EFFECTS OF MODIFIED ATMOSHPHERE PACKAGING ON RETAIL COLOR STABILITY IN FRESH BEEF

By

RENEE ELIZABETH KINSEY

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Thesis Approved:

Dr. Deb VanOverbeke

Thesis Adviser

Dr. Gretchen Mafi

Dr. Ranjith Ramanathan

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Title of Study: EFFECTS OF MODIFIED ATMOSHPHERE PACKAGING ON RETAIL COLOR STABILITY IN FRESH BEEF

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Abstract: The study aimed to evaluate the effects of different modified atmosphere packaging and different packaging styles on retail shelf life and microbial growth. Phase 1 evaluated different gas composition in modified atmosphere packaging. Ground beef and top sirloin steaks were packaged in tray overwrapped packages with 4 trays per master bag with either high oxygen (80% O_2 and 20% CO_2), bi-gas (70% N_2 and 30% CO_2), or tri-gas (69.6% N_2, 30% CO_2 and 0.4% CO). In addition, two treatments were packaged in barrier trays and film with either high oxygen MAP (80% O_2 and 20% CO_2) or low oxygen MAP (69.6% N_2, 30% CO_2 and 0.4% CO) gas mixture. Product was placed in dark storage for 6, 10 or 15 d. Product was color scored by a trained panel and total aerobic plate counts were measured. Tri-gas and low oxygen MAP had significantly brighter colored sirloins and ground beef and, therefore had, higher overall acceptability scores. High oxygen and bi-gas sirloins were never acceptable in terms of color or overall acceptability. For phase 2, sirloins and cube steaks were packaged in tray PVC overwrapped packages with 4 trays per master bag. All masters bag contained 69.96% N_2, 29% CO_2 and 0.04% CO. Three treatments were applied to the sirloins steaks and cube steaks: Single Stacked, Double Flushed (SS-DF); Double Stacked, Single Flushed (DS-SF); or Double Stacked, Double Flushed (DS-DF). Steaks were placed in dark storage for 5 or 8 d. Product was color scored by a trained panel. Aerobic Plate Counts were evaluated to determine the safety of products. No differences were observed between cube steak treatments for muscle color and overall acceptability. There were treatment differences in surface discoloration in cube steaks on d 10. The DS-SF bottom had the most ($P < 0.05$) surface discoloration while DS-DF top showed the least. Both DS-SF sirloin treatments had the brightest muscle color on d 6 and 7, although on d 9 and 10 DS-DF bottom had the darkest muscle color ($P < 0.05$). The modified atmosphere the meat in the packages does affect the color stability of beef products.

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CHAPTER I

INTRODUCTION

Fresh meat color is of the upmost importance to consumers when purchasing fresh meat products. The color of fresh red meat is of the upmost importance in meat marketing since it is the first quality attribute seen by the consumer who uses it as an indication of freshness and wholesomeness (Troy and Kerry, 2010). In order to provide a longer shelf life for retailers, processors have had to develop new packaging styles to keep up with retailer's needs. Processors have switched over to case ready packaging in order to extend the shelf life.

In order to improve the shelf life of fresh meat products, processors are using active packaging. Active packaging changes the condition of the packaging to extend the shelf life or improve safety or sensory properties of food (Nassu et al., 2010). One of the most common forms of active packaging is oxygen scavengers. Oxygen scavengers remove any residual oxygen after the mother bag has been flushed with a modified atmosphere. In modified atmosphere packaging of beef steaks, it is essential to reduce residual oxygen levels below 0.05% as quickly as possible to minimize the formation of metmyoglobin (Brandon et al., 2009). Metmyoglobin has an undesirable brown color that causes consumers to reject packaged meats (Venturini et al., 2006). This undesirable condition cause nearly 15% of retail beef to be discounted in price due to surface discoloration, which corresponds to annual revenue losses of $1 billion (Smith et al., 2000). Therefore, this project is designed to evaluate different gas compositions in modified atmosphere packaging in order to achieve a longer shelf life.

CHAPTER II

LITERATURE REVIEW

Consumer Preferences

Consumers balance the price of the product with astatically pleasing lean color. According to Mancini and Hunt (2005), meat purchasing decisions are influenced by color more than any other quality factor because consumers use discoloration as an indicator of freshness and wholesomeness. There is a strong association between color preferences and purchasing intent with consumers discriminating against beef that is not red (i.e. beef that is purple or brown; Carpenter et al., 2001). In reality, the color of fresh meat is not well correlated with eating quality; however, the consumer still demands beef to be bright cherry-red color (Troy and Kerry, 2010). When surface browning due to metmyoglobin exceeds 40%, retail meats typically are discounted or discarded (Greene et al., 1971). As a result, nearly 15% of retail beef is discounted in price due to surface discoloration which corresponds to annual revenue losses of $1 billion (Smith et al., 2000). Meat color is affected by lighting, color of trays, color of retail display and package type. Meat packaged with PVC overwrap was perceived as more red than meat packaged with headspace (Carpenter et al., 2001).

Case Ready

Fresh beef in case ready packaging is a growing segment of the beef industry. Case ready packaged beef cuts continues to increase jumping 17 percentage points during the last 8 y from 49% in 2002 to 66% in 2010 (NCBA, 2010). Case ready or centralized packaging is the fabrication and packaging of consumer-sized retail items in processing warehouse or other centralized non-retail location for transport and subsequent display in retail stores with minimal or no package manipulation of the individual package after removal from the shipping carton (McMillin, 2008). Case ready packaging is able to give the consumers the bright cherry red color they desire while decreasing the labor and overhead costs which the retailer's demand. Individual stores will no longer require a butcher on site because all meat will arrive at the store ready to enter the retail case. The central preparation of retail packages of meat offers considerable economic advantages over the traditional in-shop preparation for display (Gill and Jones, 1994). Eilert (2005) said, "As the hours of retail operations evolve to more formats with 24 h of operation, the needs for pre-packaged meats will continue to evolve. Not only is there an advantage with labor costs there is also a benefit with inventory management. Stores are able to cut down on their discounted products." Modified atmosphere packaging is probably the most widely used case-ready meat packaging technology in the U.S. (Brody, 2007). Case ready options include high oxygen modified atmosphere packaging (MAP), low oxygen MAP with carbon monoxide (CO) and vacuum packaging. Both the high oxygen MAP and low oxygen MAP with CO can be packaged in one of two methods: solid barrier trays with a non-permeable, heat sealed film or master bags. Master bags have overwrapped packaged stored in them and then are flushed with the modified atmosphere. According to Belcher (2006), several criteria must be met in order for successful case ready meat packaging: 1) obtain the longest possible quality life of the product to allow adequate distribution time from the central packing facility, 2) allow the product to be displayed in the retail store in the oxymyoglobin or red state, 3) the product needs to arrive at the retail establishment hermetically sealed, pre-priced, and labeled with a sell by date, and 4) the product needs to be clearly seen. Different packaging types have both positives and negatives to them; retailers must decide what works for them.

MAP for Retail Display

Modified atmosphere packaging is the removal and/or replacement of the atmosphere surrounding the product before sealing a vapor-barrier material. (McMilin, 2008). Modified atmosphere (MA) can be presented in two ways with the MA either within the individual package or within the master bag (Scholtz et al., 1992). Modified atmosphere packaging usually includes different combinations of these gases, O_2, CO, CO_2, and N_2. MAP for red meat destined for retail sale prolongs the microbiological shelf life and in some cases, product color (Luño et al., 1998).

High oxygen MAP is one of the more common packaging techniques used in case ready products. The high oxygen MAP gas mixture consists of 80% O_2 and 20% CO_2. These gases are flushed in rigid oxygen barrier tray sealed with a clear barrier film. Meats packaged in high oxygen MAP typically retain acceptable red color for 10-14 d of retail display, compared with 3-7 d for PVC packaged meats (Cornforth and Hunt, 2008). While the retailers and processors may have a positive outlook on high oxygen MAP, there are some negatives to the system. The drawback of high-oxygen MAP is although it maintains redness during storage, rancidity often develops while color is still desirable (Jayasingh et al., 2001). Additionally, high concentrations of carbon dioxide may result in brown discoloration on meat surfaces (Silliker et al., 1977). These negativities have led processors to look for other alternatives that will produce a longer shelf life while maintaining the safety of the product.

Low oxygen MAP can be obtained with or without CO, although low oxygen MAP without CO is very rare in the retail case. The use of CO in fresh beef and pork was termed “Generally Recognized as Safe” (or GRAS) status by the U.S. Food and Drug Administration in 2002. The levels of CO permitted are actually less than the level permitted by the U.S. Environmental Protection Agency in the air we breathe (AMI, 2008). Some consumers are concerned with the use of CO in our food products. It is not allowed for use in food products in the European Union or Canada. The use of CO in primary package of fresh meats has been practiced in Norway since 1985 (Eilert, 2005). Beef in a low oxygen environment will change from oxymyoglobin to deoxymyoglobin. Deoxymyoglobin is the purple state of meat, which is typically undesirable to consumers. Carbon monoxide in MAP (CO-MAP) prolongs the color stability of fresh meat by developing carboxymyoglobin (COMb), a more color stable redox form of myoglobin in anoxic conditions (Luño et al., 2000). To prevent surface browning, which occurs over time due to high oxygen environments, CO can be used in MAP fresh beef because it binds very strongly to the meat pigment myoglobin, allowing it to maintain its bright red color and extending its shelf life (Stetzer et al., 2006).

Modified atmosphere packaging master bag systems use similar gas mixtures as the rigid tray applications although they also use nitrogen. Nitrogen is neither antimicrobial nor color stabilizing, but it prevents the packages from collapsing, because it is not absorbed by the product (Sorheim et al., 1997). Nitrogen is used to counter the effects of pack collapse caused by the absorption of CO_2 by fatty or moist food items (Nassu et al., 2010). The master bag system not only has advantages for the processers and retailer but also for the consumers, as the product becomes more visible and acceptable in the styrofoam tray with PVC overwrap.

Oxygen Scavengers

Active packaging changes the condition of the packaging to extend the shelf life or improve safety and sensory properties of the food (Nassu et al., 2010). Oxygen scavengers are the most popular type of active packaging used in the meat industry. Master bag technologies have a flaw with the amount of oxygen residing in the mother bag. Low amounts of O_2 cause the formation of metmyoglobin (Isdel et al., 1999). One way of reducing O_2 concentration to below the critical level for discoloration is through the use of O_2 scavengers (Labuza and Breene, 1989). These are sachets of powdered iron which oxidize to form iron oxide in the presence of O_2 and moisture (Isdell et al., 1999). Scavengers have the ability to remove 1-1.5% O_2 per hour (Mancini and Hunt, 2005).

Meat Color

Muscle color is dependent on the state of the myoglobin. Myoglobin can naturally transform into three different states: deoxymyoglobin, metmyoglobin and oxymyoglobin. Deoxymyoglobin occurs when no ligand is present at the 6^{th} coordinate site and the heme iron is ferrous (Fe^{2+}) (Mancini and Hunt, 2005). Deoxymyoglobin is associated with the purplish-red color of vacuum packaged product or freshly cut product. After the muscle has had time to bloom (exposed to oxygen), the myoglobin converts from deoxymyoglobin to oxymyoglobin. Typically, it takes the muscle 10 min to develop a bright cherry-red color. No change in iron's valence occurs during oxygenation although the 6^{th} coordination site is now occupied by diatomic oxygen (Mancini and Hunt, 2005). The longer a product is exposed to oxygen the deeper the oxymyoglobin enters the muscle. Oxymyoglobin is then converted to metmyoglobin by the prolonged exposure to oxygen. Metmyoglobin is associated with the brown color often seen with unwanted surface discoloration. Carboxymyoglobin is formed by the binding of CO to myoglobin. The binding of myoglobin to CO results in a very stable bright cherry red color (Mancini and Hunt, 2005).

Conclusion

Color is typically the number one purchasing factor for consumers when purchasing fresh beef. Processors and retailers must utilize packaging technologies to improve color and meet the color criteria of customers all while maintaining a safe product. Modified atmosphere packaging has been able to do just that by meeting the color demands of consumers while meeting the shelf life longevity of retailers, without compromising the safety and quality of the product. Consumers will continue to question retailer's practices if CO is necessary in the packaging of fresh beef. With the use of oxygen scavengers, processors may be able to increase or at least maintain the shelf life without the use of CO. Ongoing research needs to be continued in order to be progressive and avoid from the use carbon monoxide. There is not one packaging technique that works for every processor, retailer, or consumer. Companies must find one that compromises in order to work for all three. Research should be focused on predicting consumer’s future demands in packaging techniques while still maintaining the color longevity and increasing the shelf life.

CHAPTER III

EFFECTS OF MODIFIED ATMOPSHER PACKAGING ON RETAIL COLOR STABILITY IN FRESH BEEF

Abstract

The study aimed to evaluate the effects of different modified atmosphere packaging and different packaging styles on retail shelf life and microbial growth. Phase 1 evaluated different gas composition in modified atmosphere packaging. Ground beef and top sirloin steaks were packaged in tray overwrapped packages with 4 trays per master bag with either high oxygen (80% O_2 and 20% CO_2), bi-gas (70% N_2 and 30% CO_2), or tri-gas (69.6% N_2, 30% CO_2 and 0.4% CO). In addition, two treatments were packaged in barrier trays and film with either high oxygen MAP (80% O_2 and 20% CO_2) or low oxygen MAP (69.6% N_2, 30% CO_2 and 0.4% CO) gas mixture. Product was placed in dark storage for 6, 10 or 15 d. Product was color scored by a trained panel and total aerobic plate counts were measured. Tri-gas and low oxygen MAP had significantly brighter colored sirloins and ground beef and, therefore had, higher overall acceptability scores. High oxygen and bi-gas sirloins were never acceptable in terms of color or overall acceptability. For phase 2, sirloins and cube steaks were packaged in tray PVC overwrapped packages with 4 trays per master bag. All masters bag contained 69.96% N_2, 29% CO_2 and 0.04% CO. Three treatments were applied to the sirloins steaks and cube steaks: Single Stacked, Double Flushed (SS-DF); Double Stacked, Single Flushed (DS-SF); or Double Stacked, Double Flushed (DS-DF). Steaks were placed in dark storage for 5 or 8 d. Product was color scored by a trained panel. Aerobic Plate Counts were evaluated to determine the safety of products. No differences were observed between cube steak treatments for muscle color and overall acceptability. There were treatment differences in surface discoloration in cube steaks on d 10. The DS-SF bottom had the most ($P < 0.05$) surface discoloration while DS-DF top showed the least. Both DS-SF sirloin treatments had the brightest muscle color on d 6 and 7, although on d 9 and 10 DS-DF bottom had the darkest muscle color ($P < 0.05$). The modified atmosphere the meat in the packages does affect the color stability of beef products.

Introduction

The color of fresh red meat is of the upmost importance in meat marketing since it is the first quality attribute seen by the consumer who uses it as an indication of freshness and wholesomeness (Troy and Kerry, 2010). In order to provide a longer shelf life for retailers, processors have had to develop new packaging styles to keep up with retailer's needs. Processors have switched over to case ready packaging in order to extend the shelf life.

An effective way to increase the shelf life of a product is to modify the atmosphere of red meat packages. Research has shown the use of oxygen scavengers with the use of carbon monoxide modified atmosphere packaging (CO MAP) will increase the shelf life. This study was conducted to determine which gas composition will extend the retail case life the longest while maintaining a safe product.

Materials and Methods

Phase I

Raw material preparation: Nine master bags of top sirloin steaks (IMPS #1184) and ground beef were obtained from Vantage Foods in Lenoir, NC. Top sirloin steaks were cut 2.54 cm thick. Top sirloin steaks were packaged in 37.47 x 20.32 x 3.65 cm black foam trays (No.15P, Cryovac Sealed Air, Duncan, SC) with Cryovac absorbent pads and wrapped with PVC film or 22.86 x 17.78 x 5.08 cm black solid barrier trays (Cryovac Sealed Air, Duncan, SC). Ground beef loaves (0.45 kilograms) were packaged in 37.47 x 20.32x 3.65 cm black foam trays (No. 15P, Cryovac Sealed Air, Duncan, SC) with Cryovac absorbent pads and wrapped with PVC film or 22.86 x 17.78 x 5.08 cm black solid barrier trays (Cryovac Sealed Air, Duncan, SC). Steaks and ground beef packaged in the black foam trays were placed in a master bag with four trays per bag. The master bags contained a gas mixture of either a high oxygen (80% O_2 and 20% CO_2), bi-gas (30% CO_2 and 70% N_2) or tri-gas (69.6% N_2, 30% CO_2, and 0.4% CO). Both the sirloin steaks and ground beef packaged in tri-gas mother bags contained an oxygen scavenger CR-20 (Multisorb Technologies, Buffalo, NY). The solid barrier trays contained a gas mixture of either a high oxygen (80% O_2 and 20% CO_2) or low oxygen (69.6% N_2, 30% CO_2, and 0.4% CO). Steaks were randomly assigned into one of the five packaging treatments: high oxygen MAP tray, high oxygen master bag, bi-gas master bag, tri-gas master bag and low oxygen MAP tray. Master bags and solid barrier trays were then boxed and transported to Oklahoma State University for further observation.

Storage: After arriving at OSU, master bags were placed in dark storage for 6, 10 or 15 d at 3°C ± 1°C. After the designated storage time, 3 master bags from each treatment group and 8 solid barrier trays from each treatment were randomly removed from dark storage.

Headspace Analysis: Mother bags were analyzed using a Bridge 900131 O_2/CO_2/CO analyzer to determine the percent O_2, CO_2, and CO present at each pull day. On each pull day, the mother bags were analyzed and the measurements were recorded. Each day before gas readings were taken the Bridge 900131 Analyzer was calibrated.

Tray Assignment: Master bags were opened on the bottom, opposite of the factory seal. Samples were then designated a number for retail evaluation. Six individual packages from each treatment were randomly selected for color and retail display evaluation under fluorescent lights. Two packages per treatment were randomly selected for initial microbial growth. At the end of display, two packages per treatment were selected from the packages being evaluated for color for a terminal microbial growth count.

Retail Case Temperature: Each sample was placed in a retail case (Model: M1-8EB, Hussmann, Bridgeton, MO) of 0°C that ran 1 h defrost cycle approximately every 7 h. Retail case temperatures were monitored throughout display. The range of the case temperature during the defrost cycle was -1.89 to 6.56°C.

Retail Case Lighting: All samples were displayed in retail cases lighted with Promolux low UV lights purchased from the Atlanta Light Bupound Company (Atlanta, GA). The temperature of the room the retail display cases were located in was between 22.8 and 23.9 °C throughout the course of the project.

Retail Shelf Life: Visual muscle color, percent surface discoloration, and overall acceptability were evaluated by a six-member trained color panel once daily. Muscle color for sirloin steaks was evaluated on a scale from 1 to 8, with 8 being extremely bright red and 1 being extremely dark red. Muscle color for ground beef was evaluated on a scale from 1 to 8, with 1 being extremely bright red and 8 being extremely dark red Discoloration analyzes the percent of lean muscle that has discoloration on the surface. Percent surface discoloration was evaluated on a scale from 1 to 7, with 1 being no discoloration and 7 being completely discolored. Lastly, overall acceptability was evaluated on a scale of 1 to 8, with 8 being extremely desirable and 1 being extremely undesirable.

Total Aerobic Plate Count Microbiological Tests: A standard total plate count (TPC) determination was obtained from two packages of each treatment on the first and last day in the retail display for each dark storage time in the Food Microbiology Lab at Oklahoma State University (Stillwater, OK). Briefly, 10 g samples were homogenized in a sterile stomacher bag containing 90 mL of sterile 0.1% peptone water and pummeled for 1 minute at 230 rpm using a Stomacher-400 (Worthington, West Sussex, UK). Total aerobic plate counts (APC) were determined by plating 1 mL of the sample homogenate on Petri Films with the respective dilutions. Plates were incubated for 2 d at 37°C before counting and reporting the TPC per cm^2. Values over 6 log CFU / gram were considered spoiled and was set as the unacceptable threshold level for microbial growth.

Statistical Analysis: Color comparison, surface discoloration and overall acceptability between treatments on each day of display for each pull and TPC data were analyzed using a General Linear Model (GLM; SAS 9.3). Treatment group (high oxygen MAP, high oxygen, bi-gas, tri-gas or low oxygen MAP) was the fixed effect. For all models, least squares means were separated when there was a significant overall F-test ($P < 0.05$). Means were separated using a pairwise t-test; significance was set at $\alpha = 0.05$.

Phase II

Raw material preparation: Master bags of top sirloin steaks (IMPS #1184) and cube steaks (IMPS #1100) were obtained from Vantage Foods in Lenoir, NC. Top sirloin steaks were cut 2.54 cm thick. Top sirloin steaks and cube steaks were packaged in 17.8 x 27.9 x 3.5 cm white foam trays (No. 11P, Cryovac Sealed Air, Duncan, SC) with Cryovac absorbent pads and wrapped with PVC film. Steaks packaged double stacked (DS) were placed in each master bag with four trays per bag, 2 trays on top and 2 trays on bottom. Double stacked (DS) packaged steaks had a white silicon paper placed between the trays. Steaks packaged single stacked (SS) were placed with two trays per bag. The master bags contained a gas mixture of 69.6% N_2, 30% CO_2, and 0.4% CO. All mother bags contained a CR-20 oxygen scavenger (Multisorb Technologies, Buffalo, NY). Double flushed (DF) treatments were back flushed twice with the gas mixture before sealing. Single flushed (SF) treatments were only back flushed once with the gas mixture before sealing. Sirloin steaks and cube steaks were randomly assigned into three treatments: single stacked, double flushed (SS-DF); double stacked, single flushed (DS-SF); or double stacked, double flushed (DS-DF). Master bags were then boxed and transported to Oklahoma State University (OSU) for further observation.

Storage: After arriving at OSU, master bags were placed in dark storage for 5 or 8 d at 3°C ± 1°C. After the designated storage time, 3 master bags from each treatment group and 8 solid barrier trays from each treatment were randomly removed from dark storage.

Headspace Analysis: Mother bags were analyzed using a Bridge 900131 O_2/CO_2/CO analyzer to determine the percent O_2, CO_2, and CO present at each pull day.

On each pull day, the mother bags were analyzed and the measurements were recorded. Each day before gas readings were taken the Bridge 900131 Analyzer was calibrated.

Tray Assignment: The bottom of the master pack, opposite the factory seal, was opened and each sample was assigned a sample number. Odd sample numbers were given to distinguish top packages while bottom packages were given even sample numbers. Eight individual packages from each treatment were randomly selected for color and retail display evaluation under fluorescent lights. Two packages per treatment were randomly selected for initial microbial growth. At the end of display, two packages per treatment were selected from the packages being evaluated for color for a terminal microbial growth count.

Retail Case Temperature: Each sample was placed in a retail case (Model: M1-8EB, Hussmann, Bridgeton, MO) of 0°C that ran 1 h defrost cycle approximately every 7 hours. Retail case temperatures were monitored throughout display. The range of the case temperature during the defrost cycle was -1.89 to 6.56°C.

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Total Aerobic Plate Count Microbiological Tests: A standard total plate count (TPC) determination was obtained from two packages of each treatment on the first day and last day in the retail display for each dark storage time in the Food Microbiology lab at Oklahoma State University (Stillwater, OK). Briefly, 10 g samples were homogenized in a sterile stomacher bag containing 90 mL of sterile 0.1% peptone water and pummeled for 1 minute at 230 rpm using a Stomacher-400 (Worthington, West Sussex, UK). Total aerobic plate counts (APC) were determined by plating 1 mL of the sample homogenate on Petri Films with the respective dilutions. Plates were incubated for 2 d on d 5, 7 and 8 and 2.5 d on d 10 at 37°C before counting and reporting the TPC per cm^2. Values over 6 log CFU / gram were considered spoiled and was set as the unacceptable threshold level for microbial growth.

Statistical Analysis: Color comparison between treatments on each day of display for each pull, oxygen concentration readings, and TPC data were analyzed using a General Linear Model (GLM; SAS 9.3). Treatment group (single stacked, double flushed (SS-DF); double stacked, single flushed (DS-SF) top; double stacked, single flushed (DS-SF) bottom; double stacked, double flushed (DS-DF) top; or double stacked, double flushed (DS-DF) bottom) was the fixed effect. For all models, least squares means were separated when there was a significant overall F-test ($P < 0.05$). Means were separated using a pairwise t-test; significance was set at $\alpha = 0.05$.

Results

Phase I

Headspace Composition: The amount of oxygen is applicable to how the product will perform in the retail case. High oxygen mother bags had the following gas composition 0.000-0.054% CO, 8.25-12.44% CO_2, and 52.97-63.87% O_2. Bi-gas mother bags had between 0.001-0.047% CO, 10.91-13.17% CO_2, and 0.001-0.211% O_2. Tri-gas mother bags had the following gas readings 0.209-0.344% CO, 13.16-23.26% CO_2, and 0.059-0.359%O_2.

Muscle Color: Beef displaying a bright cherry red is a consumer's first factor they will use to decide whether or not to buy beef. Lean color must be at 4.5 in order to be deemed acceptable. At this threshold, the lean color is considered slightly dark cherry-red and would be discounted at retailers (Appendix B). As expected, beef lean color decreased as the number of days in the retail case increased. Pull 1 was in the display case d 6 to 9, pull 2 was displayed d 10 to 13, and pull 3 was displayed d 15 to 18. The effects of modified atmosphere, storage period and display period on muscle color of sirloin steaks are presented in Tables 1, 2 and 3 by storage day.

During pull1, Bi-gas sirloin steaks were unacceptable in terms of muscle color starting on d 6 and continuing until d 9. Tri-gas and low oxygen MAP were significantly ($P < 0.05$) more cherry red color than either high oxygen treatments throughout the entire first pull. Only low oxygen MAP and tri-gas were above the acceptability line of 4.5 on d 7 and d 8. Bi-gas and both high oxygen treatments were significantly ($P < 0.05$) darker in terms of muscle color on d 8 compared to tri-gas and low oxygen MAP. On the last day of the pull, only low oxygen MAP still showed acceptable muscle color although tri-gas had significantly brighter muscle color compared to the high oxygen treatments and bi-gas ($P < 0.05$).

During pull 2, both high oxygen treatments and bi-gas were unacceptable in terms of muscle color throughout the pull. On d 10, tri-gas had a more ($P < 0.05$) cherry red color than low oxygen MAP although on d 11 the roles changed and continued as such through the remainder of the second pull. Although low oxygen MAP was acceptable in terms of color throughout the whole pull, tri-gas was only acceptable on d 10 and 11.

High oxygen MAP and high oxygen displayed an extremely dark red color the duration of the pull. Both tri-gas and low oxygen MAP had significantly brighter cherry red color compared to bi-gas ($P < 0.05$) throughout the third pull. Tri-gas and low oxygen MAP were able to maintain acceptable color on d 15 and 16. Tri-gas met the acceptable color line while low oxygen map fell below it on d 17. Strangely on d 18, low oxygen MAP was above the acceptability line while tri-gas was below it.

The effects of modified atmosphere, storage period and display period on muscle color of ground beef are presented in Tables 4, 5 and 6 by storage day. Ground beef did not display the same results as seen in the sirloin steaks. All treatments were acceptable in terms of muscle color the first three days of the first pull. The first day of the pull, tri-gas was the brightest ($P < 0.05$) between all the treatments. On d 9, high oxygen and bi-gas were above the acceptability line. Low oxygen MAP packages were a brighter cherry red in color ($P < 0.05$) than the other treatments on d 9.

On d 10, all treatments were acceptable in terms of color but by day 11 high oxygen was above the unacceptable line. As expected, low oxygen and tri-gas had a significantly lower score ($P < 0.05$) than the other treatments through d 13. High oxygen MAP was very close to becoming unacceptable on d 11. On d 12, high oxygen MAP, high oxygen and bi- gas as all unacceptable and remained unacceptable through d 13.

High oxygen MAP, high oxygen and bi-gas did not have acceptable muscle color throughout pull 3. Tri-gas was able to maintain two days of acceptable color while low oxygen MAP was able to maintain an acceptable color throughout the pull. Tri-gas had significantly better color ($P < 0.05$) than low oxygen MAP the first two days of the pull. After d 2 of the pull, low oxygen MAP had significantly better color ($P < 0.05$) than tri-gas.

Surface Discoloration: The effects of modified atmosphere, storage period and display period on surface discoloration of sirloin steaks are presented in Tables 1, 2 and 3 by storage day. Surface discoloration was evaluated during pull 1 on d 5 to 9, pull 2 on d 10 to 13, and pull 3 on d 15 to 18. Both MAP sirloin treatments as well as tri-gas showed no surface discoloration on d 6. Bi-gas showed the most ($P < 0.05$) surface discoloration on d 6 and 7. On d 6 and 7, both MAP treatments and tri-gas showed significantly less surface discoloration ($P < 0.05$) than the other treatments. High oxygen had the most surface discoloration ($P < 0.05$) on d 8 and 9.

High oxygen showed the most ($P < 0.05$) surface discoloration throughout the second pull as it had 80-100% discoloration. Low oxygen MAP did not show any surface discoloration throughout the pull. All treatments that showed discoloration followed the normal trend of an increase in surface discoloration as the display time increased.

Both high oxygen treatments had 100% surface discoloration the duration of pull 3. Throughout the third pull, bi-gas showed significantly more ($P < 0.05$) surface discoloration than either tri-gas or low oxygen MAP. On d 15 and 16, tri-gas and low oxygen MAP had similar amounts of surface discoloration. Eventually, tri-gas showed some surface discoloration meanwhile, low oxygen MAP never showed any surface discoloration throughout pull 3.

The effects of modified atmosphere, storage period and display period on surface discoloration of ground beef are presented in Tables 4, 5 and 6 by storage day. The bi-gas ground beef was the only treatment on d 6 to show any discoloration. No differences were seen between treatments on d 7 and 8. On d 9, high oxygen showed significantly more ($P < 0.05$) surface discoloration than any other treatment, all other treatments showed very little discoloration.

High oxygen ground beef showed the most ($P < 0.05$) surface discoloration throughout the second pull. High oxygen MAP, low oxygen MAP, tri-gas and bi-gas showed comparable amounts of surface discoloration on d 10 and 11. On d 13 and 14, all treatments showed significantly ($P < 0.05$) different amounts of surface discoloration.

High oxygen MAP had 100% discoloration on d 15 and 16, and by d 17, high oxygen and bi-gas also had 100% surface discoloration. Overall, low oxygen MAP had very little surface discoloration. High oxygen, bi-gas and tri-gas showed an increase in surface discoloration as the amount of display time increased. On d 17 and 18, low oxygen MAP had significantly less (P < 0.05) surface discoloration than any other treatment.

Overall Acceptability: The effects of modified atmosphere, storage period and display period on overall acceptability of sirloin steaks are presented in Tables 1, 2 and 3 by storage day. As with muscle color and surface discoloration, overall acceptability was also scored during three pulls, pull 1 was d 6 to 9, pull 2 was d 10 to 13, and pull 3 was d 15 to 18. Although both MAP sirloin treatments and tri-gas were all above the acceptability line, tri-gas and low oxygen MAP were significantly higher in overall acceptability (P < 0.05) on d 6. High oxygen and bi-gas were significantly (P < 0.05) the least acceptable throughout the duration of the first pull. On d 8, high oxygen MAP and tri-gas met or fell below the threshold, although by d 9, both had fallen below and had significantly less (P < 0.05) overall acceptability compared to low oxygen MAP.

Both MAP treatments and bi-gas sirloins were unacceptable the entire second pull. Low oxygen MAP was the only treatment above the threshold throughout the entire pull, while tri-gas was above the threshold on d 10 and 11. On d 10, 11 and 12, low oxygen MAP and tri-gas were significantly more acceptable (P <0.05) than any other treatments. Low oxygen MAP was the most acceptable (P < 0.05) on d 12 and 13.

High oxygen MAP and high oxygen were considered extremely undesirable throughout the pull, while bi-gas also was also extremely undesirable on d 17 and 18. Low oxygen MAP was acceptable throughout the entire pull. Tri-gas decreased in overall acceptability as time increased, as is expected.

The effects of modified atmosphere, storage period and display period on overall acceptability of ground beef are presented in Tables 4, 5 and 6 by storage day. As expected by the muscle color scores, ground beef treatments were all over the threshold for overall acceptability for the first three days of the first pull. Bi-gas was significantly lower ($P < 0.05$) on d 6 although by d 7 it was similar to high oxygen, tri-gas and low oxygen MAP. Low oxygen MAP and tri-gas had a higher overall acceptability score than bi-gas and both high oxygen treatments on d 8. High oxygen which was significantly ($P < 0.05$) the lowest score and was below the acceptability line on d 9. Bi-gas which was slightly above the line had a similar score to tri-gas.

All ground beef treatments were significantly different from each other on d 10. High oxygen barely met the threshold on d 10 and then fell below it the rest of pull 2. High oxygen MAP was only acceptable on d 10 while bi gas was able to maintain acceptability for two days. Tri-gas and low oxygen MAP were acceptable d 10, 11 and 12. Tri-gas started out as the most accepted although on d 12 low oxygen became the most accepted for the duration of the second pull. .

Neither high oxygen ground beef treatments were termed desirable throughout the third pull. Bi-gas on d 15 was scored at the desirable- undesirable line. Low oxygen products were the only treatment that was able to stay desirable throughout the whole study. As with the muscle color, tri-gas was only desirable for the first two days of the third pull.

Total Aerobic Plate Count: The effects of modified atmosphere, storage period and display period on microbiological growth of sirloin steaks are presented in Table 7.

An initial sample was tested the day after the product was packaged. The initial sample of sirloin steaks had an extremely low plate counts, log -0.30 coliform forming units (CFU) per gram. None of the treatments reached the unacceptable threshold of 6.0 CFU/ g. There were no significant differences ($P < 0.05$) seen between treatments.

The effects of modified atmosphere, storage period and display period on microbiological growth of ground beef are presented in Table 7. On d 6, both bi-gas and low oxygen MAP ground beef treatments were numerically below the original APC of the initial sample. Only on d 10, were any significant differences seen between treatments. On d 10, high oxygen MAP had significantly less ($P < 0.05$) microbiological growth than all other treatments. On d 15, high oxygen did go over the threshold set for undesirable spoilage of products. By d 18, high oxygen, bi-gas and tri-gas were all unacceptable.

Phase II

Headspace Composition: The amount of oxygen is applicable to how the product performs in the retail case. The master bags of the sirloins had the following gas composition: 0.282-0.428% CO, 25.402-31.728% CO_2 and 0.021-0.154% O_2. The cube steaks had similar headspace composition: 0.354-0.473% CO, 23.852-34.464% CO_2 and 0.003-0.076% O_2.

Muscle Color: Lean color must be a 4.5 or higher in order to be deemed acceptable. At this threshold, the lean color is considered slightly dark cherry-red and would be discounted at retailers (Appendix B). As expected, beef lean color decreased as the days in the retail case increased.

The effects of gas flush, stacking, storage period and display period on muscle color of sirloin steaks are presented in Tables 9 and 10 by storage day. All sirloin treatments remained acceptable throughout the display life, except DS-SF bottom on d 10, the last day of the second pull. There were no statistical treatment differences on d 5 and 8. The SS-DF and both DS-DF treatments had significantly lower ($P < 0.05$) muscle color scores on d 6 and 7 than the DS-SF treatments. Although not consistent with the first time displayed in the retail case, DS-SF bottom had significantly ($P < 0.05$) darker muscle color on d 9 and 10 than the other treatments.

The effects of gas flush, stacking, storage period and display period on muscle color of cube steaks are presented in Tables 11 and 12 by storage day. There were no statistical treatment differences in the muscle color of cube steaks ($P > 0.05$). All treatments remained acceptable during the first 5 d. On d10, both bottom treatments fell below minimum acceptability line, while DS-SF top packages barely met the acceptability line.

Surface Discoloration: Although, there is not an acceptability line, when product reaches the score of 2 (Appendix B) a retailer would typically discount that package. The effects of gas flush, stacking, storage period and display period on surface discoloration of sirloin steaks are presented in Tables 9 and 10 by storage day. Similar to the muscle color score, no significant differences ($P > 0.05$) were seen between sirloin steak treatments on the first day of display. Both DS-DF sirloin steak packages had a greater amount of surface discoloration ($P < 0.05$) on d 6 and 7 when compared to SS-DF and both DS-SF treatments. New product entered the retail case on d 8 and no significant differences were noted between the treatments ($P > 0.05$). None of the treatments displayed any surface discoloration on d 8. The DS-DF bottom sirloin steaks showed the most ($P < 0.05$) surface discoloration on the last day of the experiment.

The effects of gas flush, stacking, storage period and display period on surface discoloration of cube steaks are presented in Tables 11 and 12 by storage day. No differences were observed during the first pull ($P > 0.05$) in the surface discoloration in cube steaks. On d 8, all packages had little to no surface discoloration. Although no significant differences were noted on d 9, SS-DF and DS-SF bottom showed more numerical surface discoloration than the other treatments. Significant differences were seen on d 10. The DS-SF bottom had the most ($P < 0.05$) surface discoloration, while DS-DF top showed the least ($P < 0.05$) surface discoloration.

Overall Acceptability: Overall acceptability has a minimum threshold of 4.5. There is typically more emphasis put on this because it takes into consideration muscle color, fat color and total discoloration.

The effects of gas flush, stacking, storage period and display period on overall acceptability of sirloin steaks are presented in Tables 9 and 10 by storage day. There were no significant differences noted on the first day of either pull ($P > 0.05$). The DS-DF bottom showed a significantly ($P < 0.05$) lower overall acceptability score on d 6. The differences between treatments on d 7 were similar. DS-SF top sirloin steaks showed the highest acceptability score. Both DS-DF treatments had the same overall score, which was also the lowest statistically score ($P < 0.05$) among the treatments. Overall on d 7, all treatments were above the threshold line. The DS-SF top packages had the highest overall acceptability score, while DS-SF bottom packages had the lowest score ($P < 0.05$) on d 7.

The SS-DF had the highest (P < 0.05) overall acceptability score on d 9 and 10. DS-DF bottom was the lowest numerically among the treatments falling right below the threshold.

The effect of gas flush, stacking, storage period and display period on overall acceptability of cube steaks is presented in Tables 11 and 12 by storage day. As expected, because there were no significant differences in the muscle color of the cubes steaks there were also no significant differences (P > .05) between treatments in overall acceptability. On d 5 and 6, all treatments were very similar numerically. Both top treatments were the highest numerically acceptable on the last day of the first pull. The DS-SF bottom had the lowest numerical values on d 9 and 10. Both bottom treatments were below the acceptable threshold on d 10.

Total Aerobic Plate Count: A threshold of log 6 CFU/ g is set to determine when undesirable spoilage occurs in a product. As expected, as time post pack increased, as well as time in the display case increased, the APC also increased. No initial plate counts were taken on product on the pack day to set a basis.

The effect of gas flush, stacking, storage period and display period on microbiological growth of sirloin steaks is presented in Table 13. On d 5 and 8, there were no significant differences between treatments (P > 0.05). The DS-DF sirloin steak treatment had the lowest plate count on d 7 and d 10. Although SS-SF and DS-SF had a higher APC on d10, the sirloins did not approach the unacceptable threshold.

The effects of gas flush, stacking, storage period and display period on muscle color of cube steaks are presented in Table 14. No significant differences were seen between the cube steak treatments ($P > 0.05$). On the initial d 5 and 8, SS-DF had the highest APC. DS-DF had the highest APC on the terminal d of each pull.

Discussion

The use of CO in meat packages greatly extends the shelf life of meat products. Low oxygen MAP treatment did have the longest shelf life because it was never exposed to oxygen. The oxygen scavenger did increase the shelf life of the tri-gas packages compared to the high oxygen treatments and bi-gas. Limbo et al. (2013) found meat storage failed within 7 days without scavengers and a permanent discoloration was observed. Although, in this experiment, the trays were removed from the master bags on d 6, the sirloin steaks entering the display case were barely acceptable and some product was completely unacceptable. Sirloins steaks were very undesirable after 10 d of storage. In the ground beef, high oxygen treatments and bi gas were acceptable for the first 3 d of display after 6 d of storage. When ground beef was placed in the retail case after 10 d of storage, treatments had one to two days of acceptable display.

Oxygen scavengers play an important role in keeping the oxygen partial pressure within critical limits, ensuring proper conditions for preservation and for complete blooming of the meat inside its primary package for storage time as long as 21 d (Limbo et al., 2013). In this study, we only extended shelf life to 15 d although the tri-gas sirloin steaks and ground beef were still able to maintain 2 d and some packages of sirloin steaks 3 d of acceptable color, whereas all other treatments other than low oxygen MAP were completely unacceptable on d 8. Venturini et al. (2006) found that the use of a self-activating O_2 scavenger in association with MAP under CO_2 was more successful at preventing discoloration and extending shelf life of fresh longissimus dorsi beef steaks. Steaks from packs without O_2 scavengers for 2 weeks or longer did not bloom on exposure to an aerobic environment (Isdell et al., 1999). This was due to the residual O_2

content in mother packs and trays which caused metmyoglobin formation during storage (Isdell et al., 1999). Both high oxygen treatments of sirloin steaks and ground beef that were held in storage for 15 d did not bloom, and when taken out of the master bags remained the brown as seen when inside the master bag. According to Cornforth and Hunt (2008), meats packaged in high oxygen MAP typically retain acceptable red color for 10-14 d of retail displays. In this experiment, neither of the high oxygen treatments for sirloin steaks or ground beef displayed acceptable red color for 10-14 d. Compared to the high oxygen treatments, tri-gas and low oxygen MAP had significantly redder packages compared to the bi-gas and high oxygen treatments in both sirloin steaks and ground beef. In the case of intact packages, continuous exposure of ground beef to 0.4% CO generally increased redness up to 7 d (Jeong and Claus, 2011). Stetzer et al. (2006) found that after 14 d, high oxygen packaged raw steaks were less red than were CO-packaged steaks. The CO- packaged steaks were less red after 28 d than after 14 d of storage (Stetzer et al., 2006).

Although color is very important especially to consumers, the amount of metmyoglobin must also be taken into consideration for a products overall acceptability. Generally, the product assessed as desirable gave values for metmyoglobin that were <10% whereas metmyoglobin values for undesirable product were >20% (Gill and Jones, 1994). This study indicates that, depending on muscle color product. Product becomes undesirable when >20% surface discoloration is seen.

Conclusion

In order to reduce loss at the retail case, minimizing surface color and prolonging cherry-red muscle color is of the upmost importance. This study showed that the use of oxygen scavengers does prolong the display life when compared to high oxygen treatments or bi-gas. Low oxygen MAP did produce the longest shelf-life although retailers must decide if the longer shelf life is worth it since the consumers prefer over wrapped trays. The number of times you back flush a master bag did not have a consistent outcome on the effects of color stability. The bottom packages did not show as bright of a cherry-red lean color as the top packages although the differences were small. Double stacking the product does have economic benefits to processors and should continue being used. Further research could be done, on the value added meat products. The value added industry is growing significantly and therefore should be observed to see how meat and other food items react to oxygen scavengers together.

Table 1. Phase I: Effect of storage period, packaging treatment, and retail display period on the muscle color[1], surface discoloration[2], and overall acceptability[3] of sirloin steaks (n = 6 packages per treatment) stored for 6 days.

	Treatment[4]				
	Hi MAP[6]	Hi Ox[7]	Bi-Gas[8]	Tri-Gas[9]	Lo MAP[10]
Muscle Color					
D 6	4.94[b]	4.79[b]	4.02[c]	6.65[a]	6.14[a]
D 7	3.98[b]	4.46[ab]	4.02[b]	5.60[a]	5.46[a]
D 8	3.52[b]	3.25[b]	3.48[b]	5.29[a]	5.42[a]
D 9	2.77[c]	2.73[c]	3.00[c]	4.20[b]	5.27[a]
S.E.M.[5]	0.19	0.20	0.12	0.20	0.22
Surface Discoloration					
D 6	1.00[c]	2.00[b]	3.77[a]	1.00[c]	1.00[c]
D 7	1.35[c]	2.54[b]	3.81[a]	1.29[c]	1.04[c]
D 8	1.98[bc]	4.17[a]	3.38[ab]	2.38[bc]	1.71[c]
D 9	2.77[bc]	5.03[a]	3.53[ab]	2.83[bc]	1.80[c]
S.E.M.[5]	0.17	0.33	0.15	0.17	0.08
Overall Acceptability					
D 6	6.40[b]	4.38[c]	3.98[c]	7.58[a]	7.24[a]
D 7	5.40[a]	3.40[b]	2.94[b]	6.56[a]	6.42[a]
D 8	3.56[b]	2.10[c]	2.60[bc]	4.50[ab]	5.31[a]
D 9	2.27[bc]	1.30[d]	1.83[cd]	2.83[b]	5.33[a]
S.E.M.[5]	0.35	0.28	0.17	0.40	0.22

[1]Muscle Color: 8=extremely bright cherry red; 1=extremely dark red
[2]Surface Discoloration: 7=total discoloration (100%); 1=no discoloration (0%)
[3]Overall Acceptability: 8=extremely desirable; 4.5=acceptable; 1=extremely undesirable
[4]Treatment: Treatment represents packaging style
[5]S.E.M.: Standard Error of the Mean
[6]High oxygen MAP, 80% O_2 and 20% CO_2, barrier tray
[7]High oxygen, 80% O_2 and 20% CO_2, mother bag
[8]Bi-gas, 70% N_2 and 30% CO_2, mother bag
[9]Tri-gas, 69.6% N_2, 30% CO_2 and 0.4% CO, mother bag, oxygen scavenger
[10]Low oxygen MAP, 70% N_2, 30% CO_2 and 0.4% CO, barrier tray
[a,b]Least squares mean within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 2. Phase I: Effect of storage period, packaging treatment, and retail display period on the muscle color[1], surface discoloration[2], and overall acceptability[3] of sirloin steaks (n = 6 packages per treatment) stored for 10 days.

	Treatment[4]				
	Hi MAP[6]	Hi Ox[7]	Bi-Gas[8]	Tri-Gas[9]	Lo MAP[10]
Muscle Color					
D 10	3.56[c]	2.08[e]	2.97[d]	6.11[a]	5.06[b]
D 11	2.98[c]	1.19[d]	2.71[c]	4.86[b]	5.83[a]
D 12	2.25[c]	1.13[c]	2.10[bc]	3.38[b]	4.90[a]
D 13	2.30[cd]	1.47[d]	2.43[bc]	3.30[b]	4.63[a]
S.E.M.[5]	0.13	0.09	0.14	0.25	0.12
Surface Discoloration					
D 10	2.39[c]	6.53[a]	4.11[b]	1.00[c]	1.00[c]
D 11	3.52[b]	6.95[a]	4.45[b]	1.62[c]	1.00[c]
D 12	5.17[b]	7.00[a]	5.00[b]	3.13[c]	1.00[d]
D 13	6.03[ab]	7.00[a]	5.17[b]	4.13[b]	1.03[c]
S.E.M.[5]	0.31	0.05	0.31	0.31	0.01
Overall Acceptability					
D 10	3.19[b]	1.00[c]	2.42[b]	7.17[a]	6.72[a]
D 11	2.29[b]	1.00[c]	2.17[b]	5.67[a]	6.69[a]
D 12	1.50[c]	1.00[c]	1.56[c]	2.92[b]	6.71[a]
D 13	1.27[c]	1.00[c]	1.67[bc]	2.57[b]	6.63[a]
S.E.M.[5]	0.16	0.00	0.21	0.43	0.08

[1]Muscle Color: 8=extremely bright cherry red; 1=extremely dark red
[2]Surface Discoloration: 7=total discoloration (100%); 1=no discoloration (0%)
[3]Overall Acceptability: 8=extremely desirable; 4.5=acceptable; 1=extremely undesirable
[4]Treatment: Treatment represents packaging style
[5]S.E.M.: Standard Error of the Mean
[6]High oxygen MAP, 80% O_2 and 20% CO_2, barrier tray
[7]High oxygen, 80% O_2 and 20% CO_2, mother bag
[8]Bi-gas, 70% N_2 and 30% CO_2, mother bag
[9]Tri-gas, 69.6% N_2, 30% CO_2 and 0.4% CO, mother bag, oxygen scavenger
[10]Low oxygen MAP, 70% N_2, 30% CO_2 and 0.4% CO, barrier tray
[a,b]Least squares mean within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 3. Phase I: Effect of storage period, packaging treatment, and retail display period on the muscle color[1], surface discoloration[2], and overall acceptability[3] of sirloin steaks (n= 6 packages per treatment) stored for 15 days.

	Treatment[4]				
	Hi MAP[6]	Hi Ox[7]	Bi-Gas[8]	Tri-Gas[9]	Lo MAP[10]
Muscle Color					
D 15	1.00[c]	1.00[c]	3.10[b]	5.57[a]	5.45[a]
D 16	1.00[c]	1.00[c]	2.71[b]	5.25[a]	4.88[a]
D 17	1.00[c]	1.00[c]	1.56[b]	4.56[a]	4.19[a]
D 18	1.00[c]	1.00[c]	1.46[c]	3.62[b]	5.67[a]
S.E.M.[5]	0.00	0.00	0.19	0.18	0.13
Surface Discoloration					
D 15	7.00[a]	6.98[a]	2.26[b]	1.00[c]	1.00[c]
D 16	7.00[a]	7.00[a]	3.17[b]	1.00[c]	1.00[c]
D 17	7.00[a]	7.00[a]	5.56[b]	2.19[c]	1.00[d]
D 18	7.00[a]	7.00[a]	6.25[a]	3.79[b]	1.00[c]
S.E.M.[5]	0.00	0.01	0.37	0.28	0.00
Overall Acceptability					
D 15	1.00[c]	1.00[c]	4.02[b]	6.38[a]	6.74[a]
D 16	1.00[d]	1.00[d]	3.17[c]	6.67[a]	6.04[b]
D 17	1.00[c]	1.00[c]	1.03[c]	4.08[b]	6.69[a]
D 18	1.00[b]	1.00[b]	1.00[b]	2.21[b]	6.29[a]
S.E.M.[5]	0.00	0.00	0.30	0.40	0.07

[1]Muscle Color: 8=extremely bright cherry red; 1=extremely dark red
[2]Surface Discoloration: 7=total discoloration (100%); 1=no discoloration (0%)
[3]Overall Acceptability: 8=extremely desirable; 4.5=acceptable; 1=extremely undesirable
[4]Treatment: Treatment represents packaging style
[5]S.E.M.: Standard Error of the Mean
[6]High oxygen MAP, 80% O_2 and 20% CO_2, barrier tray
[7]High oxygen, 80% O_2 and 20% CO_2, mother bag
[8]Bi-gas, 70% N_2 and 30% CO_2, mother bag
[9]Tri-gas, 69.6% N_2, 30% CO_2 and 0.4% CO, mother bag, oxygen scavenger
[10]Low oxygen MAP, 70% N_2, 30% CO_2 and 0.4% CO, barrier tray
[a,b]Least squares mean within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 4. Phase I: Effect of storage period, packaging treatment, and retail display period on the muscle color[1], surface discoloration[2], and overall acceptability[3] of ground beef (n= 6 packages per treatment) stored for 6 days.

	Treatment[4]				
	Hi MAP[6]	Hi Ox[7]	Bi-Gas[8]	Tri-Gas[9]	Lo MAP[10]
Muscle Color					
D 6	1.56[b]	1.50[b]	2.08[a]	1.00[d]	1.29[c]
D 7	2.79[a]	2.10[b]	1.98[b]	1.40[c]	1.94[b]
D 8	3.94[ab]	4.08[a]	3.40[b]	2.56[c]	2.00[c]
D 9	3.90[b]	5.87[a]	4.57[b]	3.80[b]	2.27[c]
S.E.M.[5]	0.21	0.36	0.23	0.23	0.13
Surface Discoloration					
D 6	1.00[b]	1.00[b]	1.54[a]	1.00[b]	1.00[b]
D 7	1.00	1.00	1.04	1.13	1.00
D 8	1.21	1.38	1.27	1.29	1.00
D 9	1.20[c]	2.37[a]	1.50[bc]	1.57[b]	1.20[c]
S.E.M.[5]	0.02	0.12	0.05	0.06	0.02
Overall Acceptability					
D 6	7.75[b]	7.75[b]	6.83[c]	7.88[a]	7.88[a]
D 7	6.92[a]	7.46[b]	7.46[a]	7.58[a]	7.63[a]
D 8	5.67[b]	5.90[b]	6.13[b]	6.69[a]	7.38[a]
D 9	5.43[b]	3.70[d]	4.57[c]	5.03[bc]	6.23[a]
S.E.M.[5]	0.20	0.34	0.23	0.23	0.15

[1]Muscle Color: 1= very bright red or pinkish red; 8=tan to brown
[2]Surface Discoloration: 7=total discoloration (100%); 1=no discoloration (0%)
[3]Overall Acceptability: 8=extremely desirable; 4.5=acceptable; 1=extremely undesirable
[4]Treatment: Treatment represents packaging style
[5]S.E.M.: Standard Error of the Mean
[6]High oxygen MAP, 80% O_2 and 20% CO_2, barrier tray
[7]High oxygen, 80% O_2 and 20% CO_2, mother bag
[8]Bi-gas, 70% N_2 and 30% CO_2, mother bag
[9]Tri-gas, 69.6% N_2, 30% CO_2 and 0.4% CO, mother bag, oxygen scavenger
[10]Low oxygen MAP, 70% N_2, 30% CO_2 and 0.4% CO, barrier tray
[a,b]Least squares mean within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 5. Phase I: Effect of storage period, packaging treatment, and retail display period on the muscle color[1], surface discoloration[2], and overall acceptability[3] of ground beef (n= 6 packages per treatment) stored for 10 days.

	Treatment[4]				
	Hi MAP[6]	Hi Ox[7]	Bi-Gas[8]	Tri-Gas[9]	Lo MAP[10]
Muscle Color					
D 10	4.19[a]	4.17[a]	3.00[b]	1.33[d]	2.11[c]
D 11	4.48[a]	4.71[a]	3.71[b]	2.29[c]	2.13[c]
D 12	6.08[b]	6.71[a]	5.85[b]	3.40[c]	2.56[d]
D 13	5.83[b]	6.50[a]	6.03[ab]	3.93[c]	2.67[d]
S.E.M.[5]	0.18	0.23	0.28	0.21	0.11
Surface Discoloration					
D 10	1.17[b]	1.58[a]	1.17[b]	1.00[b]	1.00[b]
D 11	1.29[b]	1.98[a]	1.29[b]	1.14[b]	1.17[b]
D 12	3.25[c]	4.35[a]	3.73[b]	1.69[d]	1.2[e]
D 13	3.97[c]	6.00[a]	5.23[b]	3.33[d]	1.13[e]
S.E.M.[5]	0.25	0.38	0.36	0.20	0.03
Overall Acceptability					
D 10	4.78[d]	4.53[e]	6.94[c]	7.83[a]	7.25[b]
D 11	4.48[c]	3.52[d]	5.74[b]	6.93[a]	7.00[a]
D 12	2.88[c]	1.33[e]	2.31[d]	5.50[b]	6.87[a]
D 13	2.83[c]	1.57[d]	1.77[d]	3.63[b]	7.17[a]
S.E.M.[5]	0.19	0.28	0.46	0.34	0.08

[1]Muscle Color: 1= very bright red or pinkish red; 8=tan to brown
[2]Surface Discoloration: 7=total discoloration (100%); 1=no discoloration (0%)
[3]Overall Acceptability: 8=extremely desirable; 4.5=acceptable; 1=extremely undesirable
[4]Treatment: Treatment represents packaging style
[5]S.E.M.: Standard Error of the Mean
[6]High oxygen MAP, 80% O_2 and 20% CO_2, barrier tray
[7]High oxygen, 80% O_2 and 20% CO_2, mother bag
[8]Bi-gas, 70% N_2 and 30% CO_2, mother bag
[9]Tri-gas, 69.6% N_2, 30% CO_2 and 0.4% CO, mother bag, oxygen scavenger
[10]Low oxygen MAP, 70% N_2, 30% CO_2 and 0.4% CO, barrier tray
[a,b]Least squares mean within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 6. Phase I: Effect of storage period, packaging treatment, and retail display period on the muscle color[1], surface discoloration[2], and overall acceptability[3] of ground beef (n= 6 packages per treatment) stored for 15 days.

	Treatment[4]				
	Hi MAP[6]	Hi Ox[7]	Bi-Gas[8]	Tri-Gas[9]	Lo MAP[10]
Muscle Color					
D 15	8.00[a]	7.31[b]	4.76[c]	1.71[e]	2.90[d]
D 16	8.00[a]	7.50[a]	6.13[b]	2.46[d]	3.63[c]
D 16	7.83[a]	8.00[a]	7.56[a]	5.33[b]	3.97[c]
D 17	8.00[a]	7.86[a]	8.00[a]	6.76[b]	4.21[c]
S.E.M.[5]	0.02	0.06	0.28	0.44	0.15
Surface Discoloration					
D 15	7.00[a]	6.45[b]	2.00[c]	1.00[d]	1.10[d]
D 16	7.00[a]	6.71[a]	5.13[b]	1.63[c]	1.33[c]
D 17	7.00[a]	7.00[a]	6.19[b]	3.67[c]	1.50[d]
D 18	7.00[a]	7.00[a]	7.00[a]	5.69[b]	1.07[c]
S.E.M.[5]	0.00	0.05	0.42	0.40	0.08
Overall Acceptability					
D 15	1.00[d]	1.14[d]	4.43[c]	7.43[a]	6.48[b]
D 16	1.00[c]	1.08[c]	2.13[b]	6.58[a]	5.71[a]
D 17	1.00[c]	1.00[c]	1.00[c]	2.92[b]	5.72[a]
D 18	1.00[c]	1.00[c]	1.00[c]	1.62[b]	5.08[a]
S.E.M.[5]	0.00	0.02	0.31	0.53	0.14

[1]Muscle Color: 1= very bright red or pinkish red; 8=tan to brown
[2]Surface Discoloration: 7=total discoloration (100%); 1=no discoloration (0%)
[3]Overall Acceptability: 8=extremely desirable; 4.5=acceptable; 1=extremely undesirable
[4]Treatment: Treatment represents packaging style
[5]S.E.M.: Standard Error of the Mean
[6]High oxygen MAP, 80% O_2 and 20% CO_2, barrier tray
[7]High oxygen, 80% O_2 and 20% CO_2, mother bag
[8]Bi-gas, 70% N_2 and 30% CO_2, mother bag
[9]Tri-gas, 69.6% N_2, 30% CO_2 and 0.4% CO, mother bag, oxygen scavenger
[10]Low oxygen MAP, 70% N_2, 30% CO_2 and 0.4% CO, barrier tray
[a,b]Least squares mean within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 7. Phase I: Effect of packaging treatment, storage period, and retail display period on the microbial growth[1] of sirloin steaks (n= 2 packages per treatment).

	Storage, d:Display, d								
Treatment[2]	6:6	6:9	S.E.M.[3]	10:10	10:13	S.E.M.[3]	15:15	15:18	S.E.M.[3]
Hi MAP[4]	0.20	1.65	0.40	1.72	1.00	0.82	4.61	4.12	0.68
Hi Ox[5]	1.04	0.85	0.60	1.84	1.78	0.49	4.65	4.01	0.07
Bi-Gas[6]	1.38	2.48	0.77	3.09	1.78	0.11	4.25	3.97	0.04
Tri-Gas[7]	1.08	2.58	0.32	2.02	2.42	0.04	4.61	4.02	0.03
Lo MAP[8]	2.08	1.70	0.42	1.29	2.81	0.83	4.08	3.93	0.36

[1]Microbial growth: aerobic total plate count calculated in log colony forming units/gram
[2]Treatment: Treatment represents packaging style
[3]S.E.M.: Standard Error of the Mean pooled by day storage
[4]High oxygen MAP, 80% O_2 and 20% CO_2, barrier tray
[5]High oxygen, 80% O_2 and 20% CO_2, mother bag
[6]Bi-gas, 70% N_2 and 30% CO_2, mother bag
[7]Tri-gas, 69.6% N_2, 30% CO_2 and 0.4% CO, mother bag, oxygen scavenger
[8]Low oxygen MAP, 70% N_2, 30% CO_2 and 0.4% CO, barrier tray
[a,b]Least square means within a column that do not share the same superscript are significantly different ($P < 0.05$)

Table 8. Phase I: Effect of packaging treatment, storage period, and retail display period on the microbial growth[1] of ground beef (n= 2 packages per treatment).

Treatment[2]	Storage, day:Display, day								
	6:6	6:9	S.E.M.[3]	10:10	10:13	S.E.M.[3]	15:15	15:4	S.E.M.[3]
Hi MAP[4]	2.86	3.35	0.60	2.82[b]	5.68	0.97	5.92	5.38	0.54
Hi Ox[5]	3.12	3.74	0.94	4.21[a]	5.51	0.18	6.18	6.04	0.02
Bi-Gas[6]	2.33	3.48	0.35	4.62[a]	5.96	0.17	5.97	6.07	0.03
Tri-Gas[7]	3.12	3.72	0.62	4.48[a]	5.96	0.28	5.96	6.02	0.22
Lo MAP[8]	2.34	3.43	0.14	4.75[a]	5.56	0.29	5.36	5.68	0.55

[1]Microbial growth: aerobic total plate count calculated in log colony forming units/gram
[2]Treatment: Treatment represents packaging style
[3]S.E.M.: Standard Error of the Mean pooled by day storage
[4]High oxygen MAP, 80% O_2 and 20% CO_2, barrier tray
[5]High oxygen, 80% O_2 and 20% CO_2, mother bag
[6]Bi-gas, 70% N_2 and 30% CO_2, mother bag
[7]Tri-gas, 69.6% N_2, 30% CO_2 and 0.4% CO, mother bag, oxygen scavenger
[8]Low oxygen MAP, 70% N_2, 30% CO_2 and 0.4% CO, barrier tray
[a,b]Least square means within a column that do not share the same superscript are significantly different ($P < 0.05$)

Table 9. Phase II: Effect of storage period, packaging treatment, and retail display period on the muscle color[1], surface discoloration[2], and overall acceptability[3] of sirloin steaks (n= 8 packages per treatment) stored for 5 days.

	Treatment[4]				
Display, day	SS-DF[6]	DS-SF T[7]	DS-SF B[8]	DS-DF T[9]	DS-DF B[10]
Muscle Color					
D 5	7.16	7.16	7.34	7.27	7.00
D 6	6.55[ab]	6.75[a]	6.72[a]	6.52[ab]	6.38[b]
D 7	5.80[b]	6.21[a]	6.02[ab]	5.55[b]	5.55[b]
S.E.M.[5]	0.12	0.09	0.12	0.16	0.15
Surface Discoloration					
D 5	1.07	1.04	1.02	1.02	1.09
D 6	1.06[b]	1.05[b]	1.05[b]	1.20[ab]	1.33[a]
D 7	1.45[bc]	1.29[c]	1.30[c]	1.64[ab]	1.64[a]
S.E.M.[5]	0.04	0.03	0.03	0.06	0.08
Overall Acceptability					
D 5	7.63	7.59	7.66	7.66	7.57
D 6	7.48[a]	7.47[a]	7.47[a]	7.33[ab]	7.17[b]
D 7	6.13[bc]	6.55[a]	6.32[ab]	5.91[cd]	5.91[d]
S.E.M.[5]	0.14	0.10	0.13	0.17	0.18

[1]Muscle Color: 8= very bright red or pinkish red; 1=tan to brown
[2]Surface Discoloration: 7=total discoloration (100%); 1=no discoloration (0%)
[3]Overall Acceptability: 8=extremely desirable; 4.5=acceptable; 1=extremely undesirable
[4]Treatment: Treatment represents packaging style
[5]S.E.M.: Standard Error of the Mean
[6] SS-DF= Single Stacked- Double Flushed
[7] DS-SF T= Double Stacked- Single Flushed Top
[8] DS-SF B= Double Stacked- Single Flushed Bottom
[9]DS-DF T= Double Stacked- Double Flushed Top
[10]DS-DF B= Double Stacked- Double Flushed Bottom
[a,b]Least square means within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 10. Phase II: Effect of storage period, packaging treatment, and retail display period on the muscle color[1], surface discoloration[2], and overall acceptability[3] of sirloin steaks (n= 8 packages per treatment) stored for 8 days.

	Treatment[4]				
Display, day	SS-DF[6]	DS-SF T[7]	DS-SF B[8]	DS-DF T[9]	DS-DF B[10]
Muscle Color					
D 8	7.38	7.29	7.23	7.38	7.35
D 9	6.39[a]	6.27[a]	5.63[b]	6.25[a]	6.05[a]
D 10	5.28[a]	5.00[a]	4.23[b]	4.98[a]	4.75[ab]
S.E.M.[5]	0.18	0.20	0.27	0.21	0.23
Surface Discoloration					
D 8	1.00	1.00	1.00	1.00	1.00
D 9	1.00[b]	1.02[b]	1.14[ab]	1.13[ab]	1.25[a]
D 10	1.53[b]	1.63[b]	2.02[ab]	2.00[ab]	2.26[a]
S.E.M.[5]	0.06	0.07	0.10	0.10	0.12
Overall Acceptability					
D 8	8.00	7.98	7.90	7.98	7.94
D 9	6.89[a]	6.86[a]	6.16[c]	6.61[ab]	6.43[bc]
D 10	5.59[a]	5.22[ab]	4.63[c]	4.75[bc]	4.46[c]
S.E.M.[5]	0.21	0.24	0.29	0.28	0.30

[1]Muscle Color: 8= very bright red or pinkish red; 1=tan to brown
[2]Surface Discoloration: 7=total discoloration (100%); 1=no discoloration (0%)
[3]Overall Acceptability: 8=extremely desirable; 4.5=acceptable; 1=extremely undesirable
[4]Treatment: Treatment represents packaging style
[5]S.E.M.: Standard Error of the Mean
[6] SS-DF= Single Stacked- Double Flushed
[7] DS-SF T= Double Stacked- Single Flushed Top
[8] DS-SF B= Double Stacked- Single Flushed Bottom
[9]DS-DF T= Double Stacked- Double Flushed Top
[10]DS-DF B= Double Stacked- Double Flushed Bottom
[a,b]Least square means within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 11. Phase II: Effect of storage period, packaging treatment, and retail display period on the muscle color[1], surface discoloration[2], and overall acceptability[3] of cube steaks (n= 8 packages per treatment) stored for 5 days.

	Treatment[4]				
Display, day	SS-DF[6]	DS-SF T[7]	DS-SF B[8]	DS-DF T[9]	DS-DF B[10]
Muscle Color					
D 5	6.95	6.63	6.68	6.79	6.55
D 6	6.63	6.56	6.48	6.61	6.58
D 7	5.23	5.55	5.46	5.87	5.57
S.E.M.[5]	0.16	0.13	0.15	0.12	0.13
Surface Discoloration					
D 5	1.09	1.11	1.07	1.07	1.09
D 6	1.25	1.19	1.27	1.19	1.26
D 7	1.46	1.46	1.61	1.35	1.53
S.E.M.[5]	0.17	0.15	0.18	0.12	0.16
Overall Acceptability					
D 5	7.55	7.57	7.54	7.52	7.48
D 6	7.08	7.13	7.14	7.20	7.19
D 7	5.73	6.00	5.70	6.26	5.93
S.E.M.[5]	0.05	0.04	0.07	0.03	0.05

[1]Muscle Color: 8= very bright red or pinkish red; 1=tan to brown
[2]Surface Discoloration: 7=total discoloration (100%); 1=no discoloration (0%)
[3]Overall Acceptability: 8=extremely desirable; 4.5=acceptable; 1=extremely undesirable
[4]Treatment: Treatment represents packaging style
[5]S.E.M.: Standard Error of the Mean
[6] SS-DF= Single Stacked- Double Flushed
[7] DS-SF T= Double Stacked- Single Flushed Top
[8] DS-SF B= Double Stacked- Single Flushed Bottom
[9]DS-DF T= Double Stacked- Double Flushed Top
[10]DS-DF B= Double Stacked- Double Flushed Bottom
[a,b] Least square mean within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 12. Phase II: Effect of storage period, packaging treatment, and retail display period on the muscle color[1], surface discoloration[2], and overall acceptability[3] of cube steaks (n= 8 packages per treatment) stored for 8 days.

	Treatment[4]				
Display, day	SS-DF[6]	DS-SF T[7]	DS-SF B[8]	DS-DF T[9]	DS-DF B[10]
Muscle Color					
D 8	7.33	7.33	7.33	7.48	7.29
D 9	6.45	6.36	5.91	6.52	5.96
D 10	4.80	4.53	4.19	4.68	4.18
S.E.M.[5]	0.24	0.25	0.29	0.26	0.29
Surface Discoloration					
D 8	1.00	1.02	1.02	1.00	1.00
D 9	1.30	1.14	1.38	1.04	1.09
D 10	2.04[ab]	2.00[ab]	2.41[a]	1.50[b]	2.13[ab]
S.E.M.[5]	0.33	0.30	0.36	0.25	0.34
Overall Acceptability					
D 8	7.94	7.94	7.96	8.00	7.98
D 9	6.41	6.43	5.84	6.77	6.34
D 10	4.70	4.60	3.95	5.27	4.33
S.E.M.[5]	0.13	0.10	0.14	0.06	0.14

[1]Muscle Color: 8= very bright red or pinkish red; 1=tan to brown
[2]Surface Discoloration: 7=total discoloration (100%); 1=no discoloration (0%)
[3]Overall Acceptability: 8=extremely desirable; 4.5=acceptable; 1=extremely undesirable
[4]Treatment: Treatment represents packaging style
[5]S.E.M.: Standard Error of the Mean
[6] SS-DF= Single Stacked- Double Flushed
[7] DS-SF T= Double Stacked- Single Flushed Top
[8] DS-SF B= Double Stacked- Single Flushed Bottom
[9]DS-DF T= Double Stacked- Double Flushed Top
[10]DS-DF B= Double Stacked- Double Flushed Bottom
[a,b]Least squares means within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 13. Phase I: Effect of storage period, packaging treatment, and retail display period on microbial growth of sirloin steaks (n= 2 packages per treatment).

	Storage, d: Display, d					
Treatment[2]	5:5	5:7	S.E.M.[3]	8:8	8:10	S.E.M.[3]
SS-DF[4]	2.57	4.19[a]	0.17	3.24	4.73[a]	0.06
DS-SF[5]	2.81	3.62[ab]	0.28	4.50	3.33[a]	0.44
DS-DF[6]	2.93	2.96[b]	0.12	3.33	3.21[b]	0.21

[1]Microbial growth: aerobic plate count calculated in log colony forming units/gram
[2]Treatment: Treatments represent packaging style
[3]S.E.M.: Standard Error of the Mean, SEM pooled by day storage
[4]SS-DF = Single Stacked- Double Flushed
[5]DS-SF = Double Stacked- Single Flushed
[6]DS-DF = Double Stacked- Double Flushed
[a,b]Least squares means within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

Table 14. Phase II: Effect of storage period, packaging treatment, and retail display period on microbial growth of cube steaks (n= 2 packages per treatment).

	Storage, d: Display, d					
Treatment[2]	5:5	5:7	S.E.M.[3]	8:8	8:10	S.E.M.[3]
SS-DF[4]	2.92	3.85	0.22	3.60	3.97	0.26
DS-SF[5]	2.13	3.60	0.02	3.47	3.97	0.33
DS-DF[6]	2.06	3.97	0.20	3.43	4.06	0.29

[1]Microbial growth: aerobic plate count calculated in log colony forming units/gram
[2]Treatment: Treatments represent packaging style
[3]S.E.M.: Standard Error of the Mean, SEM pooled by day storage
[4]SS-DF = Single Stacked- Double Flushed
[5]DS-SF = Double Stacked- Single Flushed
[6]DS-DF = Double Stacked- Double Flushed
[a,b]Least squares means within a row by storage day that do not share a common superscript are significantly different ($P < 0.05$)

REFERENCES

AMI. 2008. Case- ready meats modified atmosphere packaging. AMI Fact Sheet. American Meat Institute, Washington, DC.

Belcher, J. N. 2006. Industrial packaging developments for the global meat market. Meat Science.74:143-148.

Brandon, K., M. Beggan, P. Allen and F. Butler. 2009. The performance of several oxygen scavengers in varying oxygen environments at refrigerated temperatures: implications for low-oxygen modified atmosphere packaging of meat . International Journal of Food Science & Technology. 44:188-196.

Brody, A. L. 2007. Case-ready packaging for red meat. Food Technology. 61:70-72.

Carpenter, C. E., D. P. Cornforth and D. Whittier. 2001. Consumer preferences for beef color and packaging did not affect eating satisfaction. Meat Science. 57:359-363.

Cornforth, D. and M. Hunt. 2008. Low-oxygen packaging of fresh meat with carbon monoxide. AMSA White Paper Series. No. 2. American Meat Science Association, Savory, IL.

Eilert, S. J. (2005). New packaging technologies for the 21st century. Meat Science. 71:122-127.

Gill, C.O. and T. Jones. 1994. The display life of retail-packages beef steaks after their storage in master packs under various atmospheres. Meat Science. 38:385-396.

Greene, B.E., E. Hsin and M. W. Zipser. 1971. Retardation of oxidative color changes in raw ground beef. Journal of Food Science. 36:940-942.

Isdell, E. E., P. Allen, A. M. Doherty, F. Butler. 1999. Colour stability of six beef muscles stored in a modified atmosphere mother pack system with oxygen scavengers. International J. of Food Science & Technology. 34:71-80.

Jayasingh, P. P., D. D. Whittier, C. E. Carpenter, and D. P. Cornforth. 2001. Evaluation of carbon monoxide treatment in modified atmosphere packaging or vacuum packaging to increase color stability of fresh beef. Meat Science. 59:317-324.

Jeong, J. Y. and J. R. Claus. 2011. Color stability of ground beef packaged in a low carbon monoxide atmosphere or vacuum . Meat Science. 87:1-6.

Labuza, T.P. and W.M. Breene. 1989. Applications of "active packaging" for improvement of shelf-life and nutritional quality of fresh and extended shelf-life foods. Journal of Food Processing and Preservation. 13:1-69.

Limbo, S., E. Uboldi, A. Adobati, S. Iametti, F. Bonomi, E. Mascheroni, S. Santagostino, T.H. Powers, L. Franzetti and L. Piergiovanni. 2013. Shelf life of case-ready beef steaks (Semitendinosus muscle) stored in oxygen-depleted master bag system with oxygen scavengers and CO_2/N_2 modified atmosphere packaging. Meat Science. 93: 477-484.

Luño, M. M., P. Roncales, and J. A. Beltran. 1998. Shelf-life extension and color stabilization of beef packaged in a low O2 atmosphere containing CO: loin steaks and ground meat. Meat Science. 48:75-84.

Luño, M. M., J. A. Beltran, D. Djenane, and P. Roncales. 2000. Beef shelf life in low O2 and high CO2 atmospheres containing different low CO concentrations. Meat Science. 55:413-419.

Mancini, R. A., & M. C. Hunt. 2005. Current research in meat color. Meat Science. 71:100-121.

McMillin, K. W. 2008. Where is MAP Going? A review and future potential of modified atmosphere packaging for meat. Meat Science. 80:43-65.

Nassu, R. T., M. Juárez, B. Uttaro, J. L. Aalhus. 2010. Fresh meat packaging trends for retail and food service. CAB Reviews: Presepectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. 5:1-9.

NCBA. 2010. A snapshot of today's retail meat case executive summary. National Meat Case Study 2010. http://www.beefretail.org/CMDocs/BeefRetail/research/2010NationalMeatCaseStudy.pdf Accessed April 6, 2014.

Scholtz, E.M., G.L. Nortje, R.T. Naude, E. Jordaan, and J. Kruger. 1992. The influence of different centralized pre-packaging systems on the shelf-life of fresh pork. Meat Science. 32:11-29.

Silliker, J.H., S.K. Wolfe, W.D. Brown, R.E. Woodruff, and J.R. Lugg. 1977. Preservation of refrigerated meats with controlled atmospheres: treatment and post treatment effects of carbon dioxide on pork and beef. Meat Science. 3:195-204.

Smith, G.C., K. E. Belk, J. N. Sofos, J. D. Tatum and S. N. Williams. 2000. Economic implications of improved color stability in beef. In E. A. Decker, C. Faustman and C. J. Lopez-Bote (Eds.), Antioxidants in muscle foods: Nutritional strategies to improve quality. 397-346.

Sorheim , O., T. Erlandsen, N. Hissen, P. Lea and T. Hoyem.1997. Effects of modified atmosphere storage on color and microbiological shelf life of normal and pale, soft and exudative pork. Meat Science. 47:147-155.

Stetzer, A. J.,R. A. Wickland, D. D. Paulson, E. M. Tucker, B. J. Macfarlane and M. S. Brewer. 2006. Effect of carbon monoxide and high oxygen modified atmosphere packaging (MAP) on quality characteristics of beef strip steaks. J.of Muscle Foods. 18:56-66.

Troy, D. J. and J. P. Kerry. 2010. Consumer perception and the role of science in the meat industry. Meat Science. 86: 214-226.

Venturini, A. C., C. J. C. Contreras , C. I. G. I. Sarantopoulos and N. D. M. Villanueva. 2006. The Effects of residual oxygen on the storage Life of retail-ready fresh beef steaks masterpackaged under a CO2 atmosphere. J. Of Food Sci. 71:s560-s566.

APPENDICES

Appendix A

STEAK COLOR SCORE CRITERIA

Muscle Color	Description
8	Extremely bright cherry red
7	Bright cherry red
6	Moderately bright cherry red
5	Slightly bright cherry red
4	Slightly dark cherry red
3	Moderately dark cherry red
2	Dark red
1	Extremely dark red

Surface Discoloration	Description
7	Total Discoloration (100%)
6	Extensive discoloration (80-99%)
5	Moderate discoloration (60-79%)
4	Modest discoloration (40-59%)
3	Small discoloration (20-39%)
2	Slight discoloration (1-19%)
1	No discoloration (0%)

Overall Acceptability	Description
8	Extremely desirable
7	Very desirable
6	Moderately desirable
5	Slightly desirable
4	Slightly undesirable
3	Moderately undesirable
2	Very undesirable
1	Extremely undesirable

Appendix B

GROUND BEEF COLOR SCORE CRITERIA

Muscle Color	Description
1	Extremely bright cherry red
2	Bright cherry red
3	Moderately bright cherry red
4	Slightly bright cherry red
5	Slightly dark cherry red
6	Moderately dark cherry red
7	Dark red
8	Extremely dark red

Surface Discoloration	Description
7	Total Discoloration (100%)
6	Extensive discoloration (80-99%)
5	Moderate discoloration (60-79%)
4	Modest discoloration (40-59%)
3	Small discoloration (20-39%)
2	Slight discoloration (1-19%)
1	No discoloration (0%)

Overall Acceptability	Description
8	Extremely desirable
7	Very desirable
6	Moderately desirable
5	Slightly desirable
4	Slightly undesirable
3	Moderately undesirable
2	Very undesirable
1	Extremely undesirable

VITA

Renee Elizabeth Kinsey

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF MODIFIED ATMOSPHERE PACKAGING ON RETAIL COLOR STABILITY IN FRESH BEEF

Major Field: Meat Science

Biographical:

Education:

Completed the requirements for the Master of Science in Meat Science at Oklahoma State University, Stillwater, Oklahoma in May, 2014.

Completed the requirements for the Bachelor of Science in Animal Science at Colorado State University, Fort Collins, Colorado in 2011.

Experience:

Graduate Research Assistant, Oklahoma State University, Stillwater, Oklahoma

January 2013- May 2014

Professional Memberships:

American Meat Science Association