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Shelf life of fresh meat products under LED or fluorescent lighting

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ABSTRACT

Enhanced pork loin chops, beef *longissimus lumborum* steaks, *semimembranosus* steaks (superficial and deep portions), ground beef, and ground turkey were displayed under light emitting diode (LED) and fluorescent (FLS) lighting in two multi-shelf, retail display cases with identical operating parameters. Visual and instrumental color, internal product temperature, case temperature, case cycling, thiobarbituric acid reactive substances (TBARS), and *Enterobacteriaceae* and aerobic plate counts were evaluated. Under LED, beef products (except the deep portion of beef *semimembranosus* steaks) showed less ($P < 0.05$) visual discoloration. Pork loin chops had higher ($P < 0.05$) L^* values for LED lighting. Other than beef *longissimus lumborum* steaks, products displayed under LED lights had colder internal temperatures than products under FLS lights ($P < 0.05$). Under LED, pork loin chops, ground turkey, and beef *semimembranosus* steaks had higher ($P < 0.05$) values for TBARS. LED provides colder case and product temperatures, more case efficiency, and extended color life by at least 0.5 d for *longissimus* and *semimembranosus* steaks; however, some LED cuts showed increased lipid oxidation.

1. Introduction

Retail customers have no way to estimate tenderness, juiciness, or flavor when evaluating similarly priced meat cuts for purchase in retail stores. Instead, meat color is the major criterion for selecting meat items (Kropf, 1993). During refrigerated display, fresh meat color changes, and customers discriminate against discolored meats, which causes up to $1 billion in annual revenue losses for the meat industry (Smith, Belk, Sofos, Tatum, & Williams, 2000).

Myoglobin is the primary pigment responsible for meat color. Pigment concentration and the chemical and physical parameters of meat, including light scattering and absorbing properties, affect meat color (Kropf, 1993). Myoglobin exists as deoxymyoglobin, oxymyoglobin, or metmyoglobin depending upon the state of the heme iron and the sixth-position ligand. Oxymyoglobin has a bright-red color, oxygen as a ligand, and reduced heme iron, whereas deoxymyoglobin is purple-red, has no ligand, and the heme iron is reduced (Faustman & Cassens, 1990). Metmyoglobin is the pigment responsible for the undesirable brown color of meat that occurs when iron has been oxidized and water occupies the sixth ligand (Faustman & Cassens, 1990).

Meat color is the result of many interactions (Kropf, 1993). Metmyoglobin formation depends on the reducing ability and oxygen consumption unique to each beef muscle (Ledward, Smith, Clarke, & Nicholson, 1977; Mancini & Hunt, 2005). Once meat is placed in retail display, other physical factors begin to influence fresh meat color. Reducing display temperatures 3 to 5 °C will retard discoloration (MacDougall & Taylor, 1975). The availability of oxygen to bind with myoglobin affects the rate of discoloration. Low oxygen partial pressure between 6 and 7.5 mm Hg promotes metmyoglobin formation (George & Stratmann, 1952). Bacterial contamination of meat also affects color. Short loins inoculated with *Pseudomonas fragi* discolored at a faster rate than untreated loins (Bala, Marshall, Stringer, & Naumann, 1977). Lipid oxidation promotes metmyoglobin formation; Chan, Faustman, and Decker (1997) found that oxidized liposomes allowed oxymyoglobin to change to metmyoglobin more rapidly than freshly prepared liposomes. Diet (French et al., 2000; Baublits et al., 2004; Realini, Duckett, Brito, Dalla Rizza, & De Mattos, 2004); genetics (King et al., 2010); and breed (Brewer et al., 2002; Brewer et al., 2004) also influence meat color. The complexity of meat color changes must take into account all these.

Retail meat appearance also depends on display lighting type and intensity. Lighting technology has the potential to extend fresh meat color. Some fluorescent (FLS) bulbs with an ultraviolet-filter plate of polycarbonate extend the color life of fresh pork sausage by 12 d compared to standard supermarket FLS tubes (Martínez, Cilla, Antonio, &

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Roncalés, 2007). Newer lighting technologies can enhance meat color and reduce other costly inputs for meat retail display. Light emitting diode (LED) lighting offers advantages for display both through energy efficiency and by reducing heat generation.

LED technology developed in the 1950s with commercial production starting in the late 1960s (DOE, 2009a). LED technology is different from traditional lighting in that it emits light when a current is applied to a semiconductor chip populated with electrons opposed to heating a filament or creating an electrical arc through gases (DOE, 2009a). Furthermore, LED lighting can be engineered to produce light in a very specific band of wavelengths. Therefore, color damaging ultraviolet light can be avoided for meat retail display cases.

Currently, less than 1% of refrigerated display cases have LED lighting technology (DOE, 2008). Phosphor converted LEDs have greater efficiency and more energy savings than either incandescent or compact fluorescent light bulbs (Arik, 2009). LED lighting can save on both cost and energy due solely to efficiency; they are also more environmentally friendly but have a higher initial cost. The United States has a 2015 goal of producing LED lighting systems costing less than $2/kilolumen with a color-rendering index (CRI) greater than 80, correlated color temperature (CCT) less than 5000 K, and 126 lm/W luminaire that emits approximately 1000 lm (DOE, 2009b). Currently, warm white LED systems with CCT less than 3300 K have 40–60 lm/W while compact fluorescent lighting have 35–60 lm/W. Although both technologies are similarly efficient, fluorescent technology is close to reaching its full efficacy while LED systems could improve two-fold on energy efficiency (DOE, 2009b). In addition, LED lighting has a longer operating life, lower maintenance and life cycle costs, minimal light loss, directional illumination, adjustable color, and uniform illumination (DOE, 2008). LED lighting would make a strong choice for retail display meat cases with potential cost savings, energy savings, and less heat generation. If the entire refrigerated market converted to LED lighting, energy savings up to 2.1 TW h of electricity is possible (DOE, 2008).

The objective of this study was to determine the effects of LED and FLS lighting on visual and instrumental meat color and shelf-life properties of five types of fresh meat products displayed in two retail display cases running at similar temperature profiles when the case lighting was off.

2. Materials and methods

2.1. Retail display cases and case efficiency

Two Hussmann Ingersoll 8 ft M5X (Bridgeton, MO) multi-shelf, meat retail display cases were installed in the Kansas State University (KSU) Meat Color Laboratory. One case was equipped with FLS lights, the other with LED lights. The cases were installed end-to-end with condenser units equipped with an on/off cycle counter and an hour meter in an adjacent room. Defrost cycles occurred simultaneously every 6 h. To minimize end-temperature fluctuations and to simulate end-to-end case placement, a 1.03 × 1.74 × .05 m piece of Owens Corning Formulator 150 insulation (Toledo, OH) was attached to the outside end of each case.

Cases were adjusted to operate with temperatures as similarly as possible to one another with case lighting off and similar condenser cycling. Temperatures were confirmed with 30 RD-Temp-XT Temperature Loggers (Omega Engineering, Stamford, CT) to be similar during 2 to 3 d of dark operation before d 0 of the study. Each display case had four adjustable shelves in two sections and a fixed bottom shelf. The top shelf depth was 35.66 cm, shelf 2 was 40.64 cm deep, shelves 3 and 4 were 45.72 cm deep, and the bottom shelf was 72.39 cm front to back. Shelves were arranged identically in both cases and were similar in vertical spacing to cases in Manhattan, KS, supermarkets. As product was removed from a case for analyses, a 454 g plastic water bag was positioned in the vacant location to simulate a full display case load. The average room temperature was 18.3 °C. The efficiency of the LED and FLS lighted cases were compared using mean case temperatures and the average case condenser run cycles/h.

2.2. Display lighting

The meat products in both cases were illuminated 24 h/d. In the LED case, a canopy lighting fixture (Hussmann® EcoShine Model Nos. 4441720 and 4441721, Bridgeton, MO) was positioned above the top shelf; it had a CCT of 2867 K and a CRI of 93. The bottom four shelves were illuminated with LED light bars (Hussmann® EcoShine Model No. 4441590, Bridgeton, MO) with a CCT of 3007 K and a CRI of 95.7. Lighting intensity in the LED case averaged 1627 lm. The FLS lighting (Sylvania Octron, F032/835/ECO, Danvers, MA) had a CCT of 3500 K, a CRI of 82, and an average lighting intensity of 1712 lm.

2.3. Case temperatures

Case temperatures were monitored throughout the study using I-button Thermochrons (DS1921 G Maxim Direct, Sunnyvale, CA). Six I-buttons were placed on each shelf near the front and toward the back with two on the far left, two on the far right, and two in the center of each shelf for a total of 30 temperature data loggers per case. Temperatures were recorded every 10 min throughout the study.

2.4. Raw materials and packaging for display

Four fresh meat products were obtained from a commercial supplier (Cargill Meat Solutions, Wichita, KS) and stored in a 4.4 °C cooler for up to 2 d before reprocessing and/or repackaging for display.

2.4.1. Pork loin chops

Boneless chops (1.91 cm thick, 6 d postmortem), enhanced with 12% pork stock, lactate, phosphate, salt, and natural ingredients, were received in packages containing four chops each and enclosed in a modified atmosphere packaging (MAP) mother bag containing 0.4% CO, 35% CO_2, and 64.6% N_2. Chops were randomly selected (after 10 d in MAP) from the mother bag and individually packaged on 13.34 × 13.34 × 1.27 cm 1S foam trays (Dyne-a-pak Inc., Laval, QC, Canada) with Dry-Loc (ac-50, Cryovac, Duncan, SC) moisture absorbent pads and overwrapped with polyvinyl chloride (PVC) film (23,250 $cm^3/m^2/24$ h @ 23 °C and 0% RH; Borden Packaging and Industrial Products, North Andover, MA).

2.4.2. Beef longissimus lumborum steaks

USDA select/low choice, boneless beef *longissimus lumborum* steaks enhanced with 8% pump of beef stock, lactate, phosphate, salt, and natural flavorings came as individually packaged steaks (1.27 cm thick on foam trays with PVC overwrap in a mother bag flushed with 0.4% CO, 35% CO_2, and 64.6% N_2). After 10 d in MAP, steaks were removed from the mother bag, and individually re-packaged on 21.59 × 11.43 × 1.43 cm 17S foam trays containing a moisture absorbent pad and overwrapped with PVC.

2.4.3. Ground beef

Coarse ground beef (85% lean and 15% fat) came in 4.54 kg chubs. On d 0, coarse ground beef was re-ground at the KSU Meat Laboratory through a 0.32 cm plate; 454 g of ground beef was then placed on a moisture absorbent pad on 20.96 × 14.61 × 1.59 cm 2S foam trays and overwrapped with PVC.

2.4.4. Ground turkey

Ground turkey containing rosemary was case-ready, in a 454 g/MAP containing 70% O_2, 20% CO_2, and 10% N_2.

2.4.5. Beef semimembranosus steaks

One day before display, vacuum packaged USDA select/low choice, boneless beef *semimembranosus* subprimals were trimmed of external