under FLO. They concluded that storage in LED lighting conditions might help to decrease the appearance of discoloration in ground beef. Cooper, Wiegand, Koc, Schumacher, & Lorenzen (2015) showed that a* decreased more rapidly in ground beef patties stored in FLO lighting than those stored in LED bulbs. The human eye may not be able to detect small differences that are detected instrumentally (Brewer & McKeith, 1999) possibly indicating that the differences in a* between patties stored under FLO or LED conditions in this study may not be detectable to consumers. Additionally, differences could be seen due to differences in intensity between the FLO and LED bulbs.

3.3.2. Myoglobin Concentration

Table 3 shows the effects of package type on the percentage of OMb, DMb and MMb. Patties packaged in HO_2-MAP were similar ($P > 0.05$) to PVC in percentage of OMb on the patty surface. Patties packaged in LO_2-MAP had a lower ($P < 0.05$) percentage of OMb formation than the other two treatments. Inversely, MMb percentage was higher ($P < 0.05$) for patties packaged in LO_2-MAP than both HO_2-MAP and PVC, which were similar ($P > 0.05$). There were not any differences ($P > 0.05$) in DMb between package types. Results on instrumental a* supports that patties packaged in HO_2-MAP will have a higher percentage of OMb than the other two packaging types. According to a* results found in this study, it was not expected that PVC would have a higher percentage of myoglobin in the OMb state than patties packaged in LO_2-MAP because PVC had the lowest a* value. One explanation could be that as oxygen is

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consumed in meat CO_2 is released and in oxygen permeable packages the CO_2 can exit the package and more oxygen can penetrate the meats surface resulting in more myoglobin being in the OMb state.

The effects of retail storage day on myoglobin state percentages are shown in Table 4. There was a decrease ($P < 0.05$) in OMb percentage on days 3, 7 and 10, where $3 > 7 > 10$. Similarly, DMb decreased ($P < 0.05$) on days 3, 7, and 10, where $3 > 7 > 10$. Inversely, MMb percentage increases ($P < 0.05$) on days 3, 7 and 10, where $3 < 7 < 10$. Overtime the red OMb state will decrease as the oxidation of the ferrous iron to the ferric state and formation of the brown MMb state. If 60% of the pigments are in the MMb state in an area of product the meat will appear to be brown (Seideman, Cross, Smith, & Durland, 1984). This data is supported by the instrumental a* measurements which, as previously stated, decreased overtime.

Light source did not have an impact on the percentage of OMb ($P = 0.2410$), DMb ($P = 0.5229$) or MMb ($P = 0.2736$, Table 5). Cooper and others (2016) showed that regardless of light source OMb decreased overtime in ground beef and MMb increased overtime. Differences were seen on day 5 where display in no light had the highest amount of OMb, followed by LED and then FLO. Inversely, MMb formation was highest in FLO on day 5 followed by LED and then storage in no light. Another study performed by Cooper and others (2015) showed ground beef patties packaged in PVC under FLO lighting conditions had a lower percentage of OMb when compared to patties stored under LED lights or in no light. This, along with the current study could indicate that LED lighting in ground beef display will not increase the formation of the brown MMb

state when compared to other lighting conditions and could possibly decrease the rate of formation.

3.3.3. Lipid oxidation

Means for TBA values are shown in Table 6 for the impacts of package type, light source and retail storage day on lipid oxidation. Patties packaged in HO_2-MAP had higher ($P < 0.05$) TBA values than patties packaged in PVC. It has been shown that meat packaged in HO_2-MAP have a dramatic increase in lipid oxidation during display (Clausen, Jakobsen, Ertbjerg, & Madsen, 2009; Esmer et al., 2011; Jayasingh et al., 2002; Kim et al., 2010). In addition to an increase in TBA values, Clausen and others (2009) also saw an increase in warmed over flavor for products packaged in HO_2-MAP. Warmed over flavor is an off flavor produced as a result of lipid oxidation that could result in misconception of the product flavor. Rogers and others (2014) showed that on day 5 of retail display, ground beef packaged in HO_2-MAP and overwrap with PVC had higher TBA values than ground beef displayed in MAP with CO or anaerobic packaging. However, Esmer and others (2011) showed that varying gas compositions has no effect on TBA values.

As expected TBA values increased ($P < 0.05$) throughout retail storage day, where day $1 < 3 < 7 < 10 < 14$. It is well documented that TBA values will increase overtime (Esmer et al., 2011; Martin, Brooks, Brooks, Legako, Starkey, Jackson & Miller, 2013; Steele et al., 2016). This is expected due to the autoxidation of lipids and the coupling of lipid and pigment oxidation.

Lighting type had no impact (P = 0.1045) on TBA values. This is supported by Steele and others (2016) which showed that there was no difference in TBA values between ground beef in PVC under FLO lights or LED. However, they did show that beef *semimembranosus* steaks stored under LED lighting had higher TBA values than steaks stored under FLO lights.

3.4. Conclusion

Package type has an impact on meat color and lipid oxidation in ground beef. The use of packages with high amounts of O_2 will display in a brighter red than other packaging types. And is further supported by a high amount of OMb on the surface of the patties. Light source only had an effect on a*, where patties displayed under LED bulbs had lower surface redness. However, I would suggest more research be done in this area as these results contradicted previous studies. And that the difference in a* might not be detectable by the human eye. Over time ground beef patties will decrease in redness and increase in lipid oxidation; however, the use of different packaging systems and retail lighting has an effect on the rate of oxidation. The influence of light intensity should be investigated in the future to determine if light source or light intensity will play a more important role in meat discoloration. Data from this study indicates that the use of HO_2-MAP in retail settings will increase redness in ground beef patties regardless of lighting source, suggesting that a movement towards LED lights in the retail setting will not be detrimental to discoloration in products packaged in HO_2-MAP.

Table 1: Impacts of Retail Storage Day and Package Type on L*a*b*

Item	Storage Day	Package Type[1] HO$_2$-MAP	LO$_2$-MAP	PVC	SEM	P-Value
	1	47.73^{ef}	47.19^{efg}	45.83^{g}		
	3	47.97^{de}	47.35^{ef}	45.73^{g}		
L*	7	49.23^{cd}	50.35^{c}	46.30^{fg}	2.69	<0.0001
	10	50.63^{bc}	52.05^{ab}	47.88^{de}		
	14	52.09^{ab}	53.09^{a}	46.52^{efg}		
	1	24.94	22.30	23.14		
	3	21.58	17.82	19.29		
a*	7	15.12	11.69	12.14	1.85	0.06
	10	11.32	6.40	8.40		
	14	6.44	4.93	8.73		
	1	21.83^{a}	20.70^{bc}	21.20^{ab}		
	3	20.12^{c}	18.33^{d}	19.16^{d}		
b*	7	17.38^{e}	16.10^{fg}	16.65^{ef}	0.3430	0.0332
	10	16.30^{f}	14.88^{h}	15.85^{fg}		
	14	15.24^{gh}	15.35^{gh}	16.48^{f}		

[a, b, c, d, e, f, g] Means within row or column lacking a common superscript differ (P < 0.05)

[1]HO$_2$-MAP = 80% O$_2$, 20% CO$_2$, LO$_2$-MAP = 20% O$_2$, 20% CO$_2$, 60% N$_2$, PVC = overwrap with polyvinyl chloride

Table 2: Impacts of Package Type, Light Source, and Retail Storage Day on a*

Package Type[1]				Light Source[2]				Retail Storage Day						P-Values[3]		
HO_2-MAP	LO_2-MAP	PVC	SEM	DRK	FLO	LED	SEM	1	3	7	10	14	SEM	1	2	3
15.88^a	12.63^b	14.34^c	1.69	15.32^a	14.31^a	13.22^b	1.69	23.56^a	19.56^b	12.98^c	8.70^d	6.70^e	1.72	<.0001	0.0005	<.0001

[a, b, c, d, e] Means within row lacking a common superscript differ ($P < 0.05$)

[1]HO_2-MAP = 80% O_2, 20% CO_2, LO_2-MAP = 20% O_2, 20% CO_2, 60% N_2, PVC = overwrap with polyvinyl chloride

[2]DRK = no light, FLO = low UV-fluorescent, LED = light emitting diode

[3]1 = Packaging Type, 2 = Lighting Source, 3 = Storage Day

Table 3: Impacts of Package Type on Oxymyoglobin, Deoxymyoglobin, and Metmyoglobin

Item[1]	Package Type[2]			SEM	P-Value
	High-O_2	Low-O_2	PVC		
OMb	51.61[a]	49.45[b]	50.84[a]	1.29	0.0012
DMb	4.47	3.35	4.00	0.62	0.06
MMb	43.92[b]	47.21[a]	45.16[b]	1.88	0.0025

[a, b] Means within row lacking a common superscript differ (P < 0.05)

[1] OMb = Oxymyoglobin, DMb = Deoxymyoglobin, MMb = Metmyoglobin

[2] HO_2-MAP = 80% O_2, 20% CO_2, LO_2-MAP = 20% O_2, 20% CO_2, 60% N_2, PVC = overwrap with polyvinyl chloride

Table 4: Impacts of Retail Storage Day on Oxymyoglobin, Deoxymyoglobin, and Metmyoglobin

Item[1]	Retail Storage Day					SEM	P-Value
	1	3	7	10	14		
OMb	55.68[a]	54.60[a]	50.45[b]	46.48[c]	45.95[c]	1.29	<0.0001
DMb	6.45[a]	6.33[a]	3.87[b]	1.63[c]	1.42[c]	0.70	<0.0001
MMb	52.65[a]	51.89[a]	45.68[b]	39.07[c]	37.87[c]	1.98	<0.0001

[a,b] Means within row lacking a common superscript differ (P < 0.05)

[1] OMb = Oxymyoglobin, DMb = Deoxymyoglobin, MMb = Metmyoglobin

Table 5: Impacts of Light Source on Oxymyoglobin, Deoxymyoglobin, and Metmyoglobin

Item[1]	Light Source[2]			SEM	P-Value
	DRK	FLO	LED		
OMb	51.04	50.76	50.09	1.29	0.2410
DMb	4.21	3.94	3.67	0.63	0.5229
MMb	44.76	45.30	46.24	1.87	0.2736

[a, b] Means within row lacking a common superscript differ ($P < 0.05$)

[1] OMb = Oxymyoglobin, DMb = Deoxymyoglobin, MMb = Metmyoglobin

[2] DRK = No light, FLO = Low – UV Fluorescent, LED = Light Emitting Diode

Table 6: Impacts of Package Type, Light Source, and Retail Storage Day on TBA[1] Values

Package Type[2]				Light Source[3]				Retail Storage Day						P-Values[4]		
HO_2-MAP	LO_2-MAP	PVC	SEM	DRK	FLO	LED	SEM	1	3	7	10	14	SEM	1	2	3
2.37[a]	2.04[ab]	1.54[b]	0.97	1.66	2.08	2.20	0.97	0.58[d]	0.98[d]	1.67[c]	2.60[b]	4.07[a]	0.99	0.0074	0.1045	<.0001

[a, b, c, d] Means within row lacking a common superscript differ (P < 0.05).

[1]TBA = thiobarbituric acid reactive substances

[2]HO_2-MAP = 80% O_2, 20% CO_2, LO_2-MAP = 20% O_2, 20% CO_2, 60% N_2, PVC = overwrap with polyvinyl chloride

[3]DRK = No Light, FLO = Low UV-Fluorescent, LED = Light Emitting Diode

[4]1 = Package Type, 2 = Light Source, 3 = Retail Storage Day

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