THE BENEFITS OF OXYGEN SCAVENGING TECHNOLOGY ON OVERWRAPPED BEEF CUTS IN A MODIFIED ATMOSPHERE PACKAGE

By

SIDNEY BRYAN CUNNINGHAM

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

2007

Submitted to the Faculty of the
Graduate College of
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2008

THE BENEFITS OF OXYGEN SCAVENGING

TECHNOLOGY ON OVERWRAPPED

BEEF CUTS IN A MODIFIED

ATMOSPHERE PACKAGE

Thesis Approved:

Dr. J. Brad Morgan

Thesis Adviser

Dr. Gretchen Hilton

Dr. Deb VanOverbeke

Dr. A. Gordon Emslie

Dean of the Graduate College

Acknowledgements

I would like thank all of the individuals who were involved with my research and those who have supported me through out my academic career. To Dr.'s Hilton, Morgan, and VanOverbeke thank you for your support and guidance. All of you have had a huge impact on my life as a meat scientist and working with the three of you has been a pleasure. Also, I owe a great deal of thanks to my fellow graduate students who have helped me and allowed me to learn from them. To Jake Nelson, thanks for always being a friend and mentor, as well as the great amount of wisdom you have bestowed upon me. To Kris Novotny, thank you for all your help; your support and wisdom have been invaluable. Also, I would like to thank my Lord, Jesus Christ, for he gives me strength and courage. Finally, I would like to extend a huge thanks to my family and Courtney; I wouldn't have made it anywhere without your support and encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Format of Thesis

This thesis is presented in Journal of Animal Science style format, as outlined by the Oklahoma State University graduate college style manual. The use of this format allows for independent chapters to be prepared suitable for submission to scientific journals.

CHAPTER I

INTRODUCTION

Delivering prepackaged case ready meat that meets consumer expectations has always been a concern of processors and retailers. Consumers base their perception of value on determining factors such as wholesomeness, freshness, and visual appearance in the fresh retail beef offering. More importantly, the meat case is a strong determinant of where consumers will shop (Gregerson, 2007). Consumers associate beef that is not bright cherry-red in color to “yesterday’s meat” and ,for consumers’, perception is reality. Kropf (1980) reported that any deviation from the bright cherry-red color leads to customer dissatisfaction and creates a “bad experience”. This unpleasant experience is most likely attributed to myoglobin oxidation and microbial spoilage (Lund et al., 2006; Mancini and Hunt, 2005; McKeena et al., 2005; Solomon, 2004). Thus, methods to help preserve and enhance beef color are needed to reduce mark-downs in the retail case. However, the beef industry has been highly scrutinized by the media and consumer advocacy groups for using low levels (< 0.5%) of carbon monoxide (CO) in fresh beef case ready packaging to help preserve color.

In response to this scrutiny and the desire for their products to have a clean label (i.e. brief list of ingredients), some large retailers have began to move away from using CO in the packaging of individual fresh beef cuts. Thus, retailers have returned to using low-oxygen modified atmosphere package (MAP) or a system of overwrapping individual beef cuts and placing those individual cuts in a MAP mother bag for storage and transport. The latter system presents a challenge in terms of free residual oxygen levels (> 0.05%) that promote the formation of metmyoglobin which leads to surface discoloration and the perception of a loss of freshness and wholesomeness. In order for retailers to reduce mark downs and improve the overall appearance of their retail cases, non-invasive methods are needed to "scavenge" free residual oxygen.

The inclusion of active packaging technologies into case ready beef packaging offers opportunities for retailers and processors to reduce free residual oxygen. As one industry representative put it:

> "Active packaging technologies effectively reduce the need for food additives and preservatives without compromising a product's shelf-life or freshness. They also create an opportunity for cleaner product lablels" (Merrett, 2007).

Active packaging technology can be used to scavenge oxygen and reduce microbial growth. Therefore, this project was designed to determine the effectiveness of three oxygen scavenging systems at reducing residual oxygen levels, improving color stability and increasing self-life.

CHAPTER II

REVIEW OF LITERATURE

Consumer Perceptions

When consumers make meat purchasing decisions at the retail location they rely on the attributes of the product they can see, such as lean color and retail price. The purchasing of food products is mainly driven by the relation of how appetizing the product appears in relation to the price. Over time, consumers have been conditioned to recognize the bright cherry-red color of beef and equate it to freshness, wholesomeness, and quality of the product. According to Faustman and Cassesns (1990), consumers perceive any deviation from the bright cherry-red lean color to be undesirable. Glitsch (2000) found that lean color is the most important intrinsic cue for the purchasing of fresh meats, and “freshness” was shown to be the most important indicator of the safety of meat. Glitsch (2000) also found lean color was considered one of the most helpful characteristics in five European countries that were surveyed. As Sherbeck et al. (1995) reported, lean color is very important to the appearance of beef products and influences consumer perception in the retail case. Carpenter et al. (2001) found consumer preferences for beef color and packaging influenced likelihood to purchase. In appearance scores, consumers rated fresh beef product packaged in PVC overwrapped trays higher than the same product packaged in vacuum skin packaging (VSP) or MAP (Carpenter et al., 2001). The consumer associates bright cherry-red color with freshness and considers the product to be one of "quality" (Faustman and Cassens, 1990). Ultimately, many visual factors such as packaging and meat color influence consumer purchasing decisions at the meat case. It is important for processors and retailers to reduce muscle surface discoloration, which results in nearly 15% of retail beef being discounted in price and a revenue loss of at least $1 billion annually (Smith et al., 2000).

Case-ready Packaging Overview

Fresh beef case-ready packaging must serve the purpose of meeting the consumer needs for a fresh bright cherry-red colored product with excellent quality and meet the retailer's demand of reducing labor and out of stock items. Several packaging technologies have made their way into the case ready offering; such as high oxygen MAP, low-oxygen MAP with CO (CO-MAP), vacuum skin packaging (VSP), and overwrap packages that are stored in MAP "mother bags" before retail display. Belcher (2006) listed several criteria for successful case ready meat packaging: 1) obtain the longest possible quality life of the product to allow adequate distribution time from preparation at a central processing facility, 2) allow the product to be displayed in the retail store in the oxymyoglobin state, 3) arrive at the retail outlet hermetically sealed, pre-priced, and labeled with a sell by date, and 4) the product must be clearly seen in the package. Each packaging type has its advantages and disadvantages once introduced into the retail case.

High-oxygen MAP consists of a usually colored barrier tray (polypropylene, polystyrene or polyethylene) coupled with a clear barrier film. This style of packaging also includes a gaseous headspace area that is normally comprised of an atmosphere of 80% O_2 and 20% CO_2. The gases must be at the proper headspace ratio in order to maintain a minimum of 55% O_2, which is needed to provide optimal color life (Jakobsen & Bertelsen, 2000). Kropf (2004) found that high O_2 levels react with the meat to extend the oxymyoglobin state while the CO_2 acts as a bacteriostatic agent. Shelf-life for high-oxygen MAP product has been reported to be approximately double traditionally overwrapped cuts. High-oxygen MAP provides many benefits for retailers and processors, but it has the disadvantage of increased lipid oxidation and off-flavor development (Jakobsen and Bertelsen, 2000). Additionally, high-oxygen MAP can cause premature browning during cooking (John et al., 2004), which can indicate a higher degree of doneness. This is especially troublesome with ground beef, which can appear to be thoroughly cooked when it is not. Due to the associated negatives with high-oxygen MAP, many processors continue to search for alternative packaging methods.

Perhaps the most recent advancement in packaging technology has been CO-MAP. With CO-MAP, individual cuts are usually placed in a colored barrier tray (polypropylene, polystyrene or polyethylene) coupled with a clear barrier film. Headspace composition of CO-MAP is most commonly referred to as the tri-gas system which is comprised of 0.4% CO, 20-30% CO_2, and the remainder N_2. The main advantage to using CO-MAP is that it maintains and stabilizes the desirable bright cherry-red color of fresh beef (Hunt et al., 2004). This, in itself, greatly reduces price mark downs at the retail level. Jayasingh et al. (2002) also found CO-MAP fresh beef exhibited improved flavor acceptability and the lack of oxidized flavors associated with high-oxygen MAP. Hunt et al. (2004) discovered CO-MAP product would maintain microbial plate counts below spoilage levels for up to 35 d of storage for whole muscle cuts. Also, CO-MAP does not promote bone darkening which is typically associated with high-oxygen MAP (Mancini et al., 2005). Carbon Monoxide-MAP is also very effective at reducing the growth of spoilage and pathogenic organisms due to anaerobic conditions and elevated CO_2 levels (Nissen et al., 2000). Lund et al. (2007) demonstrated CO-MAP fresh beef cuts had increased tenderness due to less protein oxidation. Cornforth and Hunt (2008) concluded low-oxygen, when combined with CO, in fresh meat packaging improved red color stability, flavor, and reduces premature browning during cooking.

Recently CO-MAP has received a lot of scrutiny via the media and consumer advocacy groups for using CO. Carbon Monoxide-MAP has continued to receive scrutiny even though Hunt et al. (2004) confirmed that 0.4% CO will not mask spoilage when combined with low-oxygen packaging. One cause for concern has been the negative image of CO because it is a potentially hazardous gas. Consumers are also concerned CO will “fix” meat color so it will look fresh even when it is not. Additionally, CO-MAP has received scrutiny because some believe it will not show the signs of mishandling. Unfortunately, consumer perception is reality, and the recent scrutiny of CO-MAP has caused many retailers to look at different potential avenues for their fresh beef case ready offering.

Vacuum skin packaging uses a barrier polypropylene or styrene tray and a barrier film that forms around the product. An advantage of VSP is reduction of purge loss and extended self-life of up to 22 d, depending on the cut (Belcher, 2006). Additionally, the product is displayed in the reduced, deoxymyoglobin state, so there is no loss of color associated with VSP. Oxidation issues are also minimized due to the removal of residual oxygen. However, VSP has seen limited use in case ready offerings because the meat is displayed in the purplish colored myoglobin state, which consumers do not associate with fresh beef wholesomeness, quality, or freshness.

Another system retailers and processors have employed the use of is placing individually overwrapped cuts in a MAP mother bag. Individual cuts are typically overwrapped in a Styrofoam tray with polyvinylchloride (PVC) and placed in a mother bag, which is flushed with 79.6% N_2, 20% CO_2, and 0.4% CO (Merriman et al. 2003). In this system residual O_2 must be kept below 0.05% (Belcher, 2006) in order to retard metmyglobin production. In order to meet O_2 requirements this type of packaging requires the use of an oxygen scavenger. This system allows prepackaged meat to be transported and stored in MAP, but allows for the individual meat packages to be removed from the mother bag once they are ready for retail case display. Advantages of this system are providing the consumer the perception the meat they are buying is “store cut”. It also extends the distribution life up to 10 d depending on the cut (Belcher, 2006). Final product headspace is reduced and oxidation is minimized due to the low-oxygen atmosphere. The disadvantage of this process is it requires more labor by the retailer since the individual cuts must be removed from the mother bag. Once removed from the mother bag the cuts tend to have a shorter case life as compared to high-oxygen MAP and CO-MAP.

Many avenues are available to processors and retailers for fresh beef case-ready packaging, but on-going research is needed to improve color stability and reduce oxidation. Additionally, focus must be placed on meeting the consumer’s demands while maintaining a high consumer perception.

Case-ready Phenomena

Case-ready is the broad term associated with meat that is packaged at a central processing facility and is ready for retail display upon arrival at a grocery store. Since the late 1990s, retailers have made a concerted effort to move away from store cut beef to case-ready packaged beef. Case-ready red meats are following the example of chicken, which has been sold as a case-ready item for decades (AMI, 2007). At last estimate, retailers sold more than 1.2 billion case-ready packages in 2000, which was more than double the number from 1997 (AMI, 2007). In 2006, case-ready packages accounted for 64% of the packages found in the retail meat case (Cryovac, 2007). Additionally, estimates put case-ready package sales at 8.7 billion for 2010 with 71% share of the retail meat case

(Makley, 2003). Experts believe case-ready meat sales will continue to increase at a steady pace.

The speculation that case-ready sales will continue to increase can be attributed to the many advantages it provides to the retailer and consumer. For retailers and consumers, case-ready offers numerous benefits such as (AMI, 2007):

- “Ready to go” packaging, eliminating the need for an in-store butcher
- Packages with longer shelf-life than those packaged at the store
- More effective inventory management
- Reduced out of stocks
- More consistent products
- Consumer convenience and appeal
- Increased food safety

The “ready to go” products save retailers time and money because they don’t require additional fabrication or processing, thus eliminating the need to pay and train in-store butchers. Centralized processing facilities help retailers more effectively manage their inventory by allowing retailers the ability to order only those items they need. Furthermore, case-ready meats have a higher in-stock rate, 71%, versus store wrapped packages at 50% (Cyrovac, 2007). Case-ready packages are more attractive to consumers because they do not have to deal with “bloody” or “leaky” packages (Barry, 2002). Additionally, food safety is improved with case-ready packaging because centralized processing facilities have to adhere to Hazard Analysis Critical Control Points (HACCP) and have more stringent sanitation standards than traditional in-store cutting facilities. Additionally, most case-ready packages are tamperproof, which helps give the consumer peace of mind (AMI 2007). Case-ready packaging allows retailers to run a more effective meat case leading to a more enjoyable shopping and eating experience for consumers.

Processes, such as enhancement and the inception of case-ready branded beef programs, have helped increase the case-ready presence. Case-ready has helped increase profitability and has led to a safer food supply. However, as with many technologies in the beef industry, consumer acceptance is key and some case-ready technologies are not readily accepted by consumers. As such, more research is required to better case-ready processes and improve consumers' perception of case-ready beef products.

Meat Color

Meat color is the single most influential factor affecting consumer purchasing decisions because consumers use color as an indicator of freshness and wholesomeness (Mancini and Hunt, 2005). Fresh beef purchasing decisions are based on lean surface color as well as surface discoloration. Smith et al. (2000) found fresh beef discoloration leads to annual revenue losses of $1 billion for retail beef. Beef muscle color is attributed to the respiratory pigments hemoglobin and myoglobin. Hemoglobin is primarily found in blood and serves the function of transporting oxygen to muscle where myoglobin awaits to bind the oxygen released by hemoglobin. Structurally, hemoglobin and myoglobin are similar in that both can be considered heme proteins because they are comprised of a porphyrin ring containing a central iron atom. However, hemoglobin has quaternary structure which allows it to cooperatively bind oxygen; whereas, myoglobin is a water soluble protein with tertiary structure comprised of 8 α-helices linked by nonhelical sections. Myoglobin is found in the muscle ante- and post-mortem and is the primary protein responsible for meat color as it comprises 80 to 90% of the total pigment (Hendrick et al., 1994).

The color of muscle is largely determined by the chemical state of myoglobin and the oxidation state of the iron atom (Cross et al., 1986). When iron is in the ferric (Fe^{3+}) form, it cannot bind molecules such as oxygen, but when the iron atom is in the ferrous (Fe^{2+}) state,- it can readily bind oxygen (when exposed to air). Myoglobin can naturally form three pigments: deoxymyoglobin, oxymyoglobin, and metmyoglobin (Kanner, 1994). An additional pigment, carboxymyoglobin, can also be formed by myoglobin in MAP.

Deoxymyoglobin is the reduced form of myoglobin with the iron in the Fe^{2+} state and no ligand is present at the 6^{th} coordinate (Mancini and Hunt, 2005). Deoxymyoglobin is characterized by a dark purplish-red color that is typically associated with vacuum packaged product and muscle color immediately after cutting. Oxygenation or “bloom” of myoglobin occurs when myoglobin is exposed to oxygen and is characterized by what is typically thought of as fresh beef color, bright cherry-red. After oxygenation, the 6^{th} coordinate is occupied by diatomic oxygen that interacts with the distal histidine (Mancini and Hunt, 2005). This reaction with oxygen is spontaneous and requires about 30 min for the full bright cherry-red color to develop. Increased oxygen exposure will allow the oxymyglobin to penetrate deeper beneath the meat's surface (McKeena et al., 2005). As McKeena et al. (2005) found, the oxygenation reaction and oxygen penetration depth (OPD) are highly affected by the oxygen consumption rate (OCR). Usually, lower OCR allows greater oxygen penetration of oxygen and increased color stability. However, oxygen penetration is also affected by the meat's temperature, oxygen partial pressure, pH and competition for O_2 by other respiratory processes (Mancini and Hunt, 2005). McKeena et al. (2005) concluded oxymyoglobin stability is determined by a combination of OCR and OPD.

The production of metmyoglobin is derived from oxymyoglobin, but it is an oxidation reaction that progresses slowly. The metmyoglobin reaction is characterized by the transformation of iron from the Fe^{2+} state to the Fe^{3+} state. When approximately 40 to 60% oxymyoglobin is oxidized to metmyoglobin, the muscle tissue will begin to exhibit brown discoloration characteristics (Lawrie, 1985). Metymyoglobin most readily forms under small quantities of O_2, such as the atmosphere found in low oxygen packaging systems. However, this low oxygen atmosphere can be altered with O_2 scavengers to prevent the formation of metmyoglobin.

The reduction of metmyoglobin is crucial to meat color life and consumer acceptance of fresh beef products. Reduction depends greatly on the muscle's oxygen scavenging ability, NADH pool, and reducing enzyme systems (Mancini and Hunt, 2005). The potential of the NADH pool and reducing enzyme systems is very low as both are depleted as postmortem time progresses. The oxidation reduction reaction has great potential to increase color stability, but has received little attention.

Carboxymyglobin is the chemical state of myoglobin when CO binds to the vacant 6^{th} coordinate of deoxymyoglobin. The binding of myoglobin to CO results in a very stable bright cherry-red color (Mancini and Hunt, 2005). There has been a lot of interest in carboxymyoglobin with recent use of CO in MAP, but today, many of its biochemical properties are still unknown.

Color measurement is the process of subjectively or objectively determining the color of fresh beef items. Subjective systems or visual color include the use of consumer panels or trained color panels to determine traits such as surface lean color, surface discoloration, and overall acceptability. On the other hand, objective systems employ the use of equipment such as computer vision and Hunter Lab to determine values such as L*, a*, and b*. Fresh beef color can be determined through any of the afore mentioned systems, with each system having its advantages.

Visual color preference has a strong association to consumer purchasing intent with consumers discriminating against beef that is not red (Carpenter et al., 2001). Visual color analysis allows for color to be determined under conditions that are very similar to retail case display conditions. As Carpenter et al. (2001) concluded, package type can influence red color perception, thus the effect of packaging on color perception can be determined through visual color analysis.

Visual color analysis gives researchers a method to quantify consumer's preferences toward a particular product.

Hunter Lab Colorimeter allows for the objective color determination through L*, a*, and b* values. L* values correlate to the luminance of a meat sample with a value of 0 being black and a measure of 100 correlating to white. The a* values correlated to redness with negative values indicating green and positive values indicating magenta (red). The b* values measure blue to yellow with negative b* values indicating blue and positive values indicating yellow. B* values are not typically related to meat, however, O'Sullivan et al. (2003) found b* values correlated more to brown as described by sensory panelists.

Computer vision is the most recent development in color analysis and has distinct advantages over traditional color measurement. As O'Sullivan et al. (2003) noted, several benefits are associated with digital camera obtained images such as 1) only a single observation is need for representative assessment of color, 2) digital images can be converted to numerous color measurement systems, and 3) digital images can account for surface variation in myoglobin. Computer vision is a promising method for the future of color prediction.

Meat color can be stabilized and maintained if proper care is taken by both the processor and retailer. Compounds such as CO can be used by the processor to help stabilize color, but it has received much negative scrutiny recently. Thus, care must be given to stabilizing the oxymyoglobin state of fresh beef products so they will maintain the bright cherry-red color consumers desire.

As Mancini and Hunt (2005) documented, oxygen consumption could help solve numerous practical meat color problems. However, Bekhit et al. (2003) pointed out that the amount of NADH may play a great role in beef color stability. Researchers must delve into these two areas if full color stability is to be achieved.

Oxidation

Oxidative degradation occurs when meat is exposed to high oxygen concentrations. The four pathways by which oxidation can occur are color oxidation, flavor oxidation, lipid oxidation, and microbial spoilage. Additionally, some protein oxidation may occur, which may decrease eating quality by reducing tenderness and juiciness, as well as further deteriorating flavors (Xiong, 2000). However, little is known about protein oxidation and how different atmospheres affect it. Beyond discoloration, oxidation can have very detrimental affects on consumer purchasing decisions.

Lipid oxidation is the oxidation of fatty acids that begins almost immediately post-mortem (Gray and Pearson, 1994). Lipid oxidation involves the combination of organic compounds with atmospheric oxygen that proceeds through reactions involving peroxy radicals (Gray, 1978; St. Angelo, 1996). Oxidation can also be stimulated by temperature and radiation (light). The process of lipid oxidation can be sped up by heat, metal ions, low pH, ultraviolet light, and sodium chloride (Hendrick et al.,1994). The products of lipid oxidation include aldehydes, acid, and ketones; all of which can contribute to off-flavors and odors (Hendrick et al., 1994; St. Angelo, 1996). However, the meat industry has developed several antioxidants, such as rosemary extract or the feeding of α-tocopherol, to combat post-mortem lipid oxidation. Additionally, oxidation can be slowed in retail stores if the products are held at cool (~40 °C), constant temperatures and if retail cases are properly maintained.

Oxidative spoilage can lead to the production of off-flavors, off-odors, and unwholesome food. High oxygen atmosphere will promote the growth of several aerobic organisms that are associated with spoilage, such as *Bacillus*, *Pseudomonas*, and yeasts. *Bacillus* and *Pseudomonas* can cause foods to change colors, while the formation of yeasts will be indicated by the formation of white colonies on the meat's surface. The foul odors and off-flavors associated with oxidation occur as a result of bacteria breaking down the proteins (Solomon, 2004). The increased growth of bacteria will lead to a meat product that, in the end, is unwholesome and has the potential to cause some form of food poisoning. Reduction of oxidative degradation cannot only improve meat color, but improve meat sensory properties as well. Active packaging materials with bacteriostatic properties may be used to reduce the growth of spoilage organisms (Brody, 2005). Additionally, further research must be committed to fully understand oxidative protein degradation and its effectors. Furthermore, processors and retailers must take more active roles in controlling environmental factors that can increase degradation.

CHAPTER III

METHODOLOGY

BENEFITS OF OXYGEN SCAVENGING TECHNOLOGY ON OVERWRAPPED BEEF CUTS IN A MODIFIED ATMOSPHERE PACKAGE

ABSTRACT

Lean color has been noted as one of the most important factors consumers consider when purchasing fresh beef products. Several large retail operations have converted from self-contained modified atmosphere packages (MAP) to traditional overwrapped steak packages contained in a MAP mother bag system prior to retail display. Thus, developing a method which aids processors and retailers in reducing the amount of residual oxygen inside a low-oxygen mother bag is necessary to increase retail case life and lean color stability of fresh beef cuts. The objectives of this study were to investigate the efficacy of various oxygen scavenging systems at reducing the residual oxygen levels inside the mother bag and inside individually overwrapped retail packages. To accomplish these objectives, 7 d aged U.S. Choice and Select bottom round flats (n = 188 and n = 84, respectively) were identified from the National Beef Company case-ready facility in Moultrie, GA. Bottom round flats (n = 84 U.S. Choice and Select) were enhanced to a 10% level, fabricated into roasts (6.35 cm thick), and overwrapped with polyvinylchloride film in a styrofoam tray. To

serve as negative controls, U.S. Choice non-enhanced roasts (n = 40) were packaged without the presence of any scavenger and segregated for headspace analysis at 0, 24, 48, and 72 h post packaging. The remaining enhanced and non-enhanced round roasts were randomly assigned to one of three oxygen scavenging treatments: 1) oxygen scavenger inside the mother bag (industry control) 2) activated (addition of 5mL distilled water per pad) oxygen scavenging soaker pad inside individual meat tray, or 3) non-activated oxygen scavenging soaker pad placed inside the individual meat tray package. Following overwrap packaging, individual roasts were separated by U.S. grade, enhancement treatment and scavenging treatment and were then randomly placed four to a mother bag. The mother bags were evacuated and flushed with a tri-gas (CO_2 35.0%, N_2 64.6%, CO 0.4%) system prior to sealing. Packages were transported to Oklahoma State University, where headspace analysis was collected at 8, 24, 48, 72, 168, and 336 h post-packaging. Following headspace composition determination, roasts were placed into a simulated retail case following 168 or 336 h of dark storage. Results indicated that mother bag and individual steak packages reached atmospheric equilibration at approximately 48 h post-packaging. Additionally, all scavenging systems were effective at reducing residual oxygen levels inside the mother bag or individual steak packages as dark storage time progressed. The industry control was more effective ($P < 0.05$) at reducing residual oxygen inside the mother bag of U.S. Choice enhanced and U.S. Select enhanced roasts as compared to the other two treatments. However, both oxygen scavenging soaker pad treatments were more effective (P

< 0.05) at improving color stability during retail display compared to the control system. All scavenging systems provide opportunities to reduce free oxygen levels and improve the color stability of fresh beef products in a case ready offering. However, the greatest benefit may come when the industry control and the oxygen scavenging soaker pads are used in combination with one another.

INTRODUCTION

Consumers use visual appearance as the main criterion for the evaluation of freshness, wholesomeness, and quality of fresh beef items. Visual appearance of fresh beef is mainly influenced by lean color (bright cherry-red) and lean surface discoloration. Both lean color and surface discoloration are largely impacted by oxygen levels in the package, and too high of oxygen levels can promote the formation of metmyoglobin. The formation of metmyoglobin causes surface discoloration (Hunt and Mancini, 2005), which will ultimately lead to a negative consumer perception.

Active packaging is a recent development that can be used in fresh beef packaging to reduce residual oxygen levels and microbial growth. Active packaging can include the use of polymer films, desiccants, iron-based oxygen scavengers, and soaker pads with active properties. Oxygen scavengers are used in case-ready packaging to reduce residual oxygen molecule levels, which at higher levels may attach to the myoglobin molecules in the meat and promote the formation of metmyoglobin.

Previous research has indicated that the use of iron-based oxygen scavengers inside retail packaging will reduce residual oxygen levels and help extend case-life. However, recent industry use has found that this system has not been as effective in a newly employed fresh beef case ready packaging system. Additionally, the cost of iron-based oxygen scavengers (~60 cents per package) and shrinking processor margins have left many processors searching for cheaper, more effective oxygen scavenging systems. Thus, this project was conducted to evaluate the efficacy of three different oxygen scavenging systems at reducing residual oxygen levels, stabilizing surface color, and preventing the occurrence of surface discoloration.

MATERIALS AND METHODS

Sample Collection

Bottom round flats from U.S. Choice and Select quality grades of the same aging period (7 d) were identified at the National Beef Company case-ready facility in Moultrie, GA. Approximately half (n = 84) of the U.S. Choice bottom rounds were enhanced (10% pump level) using a Metalquimia® (Auvistick-260, Girona, Spain) high-pressure, multi-needle injector with the current Wal-Mart beef formulation and under normal National Beef processing conditions. The remaining U.S. Choice rounds were not injected (n = 100). All (n = 84) of the U.S. Select bottom round flats were enhanced with the same solution and injected to a 10% pump level. All bottom rounds were cut by National Beef employees to Wal-Mart cutting specifications, a thickness of 6.35 to 7.62 cm.

After fabrication, 32 non-enhanced U.S. Choice roasts were randomly selected for packaging without the presence of any oxygen scavenger to serve as negative controls (See Appendix Figure 1). The remaining (n = 168) non-enhanced U.S. Choice bottom round roasts were randomly divided into 3 groups (n = 56 per group). Additionally, the enhanced U.S. Choice and Select roasts were divided 3 groups per grade (n = 56 per group). Each group was randomly selected to receive one of three packaging treatments: 1) packaged with a Multisorb 600cc iron-based oxygen scavenger (Multisorb Technologies, Buffalo, NY) inside the mother bag (CON), 2) an oxygen scavenging soaker pad (Paper Pak Industries, LaVerne, CA) in each individual roast package (NA), or 3) an activated (addition of 5mL of distilled water) oxygen scavenging soaker pad (Paper Pak Industries, LaVerne, CA) in each individual roast package (ACT).

Then, roasts were placed on a Styrofoam tray and overwrapped with an oxygen permeable film (1050 oxygen transmission rate, Pliant Corporation) using an Omori STN Stretch Wrapper (Omori Machinery Company, Osaka, Japan). All non-enhanced roasts were overwrap packaged first, separated by treatment, and placed four to a mother bag (CVP, Winpak, Winnipeg, MB). The U.S. Choice and Select enhanced roasts were then packaged (in order, respectively) and were also placed four to a mother bag. Each mother bag was immediately evacuated, flushed with a tri-gas (64.6% N, 35% CO_2, and 0.4% CO), and sealed using a CVP Fresh-Vac A-600 (Winpak, Winnipeg, MB). Following packaging, the mother bag packages were randomly divided into dark storage groups of 0, 8, 24, 48, 72, 168, 336, and 504 h. All packages for dark storage periods of 48, 72, 168, 336, and 504 h were transported back to the Robert M. Kerr Food and Ag Products Center, Stillwater, OK, via National Carriers.

Headspace Analysis

All mother bags and individual roast packages were analyzed for headspace composition using a PBI Dansensor (Ringsted, Denmark). Percent oxygen composition was determined at 0, 24, 48, and 72 h, for all negative control packages and at 8, 24, 48, and 72 h for all other treatments. For all treatments at dark storage periods of 168, 336, and 504 h, each mother bag was analyzed as well as two randomly select roast packages from each mother bag. Mother bag headspace composition was first determined and then a small opening (~7.5 cm) was made in the mother bag so individual roast package percent oxygen could be analyzed.

Color Analysis

Four individual roast packages were randomly selected from each treatment, U.S. grade combination and from each dark storage period of 168, 336, and 504 h, for subjective and objective color analysis. Following each dark storage period, the randomly selected packages were placed into a simulated retail case (average temperature 4 °C) under cool-white florescent light (150 foot candles) for four days. Packages were placed into the case in a random order and rotated once daily to account for any case temperature and light intensity variation. Subjective lean surface color, surface discoloration, and overall acceptability were evaluated by a three member trained color panel once daily. Surface color was evaluated on a scale of 1 to 7 (7 Very bright cherry-red and 1 Very dark red). Percent surface discoloration was evaluated on a scale of 1 to 7 (1 No discoloration and 7 Complete surface discoloration). Lastly, overall acceptability was evaluated on a scale of 1 to 6 (6 Very acceptable and 1 Very unacceptable). Instrumental, objective color analysis was conducted once daily on the cut surface of the roast using a Hunter Lab Colorimeter to determine L*, a*, and b* values (Hunter Miniscan XE Plus-45/0-L, Osaka, Japan).

Microbial Analysis

A standard total plate count (TPC) determination was obtained from Food ProTech in Stillwater, OK. Total plate counts were performed on two randomly selected samples of each treatment, U.S. grade combination following dark storage periods of 168, 336, and 504 h. Total plate counts were determined on two samples prior to retail display and two samples following 4 d of retail display. Briefly, samples were homogenized in a sterile stomacher bag containing 100 mL of sterile 0.1% peptone diluent and pummeled for 1 minute using a Stomacher-400. Total plate counts were determined by plating 1 mL (0.25 mL on each of four plates) of the sample homogenate, 0.1 mL of the homogenate and then 0.1 mL of the appropriate decimal dilutions of the same homogenate on pre-poured and dried tryptic soy agar plates. Samples were evenly spread over the surfaces of the plates with a sterile bent glass rod. Plates were incubated for 2 d at 25^{o}C before counting and reporting the TPC per cfu/g.

Statistical Analysis

The data were analyzed using the general linear model, mixed procedure, and repeated measures procedure of SAS (SAS Institute, Cary, NC). For mixed procedure the fixed variables were treatment and dark storage interval, while the random effect was panelist. The data were blocked by U.S. quality grade and enhancement treatment. The model included packaging treatment, dark storage time, day of retail display and their interactions as main effects.

RESULTS AND DISCUSSION

Effect of Packaging Treatment on Mother Bag Headspace Composition. Results summarizing the effects of various tested packaging treatments on mother bag headspace composition of varying quality grade and enhanced or non-enhanced roasts are overviewed. Least square means are provided for each quality grade and enhancement combination in tabular form. Additionally, an approximate oxygen equilibration curve using the negative control (no scavenger present) as treatment is presented (Appendix Figure 1). The figure displays the full equilibration of oxygen from the individual steak package into the mother bag. Just after packaging (within 1 h) the individual steak package oxygen percentages are much higher than the mother bag oxygen levels. Overall, the packaging system appears to be at equilibrium after dark storage periods of 48 h or greater.

U.S. Choice enhanced product, CON packages had lower ($P < 0.05$) oxygen percentages following an 8 h of dark storage period as compared to the

NA or ACT treatments where as CON and ACT packages had lower ($P < 0.05$) oxygen values after 24 h of dark storage as compared to the NA treatment mother bags. Additionally, CON packages possessed lower ($P < 0.05$) oxygen percentages than ACT packages after 168 h of dark storage. Furthermore, ACT and CON packages exhibited lower ($P < 0.05$) oxygen percentage means as compared to NA packages following 336 h of dark storage. Overall, percent oxygen decreased ($P<0.05$) over time for all treatment of Choice enhanced roasts. However, the CON packaging treatment provided the greatest benefit of reducing oxygen present over time as compared to the ACT or NA packaging treatments.

With U.S. Choice non-enhanced roasts, the only significant differences ($P < 0.05$) of oxygen percentage observed were with treatment means across all dark storage periods. These differences were high-lighted by CON packages having lower ($P < 0.05$) oxygen headspace means than NA packages. The same holds true for U.S. Select packages, with the exception that CON packages were significantly lower ($P < 0.05$) than ACT packages. Again, with both Choice non-enhanced and Select enhanced the CON packaging treatment proved to better reduce residual oxygen found inside the mother bag.

The CON packages were the most consistent at reducing oxygen inside the mother bag, however, other oxygen scavenging treatments were found to be effective at reducing oxygen at certain intervals with U.S. Choice enhanced roasts. One possible explanation for the CON's effectiveness was its location inside the mother bag versus the other oxygen scavenging treatments which were located inside the individual roast packages. It is important to note that oxygen percentage was only reduced to the recommended level of less than 0.05% at three intervals: U.S. Choice non-enhanced CON 504 h, and U.S. Select CON at 336 and 504 h. This, according to Belcher (2006), is the necessary level to retard metmyoglobin production.

Effect of Packaging Treatment on Individual Meat Package Headspace Composition. Results summarizing the effects of oxygen scavenging treatments on individual steak package oxygen percentage of differing quality grades and enhancement combination are overviewed in Tables 4-6. All oxygen scavenging treatments decreased ($P < 0.05$) oxygen present as dark storage time progressed. Again, there were a few exceptions in which an unexplainable oxygen spike occurred in the percent oxygen present. These spikes occurred following 336 h of dark storage for Choice enhanced NA packages and for ACT packages within the Choice non-enhanced group following 336 h of dark storage. Additionally, an oxygen spike occurred with U.S. Select roast ACT packages following 24 h of dark storage.

U.S. Choice enhanced steak packages; the CON oxygen scavengers provided the greatest benefit in terms of extended storage times. The CON and NA packages had lower ($P < 0.05$) oxygen values as compared to the ACT scavengers after 8 h of dark storage, while the CON and ACT packages produced significantly lower ($P < 0.05$) oxygen values after 24 h of dark storage. However, no differences were observed in oxygen percentage following 48 and 72 h of dark storage. After 168 h of dark storage, CON packages had lower (P <

0.05) oxygen percentages as compared to ACT packages and following 336 h of dark storage CON packages had lower ($P < 0.05$) oxygen values than NA packages. The CON roast packages showed the greatest decrease in percent oxygen present over extended storage times, thus suggesting that it may be the most suitable for packaging systems when extended (> 14 d) dark storage periods are necessary.

For non-enhanced U.S. Choice roasts, CON packages had lower ($P < 0.05$) oxygen levels following 8 h of dark storage compared to ACT and NA packages. Following 24 h of dark storage, CON and ACT packages displayed reduced ($P < 0.05$) oxygen percentages as compared to NA packages, while ACT and NA packages had reduced ($P < 0.05$) oxygen levels as compared to CON packages following 72 h of dark storage. The CON packages had lower ($P < 0.05$) oxygen levels as compared to NA packages following 168 h of dark storage. Additionally, CON packages had significantly ($P < 0.05$) lower oxygen levels when compared to ACT and NA packaging treatments following 336 h of dark storage. No differences ($P > 0.05$) were observed between treatment groups following 504 h of dark storage. Again, the CON treatment provided the greatest overall benefit when packaged with non-enhanced Choice roasts.

With U.S. Select roast packages, CON and NA packaging treatments had lower ($P < 0.05$) oxygen percentages than ACT packages following 24 h of dark storage. Additionally, CON packages exhibited significantly lower ($P < 0.05$) oxygen percentages than NA packages following 168 h of dark storage, as well NA and CON packages had lower oxygen levels as compared to ACT packages following 336 h of dark storage. However, no differences ($P > 0.05$) were observed following 8, 48, 72, or 504 h of dark storage. The scavengers are fairly even when used with enhanced Select roasts, but the CON treatment does provide more benefits of reducing residual oxygen at certain dark storage intervals.

All three scavenging systems provide benefits of reducing oxygen levels within individual steak packages. Again some treatments were significantly ($P < 0.05$) more effective than others following certain dark storage periods. Overall, the CON treatment provided the greatest benefit of reducing oxygen percentages inside individual roast packages. Additionally, CON treatment had the most consistent benefit over extended dark storage periods indicating its ability to continuously scavenge oxygen and work in packaging systems that require longer dark storage periods. It was theorized that the NA and ACT treatments would better reduce oxygen inside the individual roast package due to their location, but that was not the case. This suggests that the packaging system attempts to maintain a constant equilibrium. However, it should be noted that oxygen concentrations were only reduced to a level less than 0.05% in non-enhanced U.S. Choice CON packages following 504 h of dark storage and in U.S. Select CON packages following 336 and 504 h of dark storage, as well as in NA and ACT Select packages following 504 h of dark storage.

Effect of Packaging Treatment on Lean Color Characteristics. The effects of oxygen scavenging treatments on lean surface color, surface discoloration and overall acceptability were measured by a trained three member panel once daily for four days of retail display.

Muscle Surface Color. No differences ($P > 0.05$) were observed in lean surface color for U.S. Choice enhanced roasts, but the results are summarized in Figures 1 and 2. Lean color was very comparable among all treatments on the same retail display day and from the same dark storage period.

For U.S. Choice non-enhanced roasts results are summarized in Table 7, panelists ratings indicated CON packages had more acceptable ($P < 0.05$) lean surface color scores than either of the tested treatments (ACT or NA) across increasing dark storage times. Additionally, on retail display d 2, following 336 h of dark storage, CON and NA treatments had higher ($P < 0.05$) lean color scores than the ACT packages. CON packages also had higher ($P < 0.05$) lean color scores than NA or ACT treatments on retail display 2 d following 504 h of dark storage. Following d 3 of retail display of Choice non-enhanced roasts, CON packages possessed higher ($P < 0.05$) lean surface color ratings following 168 h of dark storage as compared to ACT packages. As well, CON and NA packages produced brighter colored surface lean following both 336 and 504 h of dark storage as compared to ACT packages. After 336 h of dark storage and 4 d of retail display, CON and NA packages had higher ($P < 0.05$) lean color scores compared to ACT packages. Following 504 h of dark storage CON packages had higher ($P < 0.05$) lean color scores when compared to ACT packages from the same dark storage period. The CON packaging system provided the greatest benefit of improving surface lean color of non-enhanced Choice roasts, thus indicating roasts that display a brighter more cherry-red lean surface color.

No differences (P > 0.05) were observed in U.S. Select roast surface color (Table 8), on retail display d 1, 2, and 4. However, following a dark storage period of 168 h, ACT and NA treatments on retail display d 3 had higher (P < 0.05) lean color ratings when compared to CON sample packages. Also, following an extended storage period (504 h) and 3 d of retail display CON and NA packages lean color scores were higher (P < 0.05) than ACT packages.

With U.S. Choice enhanced and U.S. Select product, no oxygen scavenging treatment appeared to more effective than another. Although, in terms of non-enhanced U.S. Choice roasts the CON and NA treatments appear to provide the greatest benefit to improve lean surface color and display the bright cherry-red color desired by consumers.

Surface Disocloration Trained panelists were asked to determine the amount of surface discoloration present on the roast at each retail display color rating interval. The amount of surface discoloration present correlates with the production of metmyoglobin on the roast's surface and values higher than 3 indicated an unacceptable score.

Packaging treatment did have an effect on U.S. Choice enhanced roast surface discoloration as presented in Table 9. Following 168 h of dark storage and on retail display d 1, NA packages had less (P < 0.05) surface discoloration than either the ACT or CON packaging treatments. Additionally, following 336 h of dark storage and 2 d of retail display, ACT and NA packaging treatments displayed significantly ($P < 0.05$) less surface discoloration than CON packages. Yet, all packages were unacceptable for surface discoloration scores. However, no differences ($P > 0.05$) were observed on retail display d 2 among treatment groups following 168 h of dark storage. Following d 3 of retail display treatment means differed ($P > 0.05$) with NA packages having lower surface discoloration scores than CON or ACT packaging treatments. Additionally, on d 4 of retail display ACT and NA treatment means were lower ($P < 0.05$) than CON means, thus indicating ACT and NA packages had less surface discoloration. Roasts from the 168 h dark storage period displayed the least surface discoloration, thus indicating the surface discoloration may increase with increased dark storage time. Within the 168 h dark storage period the NA treatment consistently displayed the least surface discoloration which indicated that less surface metmyoglobin is produced as compared to CON or ACT packages.

In addition, oxygen management packaging treatment did effect ($P < 0.05$) surface discoloration in relation to U.S. Choice non-enhanced bottom round roasts (Table 10). On the initial retail display day, a significant ($P < 0.05$) treatment interaction was observed for all dark storage periods with CON packages having less surface discoloration than ACT packages. On d 2 of retail display, NA packages had significantly less surface discoloration than CON or ACT packages following 336 h of dark storage, as well for d 2 of retail display CON and NA packages displayed less surface discoloration in comparison to ACT packages following 504 h of dark storage. However, on the second retail display day, no differences ($P > 0.05$) were noted between treatments from 168 h dark storage period. Furthermore, on d 3 of retail display NA packages had significantly less surface discoloration than ACT packages following 168 h of dark storage. Also, CON and NA packaging treatments displayed significantly less ($P < 0.05$) surface discoloration than the ACT packaging treatment following both 336 and 504 h of dark storage. On the last day of retail display (d 4), a significant ($P < 0.05$) treatment interaction was observed across all dark storage times with CON and NA packaging treatments having less detectable surface discoloration compared to the ACT packaging treatment. Again, it should be noted that all treatments were unacceptable in terms of surface discoloration on d 4. With non-enhanced Choice roasts the NA and CON packaging treatments displayed the least surface discoloration over retail display time, thus indicating that these packaging systems improve color stability more than the ACT packaging system.

The results for surface discoloration of U.S. Select roasts are overviewed in Table 11. On retail display d 1 for U.S. Select bottom round roasts, CON and ACT treatments displayed less ($P < 0.05$) surface discoloration than NA packages following a 168 h dark storage period. Additionally, after 336 h of dark storage, on the initial retail display day CON packages had less ($P < 0.05$) surface discoloration than ACT packages. Yet, no differences ($P > 0.05$) were observed for initial surface discoloration for samples in dark storage for 504 h. On d 2 of retail display, for those packages held in dark storage period for 168 h, ACT packages possessed less ($P < 0.05$) surface discoloration than NA packages. Additionally, for 504 h of dark storage, CON and NA packaging treatments displayed decreased ($P < 0.05$) surface discoloration as compared to ACT packages. However, on retail display d 2, no differences ($P > 0.05$) were observed between treatments from 336 h dark storage period. On d 3 of retail display, no difference ($P > 0.05$) was observed for packages from the 168 h dark storage period, but for packages from 336 h dark storage period the CON treatment significantly ($P < 0.05$) reduced surface discoloration as compared to NA packages. Additionally, following the 504 h dark storage interval, CON and NA packages significantly ($P < 0.05$) reduced surface discoloration as compared to the ACT treatment. Lastly, on d 4 of retail display no differences ($P > 0.05$) were observed for packages from the dark storage intervals of 168 and 336 h, but for the 504 h dark storage period, CON and NA treatments reduced ($P < 0.05$) surface discoloration as compared to the ACT treatment. It should be noted that packages from the NA and CON treatments of 504 h dark storage interval consistently produced the lowest surface discoloration values and that roasts had ratings in the acceptable range for up to 4 d. Overall the NA and CON packaging treatments most consistently reduced surface discoloration which would indicate a more shelf stable lean color.

ACT and NA treatments provided the greatest benefit of reducing surface discoloration when incorporated with U.S. Choice enhanced roasts. However, the CON and NA treatments provided the greatest benefit when used in conjunction with non-enhanced U.S. Choice roasts and U.S. Select roasts. Across the board benefit, the NA scavenger treatment had the greatest impact over all quality grade and enhancement combinations. However, discoloration can become unacceptable for all treatments on retail display d 2 for U.S. Select roasts.

Overall Acceptability Trained panelist were asked to use the roasts' lean surface color and discoloration scores to determine an overall color acceptability on each day of retail display. In general, a lower overall acceptability score correlates to a lower lean color score and an increased discoloration score. A score of 4 or below was considered unacceptable.

For U.S. Choice enhanced roasts, a significant ($P < 0.05$) effect was observed on all 4 d of retail display (Table 12). On d 1 of retail display, packages from the NA treatment after 168 h of dark storage period had the highest ($P < 0.05$) overall acceptability scores as compared to all other treatment and dark storage combinations. However, for all samples stored for 336 h, the ACT treatment performed significantly ($P < 0.05$) better and more consistent than the CON samples. Again on retail display d 2, packages from the NA treatment after 168 h of dark storage outperformed ($P < 0.05$) all other treatment and dark storage combinations with the exception of ACT packages from the 336 h dark storage group. On d 3 of retail display, a significant ($P < 0.05$) treatment effect was observed across all dark storage periods with the NA treatment having higher overall acceptability scores as compared to the ACT or CON treatments. On retail display d 4, NA packages from 168 h dark storage period had higher ($P < 0.05$) overall acceptability scores than CON packages from the same dark storage time. Following 4 d of retail display, no other significant interactions were observed. With Choice enhanced roasts the NA packaging treatment consistently has the highest overall acceptability scores which would indicate roasts that are more likely to be purchased.

With U.S. Choice non-enhanced roasts, a significant ($P < 0.05$) treatment and dark storage interaction was observed over all dark storage times for all 4 days of retail display (Table 13). On d 1 of retail display, CON samples possessed significantly ($P < 0.05$) higher acceptability scores than either the NA or ACT treatments. Additionally, on retail display d 2, 3 and 4 CON and NA treatments had higher ($P < 0.05$) overall acceptability scores when compared to the ACT treatment. Simply put, with non-enhanced U.S. Choice roasts both the NA and CON provided significantly greater benefit in terms of overall acceptability than the ACT treatment. These results can be related to consumers purchasing because consumers would more likely purchase roasts from the NA and CON packaging treatments.

A significant ($P < 0.05$) treatment and dark storage period interaction (Table 14) was observed on all days of retail display for Select roasts with the exception of d 4. On d 1 of retail display no significant ($P > 0.05$) treatment interaction was found for roasts from the 168 h dark storage period, but following 336 h and 504 h of dark storage the NA treatment had higher ($P < 0.05$) overall acceptability scores as compared to the ACT treatment. Additionally, on retail display d 2 for cuts stored for a 168 h period, the ACT treatment samples yielded higher ($P < 0.05$) overall acceptability scores than NA treatment samples. No significant ($P > 0.05$) interaction was found to have occurred for roasts from the 336 h dark storage period, but for roasts from the 504 h dark storage period on d

2 and 3 of retail display, the NA and CON treatments yielded higher (P < 0.05) overall acceptability scores when compared to the ACT treatment. Higher overall acceptability scores are considered to be more desirable and a roast that is more likely to be purchased as compared to a roast with a lower score.

Overall, each treatment appeared to have an advantage over another at some point. One treatment may improve lean surface color while another treatment has the ability to decrease surface discoloration. These factors can account for the differences in overall acceptability scores. A possible next step is testing treatments in combination with another to determine if they could work cooperatively to further improve lean color, reduce surface discoloration, and increase overall acceptability scores.

Effect of Packaging Treatment on Objective Color Scores. Roasts were objectively color scored once daily using a Hunter Lab Colorimeter to determine L*, a*, and b* values. The results are overviewed in the following section, but are not shown in tabular form.

For enhanced U.S. Choice roasts differences for L* values were only observed for cuts on retail display following 168 h of dark storage. Thus, following 168 h of dark storage CON roasts' L* values were significantly (P < 0.05) higher than both the NA and ACT roasts' L* values indicating CON roasts had significantly brighter color. However, following 336 h of dark storage, NA and ACT packaged roasts had higher (P < 0.05) b* values compared to CON treatment samples. Additionally, the only differences observed for L* values of non-enhanced U.S. Choice roasts were for the retail display time following 168 h of dark storage. ACT packaged roasts were found to have higher ($P < 0.05$) L * values than the CON treatment group, thus indicating roasts with a brighter color. The a* values for non-enhanced choice roasts were also significantly effected by packaging treatment following 336 h of dark storage for samples from the CON and NA treatment groups which had higher ($P < 0.05$) values as compared to ACT roasts, thus indicating a redder surface color. U.S. Choice non-enhanced b* values were also significantly ($P < 0.05$) effected by packaging treatment following 168 h of dark storage with the ACT and CON treatments having higher values than the NA treatment. Furthermore, b* values for non-enhanced U.S. Choice roasts were also significant ($P < 0.05$) following 336 h of dark storage, with the CON treatment having higher b* values than the NA or ACT treatments. For U.S. Select roasts, treatment was found to have a significant ($P < 0.05$) effect on L* values following 168 h and 504 h of dark storage. Following 168 h of dark storage the NA treatment had significantly ($P < 0.05$) higher L* values than both the CON and ACT treatments which indicates roasts from the NA packaging treatment had a brighter surface color. Additionally, following 504 h of dark storage higher ($P < 0.05$) L* values were observed for the ACT treatment as compared to the CON treatment, thus indicating the CON packaging treatment produced darker surface colored roasts. Given the results from all three roast types, there cannot be a determination made for which treatment most significantly improves objective color characteristics.

Effect of Packaging Treatment on TPC. Overall, few differences were observed to quantify an effect of scavenging treatment on TPC cfu/g. For enhanced U.S. Choice and U.S. Select roasts packaging treatment did not significantly ($P > 0.05$) lower or raise TPC. However, treatment did significantly ($P < 0.05$) effect TPC of non-enhanced U.S. Choice roasts prior to retail display (not in tabular form), however, no ($P > 0.05$) treatment differences were observed following 4 d of retail display. Prior to retail display NA treatment TPC's were higher ($P < 0.05$) than both the ACT and CON treatments following 168 and 336 h of dark storage. Additionally, following 504 h of dark storage ACT packages had lower ($P < 0.05$) TPC's than NA treatment packages. The NA packages may create a more aerobic environment which allows for greater microorganism growth. Additionally, a portion of the microorganism growth indicated by the TPC's may signify a greater amount of spoilage organisms. One possible explanation for the differences in results is the fact that the enhanced U.S. Choice and Select cut were treated with an antimicrobial peroxyacetic acid prior to enhancement, whereas the non-enhanced cuts were never treated with an antimicrobial.

Conclusions

The CON packaging system provided the greatest of reducing residual oxygen levels. However, it should be noted that all systems were unable to reduce the residual oxygen levels below 0.05% in a timely manner (less than 48 h), thus indicating a need for a multi-scavenger system. This also indicates that the scavengers are overwhelmed by the amount of oxygen present in the mother bag system. Another solution to improving color stability and shelf-life may be to individually gas flush each overwrapped package to remove some of the residual oxygen present. The scavenging systems have different benefits of improving lean color characteristics such as improvement of lean color score, decrease of surface discoloration, and improvement of overall acceptability. Additionally, a combination of these scavenger systems may further improve lean color characteristic and objective color scores. For microbial reduction the most effective, from a cost and time standpoint, may be to treat all non-enhanced cuts with peroxyacetic acid prior to packaging. Further consideration should be given to research to investigate the benefits of a multi-scavenger system on overwrapped beef cuts in a MAP environment, as well as the use of poly trays versus Styrofoam trays. Finally, as McKeena et al. (2005) found further consideration should be given to biochemical processes such as OCR and OPD.

It should also be noted that some additional problems were encountered throughout the study such as a low quality mother bag which led to several "leaker" packages. This was the case with enhanced U.S. Choice roasts, thus no observations were made for this group following 504 h of dark storage. Also, problems were encountered with the overwrap packages unwrapping in the case after 2 or more days of retail display. It is speculated that this was caused by excess purge wicking down the overwrap film to the bottom side of the tray, thus causing the tray to stick to the retail case. Additionally, roasts packaged with the NA and ACT treatments produced purge that was coagulated and green in color.

This could cause numerous possible issues in terms of consumer acceptance. These are all issues that must be addressed in order for retailers to run a successful overwrap packaged case-ready beef program.

Table 1. Mother bag oxygen percentage as influenced by scavenger type of enhanced U.S. Choice bottom round roasts

	Dark Storage, h					
Treatment[1]	8	24	48	72	168	336
ACT	3.80^{ab}	2.88^{de}	2.84^{de}	2.68^{de}	2.59^{def}	1.47^{gh}
NA	3.40^{bc}	4.25^{a}	2.76^{de}	2.52^{ef}	1.93^{fg}	2.64^{def}
CON	2.90^{de}	3.00^{cd}	2.73^{de}	2.72^{de}	1.36^{gh}	1.05^{h}

[1]ACT = activated; NA = not activated; CON = control

[a,b,c,d,e,f,g,h] Means lacking a common superscript differ ($P < 0.05$)

Table 2. Mother bag oxygen percentage of U.S. Choice non-enhanced bottom round roasts over all dark storage periods

Treatment[1]	Mean Oxygen %
ACT	2.19^{ab}
NA	2.54^{a}
CON	1.84^{b}

[1]ACT = activated; NA = not activated; CON = control
[a,b] Means lacking a common superscript differ ($P < 0.05$)

Table 3. Mother bag oxygen percentage of U.S. Select enhanced bottom round roasts over all dark storage periods

Treatment[1]	Mean Oxygen %
ACT	2.28[a]
NA	1.95[ab]
CON	1.70[b]

[1]ACT = activated; NA = not activated; CON = control
[a,b] Means lacking a common superscript differ ($P < 0.05$)

Table 4. Steak tray oxygen percentage as influenced by scavenger type of enhanced U.S. Choice bottom round roasts

	Dark Storage, h					
Treatment[1]	8	24	48	72	168	336
ACT	5.05^{a}	3.05^{def}	2.91^{defg}	2.71^{fgh}	2.63^{fgh}	1.78^{hi}
NA	3.78^{bc}	4.25^{b}	2.81^{efgh}	2.57^{fgh}	1.94^{ghi}	2.83^{defgh}
CON	3.44^{cde}	3.45^{cd}	2.85^{defg}	2.78^{fgh}	1.39^{i}	1.17^{i}

[1]ACT = activated; NA = not activated; CON = control
[a,b,c,d,e,f,g,h,i] Means lacking a common superscript differ ($P < 0.05$)

Table 5. Steak tray oxygen percentage as influenced by scavenger type of non-enhanced U.S. Choice bottom round roasts

	Dark Storage, h						
Treatment[1]	8	24	48	72	168	336	504
ACT	4.30[a]	2.56[de]	2.86[de]	2.05[f]	1.75[fg]	2.77[de]	0.21[h]
NA	4.82[a]	3.80[b]	2.81[de]	2.55[de]	2.33[ef]	1.92[fg]	0.38[h]
CON	3.45[bc]	2.99[cd]	3.45[bc]	2.71[de]	1.28[g]	0.30[h]	0.0[h]

[1]ACT = activated; NA = not activated; CON = control
[a,b,c,d,e,f,g,h] Means lacking a common superscript differ ($P < 0.05$)

Table 6. Steak tray oxygen percentage as influenced by scavenger type of enhanced U.S. Select bottom round roasts

	Dark Storage, h						
Treatment	8	24	48	72	168	336	504
ACT	3.42^{bcd}	4.83^{a}	2.80^{defg}	2.99^{cdefg}	2.15^{ghi}	1.94^{hi}	0.00^{j}
NA	3.55^{bc}	2.92^{cdefg}	2.78^{defgh}	2.38^{fgh}	2.24^{gh}	0.73^{j}	0.00^{j}
CON	3.75^{b}	3.13^{bcd}	2.99^{cdef}	2.39^{efgh}	0.95^{ij}	0.00^{j}	0.00^{j}

[1]ACT = activated; NA = not activated; CON = control
[a,b,c,d,e,f,g,h,I,j] Means lacking a common superscript differ (P < 0.05)

Table 7. U.S. Choice non-enhanced subjective lean color scores[1] as influenced by packaging treatment and dark storage period.

	Retail Display, d			
Treatment[2], h of dark storage	1	2	3	4
ACT, 168	6.08	5.00^{abc}	4.33^{b}	3.25^{bcde}
ACT, 336	4.79	2.00^{d}	2.23^{d}	2.25^{de}
ACT, 504	4.36	3.88^{c}	3.14^{c}	2.25^{e}
NA, 168	5.67	5.13^{ab}	4.75^{ab}	3.75^{bc}
NA, 336	5.54	4.00^{bc}	5.60^{a}	6.00^{a}
NA, 504	4.23	4.50^{bc}	4.02^{b}	2.88^{cde}
CON,168	6.33	5.50^{a}	5.22^{a}	4.67^{ab}
CON, 336	6.70	5.00^{abc}	4.77^{ab}	4.67^{ab}
CON, 504	5.73	5.25^{a}	4.64^{ab}	3.38^{bcd}

[1] Lean Color: 7=very bright red; 3=slightly dark red; 1=very dark red
[2]ACT = activated; NA = not activated; CON = control
[a,b,c,d,e] Means lacking a common superscript differ ($P < 0.05$) among retail display day
General note: shaded area corresponds to unacceptable lean color
Treatment means differed on day 1; CON 6.26^{a}, NA 5.14^{b}, ACT 5.08^{b}

Table 8. U.S. Select subjective lean color scores[1] as influenced by packaging treatment and dark storage period.

	Retail Display, d			
Treatment[2], h of dark storage	1	2	3	4
ACT, 168	6.00	5.50	5.17[a]	3.50
ACT, 336	4.80	4.00	3.17[d]	2.75
ACT, 504	5.60	4.75	3.31[a]	2.38
NA, 168	5.67	5.25	4.75[ab]	3.00
NA, 336	5.30	2.75	3.05[d]	2.50
NA, 504	5.48	5.83	4.23[bc]	2.88
CON,168	5.17	4.75	3.83[cd]	3.50
CON, 336	5.55	3.75	3.80[cd]	2.75
CON, 504	6.10	5.50	4.81[ab]	3.25

[1] Lean Color: 7=very bright red; 3=slightly dark red; 1=very dark red
[2]ACT = activated; NA = not activated; CON = control
[a,b,c,d] Means lacking a common superscript differ ($P < 0.05$) among retail display day
General note: shaded area corresponds to unacceptable lean color

Table 9. U.S. Choice enhanced subjective lean discoloration scores[1] as influenced by packaging treatment and dark storage period.

	Retail Display, d			
Treatment[2], h of dark storage	1	2	3	4
ACT, 168	2.00[ab]	2.75[b]	2.50	3.25
ACT, 336	2.00[ab]	3.00[b]	3.88	4.00
NA, 168	1.00[c]	1.25[b]	1.50	2.50
NA, 336	2.25[ab]	3.00[b]	3.00	4.00
CON,168	1.83[b]	2.62[b]	2.65	5.25
CON, 336	2.50[a]	4.75[a]	3.75	4.75

[1] Discoloration: 1=no discoloration; 3=21-40% discoloration; 7=100% discoloration

[2]ACT = activated; NA = not activated; CON = control

[a,b,c] Means lacking a common superscript differ ($P < 0.05$) among retail display day

General note: shaded area corresponds to unacceptable surface discoloration

Treatment means differed on day 3; CON 3.20[a]; ACT 3.18[a]; NA 2.25[b]

Treatment means differed on day 4; CON 5.00[a]; ACT 3.63[b]; NA 3.25[b]

Table 10. U.S. Choice non-enhanced subjective lean discoloration scores[1] as influenced by packaging treatment and dark storage period.

	Retail Display, d			
Treatment[2], h of dark storage	1	2	3	4
ACT, 168	1.92	2.88[bcd]	3.00[b]	4.50
ACT, 336	2.00	3.75[ab]	4.88[a]	6.25
ACT, 504	2.38	4.00[a]	4.14[a]	5.50
NA, 168	1.75	2.63[cd]	2.00[c]	4.00
NA, 336	1.00	2.00[d]	2.13[bc]	2.00
NA, 504	2.13	2.63[cd]	2.64[ba]	3.75
CON,168	1.44	2.83[bcd]	2.78[bc]	3.67
CON, 336	1.33	3.65[abc]	2.79[bc]	3.00
CON, 504	1.13	2.13[d]	2.64[bc]	4.25

[1] Discoloration: 1=no discoloration; 3=21-40% discoloration; 7=100% discoloration

[2]ACT = activated; NA = not activated; CON = control

[a,b,c,d] Means lacking a common superscript differ ($P < 0.05$) among retail display day

General note: shaded area corresponds to unacceptable surface discoloration

Treatment means differed on day 1; ACT 2.09[a], NA 1.63[ab], CON 1.30[b]

Treatment means differed on day 4; ACT 5.42[a], CON 3.64[b], NA 3.25[b]

Table 11. U.S. Select subjective lean discoloration scores[1] as influenced by packaging treatment and dark storage period.

	Retail Display, d			
Treatment[2], h of dark storage	1	2	3	4
ACT, 168	1.67^{bc}	2.50^{b}	2.67^{cde}	4.50^{abc}
ACT, 336	2.25^{ab}	3.00^{ab}	3.70^{abc}	5.75^{a}
ACT, 504	1.37^{cd}	3.00^{ab}	3.98^{ab}	5.63^{a}
NA, 168	2.75^{a}	3.75^{a}	3.08^{bc}	5.00^{ab}
NA, 336	2.00^{bc}	2.75^{ab}	4.45^{a}	6.25^{a}
NA, 504	0.99^{d}	1.38^{c}	1.89^{de}	2.88^{bc}
CON,168	1.83^{bc}	2.75^{ab}	3.33^{abc}	5.00^{ab}
CON, 336	1.25^{cd}	3.75^{a}	2.95^{bcd}	5.25^{a}
CON, 504	0.99^{d}	1.38^{c}	1.74^{e}	2.50^{c}

[1] Discoloration: 1=no discoloration; 3=21-40% discoloration; 7=100% discoloration

[2]ACT = activated; NA = not activated; CON = control

[a,b,c,d,e] Means lacking a common superscript differ ($P < 0.05$) among retail display day

General note: shaded area corresponds to unacceptable surface discoloration

Table12. U.S. Choice enhanced subjective overall acceptability scores[1] as influenced by packaging treatment and dark storage period.

	Retail Display, d			
Treatment[2], h of dark storage	1	2	3	4
ACT, 168	4.92[b]	4.00[b]	4.00	3.50[a]
ACT, 336	4.90[b]	4.25[ab]	3.23	2.75[ab]
NA, 168	6.00[a]	5.50[a]	5.00	4.00[a]
NA, 336	4.40[bc]	4.00[b]	3.48	2.50[ab]
CON,168	4.65[bc]	4.13[b]	3.70	2.00[b]
CON, 336	4.15[c]	3.75[b]	2.86	2.75[ab]

[1] Acceptability: 6=very acceptable; 3=slightly undersireable; 1=undersireable
[2]ACT = activated; NA = not activated; CON = control
[a,b,c] Means lacking a common superscript differ ($P < 0.05$) among retail display day
General note: shaded area corresponds to unacceptable overall acceptability
Treatment means differed on day 3; NA 4.24[a], ACT 3.62[b], CON 3.28[b]

Table 13. U.S. Choice non-enhanced subjective overall acceptability[1] as influenced by packaging treatment.

	Retail Display, d			
Treatment[2]	1	2	3	4
ACT	4.46[b]	3.50[b]	2.70[b]	1.61[b]
NA	4.72[b]	4.33[a]	4.15[a]	3.37[a]
CON	5.54[a]	4.51[a]	3.99[a]	3.13[a]

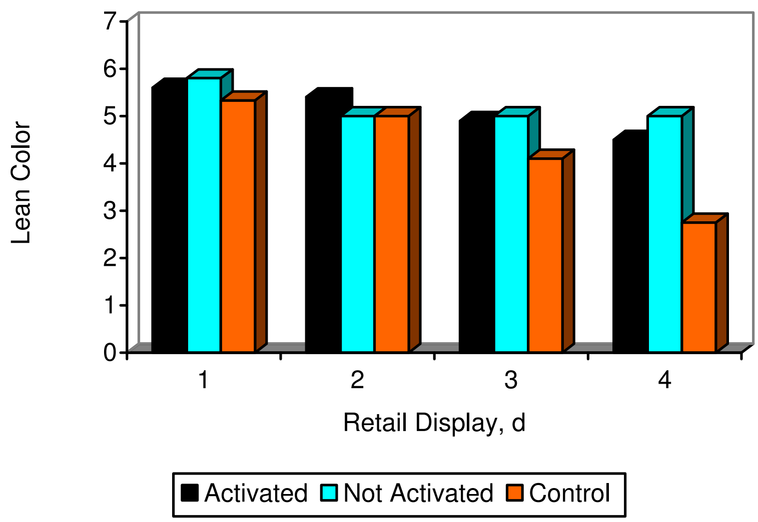
[1] Acceptability: 6=very acceptable; 3=slightly undersireable; 1=undersireable
[2]ACT = activated; NA = not activated; CON = control
[a,b] Means lacking a common superscript differ (P < 0.05) among retail display day
General note: shaded area corresponds to unacceptable overall acceptability

Table 14. U.S. Select subjective overall acceptability scores[1] as influenced by packaging treatment and dark storage period.

	Retail Display, d			
Treatment[2], h of dark storage	1	2	3	4
ACT, 168	5.00[abc]	4.00[b]	4.00[abc]	1.50
ACT, 336	4.75[c]	4.25[ab]	2.93[de]	1.50
ACT, 504	5.00[bc]	3.38[bc]	2.31[e]	1.75
NA, 168	4.42[c]	3.00[c]	3.33[bcd]	1.75
NA, 336	5.50[ab]	3.75[bc]	2.93[de]	1.00
NA, 504	5.63[a]	5.25[a]	4.20[ab]	3.38
CON,168	4.83[c]	3.75[bc]	3.00[cde]	1.50
CON, 336	5.00[abc]	3.50[bc]	3.34[bcd]	1.75
CON, 504	5.50[ab]	5.13[a]	4.81[a]	3.50

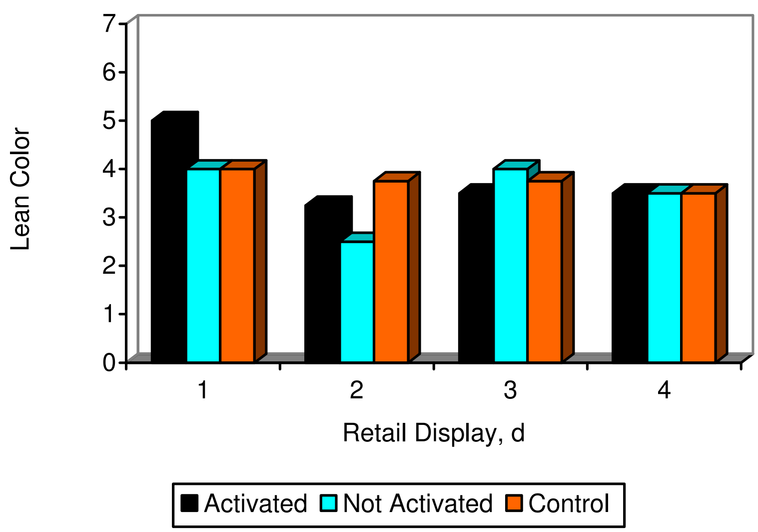
[1] Acceptability: 6=very acceptable; 3=slightly undersireable; 1=undersireable
[2]ACT = activated; NA = not activated; CON = control
[a,b,c,d,e] Means lacking a common superscript differ ($P < 0.05$) among retail display day
NS= not significant interaction
General note: shaded area corresponds to unacceptable surface discoloration

Figure 1. Lean color scores of enhanced choice bottom round roast stratified by day of display following 168 h of storage



No differences observed among treatments (P > 0.05)

Figure 2. Lean color scores of enhanced choice bottom round roast stratified by day of display following 336 h of storage



No differences observed among treatments (P > 0.05)

Literature Cited

AMI. 2007. Case-ready meats modified atmosphere packaging. American Meat Institute Fact Sheet, Washington, DC.

Barry, C. 2002. Case closed. Case-ready meat is here to stay. Accessed from: www.findarticles/p/articles/mi_m0UQX/is_7_66/ai_90163749.

Bekhit, A.E.D., G.H. Geesink, M.A. Ilian, J.D. Morton, and R. Bickerstaffe. 2003. The effects of natural antioxidants on oxidative processes and metmyoglobin reducing activity in beef patties. Food Chemistry 81(2):175-187.

Belcher, J.N. 2006. Industrial packaging developments for the global meat market. Meat Sci. 74(1):143-148.

Brody, A. 2005. Active packaging becomes more active. Food Technology 12.05: 82-84.

Carpenter, C.E., D.P. Cornforth, and D. Whittier. 2001. Consumer preferences for beef color and packaging did not affect eating satisfaction. Meat Sci. 57(4):359-363.

Cornforth, D., and M. Hunt. 2008. Low-oxygen packaging of fresh meat with carbon monoxide. AMSA White Paper Series (2).

Cross, H.R., P.R. Durland, and S.C. Seideman. 1986. Sensory qualities of Meat. p.279-320, Muscle as Food. P.J. Bechtel ed. Academic Press, Inc., Orlando, FL.

Faustman, C., and R.G. Cassens. 1990. Influence of aerobic metmyoglobin reducing capacity on color stability of beef. J. Food Sci. 55(5):1278-1279.

Glitsch, K. 2000. Consumer perceptions of fresh meat quality: a cross-national comparison. British Food J. 102(3):177-194.

Gray, J.I. 1978. Measurement of lipid oxidation: a review. F. Am. Oil Chem. Soc. 55:539-546.

Gray, J.I., and A.M. Pearson. 1994. Lipid-derived off-flavors in meat: formation and inhibition. p. 117-139, Flavor of Meat and Meat Products. 1st ed. Chapman and Hale, London, UK.

Gregerson, J. 2007. Case Studied. Meatingplace 12.07:50-52.

Hendrick, H.B., E.D. Aberl, J.C. Forrest, M.D. Judge, R.A. Merkel. 1994. Principles of Meat Science. 3rd ed. Kendal/Hunt Publishing Company, Dubuque, IA.

Hunt, M.C., R.A. Mancini, K.A. Hachmeister, D.H. Kropf, M. Merriman, and G. Deluca. 2004. Carbon monoxide in modified atmosphere packaging affects color, shelf life, and microorganisms of beef steaks and ground beef. J. Food Sci. 69:45-52.

Hunt, M.C., J.C. Acton, R.C. Benedict, C.R. Calkins, D.P. Cornforth, L.E. Jeremiah, D.G. Olson, C.P. Salm, J.W. Savell, and S.D. Shivas. 1991. Guidelines for meat color evaluation. American Meat Science Association, Savoy, IL.

Jakobsen, M. and G. Bertelsen. 2000. Colour stability and lipid oxidation of fresh beef. Meat Sci. 54(1):49-57.

Jayasingh, P., D.P. Cornforth, C.P. Brennand, C.E. Carpenter, and D.R. Whittier. 2002. Sensory evaluation of ground beef stored in high-oxygen modified atmosphere packaging. J. Food Sci. 67(9):3493-3496.

John, L., D.P. Cornforth, C.E. Carpenter, O. Sorheim, B.C. Pettee, and D.R. Whittier. 2004. Comparison of color and thiobarbuturic acid values of cooked hamburger patties after storage of fresh beef chubs in modified atmospheres. J. of Food Sci. 69(8):608-614.

Kanner, J. 1994. Oxidative processes in meat and meat products: quality Implications. Meat Sci. 36:169-189.

Kropf, D.H. 2004. Packaging/modified and controlled atmospheres, *Encyclopedia of Meat Sciences,* W. Jensen, C. Devine, and M. Dikeman (Ed.), p.962-969, Elsevier, Oxford, UK.

Kropf, D.H. 1980. Effects of retail display conditions on meat color. Proc. Reciprocal Meat Conference, 33:15-32.

Lawrie, R.A. 1985. Meat Science 4th ed. Pergamon Press, Oxford, England.

Lund, M.N., M.S. Hviid, and L.H. Skibsted. 2007. The combined effect of Antioxidants and modified atmosphere packaging on protein and lipid oxidation in beef patties during chill storage. Meat Sci. 76:226-233.

Makely, W. 2003. Packaging beefs up case-ready meat. Accessed from: www.findarticles.com/p/articles/mi_m0UQX/is_2_67/ai_98643121.

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

Mancini, R.A., M.C. Hunt, K.A. Hachmeister, D.H. Kropf, and D.E. Johnson. 2005. Exclusion of oxygen from modified atmosphere packages limits beef rib and lumbar vertebrae marrow discoloration during display and storage. Meat Sci. 69(3):339-345.

McKeena, D.R., P.D. Miles, B.E. Baird, K.D. Pfeiffer, J.W. Ellebracht, and J.W. Savell. 2005. Biochemical and physical factors affecting discoloration Characteristics of 19 bovine muscles. Meat Sci. 70:665-682.

Merrett, N. 2007. Active packaging devised for a clean label alternative. Meat Process. Accessed from:www.meatprocess.com.

Merriman, M.C., G.R. Deluca, V.K. Luthra, and S.L. Goulette. 2003. Modified atmosphere packages and methods for making the same. United States Patent Application number US 2003/0207000A1.

Nissen, H., O. Alvseike, S. Bredholt, A. Hoick, and T. Nesbakken. 2000. Comparison between the growth of *Yersinia enterocolitia, Listeria monocytogenes, Escherichia coli* O157:H7, and *Salmonella* in ground beef packaged by three commercially used packaging techniques. International J. of Food Microbiology 59:211-220.

O'Sullivan, M.G., D.V. Byrne, and M. Martens. 2003. Evaluation of pork colour: sensory colour assessment using trained and untrained panelists. Meat Sci. 63(1):119-129.

Sealed Air Corporation, NCBA, and National Pork Board. 2007. National meat case study. Sealed Air Corporation, Cryovac Division, Duncan, SC.

Sherbeck, J.A., J.D. Tatum, T.G. Field, J.B. Morgan, and G.C. Smith. 1995. Feedlot performance, carcass traits and palatability traits of Hereford and Hereford x Brahman steers. J. Anim. Sci.73:3613.

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. E.A. Decker, C. Faustman and C.J. Lopez-Bote (Ed.), p. 397-426, Wiley Interscience, New York, New York.

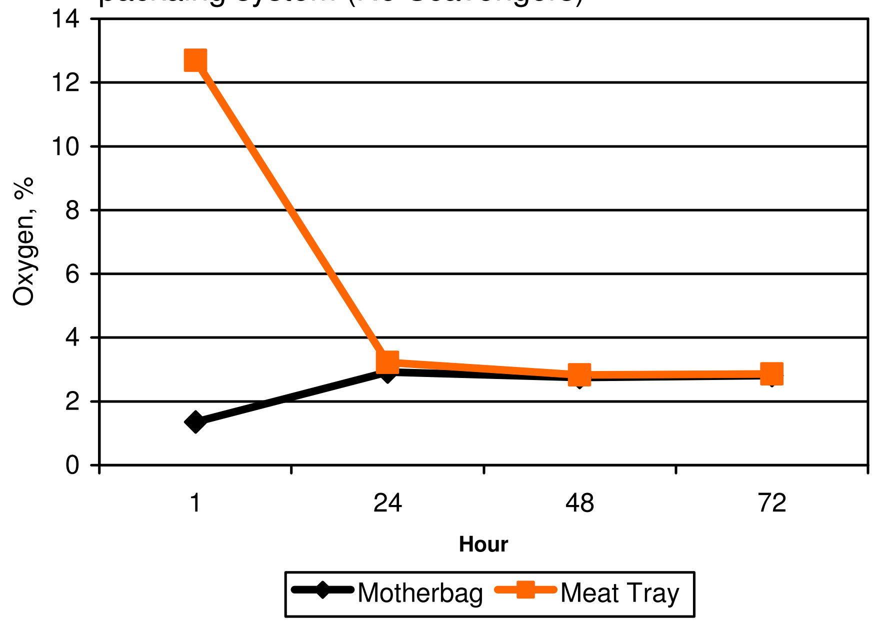
Solomon, J. 2004. Eliminating Oxygen. Meat and Poultry. Accessed from:www.meatandpoultry.com.

St. Angelo, J.A. 1996. Lipid oxidation in foods. Food Sci. Nutr. 36(3):175-224.

Xiong, Y.L. 2000. Protein oxidation and implications for muscle food quality. *Antioxidants in Muscle Foods,* E. Decker and C. Faustman (Ed.), p.85-111, John Wiley and Sons, Chichester.

APPENDIX

Appendix A. Oxygen composition of tested case-ready packaging system (No Scavengers)



VITA

Sidney Bryan Cunningham

Candidate for the Degree of

Master of Science

Thesis: THE BENEFITS OF OXYGEN SCAVENGING TECHNOLOGY ON OVERWRAPPED BEEF CUT IN A MODIFIED ATMOSPHERE PACKAGE

Major Field: Animal Science

Biographical:

Personal Data: Born in Joplin, Missouri on December 20, 1983, the son of Bryan Cunningham and Sue Points.

Education: Graduated from Carl Junction High School, Carl Junction, Missouri in May 2002; earned Bachelor of Science degree in Animal Science from Oklahoma State University, Stillwater, Oklahoma in 2007; Completed the requirements for the Master of Science degree with a major in Animal Science at Oklahoma State University in May 2008.

Experience: Raised in Carl Junction, Missouri on a show pig operation with parents who placed an emphasis on diligence, hard work, and integrity. Employed by the Oklahoma Food and Ag Products Center as an undergraduate 2004 – 2006, Tyson Fresh Meats as an intern 2005, and Oklahoma State University as a Graduate Assistant, 2007 to present.

Professional Memberships: American Meat Science Association (AMSA), Farm Bureau, and Missouri Pork Producers Association

Name: Sidney B. Cunningham Date of Degree: May, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: THE BENEFITS OF OXYGEN SCAVENGING TECHNOLOGY ON OVERWRAPPED BEEF CUTS IN A MODIFIED ATMOSPHERE PACKAGE

Pages in Study: 59 Candidate for the Degree of Master of Science

Major Field: Animal Science

Scope and Method of Study: Determine the efficacy of different oxygen scavenging systems at reducing residual oxygen levels and improving color stability when overwrapped beef cuts are stored in a modified atmosphere mother bag.

Findings and Conclusions: Iron-based oxygen scavengers reduce oxygen levels inside the mother bag and individual cut package as compared to tested soaker pad oxygen scavenging treatments. When used in the packaging of enhanced or non-enhanced roasts, non-activated and control packaging treatments improve subjective lean surface color, reduce subjective surface discoloration, and improve subjective overall acceptability as compared to the activated packaging treatment. Oxygen scavengers have the ability to reduce oxygen and improve subjective color characteristics; however, further research is necessary to reduce oxygen percentages to an acceptable level. Additionally, further research must also be conducted to help improve lean surface color and shelf stability.

ADVISER'S APPROVAL: Dr. J. Brad Morgan