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Nitrite-embedded packaging film effects on fresh and frozen beef color development and stability as influenced by meat age and muscle type

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ABSTRACT

Muscles (*Longissimus lumborum*, LL; *Psoas major*, PM, *semitendinosus*, ST) were aged (2, 9 d postmortem), cut into steaks, anaerobically packaged (nitrite-embedded film, NEF), and displayed (fresh, 19 d; frozen, 39 d). Fresh NEF increased ($P < 0.05$) in redness (first 48 h). Upon opening fresh NEF (d 6) and overwrapping in PVC film, redness declined ($P < 0.05$). NEF cooked LL had more red surface compared to non-NEF. Meat age influenced NEF color. Intact NEF maintained acceptable red color throughout display. Residual nitrite and nitrate associated with fresh NEF and nitrate in NEF cooked LL were found ($P < 0.05$) in the outer layer. Consideration should be given to providing sufficient time for nitric oxide myoglobin development when using NEF which may be influenced by meat age and muscle differences. NEF packaging has potential to extend fresh beef color display life. NEF appears to offer the opportunity to display bright red beef in frozen display by limiting typical effects of photooxidation.

1. Introduction

Meat color significantly influences consumer preferences and the likelihood they will purchase beef (Carpenter, Cornforth, & Whittier, 2001). Discoloration of packaged fresh meat in the retail case is referred to as "loss of bloom" by the meat industry (Seideman, Cross, Smith, & Durland, 1984). Every year retailers and distributors of beef lose thousands of dollars as a result of having to discount or discard beef that has turned brown.

Modified atmosphere packaging (MAP) has been used to improve color stability. High oxygen MAP (80% oxygen 20% carbon dioxide) is widely used at retail meat markets because the oxygen favors the bright red color of meat which is appealing to consumers; however, this packaging system may negatively affect meat quality characteristics by inducing lipid and myoglobin oxidation and cross-linking/aggregation of myosin by protein oxidation (Kim, Huff-Lonergan, Sebranek, & Lonergan, 2010). In addition, MAP that utilizes high oxygen has limited shelf life extension, may lead to premature browning, makes it difficult to recognize leakers, requires a bulky package to provide needed MAP headspace, and is not well suited for freezing (Siegel, 2011).

Another MAP technology employs use of low levels of carbon monoxide in an anaerobic package (Brewer, Wu, Field, & Ray, 1994; Sørheim, Nissen, & Nesbakken, 1999). Although this technology is effective on fresh beef, consumer concerns over the safety of carbon monoxide caused the industry to withdraw most applications of this technology at the retail level. Carbon monoxide has a negative image by consumers because it is a potentially hazardous gas (Cornforth & Hunt, 2008).

Red color is unstable during display, particularly associated with frozen meat. Lanari, Cassens, Schaefer, and Scheller (1993) found that color saturation rapidly declined in frozen displayed sliced (5 mm) meat obtained from animals not supplemented with vitamin E. In addition, the color of carbon monoxide packaged beef also rapidly deteriorates during frozen display (Claus, unpublished data). Such color instability is one of the main reasons why frozen meat is not commonly offered at the retail level.

A novel packaging film has recently been developed (FreshCase®, Curwood Inc., Division of Bemis Company Inc., Neenah, Wisconsin) that has the potential to overcome consumer concerns and provide a bright cherry red, desirable beef color under anaerobic conditions which offers excellent microbial shelf life. The film contains embedded crystals of sodium nitrite (nitrite-embedded film, NEF). Yang et al. (2013) found that redness (CIE a*) was greater for FreshCase-packaged beef steaks than vacuum packages not containing nitrite with the increase of storage time and this film did not influence microbial growth.

Nitrite has been used for decades to safely cure meat at approved levels (120 to 200 ppm) regulated by the USDA. Most cured meat at the retail stores contains 10 to 50 ppm nitrite. In perspective, according to Siegel (2011) the amount embedded in the film represents an ingoing nitrite level for beef of less than 2 ppm with no measurable residual amount of nitrite found in the meat. When nitrite reacts with proteins, the residual nitrite level decreases (Woolford, Cassens, Greaser, & Sebranek, 1976). However, studies on residual nitrite in the outer meat layer of NEF packaged products have not been reported. This packaging technology does present the opportunity to deposit

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residual nitrite in the meat either as a direct deposit or after pigment oxidation (chemical and photooxidation induced) where released nitric oxide oxidizes to nitrite and nitrate.

The bright red color is formed in beef from the reaction of nitrite with the myoglobin in meat. Nitrite is reduced to nitric oxide by the meat's inherent reducing ability (Aberle, Forrest, Gerrard, & Mills, 2012). The nitric oxide binds to the 6th coordinate position on the iron in the heme ring. If the iron is in the ferrous state (reduced, Fe^{2+}) the raw meat pigment that is formed is nitric oxide myoglobin (NOMb, bright red). If nitric oxide binds to iron in the oxidized state (Fe^{3+}) the pigment formed is nitric oxide metmyoglobin (NOMMb, brown). This latter pigment typically occurs in the presence of oxygen. In anaerobically packaged fresh meat, the meat continues to respire (consume oxygen) and has good reducing ability. As such the NOMMb will convert into NOMb with refrigerated storage time.

Considerable effort has been done to stabilize a bright red color of beef during frozen display. Studies were conducted on beef fed Vitamin E, beef exposed to pure oxygen to fully bloom the meat, as well as exposure to carbon monoxide (Huffman, Davis, Marple, & Mcguire, 1975; Jeong & Claus, 2011; Liu, Lanari, & Schaefer, 1995). However, none of these approaches improved the color shelf life to the point of producing a commercial viable extension.

Areas that need to be addressed pertain to the development of the nitrite color chemistry as affected by age of the beef at the time the meat is packaged and the response due to different muscles. As meat ages postmortem, oxygen consumption decreases but oxygen penetration increases. Also, as meat ages the reducing ability of the muscle decreases. Beef muscles are known to vary in these biochemical properties (Claus, Mohanan, & Russell, 2005; Seyfert et al., 2006).

The objectives in this research were to determine the effect of postmortem meat age on display color development and stability associated with nitrite-embedded packaging on fresh and frozen beef, and to assess the color response associated with three different beef muscles during display. Another objective was to determine the color stability of fresh beef upon opening the nitrite-embedded bags. This objective would have implications in terms of what color changes the consumer might see upon opening NEF packages. Another objective was to determine the effects of the NEF and muscle on residual NO_x species.

2. Material and methods

2.1. Beef muscles and aging

U.S.D.A Select beef was obtained from a commercial beef packer. Only normal quality beef (visually selected) was used to avoid dark cutters or pale soft exudative meat. Three beef muscles selected included the *Longissimus lumborum* (LL, strip loin), *Psoas major* (PM, tender loin), and *Semitendinosus* (ST, eye of round). Muscles from four different animals were used for these experiments to provide four replications.

Beef obtained was aged for two different times postmortem (2 and 9 d). Each muscle was removed by a commercial plant and vacuum packaged for delivery. After steaks were removed for the 2 d aged portion of the study, the remaining muscle section was vacuum packaged and aged until 9 d postmortem. At each specified aging time, the beef muscles were cut into steaks (19 mm thick) for the fresh (unfrozen) and frozen color display experiments. In order to create independent steak samples, muscles were cut from random anatomical regions (e.g. anterior-posterior, dorsal-ventral) and steaks from the same muscle type were randomly assigned to each experiment for fresh and frozen display.

2.2. Fresh beef experimental designs

2.2.1. Fresh beef display

Three muscles (LL, PM, ST) aged 2 or 9 d postmortem were cut into steaks (n = 1 per treatment), packaged in NEF shrink bags, and stored for 48 h in the dark (2 °C) for color development prior to being continuously displayed unfrozen (19 d, 2 °C). Color was measured during first 48 h of display (0, 12, 24, 36 and 48 h) in order to analyze initial stability and then every 24 h thereafter. For color analysis, an average for each consecutive 5 d was designated as display periods (1, 2, 3 and 4). The color display study was terminated after 19 d of display.

2.2.2. NEF packages opened and overwrapped in PVC (fresh beef)

NEF packaged fresh displayed steaks from 2 and 9 d postmortem aged muscles (LL, PM, ST) were opened (6 d of display) and then overwrapped in oxygen permeable film (polyvinylchloride, PVC; oxygen transmission rate = 22,480 cm^3/m^2/24 h at 23 °C, water vapor transmission rate = 496 g/ m^2/24 h at 37.8 °C and 90% relative humidity; Product code 75003815, AEP Industries Inc., South Hackensack, NJ). Steaks were continuously displayed (2 °C) for 24 h. Color was measured during display (0, 6, 24 h).

2.2.3. Cooked color of fresh NEF displayed steaks

Steaks from the LL of four different animals and the two postmortem age groups (2 and 9 d) were packaged (NEF and control bag) and underwent display at the same time with the fresh display experimental samples. On the 5th d of their display they were convection-oven cooked (temperature 177 °C, Garland Master 450 NSF, D033784, Norcross, GA). Once the internal temperature of steaks reached 41–43 °C, they were flipped and then cooked to an internal temperature of 69 °C. The final temperature rise was recorded (average 3 °C). Temperature was monitored with a scanning thermometer (Model 321, Digi-Sense, Cole Parmer, Vernon Hills, IL) by inserting a probe in the geometric center of each steak. The cooked color was measured on the surface of the steaks after they were cooled to room temperature.

2.3. Frozen beef experimental designs

2.3.1. Frozen beef display

Three muscles (LL, PM, ST) aged 2 or 9 d postmortem were cut into steaks (n = 1 per treatment), packaged in NEF pouches and stored for 72 h in the dark (2 °C) for color development before being frozen (−20 °C) for 24 h. Steaks to be frozen where given additional color development time as once frozen additional development of NOMb would be unlikely in contrast to fresh displayed steaks. Frozen steaks were then continuously displayed for 39 d at −11 °C in an open top display case. Color was measured during the first 48 h of display (0, 12, 24, 36, 48 h) and then every 24 h thereafter. For color analysis, the average of each consecutive 5 d was designated as a display period (1 to 8). The color display study was terminated after 39 d of display.

2.3.2. Frozen beef under light versus dark comparison

As a positive control, companion NEF packaged steaks (muscles aged 2 d and 9 d postmortem) of the frozen beef display were stored in dark for a color comparison during the same time period in the same open-topped display case (−11 °C) as the frozen beef display experimental samples. Color of those companion steaks stored in dark was measured at the end of display (39th d) and compared to the corresponding displayed steaks.

2.4. Residual NO_x experiments

Prior to packaging in nitrite-embedded film, 9 d aged beef muscle (LL, PM, ST) steaks were sliced into 9-mm thick slices and stored in ultralow freezer for the NO_x (NO_2^-, NO_3^-) detection as reference samples. After the display ended, 3-mm thick surface samples of the fresh display steaks (19 d) from 9 d postmortem aged muscles (LL, PM and ST) were excised and stored in ultralow freezer prior to NO_x detection. For cooked fresh LL steaks from 9 d aged muscles, 3-mm thick surface samples were excised and stored in ultralow freezer prior to