CHARACTERIZING GRASS-FED GROUND BEEF AND ENHANCED STEAKS USING MODIFIED ATMOSPHERE PACKAGING

Except where reference is made to the work of others, the work described in this thesis is my own or was done in collaboration with my advisory committee. This thesis does not include proprietary or classified information.

Lillie Marie Sledge

Certificate of Approval:

Manpreet Singh
Assistant Professor
Poultry Science

Christopher R. Kerth, Chair
Associate Professor
Animal Science

Kyle Willian
Assistant Professor
Department of Chemistry
Tuskegee University
Tuskegee, Alabama

George T. Flowers
Interim Dean
Graduate School

CHARACTERIZING GRASS-FED GROUND BEEF AND ENHANCED STEAKS USING MODIFIED ATMOSPHERE PACKAGING

Lillie Marie Sledge

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn University
December 19, 2008

CHARACTERIZING GRASS-FED GROUND BEEF AND ENHANCED STEAKS USING MODIFIED ATMOSPHERE PACKAGING

Lillie Marie Sledge

____
Signature of Author

____
Date of Graduation

VITA

Lillie Marie Sledge, the daughter of Tom and Emily Rogers and Shalon Sledge, was born on June 1, 1984 in Florence, Alabama. Lillie grew up on the family farm (aka Noah's Ark) in Rogersville, Alabama. In May 2002, Lillie graduated from Lauderdale County High School and enrolled at the University of North Alabama. In July of 2003 Lillie moved to Auburn to attend Auburn University and graduated in May 2006 with a B.S. degree in Animal Sciences Pre-Vet. The following August Lillie began her Masters of Science degree in Animal Science with an emphasis on Meat Science and Muscle Biology. Lillie will graduate in December 2008 with her M. S. degree. Starting in August 2008 she will be attending Auburn University's College of Veterinary Medicine with hopes of pursuing a food animal or public health veterinarian career following graduation in May 2012.

THESIS ABSTRACT

CHARACTERIZING GRASS-FED GROUND BEEF AND ENHANCED STEAKS USING MODIFIED ATMOSPHERE PACKAGING

Lillie Marie Sledge

Master of Science, December 19, 2008
(B.S., Auburn University, 2006)

138 Typed Pages

Directed by Christopher R. Kerth

Fall-born Angus x Continental crossbred steers (n = 18) were randomly assigned to six 1.4 ha paddocks with 3 head in each paddock. The paddocks had been randomly planted with Marshall Ryegrass (*Lolium multiflorum* L.), Wren's Abruzzi Rye (*Secale cereael* L.) and Harrison Oats (*Avena sativa* L.). Boneless strip loins and ribeyes from the left side of the carcass were collected at 48 h postmortem, vacuumed-packaged and stored at 2°C until 14 d postmortem. On d 14 postmortem three 2.54-cm-thick steaks were cut from the anterior end of the left strip loin from all 18 carcasses. The strip loins and ribeyes were cut in half and the posterior and anterior ends were randomly assigned to an injection treatment resulting in 0.6% salt, 0.4% phosphate (BRIFISOL 85 Instant, BK Giulini Corporation, Simi Valley, CA), 2.5% potassium lactate (Ultra-Pure PL-85

(60%), Trumark Inc., Linden, NJ), and 0.055% beef stock (Proliant Meat Ingredients, Ankeny, IA). They were pumped to a 112% of their green weight and cut into four 2.54-cm-thick steaks. Packaging treatments used for this study were a high oxygen (HO; 80% O_2/20% CO_2), low oxygen (LO; 65% N_2/35% CO_2), carbon monoxide (CO; 65% N_2/34.6% CO_2/0.4% CO), and vacuum packaging (VAC). Results indicated that the pumped strip loin steaks showed higher sensory scores for initial and sustained juiciness, initial and sustained tenderness, flavor intensity, and off flavor ($P < 0.05$). The HO resulted with the lowest scores for the sensory characteristics ($P < 0.05$) except for initial juiciness. Retail visual and instrumental scores were the highest for the CO which produced and maintained a bright, cherry-red appearance ($P < 0.05$) for both the strip loins and ribeyes. TBARS was conducted only on the ribeye steaks which indicated that the pumped steaks resulted with the most oxidation and the LO had the least oxidation ($P < 0.05$).

Eighteen kilograms of grass-fed beef trim from fall-born Angus x Continental crossbred steers and eighteen kilograms of grain-fed beef trim were ground to achieve separate batches with approximately 20% fat. Six titrations were made from each of the ground trimmings containing: 0% grass/100% grain (0/100), 20% grass/80% grain (20/80), 40% grass/60% grain (40/60), 60% grass/40% grain (60/40), 80% grass/20% grain (80/20), and 100% grass/0% (100/0) grain. Each titration was packaged using a high oxygen (HO; 80% O_2/20% CO_2), low oxygen (LO; 65% N_2/35% CO_2), carbon monoxide (CO; 65% N_2/34.6% CO_2/0.4% CO) or OV (overwrap). Results showed that there was no difference in diet*modified atmosphere packaging (MAP; $P > 0.05$) for initial and sustained juiciness, cohesiveness, flavor intensity, off flavor, or cookloss. The 100/0 titration resulted in better ($P < 0.05$) instrumental (a*) and visual color scores. The CO package produced and maintained a bright, cherry-red color through out the retail display. TBARS values were the lowest for the titrations with the most grass percentage ($P < 0.05$).

ACKNOWLEDGEMENTS

I would like to thank my family and friends for providing unconditional support over the past two years. They have always been there for me when I have least expected. I would like to give thanks to my major professor Dr. Chris Kerth for providing me with financial support as well as directing me through this project. A thank you also goes out to my other committee members Dr. Manpreet Singh and Dr. Kyle Willian for providing support and help when needed.

A special thanks goes to Abby Frank Crow for helping me stay focused and sane during the past two years. The other Animal Science graduate students, faculty members and meat lab employees, especially Barney Wilborn, Pete Holloway, Clint Rowe and Dr. Christy Bratcher, have provided much support and hours and I would not have been able to have completed this without their contributions.

Style manual or journal used: Journal of Animal Science

Computer software used: Microsoft Word

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER III

CHAPTER IV

LIST OF FIGURES

CHAPTER III

CHAPTER IV

CHAPTER I

INTRODUCTION

Forage-fed beef accounted for the majority of beef production and sales in the United States prior to World War II (Schupp et al., 1980). Popularity of forage-fed beef declined in the 1950s and 1960s when the large-scale cattle finishing system was developed which demanded an increase in grain-based finishing regimens. Soon consumers became accustomed to the characteristics, such as flavor, tenderness, and juiciness, which results from high quality, well-marbled grain-fed beef. During the late 1970s, consumer health consciousness and demand for “healthy” foods greatly increased due to a shift in the American diet (Schupp et al., 1980; Griebenow et al., 1997).

Today consumers are still attracted to the promotion of “healthy” foods. Because of this demand, organic, natural, and grass-fed beef has regained recognition in niche markets which seems to follow the demand theory that states that consumers should be influenced by the factors related to human health and beef production supplies (Schupp et al., 1980). Many consumers desire a product that is leaner and environmentally friendly which is a result from forage-fed systems. A drive for forage-fed beef production has been created by the rapid increase in the world’s human population. This population increase could possibly create a shortage in the supply of grain worldwide, thus creating an importance for grass or forage production systems (Reverte et al., 2003).

The southeastern United States is a region that has optimum conditions for a year-round forage production system (Cox, 2004; Sapp et al., 1999). In the United States, consumers demand products that are developed from an array of specialty areas (Braden, 2006; Resurreccion, 2003) such as forage-finished beef which is now a leading niche market (Braden, 2006; Prevatt et al., 2006). Since today's consumers are interested in convenient, heat-and-eat products the beef industry is in competition with the poultry industry that already has several convenience products available to consumers. The beef industry has been able to meet consumers' needs by providing them with a safe yet flavorful product.

To meet the growing demands for beef, the beef industry and researchers have been working on improving shelf-life stability and palatability of forage-fed beef to provide a longer-lasting product for the niche market. Since forage–fed beef naturally contains more vitamin E than grain-fed beef it is possible that the beef will naturally improve oxidative stability, enhance color retention, and increase retail shelf life offering an opportunity for "value added" consumer products with enhanced nutrient value according to Decker et al. (2000). Animals finished on forage diets have been noted to provide acceptable carcass weights and degrees of finish when finished at a young age (Muir et al., 1998a). This study also showed that acceptable quality characteristics can also be achieved by a forage-finishing system when compared to a grain-based diet.

The purpose of the research presented is to study the effects of modified atmosphere packaging using high-oxygen, carbon monoxide, and low-oxygen gas mixtures with a traditional overwrap as the control and brine injection on forage-fed beef as well as the study of modified atmosphere packaging (MAP) on ground beef when mixed with grain-fed and forage-fed beef. Few studies have been done on MAP with forage-fed beef and enhancement. Enhancement of the forage-fed beef as well as a specific modified atmosphere packaging system will possibly improve the quality, shelf-life, and organoleptic characteristics of the meat. Three different forage treatments were also included in this study to determine which forage will benefit the grain-fed meat quality characteristics the most.

CHAPTER II

REVIEW OF LITERATURE

Forage-fed Beef

The niche market for forage-fed beef is increasing rapidly. Forage-finishing systems have been around for many years. Countries such as Argentina, Australia, and Brazil have always had high quality forage-finishing systems due to abundant forage production. Cattle convert forages, a low-quality food source, into a high-quality food source that can be used for human consumption very efficiently (Bidner et al., 1986). The cycle for forage-fed beef production typically recurs when grain production is decreased (Bowling et al., 1977; Schupp et al., 1980). Besides the decrease in grain production and higher cost for grain products tending to lead to more forage-finishing systems, forage-fed beef has been known to provide many health benefits such as to prevent heart disease, obesity, diabetes, and cancer (Pariza, 1997; Weiss et al., 2004). According to Wanderstock and Miller (1948) grass-fed beef was lower quality, less tender, yellower in fat color, and trimmer both externally and internally than traditional grain-fed beef. Additionally, others have reported grain-fed beef to be more tender, more flavorful, and more palatable than grass-fed beef (Bowling et al., 1977; Kropf et al., 1975). By using appropriate tenderization techniques such as electrical stimulation or blade tenderization, it may be possible to make forage-fed beef comparable to grain-fed beef in tenderness (Bidner et al., 1985).

Consumer Demand and Health Benefits

Consumers have been known to pay more for a product that provides many health benefits as well as a product that is environmentally friendly (Moloney, 2001; Tarrant, 1998). Forage-fed beef is known to provide many health benefits such as reducing the risk of heart disease (Weiss et al., 2004). Cattle reared on forage are known to contain higher amounts of omega-3 fatty acids and a more favorable omega-6 to omega-3 fatty acid ratio (French et al., 2000). Research on forage-fed beef has shown that the meat contains high levels of conjugated linoleic acid (CLA), poly-unsaturated and omega-3 fatty acids, and a higher ratio of unsaturated fatty acids to saturated fatty acids (Mitchell et al., 1991; Mandell et al., 1997; and French et al., 2001). Forage-fed beef has superior fatty acid composition when compared to the traditional grain-fed beef. Pathogenic organisms such as E. coli (Callaway et al., 2003) that are found in the GI tract of meat animals is lower in forage-fed animals therefore providing a smaller threat to food contamination (Keen et al., 1999). Forage-fed diets create conditions in the GI tract that results in decreased shedding of pathogenic organisms (Johnsson et al., 2001). Consumers are tending to focus more on food safety rather than being concerned about their nutritional diet (Schafer et al., 1993).

Many consumers believe highly in the animal welfare act (Bennett, 1996). The animal welfare act has always scrutinized the way the U.S. produces meat animals. Perceptions that these production (feed lot) and harvest or slaughter systems are inhumane have caused many consumers to refrain from purchasing meat products

(Harper and Makatouni, 2002). Since the "natural", "organic", and many other specialty production systems are becoming more popular, many consumers may increase their purchase of beef because of labeling forage-fed beef as "pasture-fed beef" (Harper and Makatouni, 2002; Prevatt et al., 2006).

Lean Color

Myoglobin is the basic color pigment for meat. Deoxymyoglobin is the more specific state for myoglobin when there is no oxygen bound to the myoglobin complex, therefore the meat is a dark red/ purple color (Aberle et al., 2001). When meat is exposed to oxygen, the myoglobin is oxygenated to form an oxymyoglobin pigment which is best described as a bright, cherry-red color. This bright, cherry-red color is associated with the "freshness" of the meat and it is what consumers are attracted to (Muir et al., 1998a). As the meat remains exposed to low partial pressures of oxygen, the myoglobin oxidizes and forms an unattractive brown color known as metmyoglobin. The formation of metmyoglobin is affected by chemical changes in the muscle such as the pH level and postmortem decline, as well as the content of oxygen that is present within the muscle post-mortem (Renerre and Labas, 1987). The level of pigmentation and the percentages of myoglobin, oxymyoglobin and metmyoglobin formation in the muscle ultimately determine the meat color. Consumers perceive discolored meat as unwholesome, un-fresh, or from older cattle (Muir et al., 1998a). Two factors must be considered when analyzing fresh meat lean color: surface color of the fresh meat and rate of discoloration caused by metmyoglobin formation over time.

The bright, cherry-red lean color is typical for young grain-fed cattle. Older animals and animals that have been stressed often have a darker lean color. Lean color is influenced by the glycogen stores in the muscle that allow the pH of the muscle to decrease post-mortem. Thompson (2002) reported that a minimum of 57 µmol/g of glycogen is necessary for the pH of muscle to reach the ultimate level of 5.5 in post-mortem muscle. Meat with a dark color, typically known as dark cutting or dark firm dry (DFD), results when the ultimate pH has elevated due to the glycogen reserves depleting below this threshold. The meat may become less juicy, lack visual appeal, and have reduced shelf life due to the increase in the ultimate pH (Thompson, 2002).

According to Muir et al. (1998a) production factors and stress are two important factors that may influence glycogen in the muscle at time of slaughter therefore resulting in a darker lean color due to reduced pH decline. Muir et al. (1998a) states that in several studies comparing forage-finished and grain-finished cattle there were no differences found in lean color. French et al. (2001) and Mandell et al. (1997) support this by reporting similarities in lean color of forage-finished and concentrate-finished cattle. Differences have been found by other researchers in lean color between feeding regiments; forage-finished cattle were found to have a darker lean color than grain-fed cattle (Bennett et al., 1995; Bidner et al., 1986; Schroeder et al., 1980). Bidner et al. (1986) stated that a higher myoglobin concentration is linked to the darker lean color that is seen in forage-fed beef. Grass-fed steers have a higher ultimate pH than grain-fed steers according to Muir et al. (1998b). Since grass-fed steers are known to have higher ultimate pH values, researchers believe the increased pH is because grass-fed steers were more susceptible to pre-slaughter stress and therefore they would suffer glycogen depletion in the factory pre-slaughter process (Muir et al., 1998b). A higher pH value is correlated to a darker lean or muscle tissue. Research has been conducted to possibly link a type of forage with an outcome on lean color. A study by Schaake et al. (1993) reported that there is no difference in animals reared on a spring fescue-clover pasture when compared to animals that are finished in a drylot, but in this study the cattle on summer pastures produced a darker lean color.

Tenderness

According to consumer studies, tenderness is considered the most important contributor to the eating quality of meat (Maltin et al., 2003). The muscle and collagen or connective tissue components are known to be the major two influences on meat tenderness (Koohmaraie, 1992). During the aging process of the carcass post-mortem, the muscle or myofibrillar proteins are often degraded by proteolytic enzymes (especially calpains) and appears to affect tenderness more than the pre-slaughter characteristics of collagen or connective tissue (Koohmaraie, 1992). According to McIntyre and Ryan (1984), there have been no differences in the shear force values or taste panel assessment of beef tenderness when grain-fed cattle and grass-fed cattle grew at a similar rate prior to harvest at the same age and weight. Mitchell et al. (1991) stated that from the 10 grain-fed and 10 forage-fed carcasses the steaks from the grain-fed carcasses were more tender and more flavorsome than the forage-fed steaks.

Forage-fed animals are finished at an older chronological age that grain-fed animals (Bowling, 1978). Finishing requires more time on forage to achieve desired weight gain; therefore forage-finished cattle have a slower weight gain than grain-finished cattle (Muir et al., 1998a). The age of the animal at slaughter, growth rate, and chilling rate are all interrelated and seem to be factors that are influential on the tenderness of forage-finished beef. Aberle et al. (2001) states that as the animal ages, the cross-links between collagen increases and becomes less soluble. Forage-finished cattle seem to have little to no difference on tenderness values overall when compared to tenderness values of grain-fed cattle, when comparing both finishing systems at the same weight and fat thickness. Cox et al. (2006) found no difference in insoluble or soluble collagen based on finishing-diets.

Thompson (2002) states that tenderness is also a function of processing, production, value-adding and cooking methods used in meat preparation for consumer consumption. The risk of a poor eating experience for the consumer increases when one or more of these links in the beef supply chain fails. Consumers are willing to pay a greater price for meat that is guaranteed to be more tender (Boleman et al., 1997). In literature by Simone et al. (1958), Bowling et al. (1977, 1978), and Miller et al. (1987), all have commented that there is a distinct positive correlation with meat tenderness and carcass fat thickness. Despite lower fat cover, Hedrick et al. (1983) found that meat from cattle finished on silage was just as tender or more tender than grain-fed cattle. Bowling et al. (1977) discovered differences in cooling rates of identical carcasses within chillers. This statement then lead to the conclusion that cooling rate differences may only be partly responsible for tenderness differences that are shown in grain- and forage-finished cattle. The connection between fat thickness and meat tenderness in carcasses is evidentially responsible partly by the chilling rate (Muir et al., 1998a).

In a study by Smith et al. (1979) several methods were analyzed to possibly improve the tenderness of forage-finished beef. Methods tested singularly and collectively for tenderization included electrical stimulation, delayed chilling, pelvic suspension of sides, cooler aging, and blade tenderization of wholesale loins and top rounds of forage-finished beef carcasses. Maximum tenderization values of the longissimus muscle was by electrical stimulation or delayed chilling of the sides followed by blade tenderization or cooler aging of shortloins. When the initial treatments were combined and followed by blade tenderization; tenderness was increased as well as decreasing the shear force of the top round steaks, but when treatments where used individually, they showed no affect on the semimembranosus muscle.

Blade tenderization, electrical stimulation, and vacuum-aging was used by Bidner et al. (1981a, 1985) to study forage-finished beef tenderization. The Warner-Bratzler shear force was significantly improved by electrical stimulation but showed no difference on the palatability. Positive effects were shown by the blade tenderization and vacuum-aging on improving shear force and tenderization values conducted by a taste panel in conjunction with the amount of connective tissue. In this study the most benefits for improving tenderness was by combining treatments. Steaks that were both electrically stimulated and either blade-tenderized or vacuum-aged resulted to be more tender than steaks that received only one method of treatment.

Flavor

When comparing forage-fed cattle and grain-fed cattle, forage-fed cattle are known to have a less desirable flavor than cattle finished on grain (Wanderstock and Miller, 1948; Kropf et al., 1975; Bowling et al., 1977). The less desired flavor of grass-fed beef is linked to two factors: a lower fat content (Moody, 1976; Harrison et al., 1978) and the fatty acid composition (Brown et al., 1979; Westerling and Hedrick, 1979). The characteristic flavor of beef can be influenced by the fat composition (Bagley and Feazel, 1987) and is dependent on species of animal (Field et al., 1978). In a study by Melton in

1983, steers on pasture grasses and bermudagrass pellets had a less desirable or less intense beefy flavor when compared to high-energy-fed steers. Melton (1983) also stated that the largest difference in flavor was found between the steers harvested directly off grass pasture and from steers finished with a high-energy diet. This difference in the diets is correlated with differences in animal fatness. Owens and Gardner (1999) state that as the fat content increases, the flavor desirability and flavor intensity increases as well.

Since fat is known to store the aromatic compounds for beef flavor (Young and Baumeister, 1999), certain chemical changes in the fatty acid composition of forage-fed beef will contribute to a potent aroma during cooking (Melton, 1990). Forage-fed cattle have naturally high levels of α-linolenic acid (18:3) and long chain n-3 polyunsaturated fatty acids (PUFA) which impact flavor by producing a grass-fed taste (Wood et al., 2003). The products formed from the oxidation of linolenic acid and its derivatives that are derived from grass-feeding give meat from cattle a pastoral flavor (Priolo et al., 2001). Several researchers have noted that flavors and aromas in cooked forage-fed beef tend to be milky, grassy, cowy, fishy, painty, bloody, livery, medicinal, cardboard, sour, and soapy (Moloney et al., 2001; Stika et al., 2007).

Forage-fed cattle are known to have a more yellow fat color (Wanderstock and Miller, 1948) which is affected by the fatty acid content (Wood et al., 2003). According to Dikeman (1990), a yellower fat color is associated with an older or diseased animal by consumers, therefore making it undesirable (Yang et al., 1993). The diet the animal is receiving as well as the animal's age, sex, and genotype are all factors that can affect the fat color which in turn affects the flavor (Pearson, 1966; Morgan and Everitt, 1969; Walker et al., 1990).

Mandell et al. (1997) used 108 Charolais cross steers to study the effects of forage- versus grain-feeding systems on palatability of the beef as well as the carcass composition at a specified back fat thickness (4, 7,or 10 mm). The type of diet did not significantly influence the palatability, but forage-fed steers resulted in slightly less beef flavor and more off flavor than the grain-fed steers. Mandell et al. (1997) concluded that the differences in flavor may be related to the diet since the forage-fed steers had higher linolenic acid concentrations and lower oleic acid concentrations. This study agreed with Cross et al. (1978) where forage had significant effects on fat color, quality grade, and amount of marbling which all contribute to the flavor of the meat. Cross et al. (1978) also stated that steers fed ground alfalfa and orchardgrass hay produced a more tender, juicy, and intense flavor; when steers fed orchardgrass pasture resulted in less tender, less juicy, and detectable connective tissue when assessed by panelists. Therefore the type of grass consumed by the steers does influence the meat quality.

Juiciness

Juiciness is commonly associated with the amount of moisture released and degree of salivation during chewing or mastication (Lawrie, 2006). There are two organoleptic parameters that are associated with juiciness in cooked meat. The first is the initial juiciness that is associated with the amount of wetness from the first few chews; the second is the sustained juiciness that is associated with the amount of salivation that is produced due to the stimulatory effect of fat (Lawrie, 2006). Forage-fed beef is noted by several researchers to have lower juiciness scores when compared to grain-fed beef

(Hedrick et al., 1983; Sapp et al., 1999). There are several researchers such as Cross et al. (1978) and Bidner et al. (1981b) that reported no differences in juiciness between the two feeding systems. Muir et al. (1998a) reported that the increased amount of juiciness in the grain-fed cattle versus the forage-fed cattle was due to the differences in growth rate and/or fat covering. Higher fat covering or higher quality meat produces a more juicy product than low quality meat because of the amount of intramuscular fat content (Lawrie, 2006). However, in the study by French et al. (2001), both intra-muscular fat content and carcass growth correlated poorly with juiciness for carcasses associated with a grass diet. High-temperature chilling and blade tenderization of forage-fed beef has resulted in a less juicy product (Bowling et al., 1977; Bidner et al., 1981a).

Overall Acceptability

In a study conducted by Cox et al. (2006) consumers participating in a retail study and a take home study, one-third to one-half of consumers preferred forage-fed beef over grain-fed beef across three southeastern states: Alabama, Tennessee, and Kentucky. Among the three states, 34.1% of the retail consumers and 54% of the take-home consumers preferred forage-fed steaks. Approximately one-third of the consumers preferred the taste of forage-fed beef and was willing to pay a premium. This data supports Umberger et al. (2002) statements of 20% of consumers surveyed in their study conducted in Chicago and San Francisco preferred Argentine, forage-finished beef to traditional American, grain-finished beef. This study as well as the study of Cox et al. (2006) has showed that the geographical region (three southeastern states, Chicago and San Francisco) can have an influence on the acceptability of the forage-finishing system. A study conducted by Kerth et al. (2007) showed that 20% of consumers surveyed in their study preferred grass-fed beef and were willing to pay a premium; therefore a niche market could possibly be an alternative to current production and marketing methods.

Retail Shelf Life

Color has been noted to be the most important factor associated with meat quality from a consumer's perspective. To extend the shelf-life of the meat products, researchers have been analyzing several methods such as type of diet and packaging systems to increase the shelf-life of the product. Since the bright, cherry-red appearance is associated with a good quality and healthy product, researchers such as C. O. Gill believe that preservative packaging for raw meats must be able to delay both the color deterioration and retard bacterial spoilage (Gill, 1996). Diets containing high levels of vitamin E and low amounts of intramuscular fat, such as forage-fed diets, have resulted in better maintenance of color and lipid oxidation when compared to grain-fed animals (O'Sullivan et al., 2003).

Packaging systems such as a modified atmosphere have been noted also to help improve shelf-life stability (Gill, 1996; O'Sullivan et al., 2003; Sorheim et al., 1999). Even though the animal's forage diet and modified atmosphere packaging improves color and oxidation rates, color depletion and oxidation will eventually occur as the days in the retail display continue (Sorheim et al., 1999).

Gill (1996) explains that controlling the formation of brown metmyoglobin formation on the muscle surface can be slowed by using atmospheres that are rich in oxygen or prevented by using an oxygen-depleted atmosphere. Packaging atmospheres high in carbon dioxide or under anaerobic conditions retard bacterial spoilage as long as temperatures are maintained at the optimum for chilled storage as well as pre-packaging hygienic conditions are noted (Gill, 1996).

The rate of oxidation for deoxymyoglobin is more rapid than the rate of oxidation for oxymyoglobin (Robach and Pierson, 1979) resulting in faster oxidation of myoglobin at low concentrations of oxygen than at high oxygen concentrations (O' Keeffe and Hood, 1982). There are two ways to preserve muscle color apart from retarding pigment oxidation by maintaining a low temperature environment; they are by exposing the meat to high concentrations of oxygen and largely, or completely, excluding oxygen from the meat which results in the increase of the fraction of oxidation-resistant oxymyoglobin (Renerre, 1990). According the Millar et al. (1994), high oxygen atmospheres are used mainly for retail-ready products. Use of high-oxygen atmospheres is usually inappropriate for poultry due to their limited ability to bloom (Millar et al., 1994).

Storage

Modified atmosphere packaging (MAP) is one of the newest technologies for packaging systems today. There are several different modified atmospheres that are used individually and in combinations that promote the benefits of the individual product (Sorheim et al., 1999). The most important properties to consider when packaging a product are a gas mixture that will retard microbial growth, stabilize the product's color, and a gas that is used as a filler (Gill, 1996; Sorheim et al., 1999). The gases used most commonly are carbon dioxide, oxygen and nitrogen. Carbon dioxide limits the microbial growth within the package, oxygen stabilizes the products color but it is known to contribute to microbe growth, and nitrogen is the filler gas (Gill, 1996). The most common MAP packaging treatments in the industry for retail-ready systems is high oxygen (70% O) and carbon dioxide (30% CO ; Gill, 1996; O' Sullivan et al., 2002; Hunt et al., 2004).

There are several advantages and disadvantages to this system. Advantages include promoting the desired product color that consumers accept as the preferred meat color which is a bright, cherry-red for red meats and creating head space over the product which assists in preventing the product from collapsing (Gill, 1996). Disadvantages to the system also occur, such as requiring more storage space for the larger packages; therefore not increasing the shelf-life of the product. Since the high oxygen system is not stable due to property changes within the gases the CO concentration remains relatively stable but the O concentration will decrease and the N concentration will increase progressively over time therefore leakers may be difficult to identify and monitor (Gill, 1996; Monahan, 2000).

The use of high oxygen gas (80% O and 20% CO) is known to extend shelf-life for red meats because the high content of oxygen supports the formation of oxymyoglobin, while microbial growth is retarded by the carbon dioxide content (O'Sullivan et al., 2002). Reports by Monahan (2000) showed that some high-oxygen packaging can promote oxidation and adversely affect color, but with the advantages of forage-fed beef the natural Vitamin E content has been researched to delay lipid and pigment oxidation therefore resulting in an extended shelf-life (Houben et al., 2000; Kerry et al., 2000; O'Sullivan et al., 2002)

The use of carbon monoxide was approved by the U. S. Food and Drug Administration in 2002 with "generally recognized as safe" (GRAS) status for packaging as long as the meat was removed from the CO atmosphere prior to retail display and sale

(USFDA, 2002). Since myoglobin has a high affinity for the CO gas, it creates a bright, cherry-red color and is used in muscles that are known to discolor easily (Hunt et al., 2004). Norway has been using the CO system for several years because the shelf-life and color stability has been increased by the 0.4% CO gas mixture (Sorheim et al., 1999). This packaging system accounts for a 50-60% share of the domestic, retail, red meat market. Based on a toxicological, hygienic, and technological standpoint, the use of CO up to a 1% concentration does not present any toxic hazards to the consumer (Sorheim et al., 1997), but at the same time the CO may mask spoilage because the stable bright red color has been noted to outlast the microbiological shelf-life of the meat product (Kropf, 1980).

Enhanced Beef

In a study by Stika et al. (2007), trimmings from nine mature cows were reconstructed into steaks. The steaks were formulated with a beefy flavoring agent or in combination with propyl gallate to promote palatability and stabilization over a six month frozen storage period. The propyl gallate reduced the lipid oxidation, rancidity, and loss of beef flavor in the restructured steaks. By adding the beefy flavoring agent, the mature, forage-fed beef off-flavors were masked, beefy flavor was intensified and the tenderness, juiciness, and cook yields of the steaks were improved (Stika et al., 2007). The study by Robbins et al. (2003a) agreed that enhanced steaks were more acceptable than non-enhanced steaks for juiciness and tenderness. A study by Pietrasik et al. (2006) showed that injected steaks containing salt and/or phosphate improved the color stability during retail display. In contrast, studies by Robbins et al. (2003b) and Jensen et al. (2003) have reported that color stability of beef and pork is decreased during retail display due to the enhancement with a salt or phosphate. Steaks supplemented with vitamin E were less discolored indicating that the vitamin E may improve color short term (up to 2 d retail display) on beef enhanced with a salt/phosphate solution (Robbins et al., 2003b).

The use of enhancement systems has been proven by several researchers, and for consecutive years (Robbins et al., 2002, 2003b), to improve juiciness and tenderness as well as improving flavor, but the use of salt and phosphate solutions has shown a negative attribute on shelf life (Robbins et al., 2002, 2003b; Stika et al., 2007).

Conclusion

In conclusion, forage-fed animals are great convertors of cellulose into products for human consumption (Bagley and Feazel, 1987) as well as providing health benefits associated with the meat such as prevention against heart disease, obesity, diabetes, and cancer (Pariza, 1997; Weiss et al., 2004). Since consumers are demanding a more convenient and healthy product researchers, producers, and industry have to step up and meet this demand while at the same time produce a product with a good shelf life and meat quality characteristics. The use of MAP and enhancement will possibly provide many areas for improving forage-fed beef systems. Improving quality is essential since forage-fed beef contains some negative characteristics such as a yellower fat (Wanderstock and Miller, 1948) and off-flavors (Moloney et al., 2001; Stika et al., 2007) when compared with grain-fed cattle.

Research Objectives

The purpose of the research presented is to study the effects of modified atmosphere packaging using high-oxygen, carbon monoxide, and low-oxygen gas mixtures with a traditional overwrap as the control and brine injection on forage-fed beef as well as the study of modified atmosphere packaging on ground beef when mixed with grain-fed and forage-fed beef. Few studies have been done on MAP with forage-fed beef and enhancement. Enhancement of the forage-fed beef as well as a specific modified atmosphere packaging system will possibly improve the quality, shelf-life, and organoleptic characteristics of the meat. Three different forage treatments were also included in this study to determine which forage will benefit the meat quality characteristics the most.

CHAPTER III

CHARACTERIZING GRASS-FED ENHANCED STEAKS USING MODIFIED ATMOSPHERE PACKAGING

ABSTRACT

Fall-born Angus x Continental crossbred steers (n = 18) were randomly assigned to six 1.4 ha paddocks with 3 head in each paddock. The paddocks had been randomly planted with Marshall Ryegrass (*Lolium multiflorum* L.), Wren's Abruzzi Rye (*Secale cereael* L.) and Harrison Oats (*Avena sativa* L.). Boneless striploins and ribeyes from the left side of the carcass were collected at 48 h postmortem, vacuumed-packaged and stored at 2°C until 14 d postmortem. On d 14 postmortem three 2.54-cm-thick steaks were cut from the anterior end of the left striploin from all 18 carcasses. The striploins and ribeyes were cut in half and the posterior and anterior ends were randomly assigned to an injection treatment resulting in 0.6% salt, 0.4% phosphate (BRIFISOL 85 Instant, BK Giulini Corporation, Simi Valley, CA), 2.5% potassium lactate (Ultra-Pure PL-85 (60%), Trumark Inc., Linden, NJ), and 0.055% beef stock (Proliant Meat Ingredients, Ankeny, IA). They were pumped to 112% of their green weight and cut into four 2.54-cm-thick steaks.

Packaging treatments used for this study were a high oxygen (HO; 80% O_2/20% CO_2), low oxygen (LO; 65% N_2/35% CO_2), carbon monoxide (CO; 65% N_2/34.6% CO_2/0.4% CO), and vacuum packaging. Results indicated that the pumped striploin steaks showed higher sensory scores for initial and sustained juiciness, initial and sustained tenderness, flavor intensity, and off flavor ($P < 0.05$). The HO resulted with the lowest scores for the sensory characteristics ($P < 0.05$) except for initial juiciness. Retail visual and instrumental scores were the highest for the CO which produced and maintained a bright, cherry-red appearance ($P < 0.05$) for both the striploins and ribeyes. TBARS on the ribeye steaks indicated that the pumped steaks resulted in the most oxidation and the LO had the least oxidation ($P < 0.05$).

INTRODUCTION

Forage-fed beef accounted for the majority of beef production and sales in the United States prior to World War II (Schupp et al., 1980). Popularity of forage-fed beef declined in the 1950s and 1960s when the large-scale cattle finishing system was developed which demanded an increase in grain-based finishing regimens. Soon consumers became accustomed to the characteristics, such as flavor, tenderness, and juiciness, which results from high quality, well-marbled grain-fed beef. During the late 1970s, consumer health consciousness and demand for “healthy” foods greatly increased due to a shift in the American diet (Schupp et al., 1980; Griebenow et al., 1997).

Today consumers are still attracted to the promotion of “healthy” foods. Because of this demand, organic, natural, and grass-fed beef has regained recognition in niche markets which seems to follow the demand theory which states that consumers should be influenced by the factors related to human health and beef production supplies (Schupp et al., 1980). Many consumers desire a product that is leaner and environmentally friendly which is a result from forage-fed systems. A drive for forage-fed beef production has been created by the rapid increase in the world's human population. This population increase could possibly create a shortage in the supply of grain worldwide, thus creating an importance for grass or forage production systems (Reverte et al., 2003).

The southeastern United States is a region that has optimum conditions for a year-round forage production system (Cox, 2004; Sapp et al., 1999). In the United States, consumers demand products that are developed from an array of specialty areas (Braden, 2006; Resurreccion, 2003) such as forage-finished beef which is now a leading niche market (Braden, 2006; Prevatt et al., 2006). Since today's consumers are interested in convenient, heat-and-eat products the beef industry is in competition with the poultry industry that already has several convenience products available to consumers. The beef industry has been able to meet consumers' needs by providing them with a safe yet flavorful product.

To meet the growing demands for beef, the beef industry and researchers have been working on improving shelf-life stability and palatability of forage-fed beef to provide a longer-lasting product for the niche market. Since forage–fed beef naturally contains more vitamin E than grain-fed beef it is possible that the beef will naturally improve oxidative stability, enhance color retention, and increase retail shelf life offering an opportunity for "value added" consumer products with enhanced nutrient value according to Decker et al. (2000). Animals finished on forage diets have been noted to provide acceptable carcass weights and degrees of finish when finished at a young age

(Muir et al., 1998a). This study also showed that acceptable quality characteristics can be achieved by a forage-finishing system when compared to a grain-based diet.

Several studies have been conducted on forage-fed beef. Some researchers have stated that forage-fed beef is known to improve the color stability of the product (Arnold et al., 1992). A problem faced with forage-fed beef is that the beef has several off flavors such as grassy, rancid, livery, and metallic. Enhancing forage-fed beef with a beef flavoring agent in a salt/phosphate solution has been noted to decrease the intensity of the off flavors produced by the forage-fed beef.

Modified atmospheres are being used more widely to assist in the shelf-life of the product. Atmospheres that promote the blooming of color pigments may not always be safe because consumers determine meat quality based on color. According to Zhao et al. (1994) lipid oxidation has been noted to occur at a slower rate than the deterioration of the color pigments. An elevated oxygen level is known to extend color stability, but the increased rate of oxidation can also be expected (Zhao et al, 1994). In the CO packaging, a pigment known as carboxymyoglobin is formed. The carboxymyoglobin is similar to the bright red oxymyoglobin pigment that is formed at the surface of fresh meat in air. Carboxymyoglobin is known to less readily oxidize to brown metmyoglobin than is oxymyoglobin because of the strong binding of CO to the iron site on the myoglobin molecule (Lanier et al., 1978). Results from Sorheim et al. (1999) state that a low CO/high CO_2 atmosphere is effective for preserving retail-retail meats.

The purpose of the research presented is to study the effects of modified atmosphere packaging using high-oxygen, carbon monoxide, and low-oxygen gas mixtures with a traditional overwrap as the control and brine injection on forage-fed beef.

Few studies have been done on MAP with forage-fed beef and enhancement. Enhancement of the forage-fed beef as well as a specific modified atmosphere packaging system will possibly improve the quality, shelf-life, and organoleptic characteristics of the meat. Three different forage treatments were also included in this study to determine which forage will benefit the meat quality characteristics the most.

MATERIALS AND METHODS

Animals and Diet

Fall-born Angus x Continental crossbred steers (n = 18) from the Wiregrass Research and Extension Center in Headland, Alabama were randomly assigned to six 1.4 ha paddocks with 3 head in each paddock. The paddocks had been randomly planted with Marshall Ryegrass (*Lolium multiflorum* L.), Wren's Abruzzi Rye (*Secale cereael* L.) and Harrison Oats (*Avena sativa* L.) ryegrass (*Lolium perenne*). Two paddocks were assigned for each of the forages. Grazing began in December 2006 and animals were humanely harvested on May 1 and May 8 of 2007 at the Auburn University Lambert-Powell Meats Laboratory.

Sample Collection and Preparation

Boneless striploins and ribeyes from the left side of the carcass were collected at 48 h postmortem, vacuum-packaged and stored at 2°C until 14 d postmortem. On d 14 postmortem three 2.54-cm-thick steaks were cut from the anterior end of the left striploin from all 18 carcasses. The three steaks in order were assigned to fatty acid, sensory, and WBS analyses (not discussed in this review). The remaining striploins and ribeyes were cut in half and the posterior and anterior ends were randomly assigned to an injection (112% of green weight; PUMP) treatment resulting in 0.6% salt, 0.4% phosphate

(BRIFISOL 85 Instant, BK Giulini Corporation, Simi Valley, CA), 2.5% potassium lactate (Ultra-Pure PL-85 (60%), Trumark Inc., Linden, NJ), and 0.055% beef stock (Proliant Meat Ingredients, Ankeny, IA) in final product. A multi-needle pickle injector (Gunther Model Typ PI 21, Dieburg, Germany) was used to inject the brine into the muscle. The ends that were to receive the injection treatment were placed aside to have green weight recorded prior to receiving the brine injection. After the ends were injected and weighed they were cut into four 2.54-cm-thick steaks and then randomly assigned a packaging treatment.

Packaging treatments used for this study were a high oxygen (HO; 80% O_2/20% CO_2), low oxygen (LO; 65% N_2/35% CO_2), carbon monoxide (CO; 65% N_2/34.6% CO_2/0.4% CO), and vacuum (VAC) packaging. The modified atmosphere packages were packaged using a Koch ILPRA FoodPack (Model 400V/G, Corso Pavia, Italy). A Cryovac T7225B Laminate (Duncan, SC) film was used to seal the lids of the trays. The film possessed an oxygen transmission rate of 0.3cc/100 in^2 /day.

Initial Color Measurements

Following a 48 h postmortem chill, Commission Internationale de l'Eclairage (CIE) lean and external fat L* (muscle lightness), a* (muscle redness), and b* (muscle yellowness) for the initial color measurements before packaging for the striploins and ribeyes were evaluated by utilizing the Hunter Miniscan XE Plus (Hunter Laboratories Model 45/0-L, Reston, VA) with a illuminant D65 at a 10° observation angle and a 3.5-cm aperture. Reflectance spectra values for the initial lean color were also determined. Spectral reflectance values were determined at 520-, 530-, 570-, and 580-nm and interpolated to determine the values for 525-nm and 575-nm respectively. Readings for

L*, a*, b*, 525 nm and 575 nm reflectance values for lean color were taken from two readings on the anterior face of the ribeye and striploin steaks and averaged to obtain a representation of the initial lean color.

Storage and Retail Display

Steaks were stored for 21 d in dark storage at 2°C until placed on retail display for panel analysis. Steaks were checked 48 h after packaging and noted for leakers. After 21 d dark storage, steaks were placed in a Tyler (Model DMG-8, Niles, MI) retail display case at 2°C for retail panel analysis for 5 d. The illumination intensity was 800lx at the surface of the steak, utilizing Sylvania© Designer Cool White Plus bulbs (F40/DCWP). Every day, six trained panelists rated the ribeye and striploin steaks for color, uniformity, surface discoloration and browning. Color was based on an 8 point hedonic scale; 1 equaling extremely dark red and 8 equaling extremely bright cherry-red. Uniformity was based on a 5 point hedonic scale; 1 equaling uniform and 5 equaling extreme two toning. A 7 point hedonic scale was used for surface discoloration; 1 equaling zero percent discoloration and 7 equaling 100 percent discoloration on surface. Browning was based on a 5 point hedonic scale; 1 equaling none and 5 equaling dark brown.

Retail Color Measurements

Post retail color measurements were taken on d 5 of the display for lean muscle and fat color (L*, a* and b*) and lean reflectance values at 520, 530, 570, and 580. Hue angles and saturation index (chroma) values were appropriately using the a* and b* values. Readings for lean color were taken from two readings on the anterior face of the ribeye and striploin and averaged to obtain a representation of the post retail lean color. External fat color was obtained by averaging the two measurements from the external fat.

The ribeye and striploin steaks were vacuumed packaged and frozen at -20°C until sensory and TBARS analyses.

Sensory

Striploin steaks for sensory were thawed (4°C for 12-18 h), weighed, and placed in a pre-heated George Foreman clam-shell-style grill (Model GRP4A, Macon, MO) for 7 min (Kerth et al., 2007), resulting in a final internal temperature of 71°C (AMSA, 1995). Cooked steaks were weighed to determine the percentage cooking loss by dividing the weight lost during cooking by the pre-cooked weight. Each steak was trimmed of fat and connective tissue after cooking and the longissimus muscle from each steak was cut into cubes 1cm x 1cm x steak thickness and placed in double boilers, with warm sand in the bottom, until served to a six-member trained sensory panel. Each of the trained panel members evaluated two samples from each steak in a cubicle supplied with red light; evaluation forms; two salt-free saltine crackers and water for cleansing the palate; and a cup for expectoration. An eight-point scale was used for the evaluations of initial and sustained juiciness, initial and sustained tenderness, flavor intensity, and off flavor (1= extremely dry, extremely tough, extremely bland and no off flavor to 8= extremely juicy, extremely tender, extremely intense beef, and extreme off flavor). Panelists noted appropriate off flavor descriptors provided on form if scores were noted for an off flavor.

Determination of Lipid Oxidative Stability

Lipid oxidative stability was analyzed by using the thiobarbituric acid (TBA) reactive substance assay modified from Buege and Aust (1978). Ribeye samples used for lipid oxidative stability were removed from frozen storage and a 5-g sample was homogenized with 15 mL of distilled water. Approximately 2 mL homogenate was combined with 4 mL of trichloracetic/thiobarbituric acid reagent and 100 μL of 10% butylatedhydroxyanisole. Samples were incubated in a 99°C water bath for 15 min, allowed to cool in cold water for 10 min, and filtered through Whatman paper. The absorbance of the samples was read against a blank containing like reagents at 531 nm. Malonaldehyde standards were constructed utilizing 1, 1, 3, 3-tetraethoxypropane and thiobarbituric acid reactive substances were reported as mg/5g of meat.

Statistical Analysis

Data for sensory, cook-loss, off descriptors, and TBA was analyzed as a 2 (pumped or non-pumped) by 4 (CO, HO, LO, or VAC packaging) factorial arrangement of a completely randomized design using GLM procedure of SAS. Type of forage had no significant effect ($P > 0.10$) and was not included in the analyses. Significant ($P \leq 0.05$) main and interaction effect means were separated with Fisher's protected LSD using the PDIFF option of LSMEANS in SAS. For retail display data, the effect of day was analyzed as a repeated measure using the replication within packaging and pump treatment as the error term for packaging, pump, and their interaction, and the residual error to test for day and day interaction effects. The effect of the three different forages was tested and found to not be a significant ($P> 0.10$) source of variation, so data for forage type was pooled together for analyses.

RESULTS

Initial Color

The interaction of MAP*Day*Pump was not significant ($P > 0.05$) for the CIE L* instrumental value for striploin and ribeye steaks (Figure 3.1 and 3.17). No differences ($P > 0.05$) in L* were found among packaging or pump treatments at the beginning of the shelf life. The CO and HO packaging increased ($P < 0.05$) the CIE L* value while the vacuum packaging decreased the L* value for the striploin and ribeye steaks at the end of shelf life. The non-pumped striploin and ribeye steaks resulted in higher ($P < 0.05$) L* values than the pumped treated steaks.

For a* value the interaction of MAP*Day*Pump was significant ($P < 0.05$) for the striploin steaks (Figure 3.2). At the beginning of retail display a* was not different ($P > 0.05$) for all MAP and pump treatments. By the end of the retail display, a* values were the highest for CO and lowest for HO ($P <0.05$). The a* values for HO, LO, and Vac had decreased ($P < 0.05$) significantly by the end of the retail display. Non-pumped a* values were higher ($P < 0.05$) than pumped a* values within HO at the end of retail display. The interaction of MAP*Day*Pump for ribeye steaks was not significant ($P > 0.05$; Figure 3.18). All modified atmosphere packages decreased in a* at the end of the retail display except for CO which increased ($P > 0.05$). The non-pumped a* values ($P < 0.05$) were higher than the pumped a* within the CO and HO at the end of retail display.

At the beginning of retail display b* was not different ($P > 0.05$) for all MAP and pump for the striploin steaks (Figure 3.3). By the end of retail display, b* values for LO and Vac were the lowest ($P < 0.05$). The non-pumped b* p-value was higher than the pumped b* within LO and HO at the end of retail display for the striploin steaks. For the ribeye steaks, the b* was not different ($P > 0.05$) at the beginning of the retail display for all MAP and pump (Figure 3.19). The b* values for the pumped ribeyes were lower ($P < 0.05$) than the non-pumped b* at the end of the retail display for all MAP.

For the striploin steaks, the pumped steaks had a higher fat L* values than non-pumped fat L* values ($P < 0.05$; Figure 3.4). The HO fat had the highest ($P < 0.05$) L* value for both pumped and non-pumped. CO and HO ribeyes had higher ($P < 0.05$) fat L* values than LO or Vac fat L* values for ribeyes (Figure 3.20).

The striploin fat a* was the highest ($P < 0.05$) for CO and lowest for HO than all other MAP (Figure 3.5). There was no difference ($P > 0.05$) between the non-pumped and pumped fat a*. Non-pumped, CO ribeyes had higher fat a* values than pumped CO fat a* values (Figure 3.21). CO fat a* values were the highest for both pumped and non-pumped ribeyes. The fat b* values for the HO in the striploin and ribeye steaks was the lowest ($P < 0.05$) of all the MAPs (Figure 3.6 and 3.22).

At the beginning of retail display, there was no difference ($P > 0.05$) in hue values for all MAP and pump striploins (Figure 3.7). By the end of retail display, HO had the highest ($P < 0.05$) hue value and CO had the lowest ($P < 0.05$) hue value. Pumped striploins had a higher ($P < 0.05$) hue value within the CO and HO than the non-pumped hue values, but the pumped hue value was lower ($P < 0.05$) than the non-pumped hue value within the LO and Vac. At end of the retail display, the ribeye HO steaks had the highest ($P < 0.05$) hue value and CO had the lowest ($P < 0.05$) hue value (Figure 3.23). The non-pumped ribeyes had a higher ($P < 0.05$) hue value than the pumped ribeyes within the LO and Vac at the end of retail display.

The chroma values for the striploin steaks at the beginning of retail display had no difference ($P > 0.05$) for all MAP and pump (Figure 3.8). The CO had the highest ($P < 0.05$) and HO pumped had the lowest ($P < 0.05$) chroma value at the end of retail display. The ribeye steaks had no difference ($P > 0.05$) at the beginning of the retail display for all of the MAP and pump (Figure 3.24). The CO had the highest ($P < 0.05$) chroma value at the end of retail display. The non-pumped ribeyes had higher ($P < 0.05$) chroma values at the end of the retail display than the pumped ribeyes.

In the striploin steaks, the fat hue values were the higher ($P < 0.05$) for the HO in the pumped than the non-pumped (Figure 3.10). Fat Hue values for the ribeye steaks were the highest ($P < 0.05$) for the HO and lowest for CO (Figure 3.25).

Striploin steaks had highest ($P < 0.05$) fat chroma values for both the pumped and non-pumped steaks within the CO (Figure 3.11). The ribeye steaks had higher ($P < 0.05$) fat chroma values for the non-pumped steaks than the pumped steaks (Figure 3.26). The CO fat chroma values were the highest ($P < 0.05$) for both pumped and non-pumped treatments.

The lean metmyoglobin values in the striploin steaks were the higher ($P < 0.05$) in the pumped steaks versus the non-pumped steaks within the HO (Figure 3.9). Vac non-pumped had the lowest ($P < 0.05$) lean metmyoglobin values. The HO in the ribeye steaks had the highest ($P < 0.05$) values for the lean metmyoglobin values (Figure 3.27). The pumped lean metmyoglobin values were higher ($P < 0.05$) than the non-pumped lean metmyoglobin values.

Sensory

For all sensory characteristics, except for off flavor intensity and flavor intensity, the pumped striploin steaks had higher ($P = 0.001$) scores than the non-pumped striploin steaks (Table 3.1). The HO treatment resulted in lower ($P < 0.05$) sensory traits except for the initial juiciness. The off flavor intensity was highest for all of the pumped steaks versus the non-pumped steaks. The HO non-pumped had higher ($P < 0.05$) off flavor intensity scores than all other MAP.

Off Flavor

Non-pumped striploins had higher ($P < 0.05$) off flavor descriptor scores for bloody, bitter, grassy, and metallic than the pumped steaks (Table 3.2). The HO packages were higher ($P < 0.05$) for bitter, but lower for grassy, and metallic off flavors than all other MAPs within the non-pumped. For the rancid and salty off flavor descriptors within the HO were significantly different ($P < 0.05$) from all other MAP. The non-pumped striploins showed a higher ($P < 0.05$) rancid off flavor than the pumped. The pumped striploins noted a higher ($P < 0.05$) salty off flavor than the non-pumped striploins.

Retail shelf-life

The visual lean color for HO decreased ($P < 0.05$) in color scores over the day of retail display for both striploin and ribeye steaks. Non-pumped striploins and ribeyes had higher ($P < 0.05$) color scores than the pumped (Figures 3.12 and 3.28). The non-pumped ribeye steaks decreased ($P < 0.05$) gradually for HO in color scores as the day of retail display lengthened.

On day 1 of the retail display there was no difference ($P > 0.05$) in the uniformity scores for the pumped and non-pumped striploins and ribeyes (Figures 3.13 and 3.29). On day 2 the CO pumped and HO non-pumped striploins increased ($P < 0.05$) in uniformity. The HO non-pumped and pumped striploins on day 5 increased ($P < 0.05$) in uniformity scores. HO pumped and non-pumped ribeyes increased ($P < 0.05$) in uniformity scores for day 3 and day 5. On day 4, both the CO pumped and non-pumped ribeyes increased ($P < 0.05$). Day 2 LO non-pumped ribeyes increased ($P < 0.05$).

The discoloration scores for the striploin steaks increased ($P < 0.05$) for HO as the day of retail display increased (Figure 3.14). As the day of display increased, the CO remained relatively consistent in color and LO discoloration decreased ($P < 0.05$). The discoloration scores for the ribeye steaks within the CO had the lowest ($P < 0.05$) scores. The HO scores increased ($P < 0.05$) as the day of retail increased. The pumped steaks showed a more gradual decrease ($P < 0.05$) versus the non-pumped steaks which had a rapid decrease ($P < 0.05$) in discoloration scores within the LO (Figure 3.30).

The HO treatment for the striploin and ribeye steaks increased ($P < 0.05$) in lean browning scores as the day of retail display increased (Figures 3.15 and 3.31). The CO scores remained unchanged.

Lipid oxidation

Lipid oxidation was noted more ($P < 0.05$) in the pumped ribeyes than the non-pumped (Figure 3.16). The CO and HO showed higher ($P < 0.05$) tbars scores than the LO and vac. The lowest ($P < 0.05$) scores were noted in the LO for the pumped ribeyes.

DISCUSSION

Initial Color

Modified atmosphere packaging is commonly used to extend shelf-life and meat quality of beef. A combination of 20-30% CO_2 and 70-80% O_2 gases are normally used for fresh MAP beef (Blakistone, 1998). A study by O'Sullivan et al. (2003) stated that the levels for lipid oxidation were much higher in the MAP beef steak samples when compared to the aerobic packaged samples. Even though greater color stability is due to high oxygen levels, which support oxymyoglobin formation, and carbon dioxide, which acts as an antimicrobial agent, often associated with MAP; the high oxygen content of MAP can eventually lead to lipid oxidation and decrease color (Zhao et al., 1994).

The study by Robbins et al. (2003b), agrees with the present study that the non-pumped or control steaks have higher L*, a*, and b* values than the pumped or enhanced steaks. The a* values in the present study for the striploin and ribeye steaks decreased by the end of the retail display for all MAP except the CO which increased. The reduction in a* values demonstrates that there was a discoloration (loss) in red color. A study by Hunt et al. (2004) also stated similar results for the decreasing values for a* within ground beef, longissimus dorsi, and outside semimembranosus. The present study agrees with the study conducted by Stika et al. (2007) in which the pumped steaks resulted in lower a*, b*, and chroma or saturation index values than the non-pumped steaks because of the beef flavoring agent which was dark in color. The Fat a* values for the CO in both the striploins and ribeyes were higher than all other MAPs. The HO tended to increase the lightness of the Fat L*. Hue values increased for HO, LO, and Vac by the end of retail display for both striploins and ribeyes. The present study disagrees with the study by Robbins et al. (2002) which stated that hue angles increased significantly and to a greater degree in enhanced steaks when compared to the control steaks. The hue for HO increased significantly when compared to other MAPs and pumped was higher than non-pumped. The increase in hue value indicates that the color was moving away from the true red axis. The chroma values for both the striploins and ribeyes decreased significantly within the HO, LO, and Vac. The CO increased slightly. This study agrees with the study by Robbins et al. (2002) which states that the decrease in chroma values indicates that the intensity of the red color is decreasing.

Sensory

In the present study, the pumped treatment increased the sensory scores for juiciness, tenderness, off flavor, and decreased the cook-loss percent. The present study agrees with the study by Robbins et al. (2002) where enhancement of beef round steaks increased the sensory scores for tenderness and juiciness. The present study decreased the cook-loss percent for pumped steaks when compared to non-pumped steaks. The study by Robbins et al. (2002) disagrees with the present study, stating that enhancement increased the cook-loss percent when compared to a no-pump control. Pumped steaks were more salty when compared to the non-pumped steaks, which was expected since the injection treatment contained sodium phosphate and salt.

Off Flavor

In grass-fed beef, off flavors such as bitter, bloody, livery, salty, and metallic have been noted by several researchers (Robbins et al., 2002; Reverte et al., 2003; Stika et al., 2007). The panelists in the present study noted the same off flavors for the pumped and non-pumped striploins. The pumped striploins masked the grassy off flavor and decreased other off flavors as noted because of the addition of a beef flavoring agent. Similar observations were also noted by Reverte et al. (2003) and Stika et al. (2007).

Retail shelf-life

In the present study, the color scores decreased for all MAP for both the striploin and ribeye steaks. The non-pumped steaks had greater color scores than the pumped steaks. Data by Robbins et al. (2003b) supports the findings from the present study. The uniformity of the steaks were influenced by the MAP*Day interaction. As the retail display increased, the uniformity scores increased representing as less uniform product by the end of the retail display. The HO treatment tended to show the most changes in uniformity. Discoloration and metmyoglobin formation was noted the highest in the HO. The increase in discoloration and metmyoglobin values coincides with the low a* values for the HO packages. Results from Pietrasik et al. (2006) supports the findings from the present study as noted that as the retail display lengthened, more browning or discoloration was noted. Leakers were noted in several MAP packages that may result in lower shelf-life, sensory, and TBARS scores.

Lipid oxidation

In the present study thiobarbituric reactive substance values (TBARS) was conducted only on the ribeye steaks. The pumped ribeyes resulted in higher TBARS values than the non-pumped. As noted by other researchers, the increased TBARS values may be due to the addition of salt which serves as a prooxidate which promotes pigment oxidation by lowering the oxygen tension and decreasing the meat's buffering capacity, therefore the potential for myoglobin oxidation is increased (Seideman et al., 1984 and Akamittath et al., 1990). The Houben et al. (2000) study states that with the higher the amounts of grass percentage, the less lipid oxidation. This demonstrates the antioxidant effect of Vitamin E.

IMPLICATIONS

The results in the present study indicated that the pumped treated steaks did not have as well of color stability instrumentally as the non-pumped steaks in the retail display. Overall sensory characteristics were improved by the pumped treatment. The carbon monoxide packaging maintained the bright-cherry, red color that consumers desire.

Table 3.1. Least Square Means ± SEM of Sensory Loin Steaks from four different MAP packaging treatments and two pump treatments.

	Non-Pumped				Pumped					P > F		
	CO^{e}	HO	LO	Vac	CO	HO	LO	Vac	SEM	Pump	MAP	Pump*MAP
Initial Juiciness^{a}	5.6	5.3^{A}	5.6^{B}	5.6	6.3	6.1	6.3	6.3	0.128	0.001	0.12	0.93
Sustained Juiciness^{a}	5.3^{f}	5.0^{gA}	5.3^{fB}	5.3^{f}	6.2^{f}	5.9^{g}	6.1^{f}	6.1^{f}	0.133	0.001	0.04	0.90
Initial Tenderness^{b}	5.8^{f}	5.1^{gA}	5.5^{fB}	5.6^{f}	6.9^{f}	6.2^{g}	7.0^{f}	7.1^{f}	0.131	0.001	0.001	0.30
Sustained Tenderness^{b}	5.3^{f}	4.6^{gA}	5.0^{fB}	5.2^{f}	6.7^{f}	5.8^{g}	6.7^{f}	6.7^{f}	0.147	0.001	0.001	0.32
Flavor Intensity^{c}	6.1^{f}	4.6^{gA}	5.8^{fB}	5.8^{f}	5.8^{f}	4.4^{g}	5.8^{f}	5.8^{f}	0.098	0.11	0.001	0.17
Off Flavor Intensity^{d}	2.5^{i}	5.9^{gA}	2.9^{iB}	2.9^{i}	5.0^{h}	6.8^{f}	4.8^{h}	4.7^{h}	0.190	0.001	0.001	0.005
Cook Loss,%	12.9^{f}	8.7^{gA}	11.0^{fB}	11.5^{f}	8.8^{f}	5.8^{g}	9.6^{f}	9.9^{f}	0.665	0.001	0.001	0.13

[f, g, h, i] Means in a row with different superscripts differ ($P < 0.05$).

[a] 5=slightly juicy, 6=moderately juicy.

[b] 5=slightly tender, 6=moderately tender.

[c] 5=slightly intense beef, 6=moderately intense beef.

[d] 5=moderate off flavor, 6=very off flavor.

[e] CO=Carbon monoxide packaging, HO=High Oxygen packaging, LO=Low oxygen packaging, Vac=Vacuum Packaging

[A] SEM=0.116, 0.120, 0.118, 0.133, 0.088, 0.172, 0.602 for Initial Juiciness, Sustained Juiciness, Initial Tenderness, Sustained Tenderness, Flavor Intensity, Off Flavor, and Cook Loss% respectively.

[B] SEM=0.125, 0.129, 0.127, 0.143, 0.095, 0.185, 0.648 for Initial Juiciness, Sustained Juiciness, Initial Tenderness, Sustained Tenderness, Flavor Intensity, Off Flavor, and Cook Loss% respectively.

Table 3.2. Incidence of Off flavor descriptors as a percent for striploin steaks for non-pumped and pumped injection treatments and MAP packages.

	Non-Pumped				Pumped				P > F		
	CO^{e}	HO	LO	Vac	CO	HO	LO	Vac	Pump	MAP	Pump*MAP
Other	0.8±0.77	0.6±0.63	2.1±0.72	0.7±0.75	0.0±0.68	0.0±0.62	1.9±0.68	0.6±0.67	0.39	0.06	0.96
Rancid	18.2±3.87^{c}	62.0±3.15^{a}	25.8±3.59^{c}	18.2±3.73^{c}	24.0±3.38^{c}	50.0±3.12^{b}	17.0±3.42^{c}	23.1±3.35^{c}	0.31	0.001	0.01
Bloody	1.6±1.03	0.6±0.84	3.4±0.95	4.4±0.99	1.2±0.90	0.1±0.83	1.3±0.91	0.03±0.89	0.004	0.08	0.12
Bitter	3.2±1.54^{b}	4.3±1.26^{b}	2.8±1.43^{b}	8.7±1.49^{a}	2.4±1.35^{b}	1.1±1.24^{b}	1.2±1.36^{b}	3.0±1.34^{a}	0.004	0.03	0.31
Grassy	24.5±3.12^{a}	18.9±2.54^{b}	22.4±2.89^{ab}	24.8±3.00^{a}	13.8±2.72^{a}	4.2±2.51^{b}	8.0±2.76^{ab}	10.7±2.70^{a}	0.001	0.03	0.88
Livery	0.0±0.69	1.1±0.57	1.4±0.64	0.71±0.67	0.0±0.61	1.5±0.56	0.0±0.61	0.0±0.60	0.36	0.17	0.42
Salty	7.7±3.60^{c}	8.9±2.93^{c}	9.2±3.34^{c}	3.8±3.47^{c}	51.5±3.14^{a}	41.0±2.90^{b}	55.7±3.19^{a}	53.7±3.12^{a}	0.001	0.11	0.02
Metallic	8.6±1.97^{ab}	3.1±1.60^{b}	8.0±1.82^{a}	8.1±1.89^{a}	2.4±1.72^{ab}	1.5±1.58^{b}	8.0±1.74^{a}	4.7±1.71^{a}	0.02	0.005	0.35

$^{a, b, c, d}$ Means in a row with different superscripts differ for ($P < 0.05$).

^{e}CO=Carbon monoxide packaging, HO=High Oxygen packaging, LO=Low oxygen packaging, Vac=Vacuum Packaging

Figure 3.1. Least square means ± SEM for CIE L* instrumental values of striploin steaks by pumped and non-pumped treatments at beginning and end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped, D= day of retail display. CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE L* Value (increasing value indicates a lighter color).

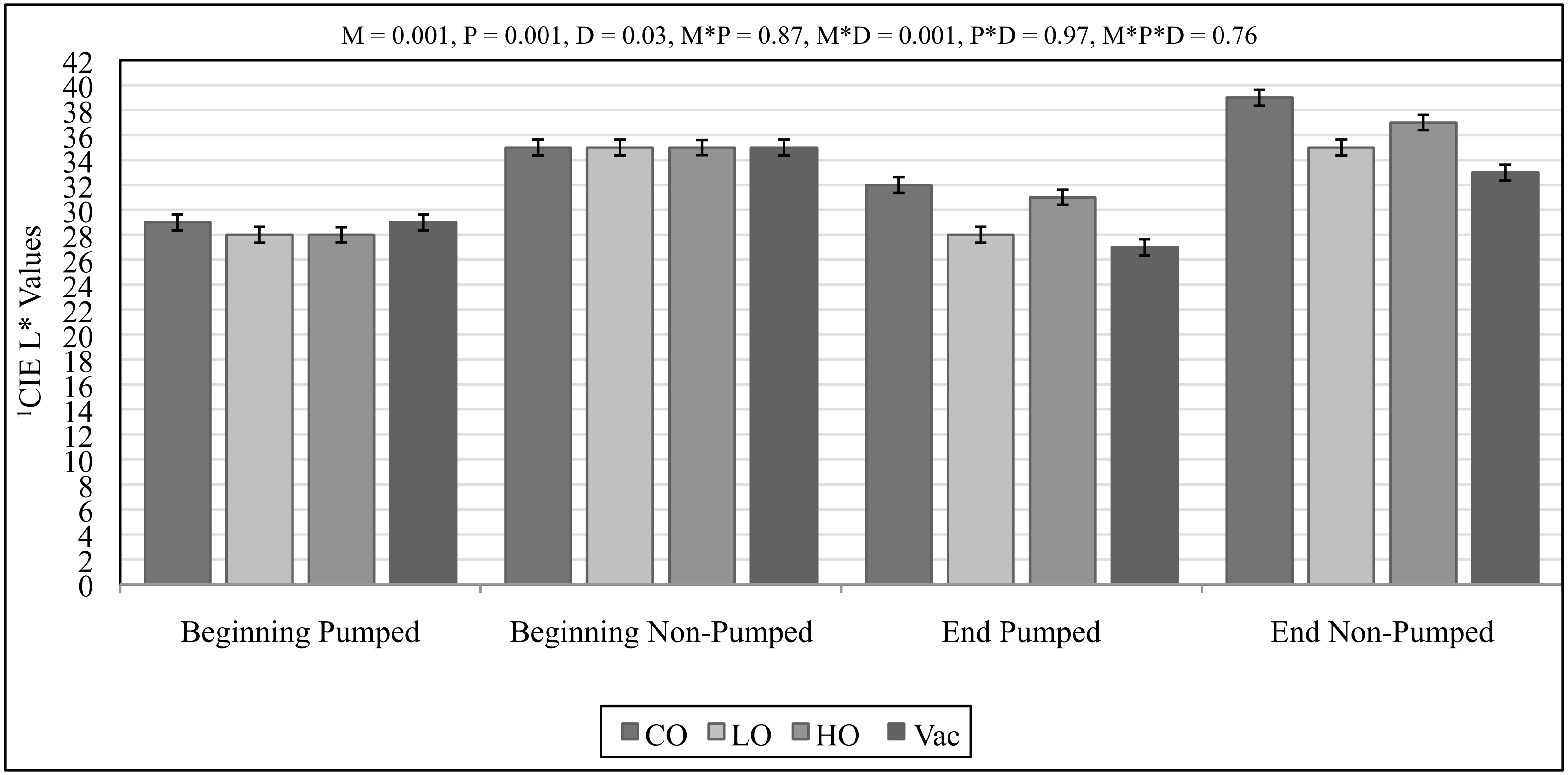


Figure 3.2. Least square means ± SEM for CIE a* instrumental values of striploin steaks by pumped and non-pumped treatments at beginning and end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped, D= day of retail display. CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE a* Value (positive = red, 0 = neutral, negative = green).

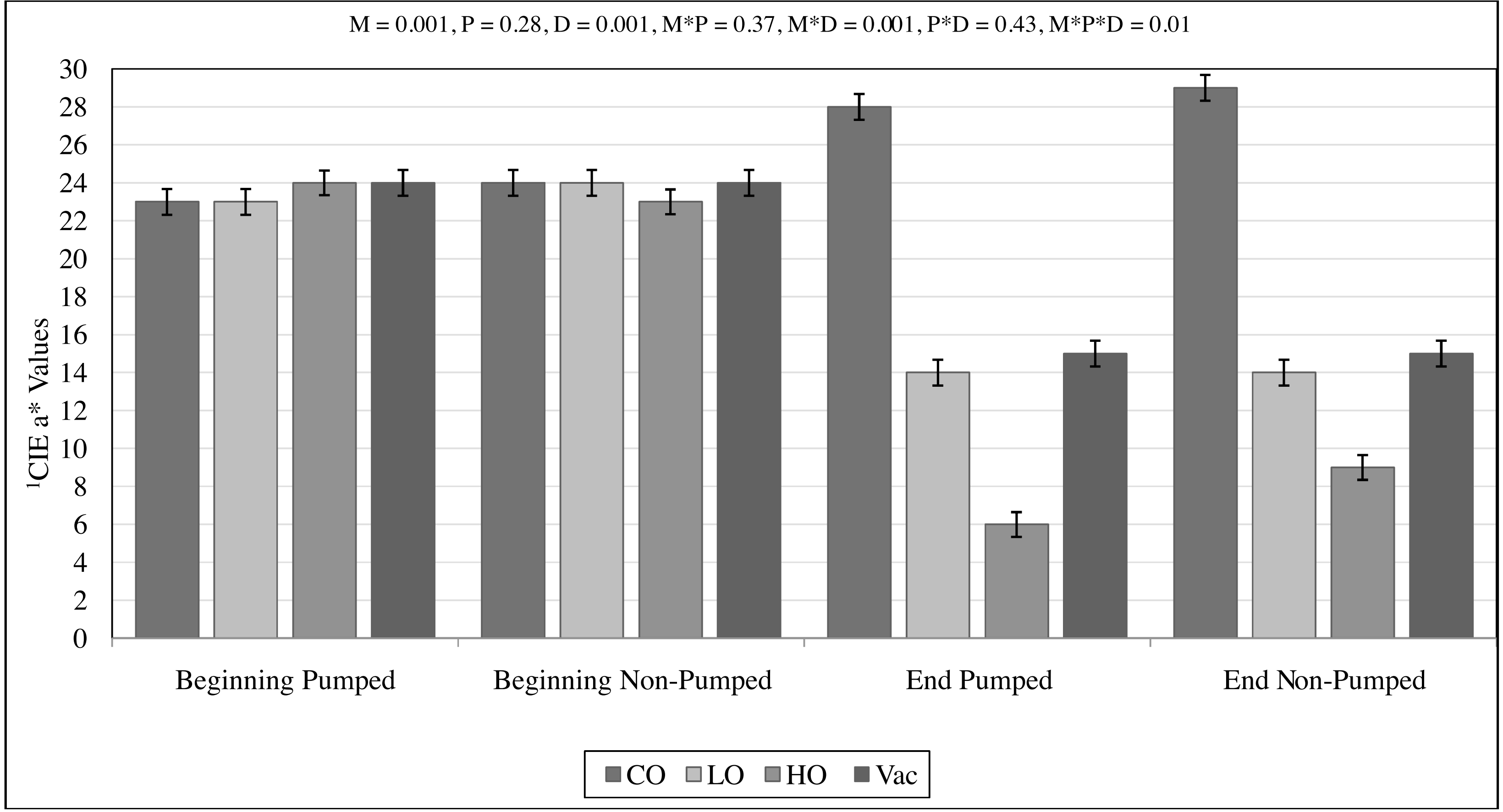


Figure 3.3. Least square means ± SEM for CIE b* instrumental values of striploin steaks by pumped and non-pumped treatments at beginning and end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped, D= day of retail display. CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE b* Value (positive = yellow, 0 = neutral, negative = blue).

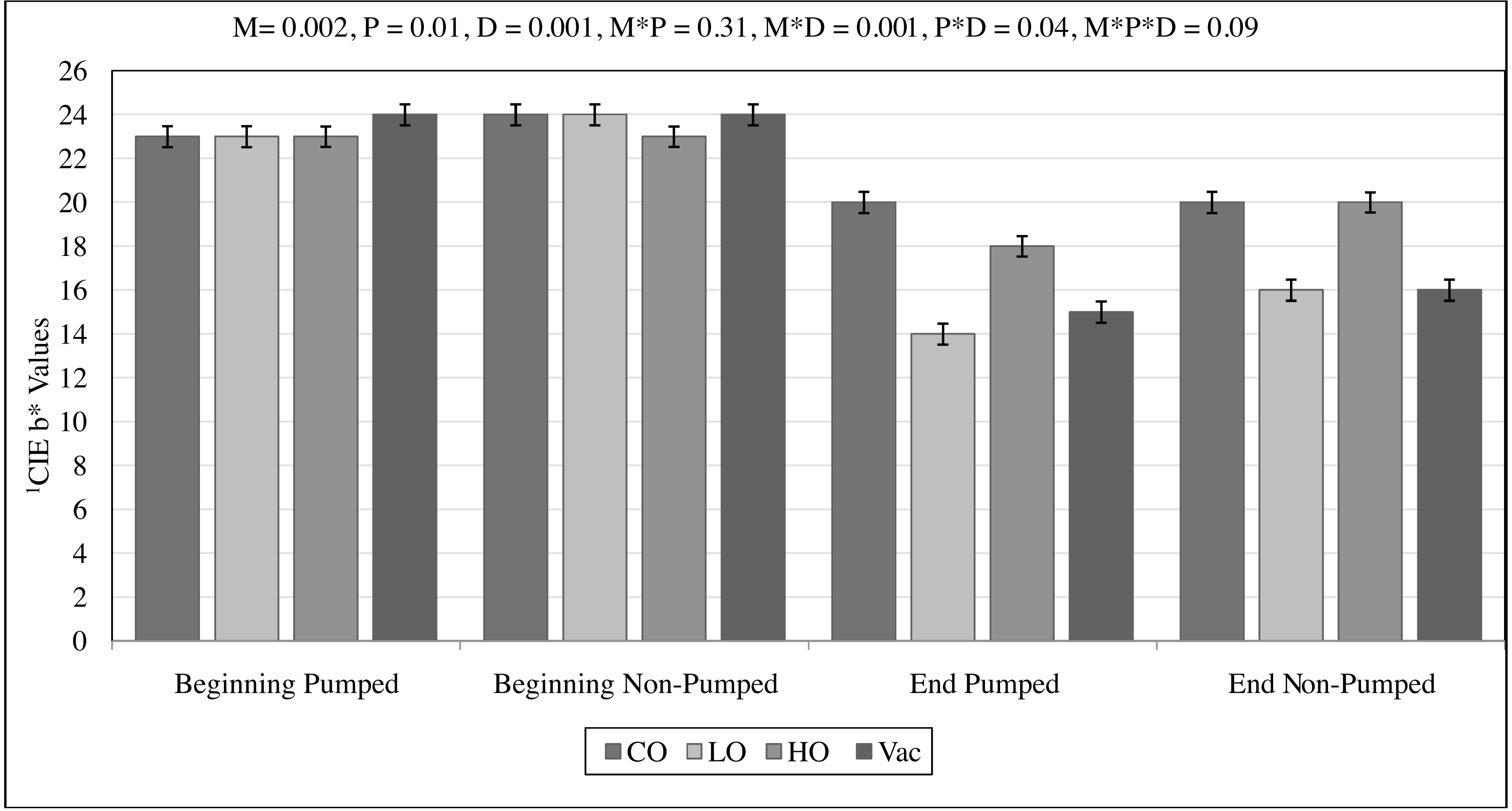


Figure 3.4. Least square means ± SEM for CIE Fat L* instrumental values of striploin steaks by pumped and non-pumped treatments at the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped; CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE Fat L* Value (increasing value indicates a lighter color).

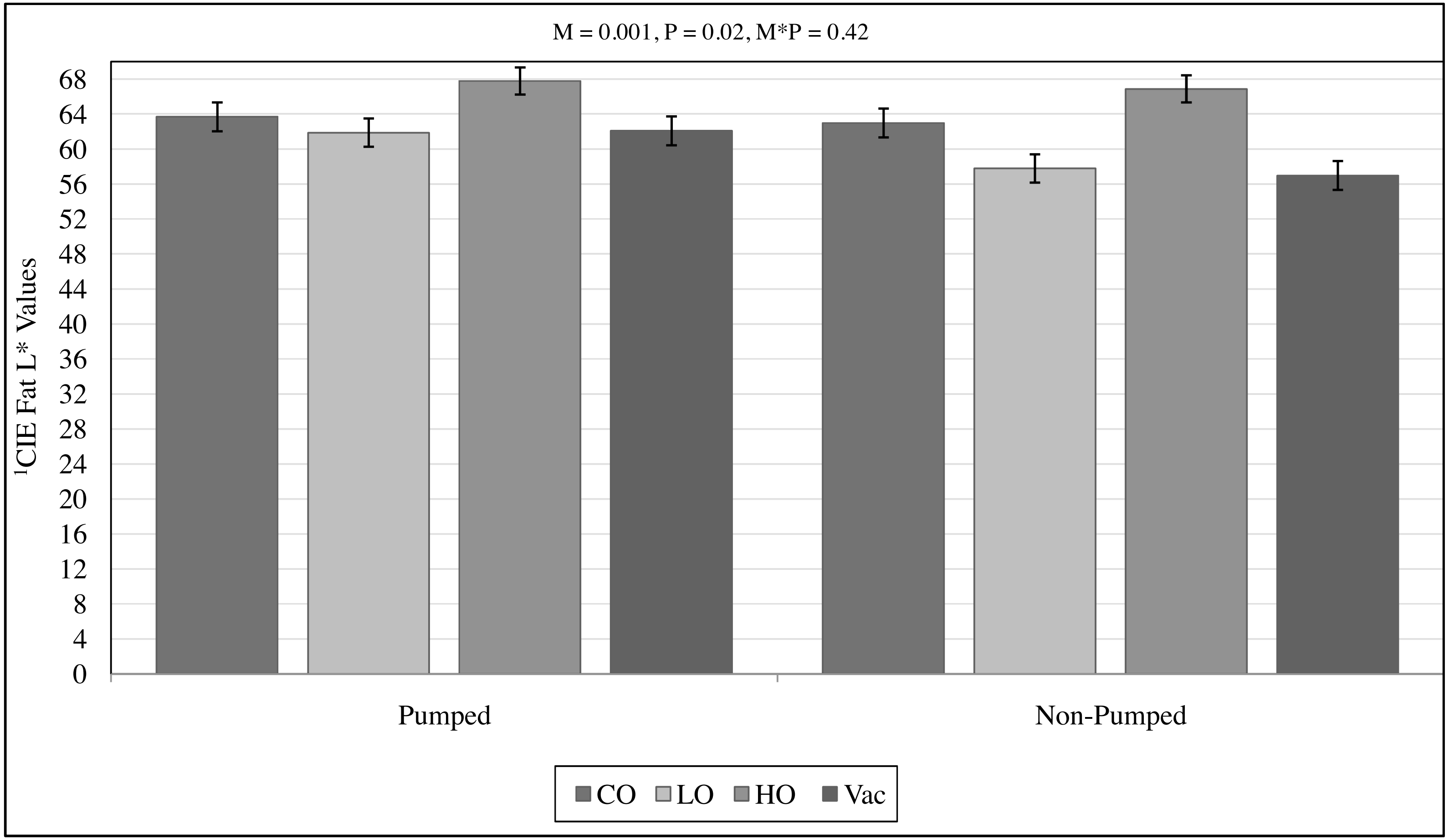


Figure 3.5. Least square means ± SEM for CIE Fat a* instrumental values of striploin steaks by pumped and non-pumped treatments at the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped; CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE Fat a* Value (positive = red, 0 = neutral, negative = green).

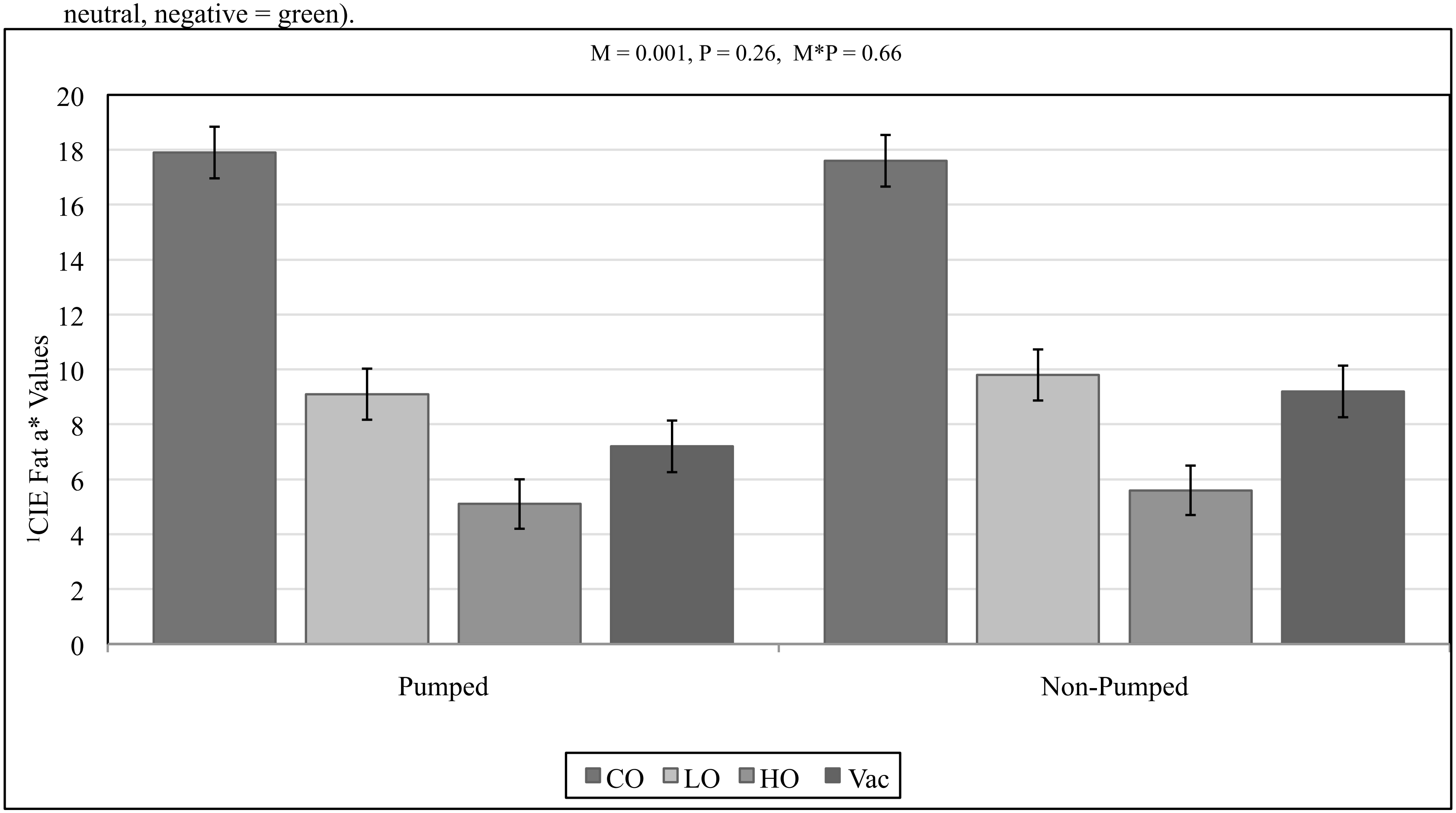


Figure 3.6. Least square means ± SEM for CIE Fat b* instrumental values of striploin steaks by pumped and non-pumped treatments at the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non- pumped; CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE Fat b* Value (positive = yellow, 0 = neutral, negative = blue).

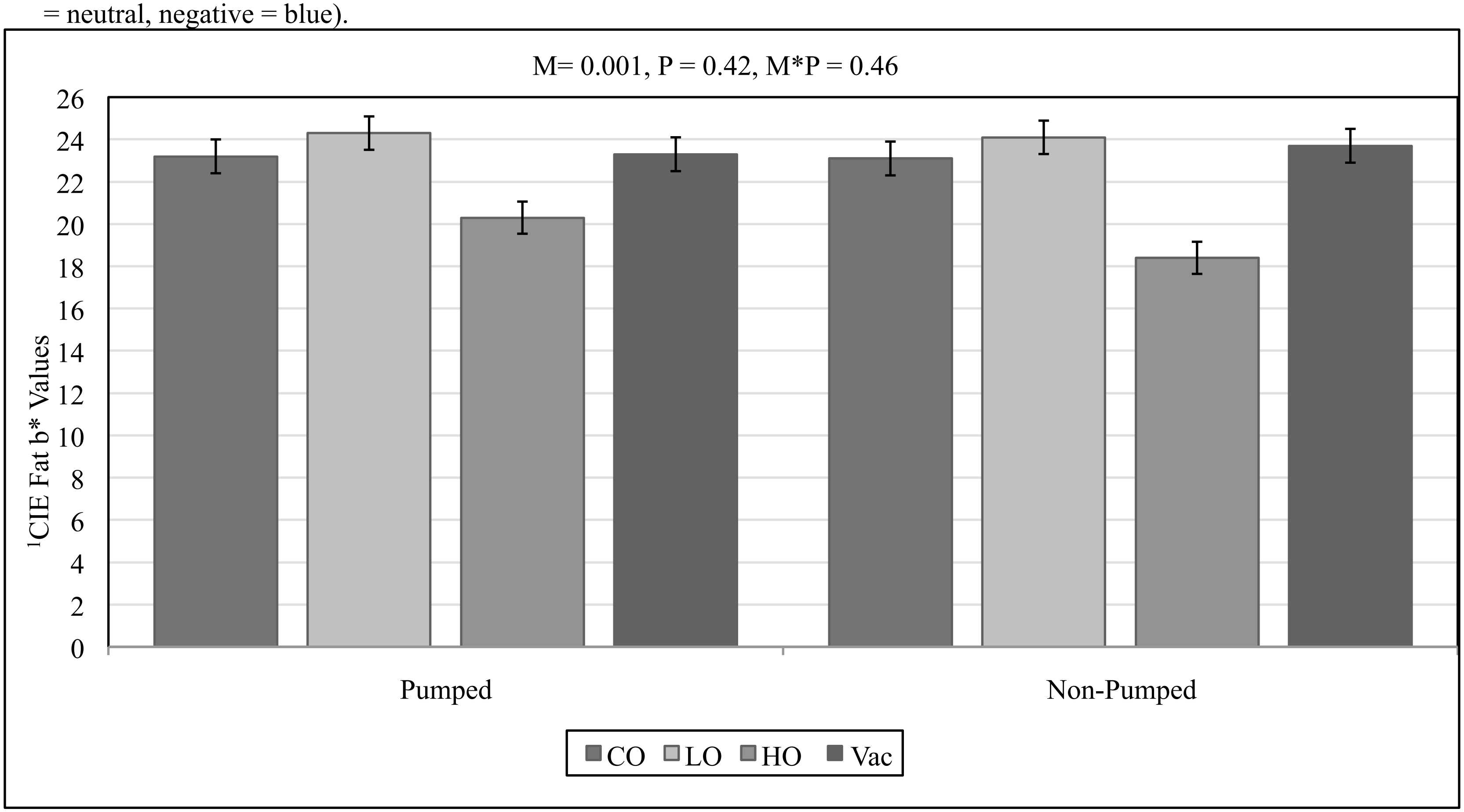


Figure 3.7. Least square means ± SEM for lean Hue instrumental values of striploin steaks by pumped and non-pumped treatments at beginning and end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped, D= day of retail display. CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]Lean Hue Value (numerically decreasing true red color).

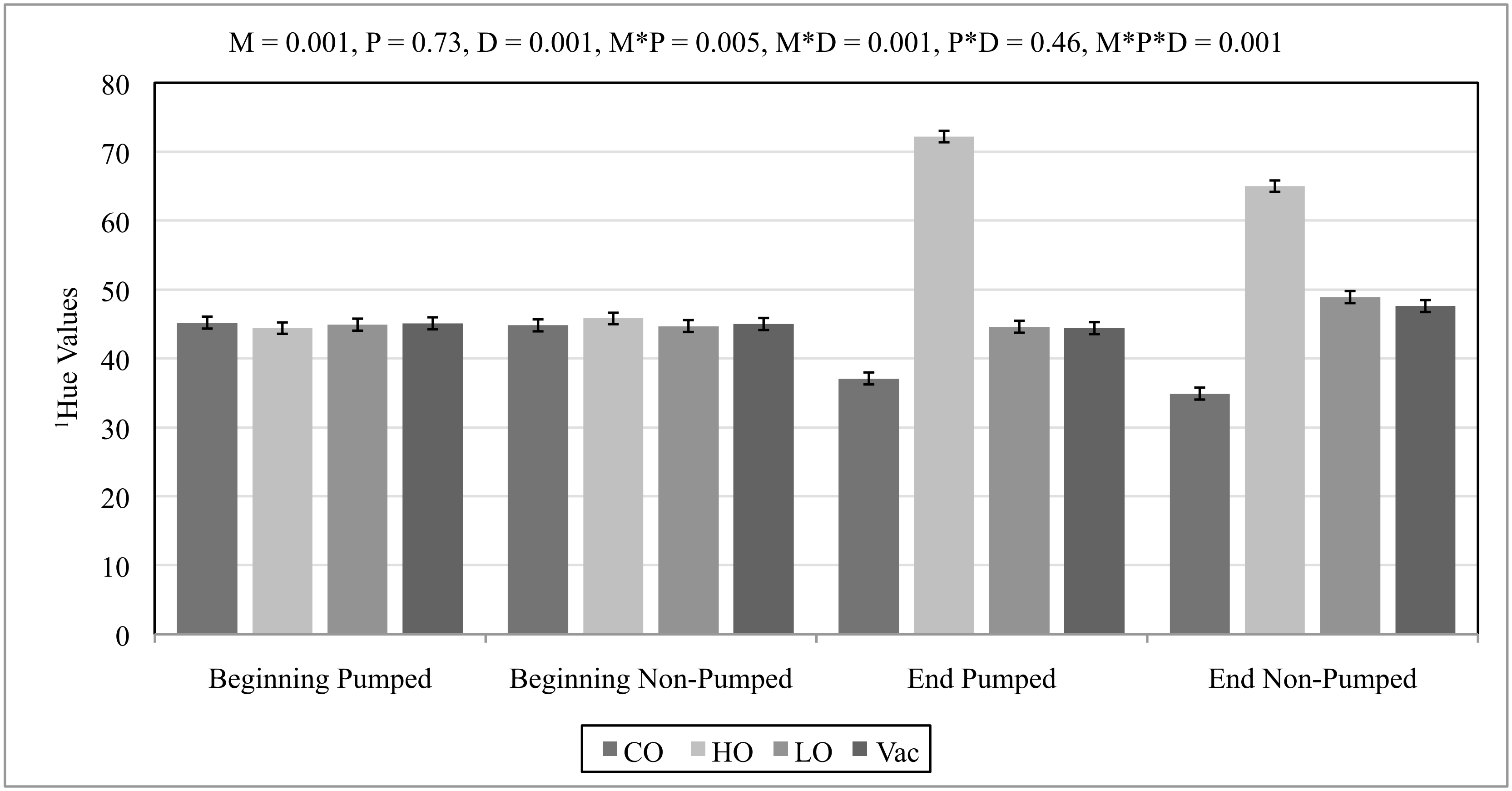
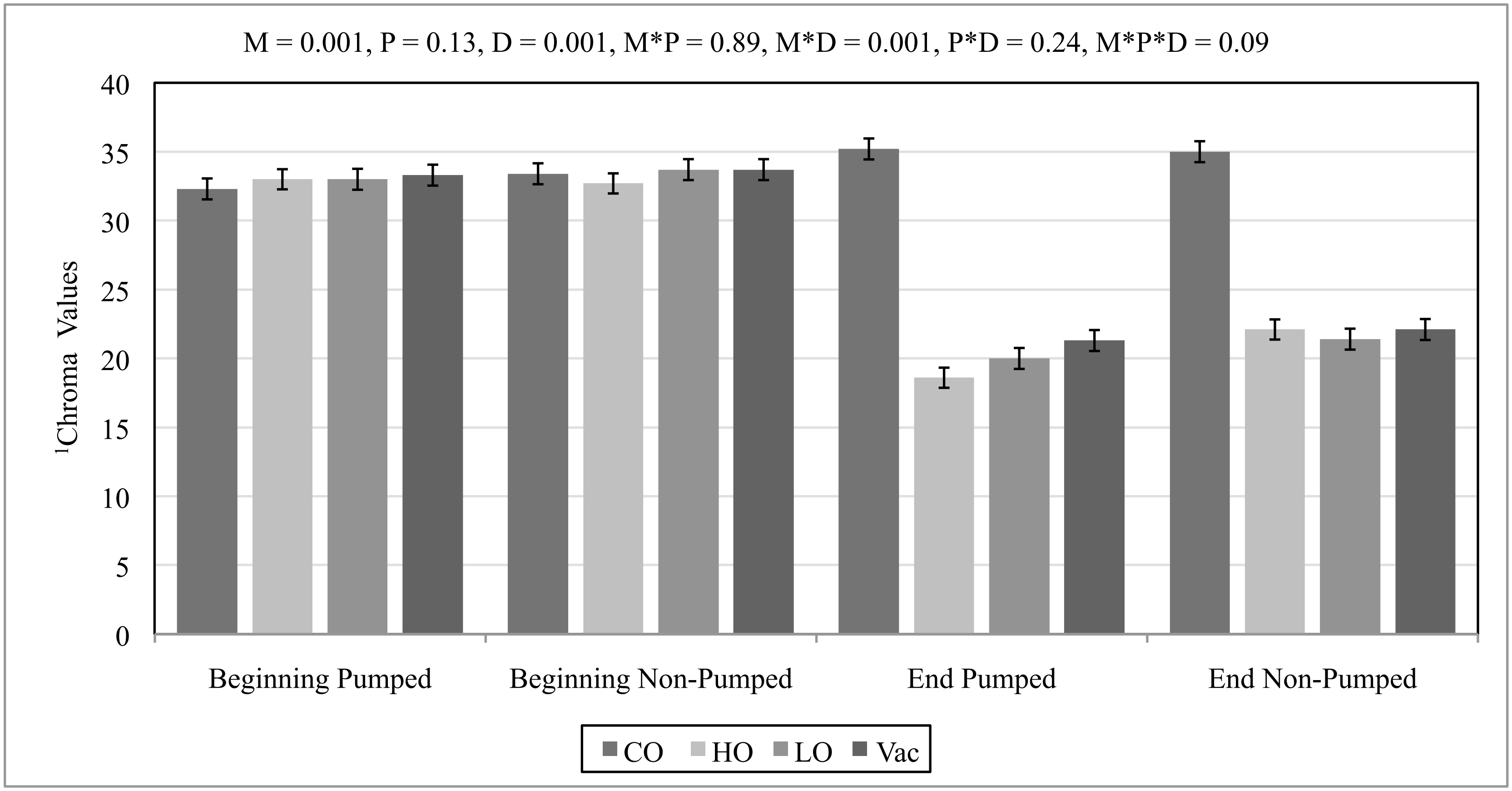


Figure 3.8. Least square means ± SEM for lean Chroma instrumental values of striploin steaks by pumped and non-pumped treatments at beginning and end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped, D= day of retail display. CO= carbon monoxide, LO= low oxygen, HO= high oxygen, Vac= vacuum packed; [1]Lean Chroma Value (numerically increasing color saturation).



M = 0.001, P = 0.13, D = 0.001, M*P = 0.89, M*D = 0.001, P*D = 0.24, M*P*D = 0.09

Figure 3.9. Least square means ± SEM for lean metmyoglobin instrumental values of striploin steaks by pumped and non-pumped treatments the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped. CO= carbon monoxide, LO= low oxygen, HO= high oxygen, Vac= vacuum packed; [1]Lean Metmyoglobin percentage (oxidized myoglobin pigment)

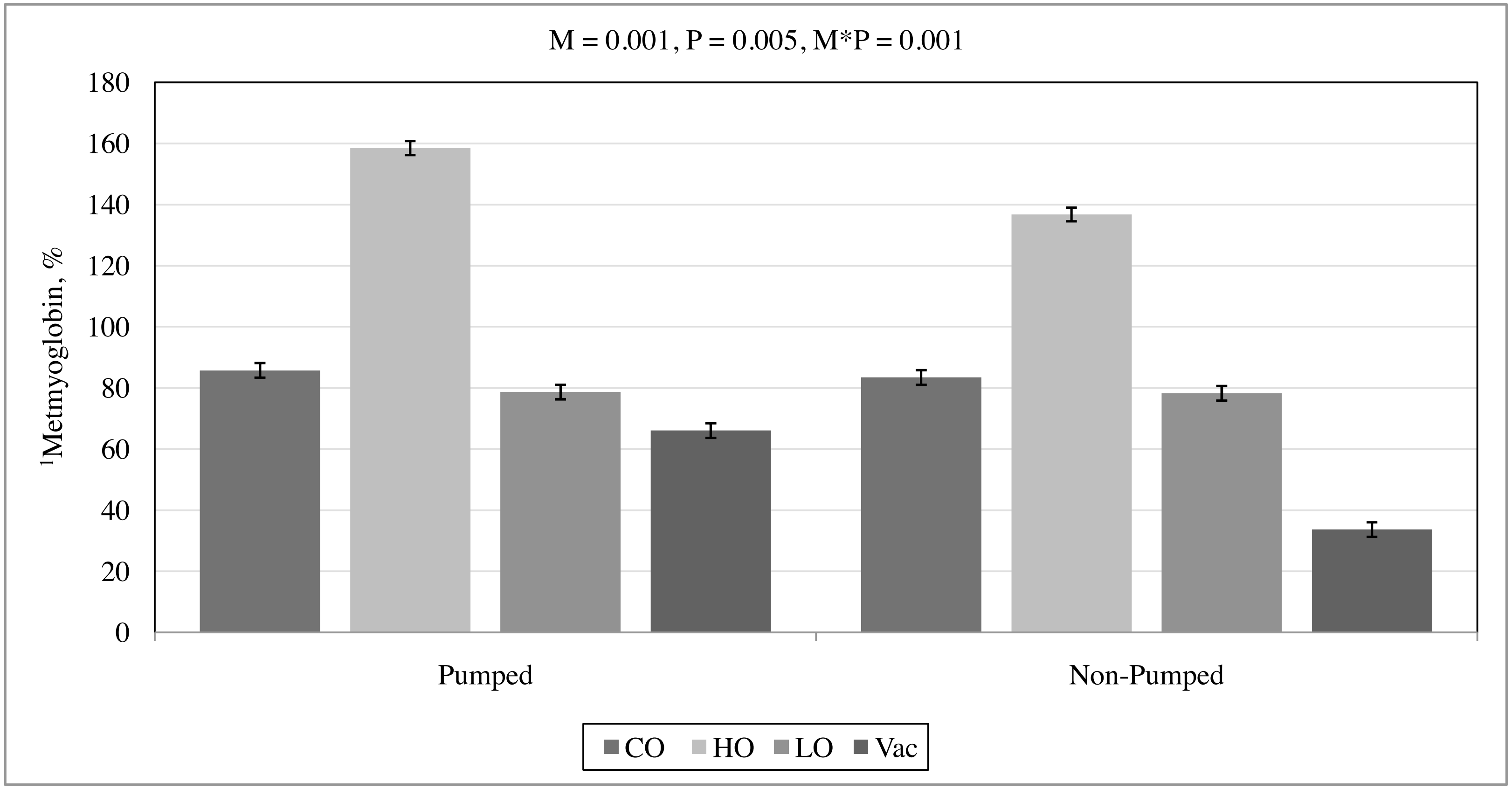


Figure 3.10. Least square means ± SEM for fat Hue instrumental values of striploin steaks by pumped and non-pumped treatments at the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped; CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]Fat Hue Value (numerically increasing true red color).

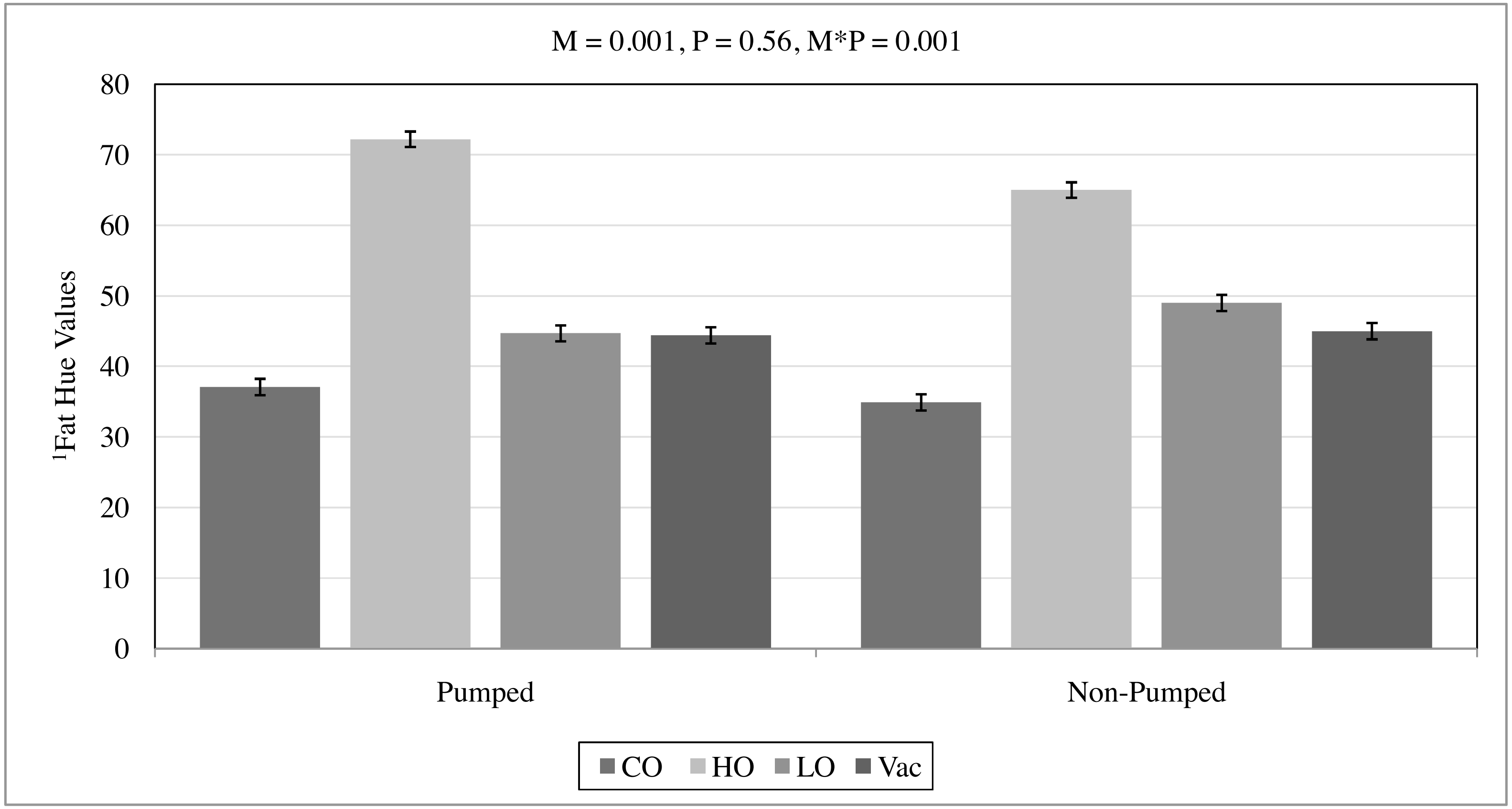


Figure 3.11. Least square means ± SEM for fat Chroma instrumental values of striploin steaks by pumped and non-pumped treatments at the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped; CO= carbon monoxide, LO= low oxygen, HO= high oxygen, Vac= vacuum packed; [1]Fat Chroma Value (numerically increasing color saturation).

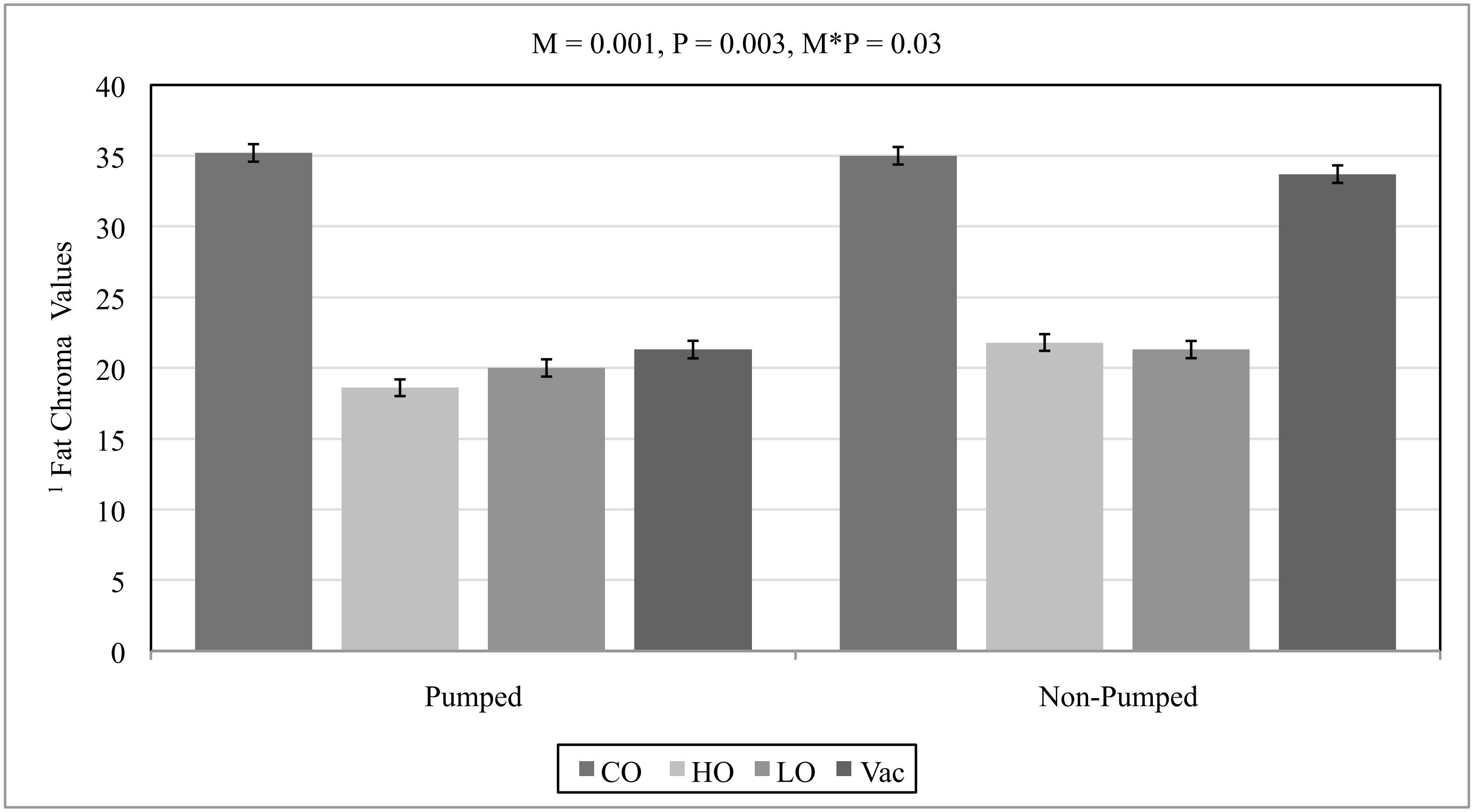


Figure 3.12. Least square means ± SEM for visual lean color of striploin steaks by retail display day within pumped and non-pumped treatments for MAP. M= modified atmosphere packaging, P = pumped or non-pumped, D = day of retail display. CO = carbon monoxide, LO = low oxygen, HO = high oxygen; [1]Lean color (1 = extremely dark red; 8 = extremely bright cherry-red)

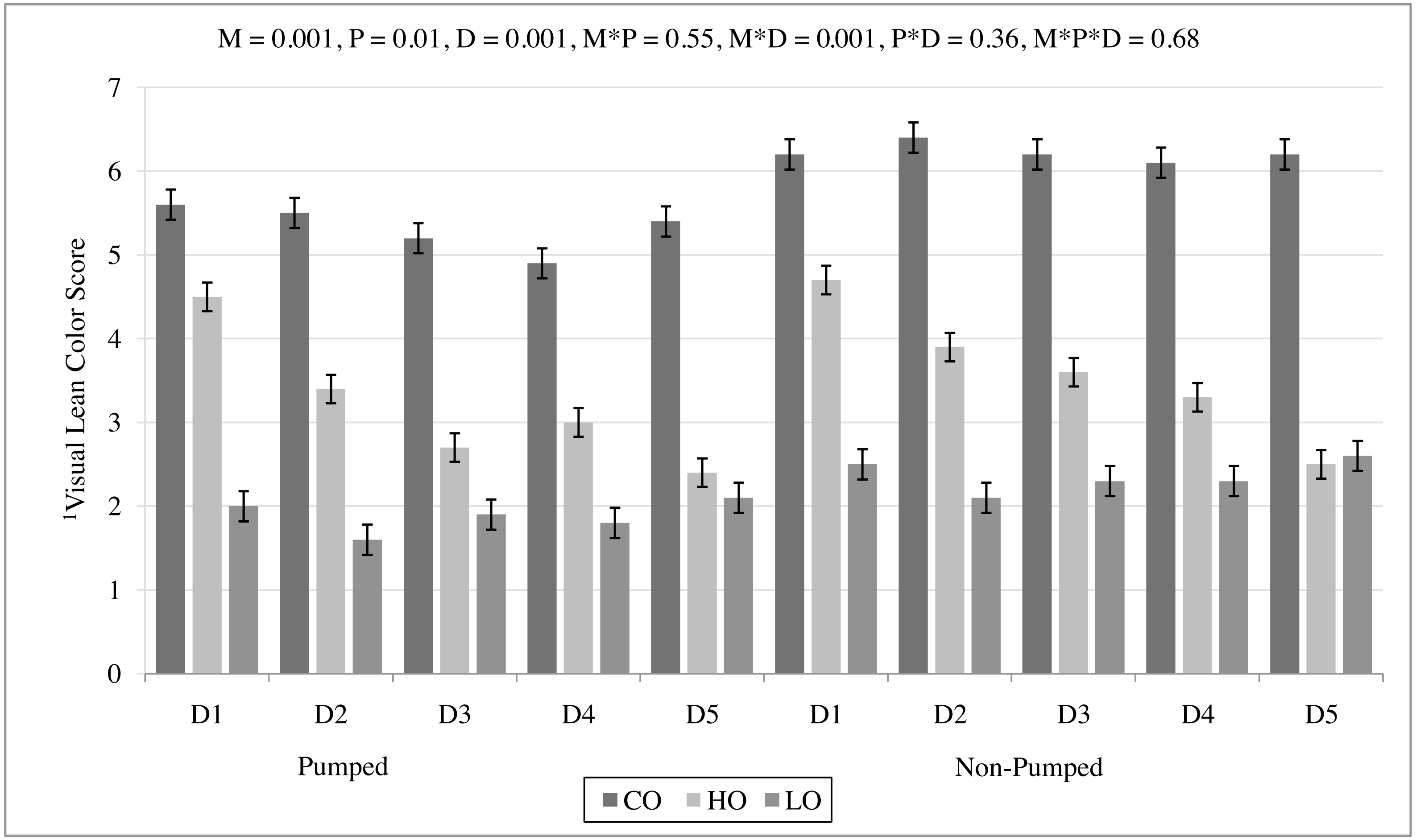


Figure 3.13. Least square means ± SEM for visual lean uniformity of striploin steaks by retail display day within pumped and non-pumped treatments for MAP. M= modified atmosphere packaging, P = pumped or non-pumped, D = day of retail display. CO = carbon monoxide, LO = low oxygen, HO = high oxygen; [1]Lean color uniformity (1 = uniform; 5 = extreme two-toning)

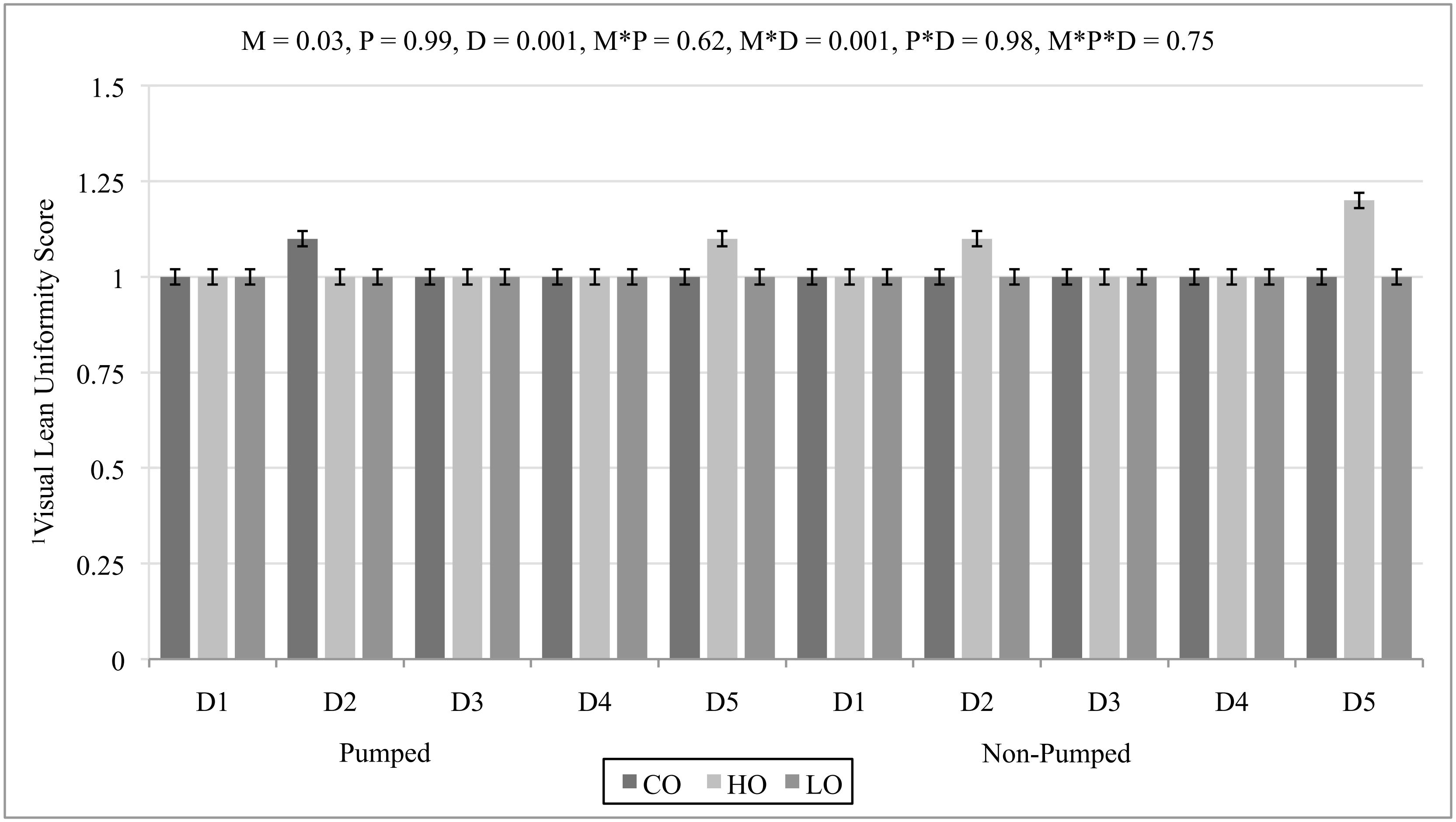


Figure 3.14. Least square means ± SEM for visual lean discoloration of striploin steaks by retail display day within pumped and non-pumped treatments for MAP. M= modified atmosphere packaging, P = pumped or non-pumped, D = day of retail display. CO = carbon monoxide, LO = low oxygen, HO = high oxygen; [1]Lean discoloration (1 = none; 7 = total discoloration)

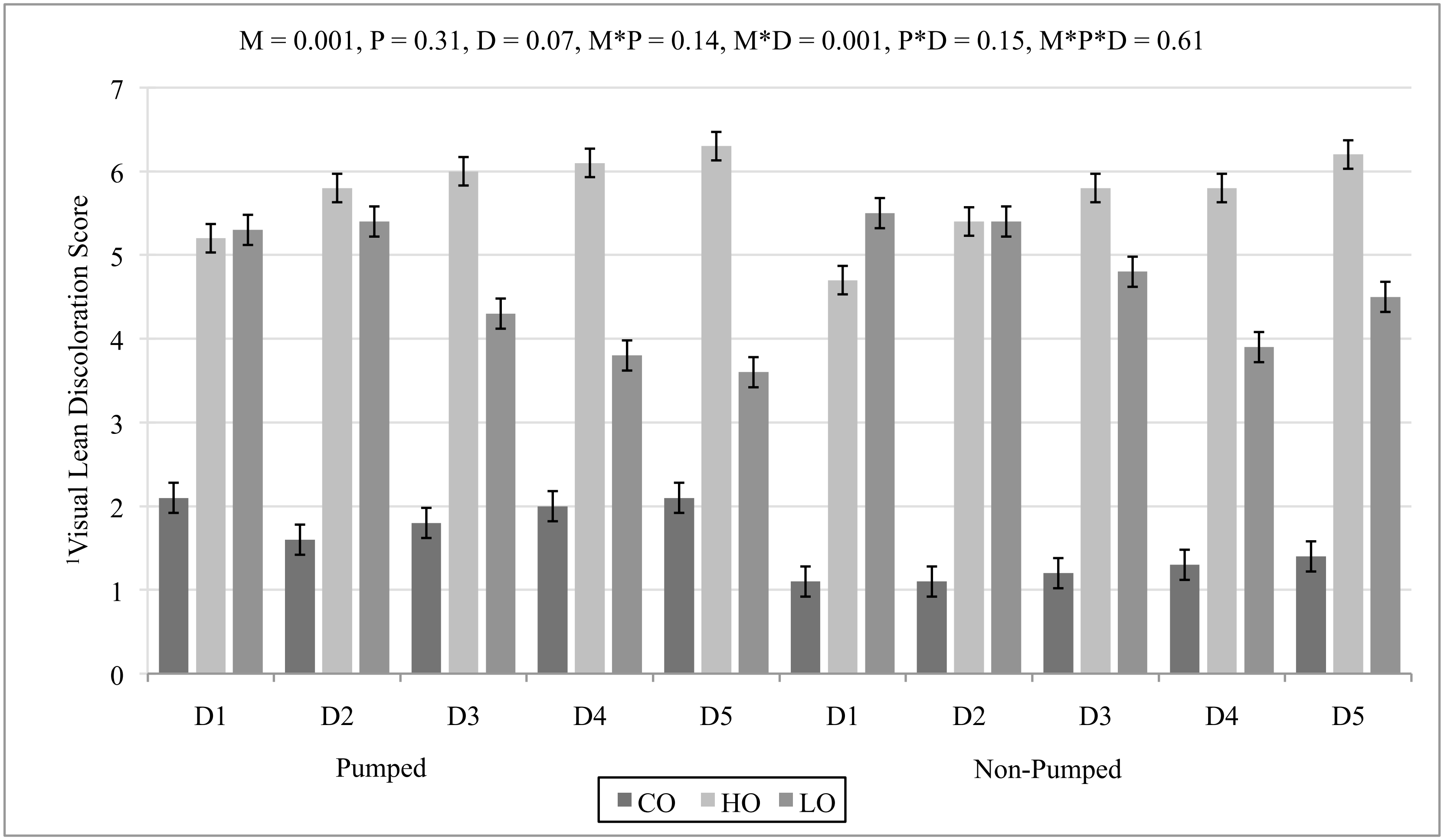


Figure 3.15. Least square means ± SEM for visual lean browning of striploin steaks by retail display day within pumped and non-pumped treatments for MAP. M= modified atmosphere packaging, P = pumped or non-pumped, D = day of retail display. CO = carbon monoxide, LO = low oxygen, HO = high oxygen; [1]Lean browning (1 = none; 5 = dark brown)

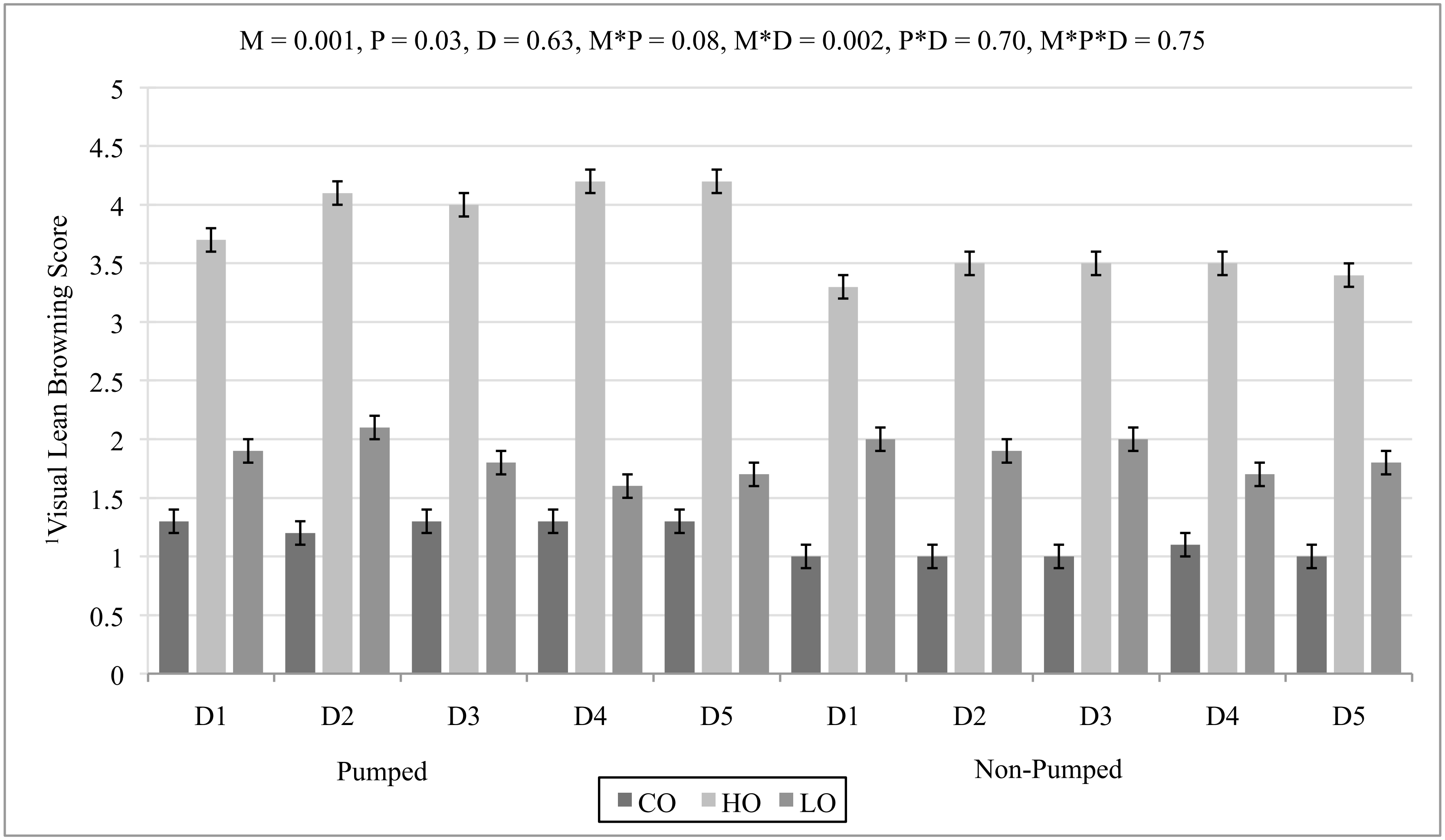


Figure 3.16. Least square means ± SEM for thiobarbituric reactive substance values of ribeye steaks at the end of retail display by pumped and non-pumped treatments for MAP. M = modified atmosphere packaging, P = pumped or non-pumped; CO = carbon monoxide, HO = high oxygen, LO = low oxygen

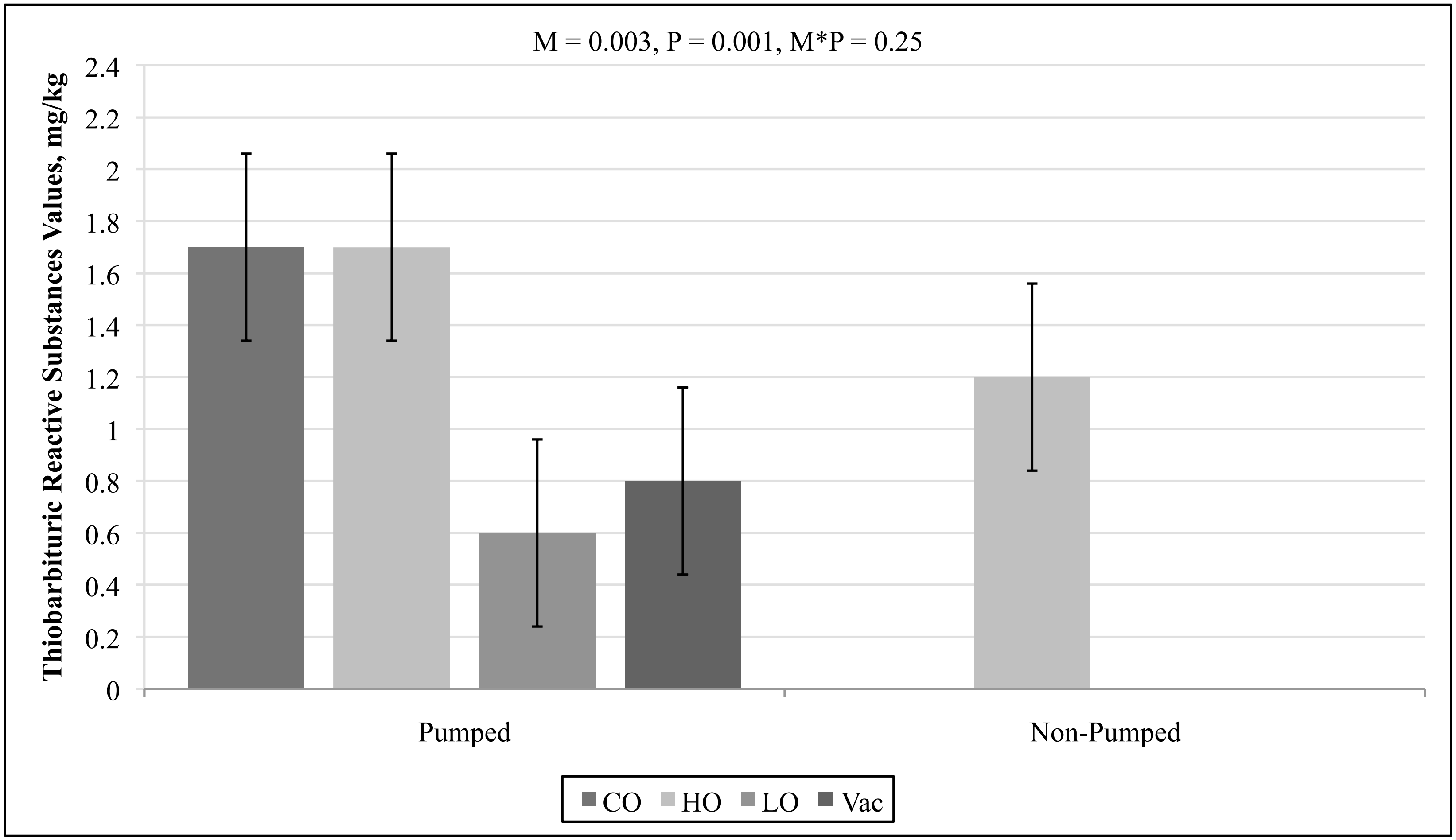


Figure 3.17. Least square means ± SEM for CIE L* instrumental values of ribeye steaks by pumped and non-pumped treatments at beginning and end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped, D= day of retail display. CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE L* Value (increasing value indicates a lighter color).

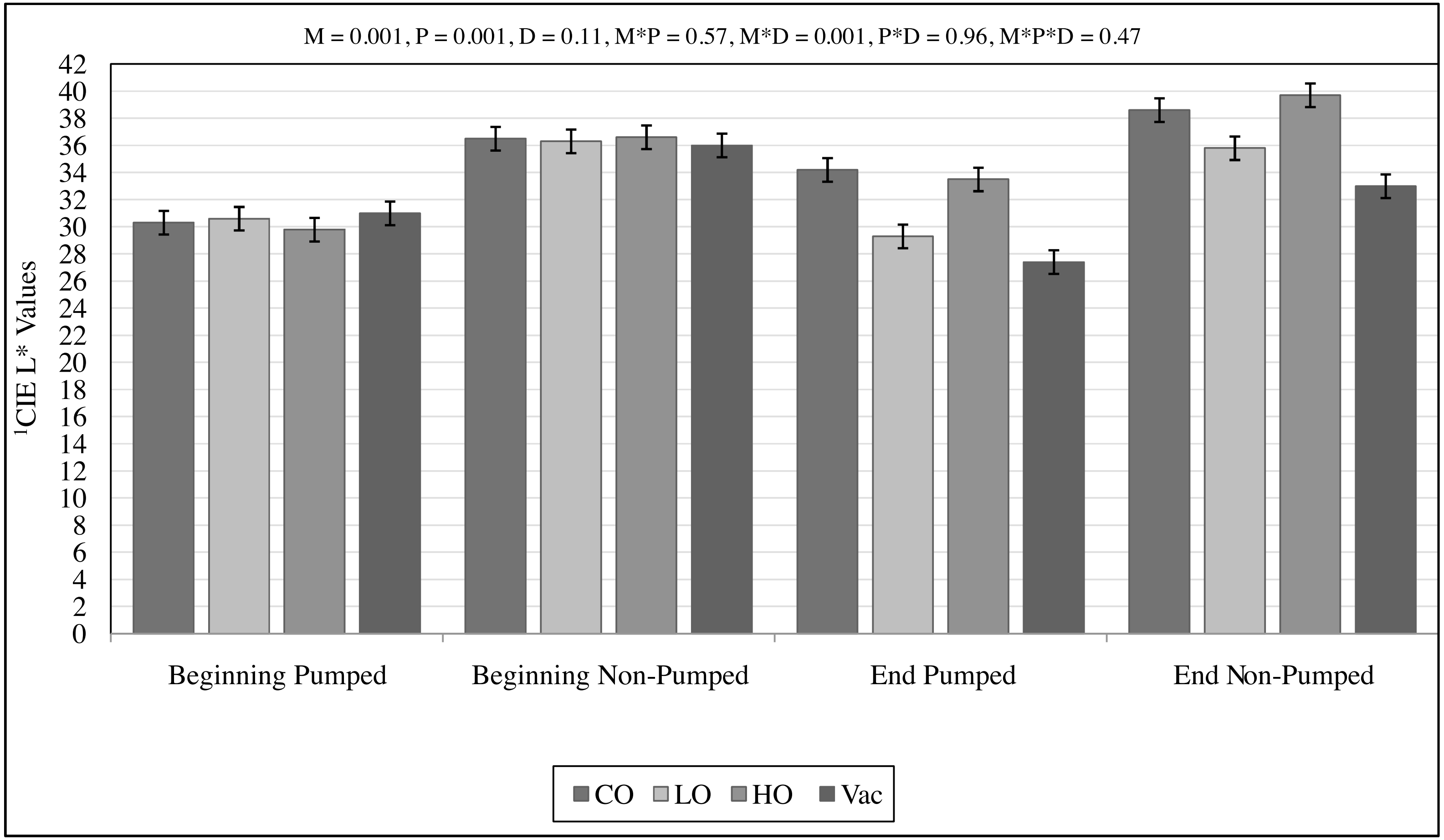


Figure 3.18. Least square means ± SEM for CIE a* instrumental values of ribeye steaks by pumped and non-pumped treatments at beginning and end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped, D= day of retail display. CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE a* Value (positive = red, 0 = neutral, negative = green).

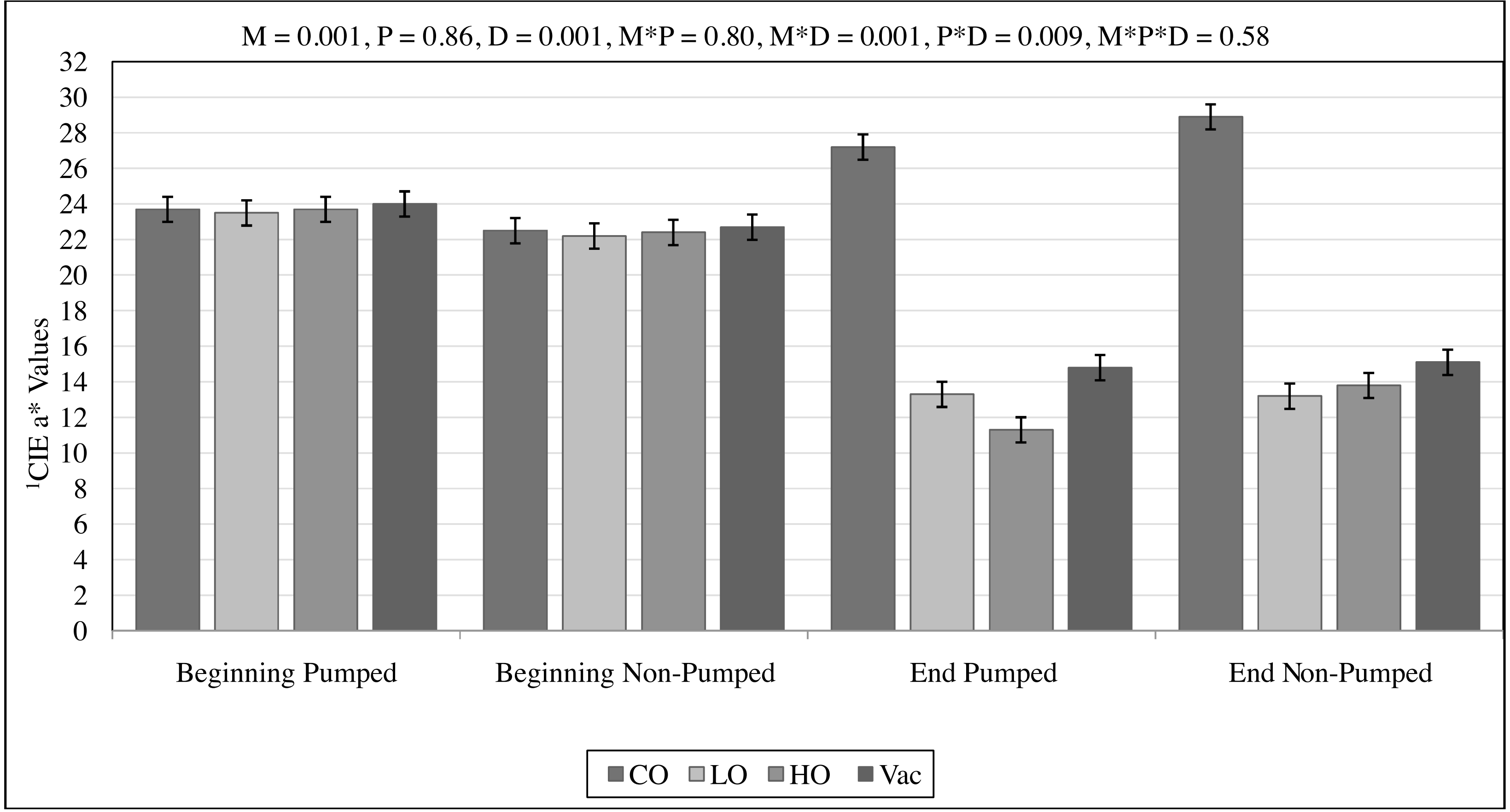


Figure 3.19. Least square means ± SEM for CIE b* instrumental values of ribeye steaks by pumped and non-pumped treatments at beginning and end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped, D= day of retail display. CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE b* Value (positive = yellow, 0 = neutral, negative = blue).

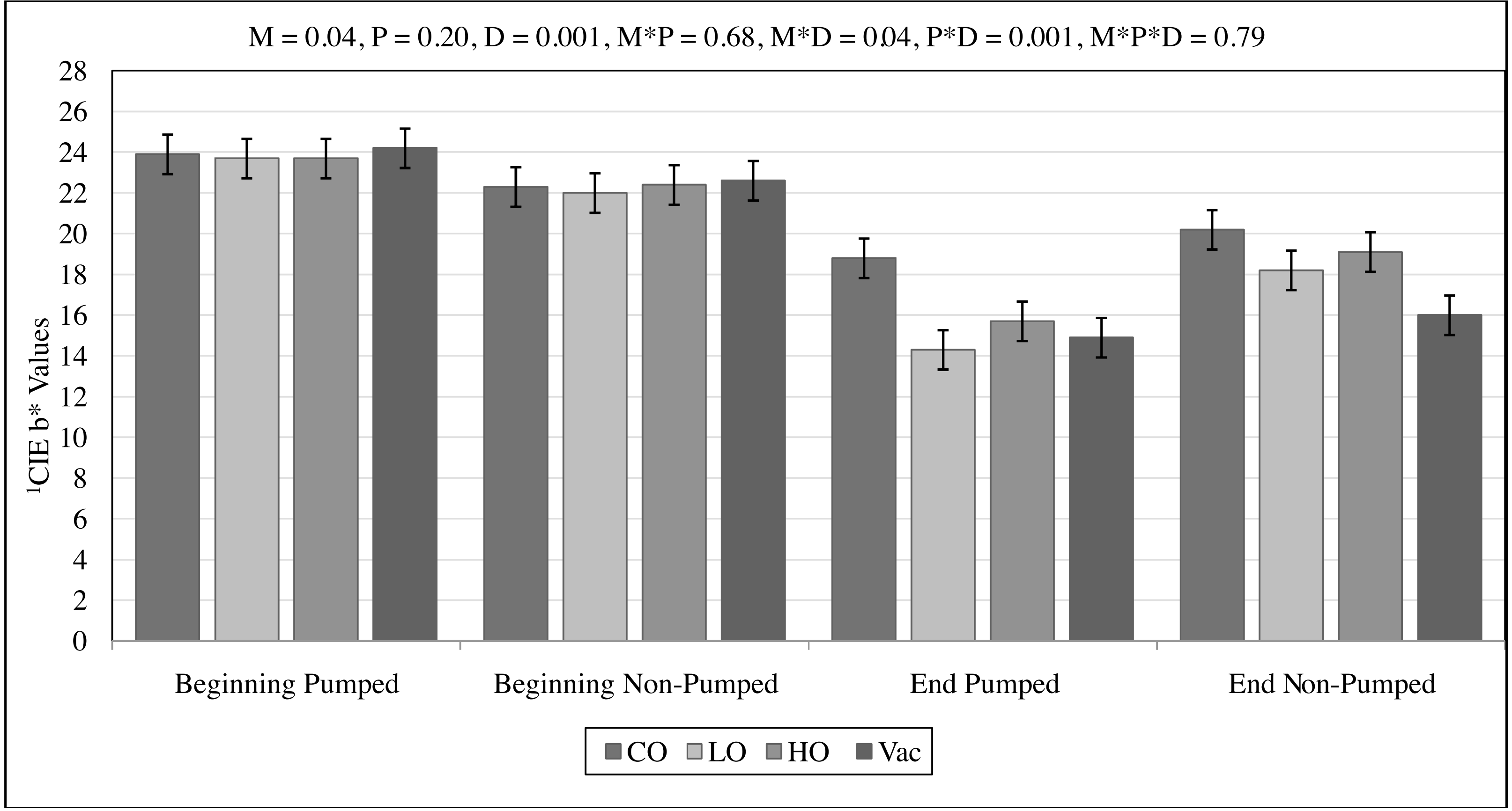


Figure 3.20. Least square means ± SEM for CIE Fat L* instrumental values of ribeye steaks by pumped and non-pumped treatments at the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped; CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE Fat L* Value (increasing value indicates a lighter color).

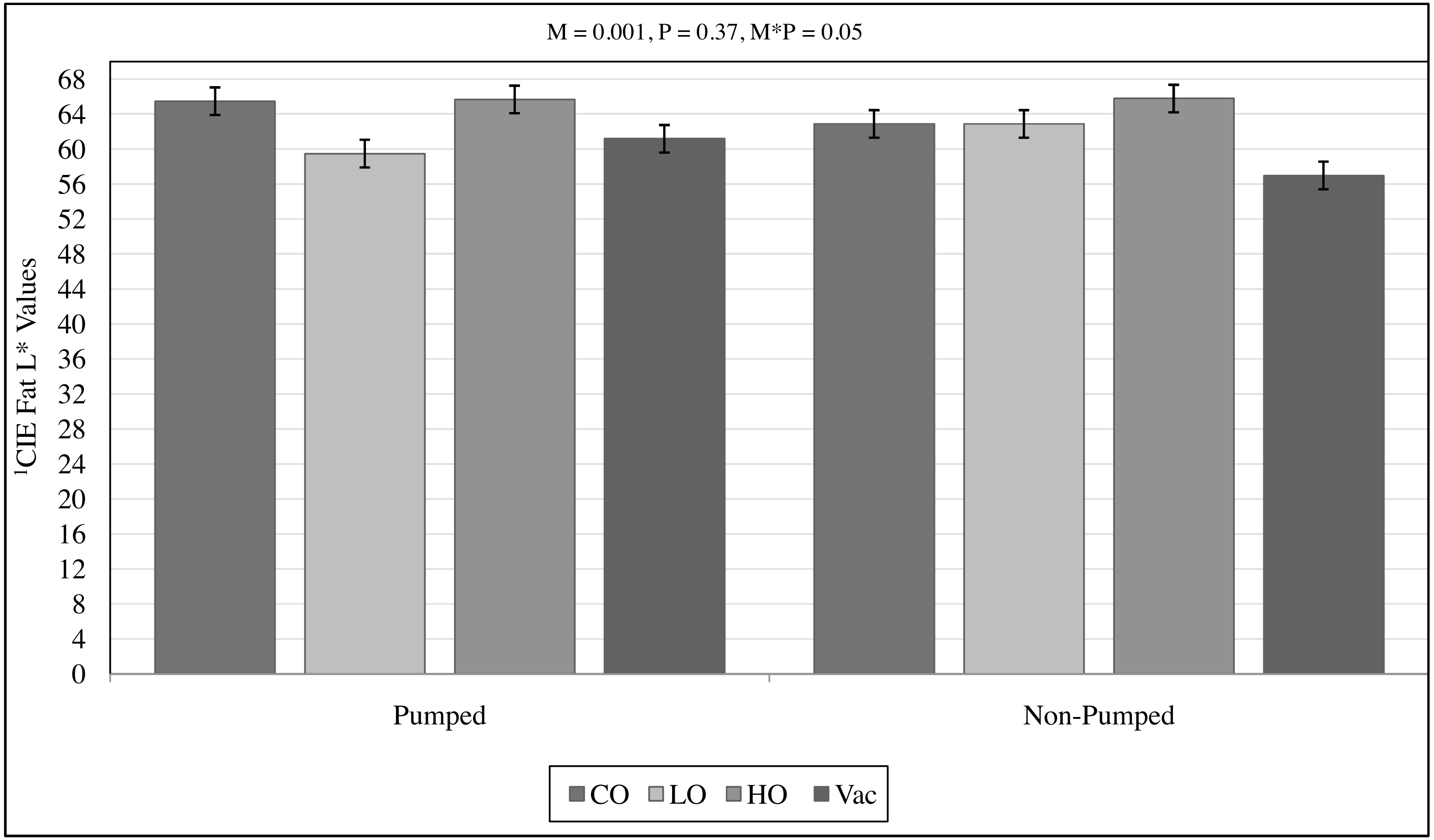


Figure 3.21. Least square means ± SEM for CIE Fat a* instrumental values of ribeye steaks by pumped and non-pumped treatments at the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped; CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE Fat a* Value (positive = red, 0 = neutral, negative = green).

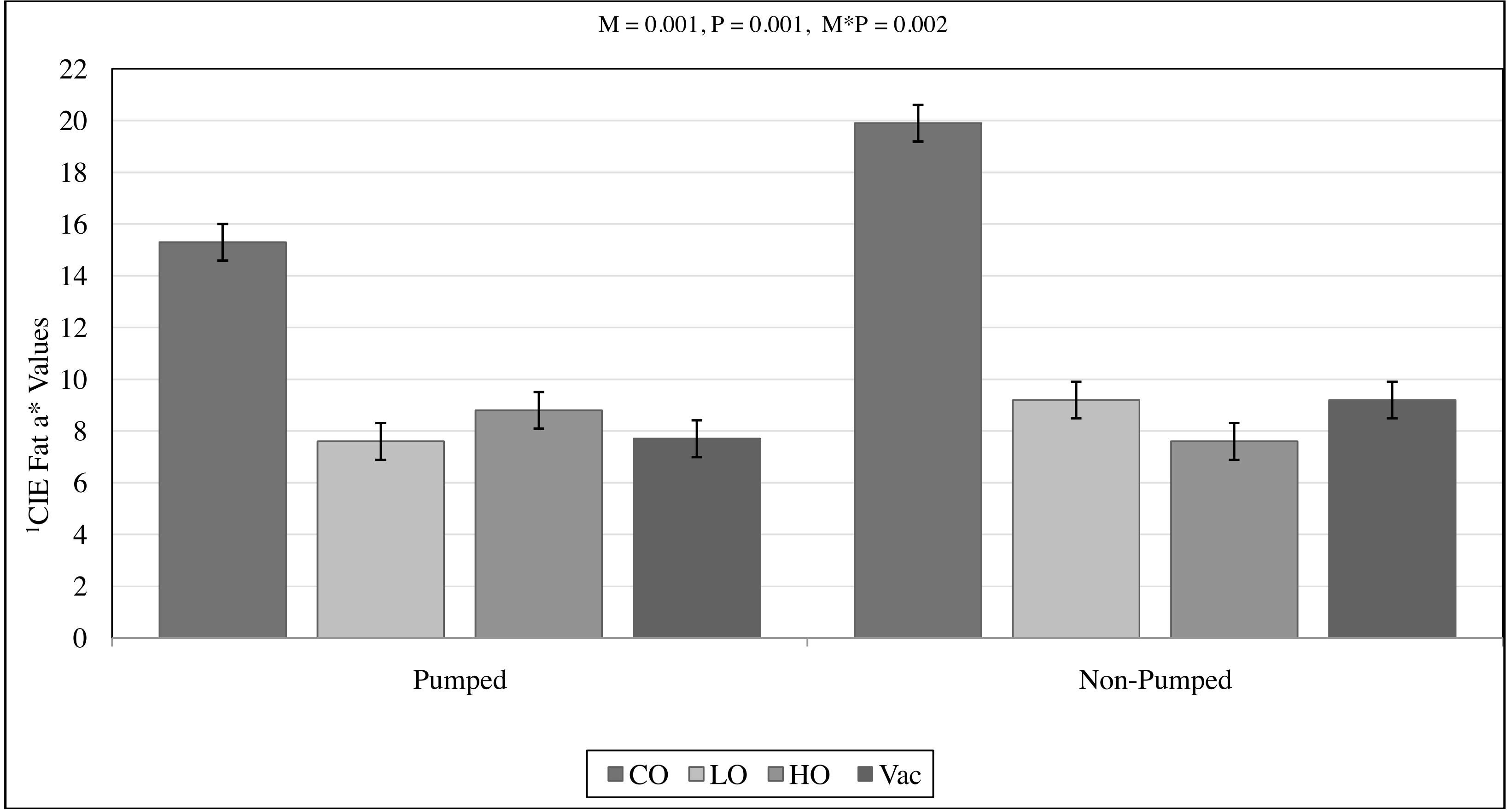


Figure 3.22. Least square means ± SEM for CIE Fat b* instrumental values of ribeye steaks by pumped and non-pumped treatments at the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non- pumped; CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]CIE Fat b* Value (positive = yellow, 0 = neutral, negative = blue).

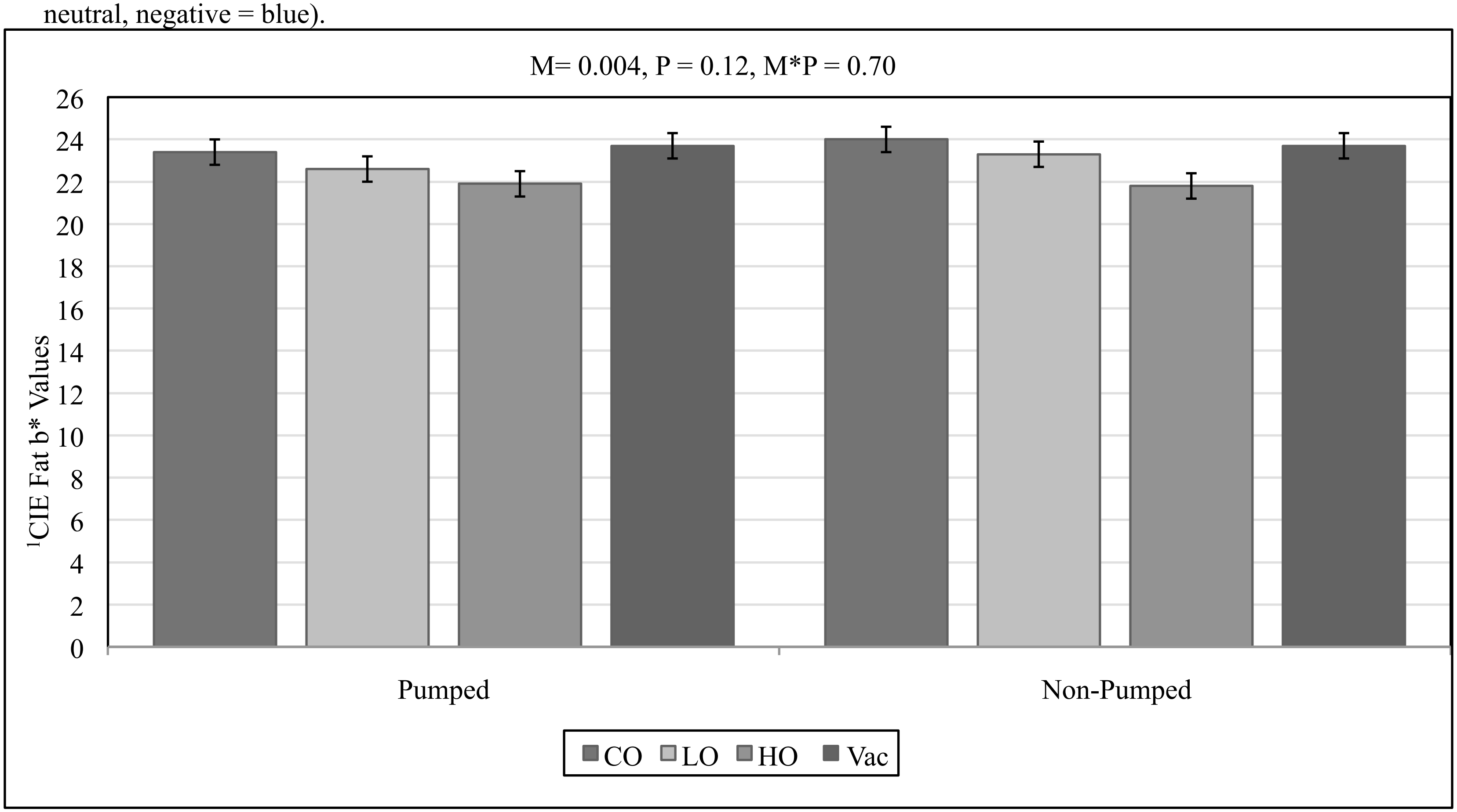


Figure 3.23. Least square means ± SEM for lean Hue instrumental values of ribeye steaks by pumped and non-pumped treatments at beginning and end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped, D= day of retail display. CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]Lean Hue Value (numerically decreasing true red color).

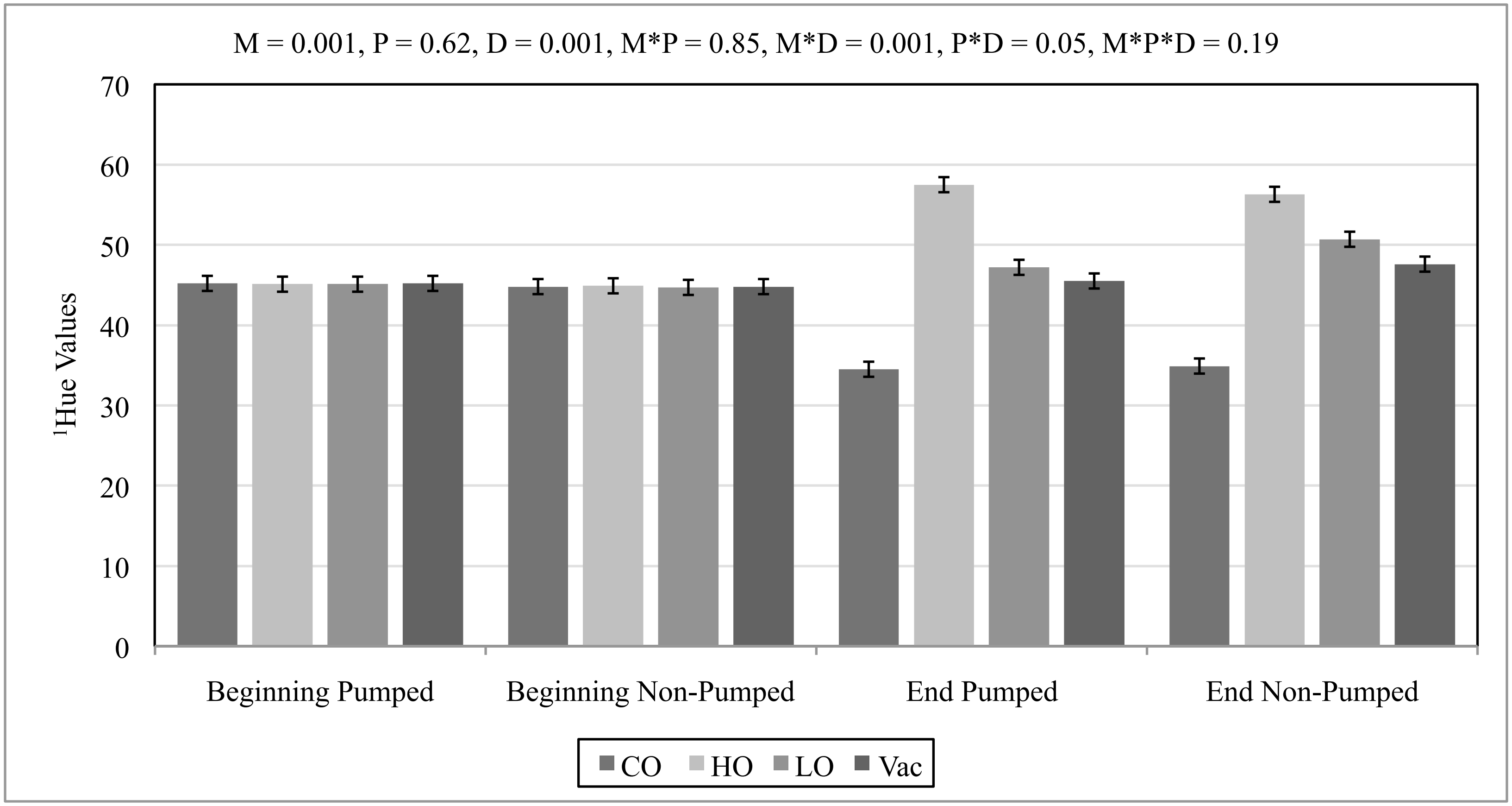


Figure 3.24. Least square means ± SEM for lean Chroma instrumental values of ribeye steaks by pumped and non-pumped treatments at beginning and end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped, D= day of retail display. CO= carbon monoxide, LO= low oxygen, HO= high oxygen, Vac= vacuum packed; [1]Lean Chroma Value (numerically increasing color saturation).

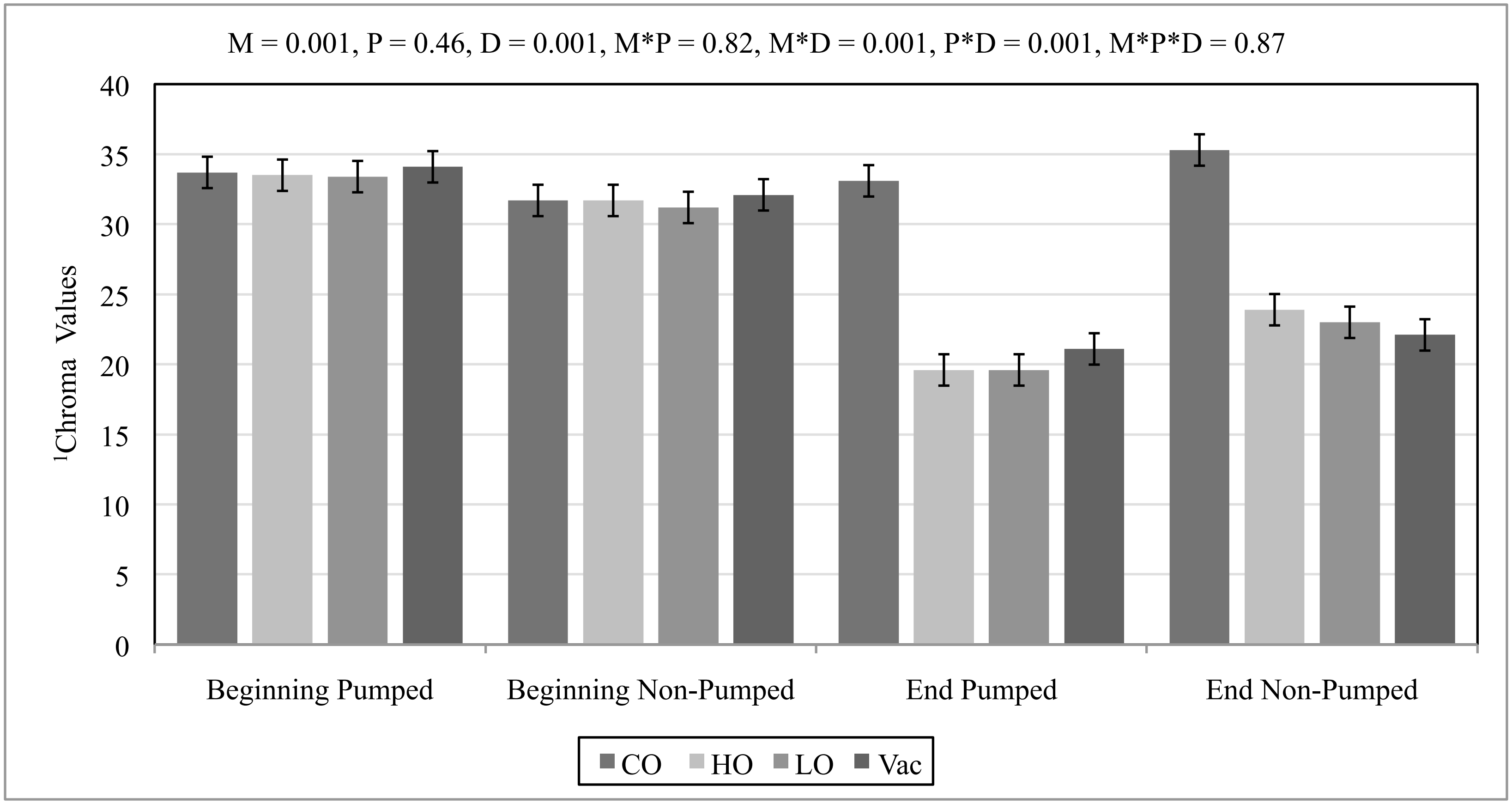


Figure 3.25. Least square means ± SEM for fat Hue instrumental values of ribeye steaks by pumped and non-pumped treatments at the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped; CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, Vac= Vacuum packed; [1]Fat Hue Value (numerically increasing true red color).

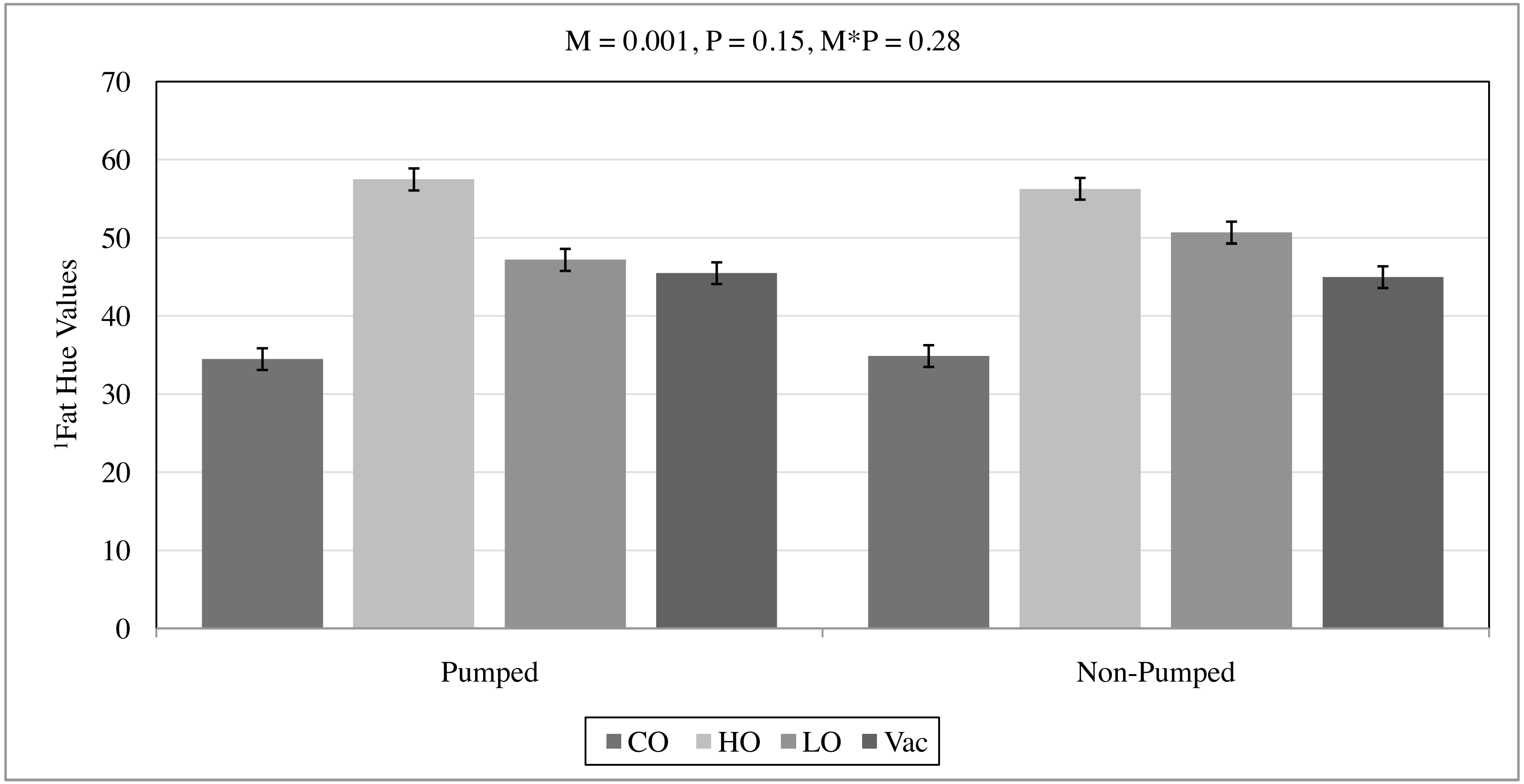


Figure 3.26. Least square means ± SEM for fat Chroma instrumental values of ribeye steaks by pumped and non-pumped treatments at the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped; CO= carbon monoxide, LO= low oxygen, HO= high oxygen, Vac= vacuum packed; [1]Fat Chroma Value (numerically increasing color saturation).

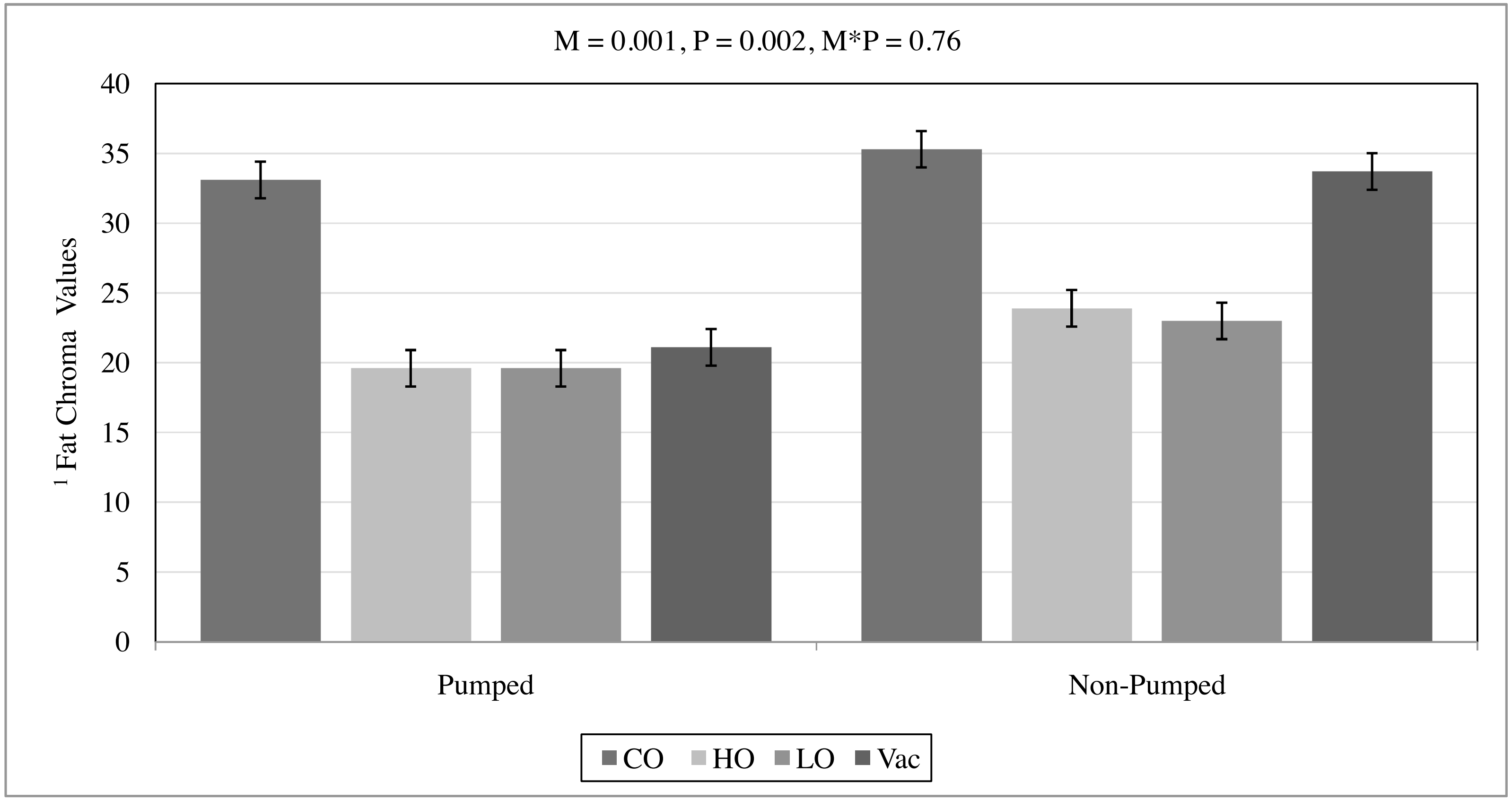


Figure 3.27. Least square means ± SEM for lean metmyoglobin instrumental values of ribeye steaks by pumped and non-pumped treatments the end of retail display for MAP. M= modified atmosphere packaging, P= pumped or non-pumped. CO= carbon monoxide, LO= low oxygen, HO= high oxygen, Vac= vacuum packed; [1]Lean Metmyoglobin percentage (oxidized myoglobin pigment)

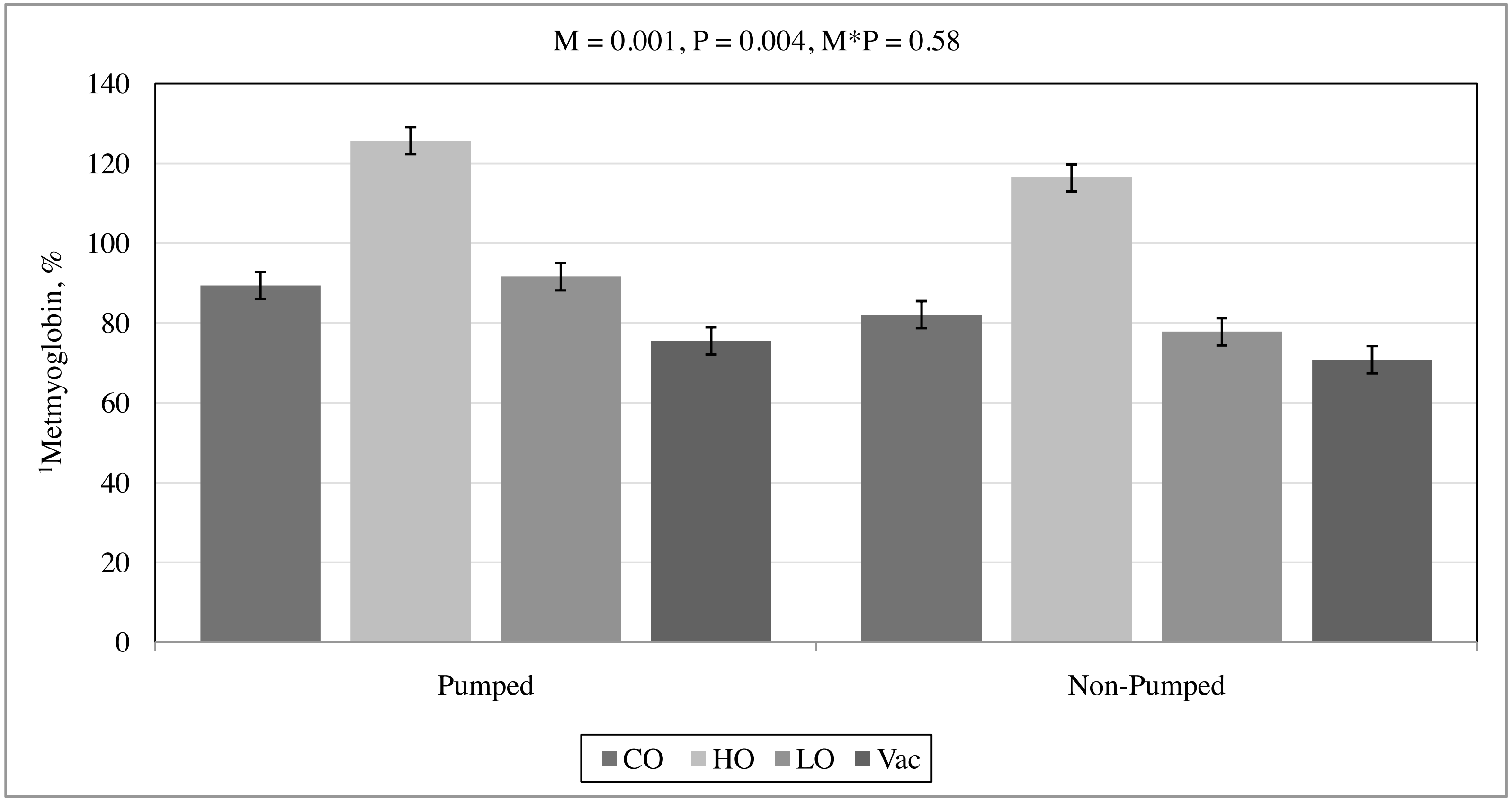


Figure 3.28. Least square means ± SEM for visual lean color of ribeye steaks by retail display day within pumped and non-pumped treatments for MAP. M= modified atmosphere packaging, P = pumped or non-pumped, D = day of retail display. CO = carbon monoxide, LO = low oxygen, HO = high oxygen; [1]Lean color (1 = extremely dark red; 8 = extremely bright cherry-red)

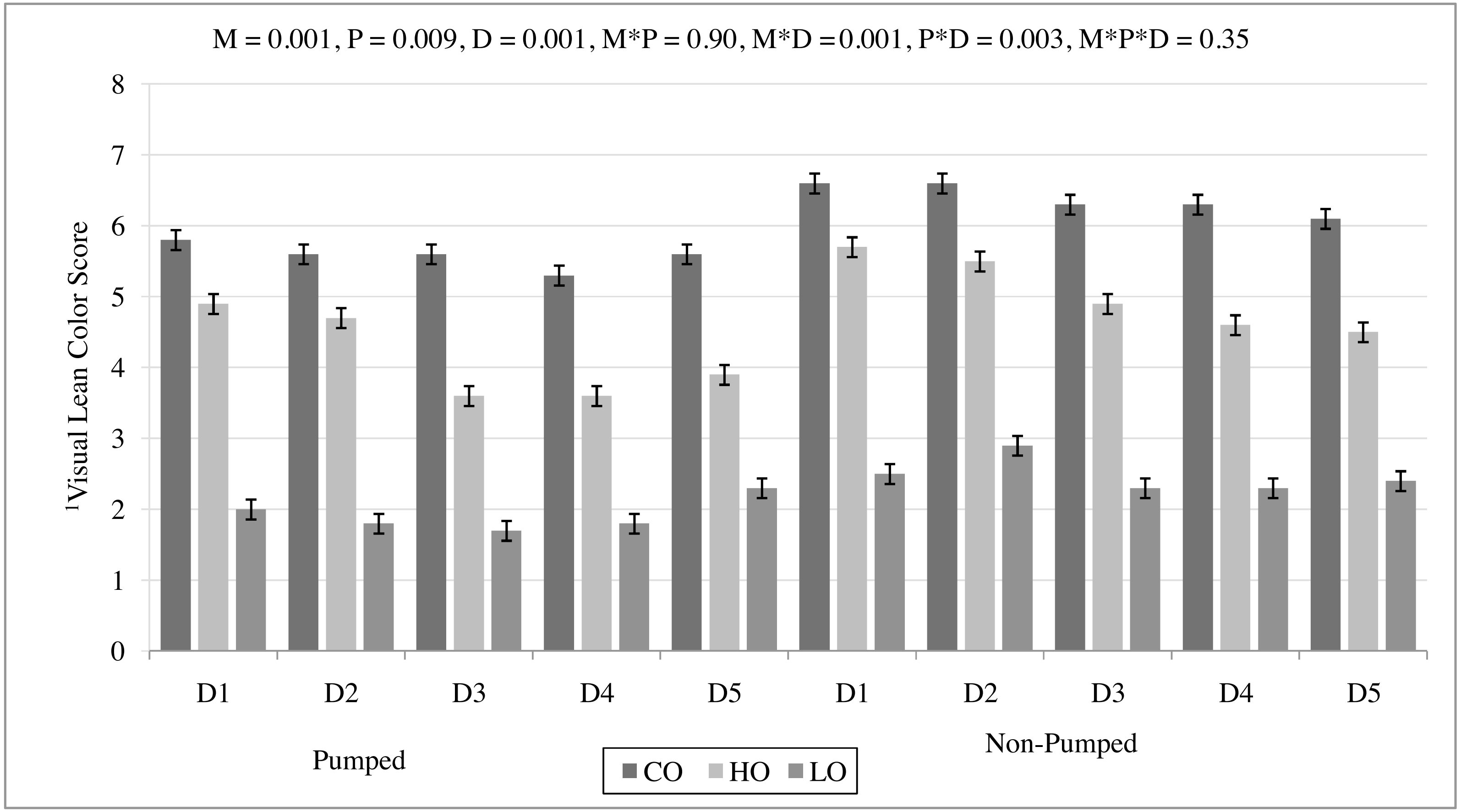


Figure 3.29. Least square means ± SEM for visual lean uniformity of ribeye steaks by retail display day within pumped and non-pumped treatments for MAP. M= modified atmosphere packaging, P = pumped or non-pumped, D = day of retail display. CO = carbon monoxide, LO = low oxygen, HO= high oxygen; [1]Lean color uniformity (1 = uniform; 5 = extreme two-toning)

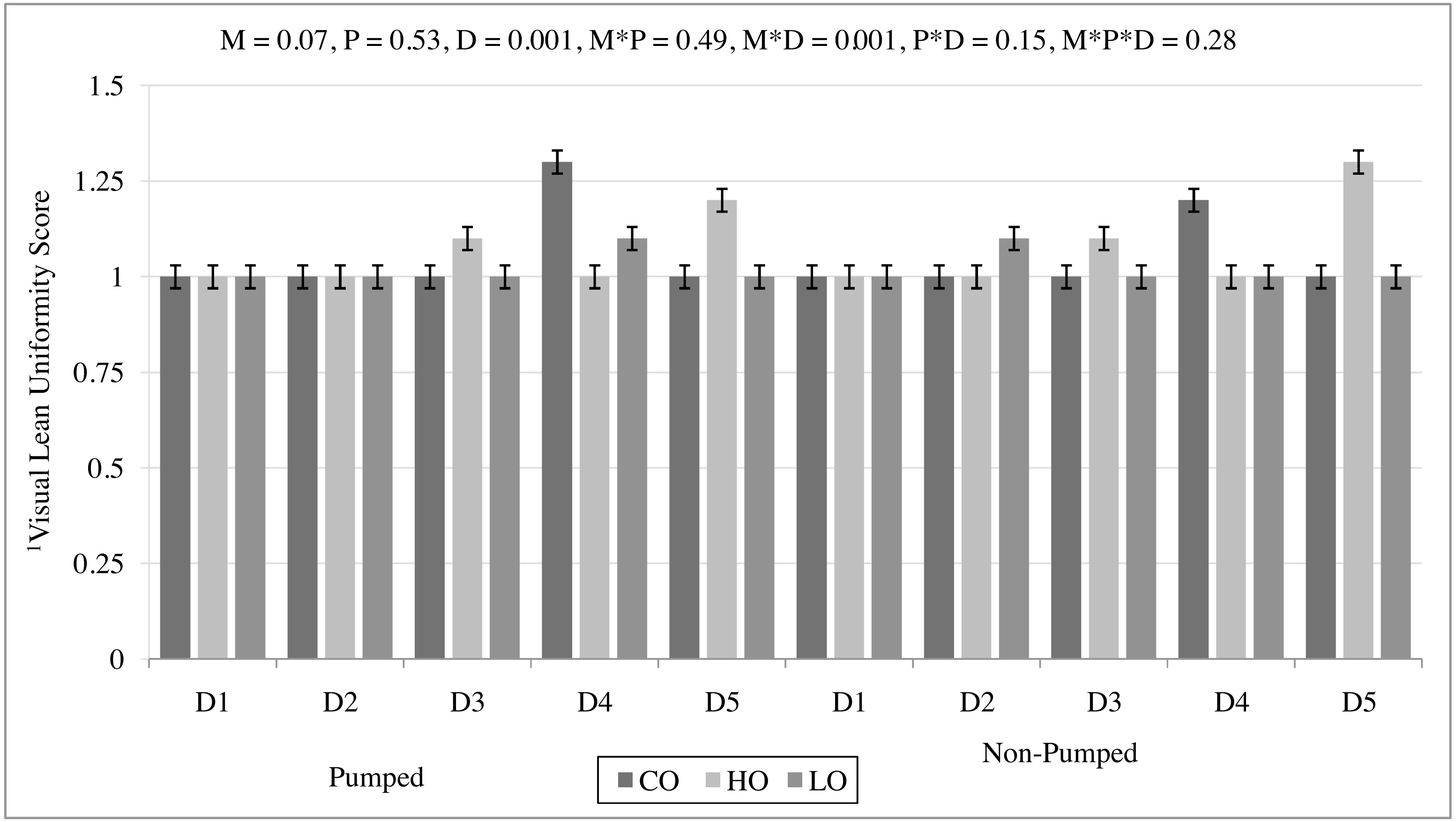


Figure 3.30. Least square means ± SEM for visual lean discoloration of ribeye steaks by retail display day within pumped and non-pumped treatments for MAP. M= modified atmosphere packaging, P = pumped or non-pumped, D = day of retail display. CO = carbon monoxide, LO = low oxygen, HO = high oxygen; [1]Lean discoloration (1 = none; 7 = total discoloration)

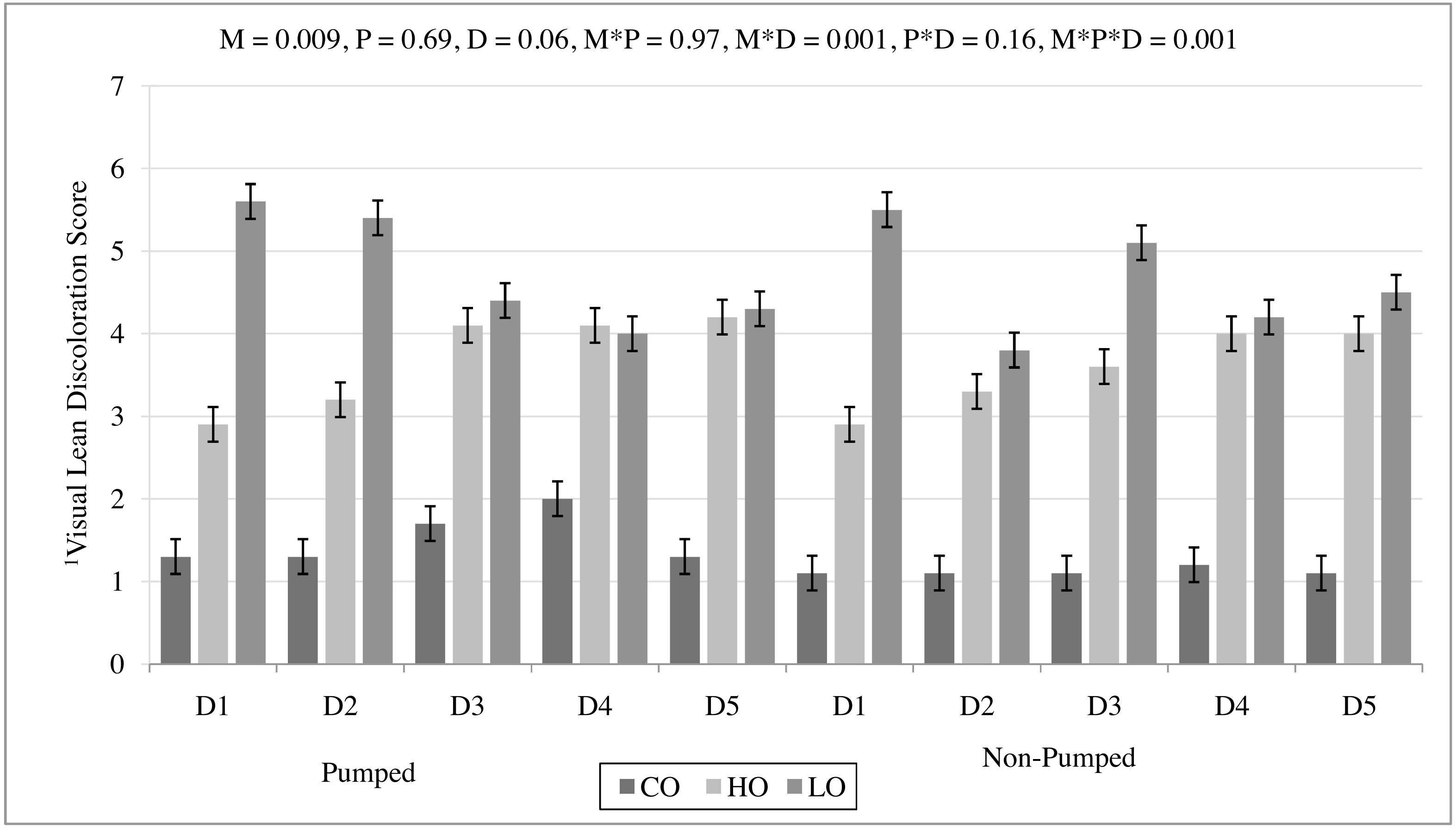
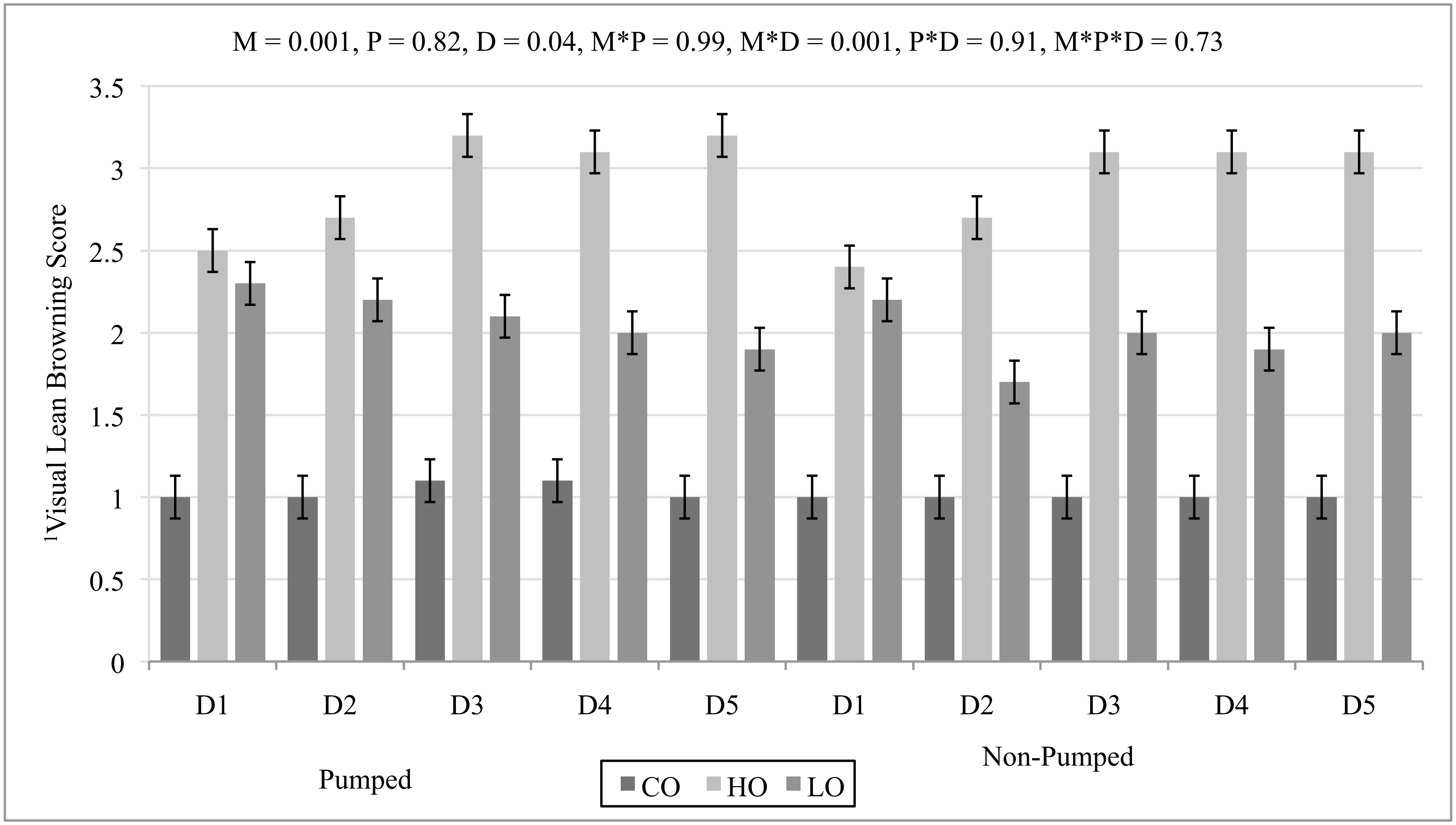


Figure 3.31. Least square means ± SEM for visual lean browning of ribeye steaks by retail display day within pumped and non-pumped treatments for MAP. M= modified atmosphere packaging, P = pumped or non-pumped, D = day of retail display. CO = carbon monoxide, LO = low oxygen, HO = high oxygen; [1]Lean browning (1 = none; 5 = dark brown)



CHAPTER IV

CHARACTERIZING GRASS-FED GROUND BEEF USING MODIFIED ATMOSPHERE PACKAGING

ABSTRACT

Eighteen kilograms of grass-fed beef trim from fall-born Angus x Continental crossbred steers and eighteen kilograms of grain-fed beef trim were ground to achieve separate batches with approximately 20% fat. Six titrations were made from each of the ground trimmings containing: 0% grass/100% grain (0/100), 20% grass/80% grain (20/80), 40% grass/60% grain (40/60), 60% grass/40% grain (60/40), 80% grass/20% grain (80/20), and 100% grass/0% (100/0) grain. Each titration was packaged using a high oxygen (HO; 80% O_2/20% CO_2), low oxygen (LO; 65% N_2/35% CO_2), carbon monoxide (CO; 65% N_2/34.6% CO_2/0.4% CO) or OV (overwrap). Results showed that there was no difference in diet*modified atmosphere packaging (MAP; $P > 0.05$) for initial and sustained juiciness, cohesiveness, flavor intensity, off flavor, or cookloss. The 100/0 titration resulted in better ($P < 0.05$) instrumental (a*) and visual color scores. The CO package produced and maintained a bright, cherry-red color through out the retail display. TBARS values were the lowest for the titrations with the most grass percentage ($P < 0.05$).

INTRODUCTION

Forage-fed beef accounted for the majority of beef production and sales in the United States prior to World War II (Schupp et al., 1980). Popularity of forage-fed beef declined in the 1950s and 1960s when the large-scale cattle finishing systems were developed which demanded an increase in grain-based finishing regimens. Soon consumers became accustomed to the characteristics, such as flavor, tenderness, and juiciness, which results from high quality, well-marbled grain-fed beef. During the late 1970s, consumer health consciousness and demand for "healthy" foods greatly increased due to a shift in the American diet (Schupp et al., 1980; Griebenow et al., 1997).

Today consumers are still attracted to the promotion of "healthy" foods. Because of this demand, organic, natural, and grass-fed beef has regained recognition in niche markets which seems to follow the demand theory that states that consumers should be influenced by the factors related to human health and beef production supplies (Schupp et al., 1980). Many consumers desire a product that is leaner and environmentally friendly which is a result from forage-fed systems. A drive for forage-fed beef production has been created by the rapid increase in the world's human population. This population increase could possibly create a shortage in the supply of grain worldwide, thus creating an importance for grass or forage production systems (Reverte et al., 2003).

The southeastern United States is a region that has optimum conditions for a year-round forage production system (Cox, 2004; Sapp et al., 1999). In the United States, consumers demand products that are developed from an array of specialty areas (Braden, 2006; Resurreccion, 2003) such as forage-finished beef which is now a leading niche market (Braden, 2006; Prevatt et al., 2006). Since today's consumers are interested in convenient, heat-and-eat products the beef industry is in competition with the poultry industry that already has several convenience products available to consumers. The beef industry has been able to meet consumers' needs by providing them with a safe yet flavorful product.

To meet the growing demands for beef, the beef industry and researchers have been working on improving shelf-life stability and palatability of forage-fed beef to provide a longer-lasting product for the niche market. Since forage–fed beef naturally contains more vitamin E than grain-fed beef it is possible that the beef will naturally improve oxidative stability, enhance color retention, and increase retail shelf life offering an opportunity for "value added" consumer products with enhanced nutrient value according to Decker et al. (2000). Animals finished on forage diets have been noted to provide acceptable carcass weights and degrees of finish when finished at a young age (Muir et al., 1998a). This study also showed that acceptable quality characteristics can be achieved by a forage-finishing system when compared to a grain-based diet.

Several studies have been conducted on forage-fed beef and in some cases are known to improve the color stability of the product (Arnold et al., 1992). A problem faced with forage-fed beef is that it has several off flavors such as grassy, rancid, livery, and metallic. Enhancing forage-fed beef with a beef flavoring agent in a salt/phosphate solution has been noted to decrease the intensity of the off flavors.

Modified atmospheres are being used more widely to assist in the shelf-life of the product (Jakobsen and Bertelsen, 2000). Atmospheres that promote the blooming of color pigments may not always be safe because consumers determine meat quality based on color. According to Zhao et al. (1994) lipid oxidation occurs at a slower rate than the deterioration of the color pigments. An elevated oxygen level is known to extend color stability, but the increased rate of oxidation can also be expected (Zhao et al., 1994). In the CO packaging, a pigment known as carboxymyoglobin is formed (Lanier et al., 1978). The carboxymyoglobin is similar to the bright red oxymyoglobin pigment that is formed at the surface of fresh meat in air. Carboxymyoglobin is known to less readily oxidize to brown metmyoglobin than is oxymyoglobin because of the strong binding of CO to the iron site on the myoglobin molecule (Lanier et al., 1978). Results from Sorheim et al. (1999) show that a low CO/high CO_2 atmosphere is effective for preserving retail-retail meats.

Objectives of this study were to determine if the percent of grass-fed and grain-fed beef trim and modified atmosphere would improve the quality and shelf-life stability of ground beef. Organoleptic factors were also studied to determine if the grass-fed beef trim produced off flavors commonly associated with grass-fed beef.

MATERIALS AND METHODS

Sample Collection and Preparation

Eighteen kilograms of grass-fed beef trim from fall-born Angus x Continental crossbred steers was ground through a 4.8 mm plate and fat analysis run using the Univex Fat Analyzer (Model FA73 Salem, NH). Fat percent was formulated and re-ground to be approximately 20%. It took 4 runs through the grinder to achieve the desired percent fat in the product. This same procedure was performed using 18 kg of grain-fed beef trim. Percent fat was achieved in two grinds but since the grass-fed beef trim took 4 grinds, the grain-fed trim was ground two more times to equal the same number of grinds as the grass-fed beef trim. Once fat percent was finalized the two ground beef feeding treatments were mixed by hand in edible white lugs and then mixed (30 revolutions) using a table top hand mixer to produce mixtures of 0/100, 20/80, 40/60, 60/40, 80/20, 100/0 respectively for grass-fed ground beef / grain-fed ground beef. A 454 g batch was taken from each percentage mixture and placed in one of four packaging treatments: high oxygen (HO; 80% O_2/20% CO_2), low oxygen (LO; 65% N_2/35% CO_2), carbon monoxide (CO; 65% N_2/34.6% CO_2/0.4% CO; Koch ILPRA Model FoodPack 400V/G, Corso Pavia, Italy), or overwrap (OV). This procedure was replicated two more times to assure proper packaging techniques and for use in retail display, sensory, and TBARS analyses. A replication of this entire process (Run 1) was repeated the following day (Run 2). All packages were labeled for appropriate run and packaging treatment. Fresh samples and 18 h samples were collected to use as controls. Eighteen hour samples (114g) were collected from the overwrap packages and then re-wrapped.

Initial and Retail Display Color Measurements

Before packaging, an initial color measurement for CIE lean values for L*(lightness), a* (redness), and b* (yellowness) were recorded utilizing a Hunter Miniscan XE Plus (Hunter Laboratories Model 45/0-L, Reston, VA) with a illuminant D65 at a 10° observation angle and a 3.5-cm aperture. Readings for lean color were taken from two readings on the anterior face of the ground beef and averaged to obtain a representation of the initial lean color. Reflectance spectra values for the initial lean color were also determined. Spectral reflectance values were determined at 520-, 530-, 570-, and 580-nm and interpolated to determine the values for 525-nm and 572-nm respectively. Readings for L*, a*, b*, 525 nm and 572 nm reflectance values for lean color were taken from two readings on the anterior face of the ground beef and averaged to obtain a representation of the initial lean color.

On d 1 of the retail display, the CIE lean color values (L*, a*, b*) was measured from each overwrap titration. Each overwrap package was divided into two 227g samples, separately vacuumed packaged and frozen at -20°C for sensory and TBARS analyses. Post retail color measurements from the remaining packages were taken on d 5 of the display. A Hunter Miniscan XE Plus (Hunter Laboratories Model 45/0-L, Reston, VA) with a illuminant D65 at 10° and a 3.5-cm aperture was used to measure the CIE lean values for L*(lightness), a* (redness), and b* (yellowness) values and spectral reflectance values were determined at 520-, 530-, 570-, and 580-nm and averaged to determine the values for 525-nm and 572-nm respectively. The remaining ground beef samples were vacuumed packaged and frozen at -20°C until sensory and TBARS analyses.

Storage and Retail Display

Ground beef packages were stored for 5 d dark storage at 2°C. The packages were checked 48 h post packaging and noted for leakers. The ground beef packages were placed in a Tyler (Model DMG-8, Niles, MI) retail display case at 2°C for retail panel analysis for 5 d. The illumination intensity was 800lx at the surface of the package, utilizing Sylvania© Designer Cool White Plus bulbs (F40/DCWP). Six trained panelist rated ground beef packages for color, surface discoloration, and browning. Color was based on an 8 point hedonic scale; 1 equaling extremely dark red and 8 equaling extremely bright cherry-red. A 7 point hedonic scale was used for surface discoloration; 1 equaling zero percent discoloration and 7 equaling 100 percent discoloration on surface. Browning was based on a 5 point hedonic scale; 1 equaling none and 5 equaling dark brown.

Sensory

Ground beef samples (approximately 150 g and formed with a basic kitchen hamburger patty press) for sensory were thawed (4°C for 12-18h), weighed, and placed in a pre-heated George Foreman clam-shell-style grill (Model GRV120, Macon, MO) for 8 min(Kerth et al., 2007), resulting in a final internal temperature of 76°C (AMSA, 1995). Cooked patties were weighed to determine the percentage cooking loss by dividing the weight lost during cooking by the pre-cooked weight. Patties were divided using an apple cutter which produced eight pie-shaped samples and then placed in double broilers, with warm sand, until served to a six-member trained sensory panel. In a cubicle supplied with red light, each of the trained panel members evaluated one sample from each ground beef patty and noted opinion on the evaluation form. Panel members were asked to take a bit of a salt-free saltine cracker and sip water to aid in cleansing the palate and expectorate the sample in the cup provided. An eight-point scale was used for the evaluations of initial and sustained juiciness, cohesiveness, flavor intensity, and off flavor (1= extremely dry, extremely crumbly, extremely bland, no off flavor to 8= extremely juicy, extremely cohesive, extremely intense beef, and extreme off flavor). Panelists noted appropriate off flavor descriptors provided on form if scores were noted for an off flavor.

Determination of Lipid Oxidative Stability

Lipid oxidative stability was analyzed by using the thiobarbituric acid (TBA) reactive substance assay modified from Buege and Aust (1978). Ground beef samples used for lipid oxidative stability were removed from frozen storage and a 5-g sample was homogenized with 15 mL of distilled water. Approximately 4 mL homogenate was combined with 8 mL of trichloracetic/thiobarbituric acid reagent and 200 µL of 10% butylatedhydroxyanisole. Samples were incubated in a 99°C water bath for 15 min, allowed to cool in cold water for 10 min, and filtered through Whatman paper. The absorbance of the samples was read against a blank containing like reagents at 531 nm. Malonaldehyde standards were constructed utilizing 1, 1, 3, 3-tetraethoxypropane and thiobarbituric acid reactive substances were reported as mg/5g of meat.

Statistical Analysis

Data for sensory, cook-loss, off descriptors, and TBA was analyzed as a 6 (0/100, 20/80, 40/60, 60/40, 80/20, 100/0, grass/grain diet) by 4 (CO, HO, LO, or VAC packaging) factorial arrangement of a completely randomized design using GLM procedure of SAS. Run had no significant effect ($P > 0.10$) and was not included in the analyses. Significant ($P \leq 0.05$) main and interaction effect means were separated with Fisher's protected LSD using the PDIFF option of LSMEANS in SAS. For retail display data, the effect of day was analyzed as a repeated measure using the replication within packaging and grass/grain titration as the error term for packaging, grass/grain, and their interaction, and the residual error to test for day and day interaction effects. The effect of the two runs was tested and found to not be a significant ($P> 0.10$) source of variation, so data for the runs was pooled together for analyses.

RESULTS

Initial Color

At the fresh or initial recordings for CIE L* before packaging, there was no difference ($P > 0.05$) in the MAP (Figure 4.2). The titrations for 20/40, 40/60, and 60/40 had higher ($P < 0.05$) L* values than the other grass/grain titrations. At the beginning of the retail display (d 2) all MAPs and titrations had decreased ($P < 0.05$) in L* values. The 100/0 titration was the lowest ($P < 0.05$) within the HO for d 2. At the end of the retail display, the 100/0 titration had the highest ($P < 0.05$) value for L* within the OV.

All a* values taken on d 1 (fresh) showed no difference ($P > 0.05$) for the titrations and MAPs (Figure 4.3). At the beginning of the retail display, the CO had the highest ($P < 0.05$) a* values over all other MAP. The 0/100 had the lowest ($P < 0.05$) a* value within the OV at the beginning of retail display. By the end of the retail display, the CO still had the highest ($P < 0.05$) a* values over all other MAP. The 100/0 had the highest ($P < 0.05$) a* values than all other titrations at the end of the retail display within all MAPs.

The MAP*Day interaction for b* was significant ($P < 0.05$) therefore showing that the b* values decreased for all MAP as the retail display lengthened (Figure 4.4). The titrations for 0/100, 80/20, and 100/0 had the highest ($P < 0.05$) b* values on d 1. At the beginning of the retail display, some b* values increased ($P < 0.05$) while others decreased ($P < 0.05$), but by the end of the retail display the 100/0 titration was the highest ($P > 0.05$) for b* values within all MAP.

On d 1, there were no differences ($P > 0.05$) in the MAP and grass/grain titrations for metmyoglobin instrumental values (Figure 4.5). At the beginning of retail and end of retail display, the CO had the lowest (P < 0.05) metmyoglobin values. The beginning of retail display, 0/100 had the highest (P > 0.05) metmyoglobin values within the OV. At the end of the retail display, the 100/0 had the lowest (P < 0.05) metmyoglobin values. This means that there was less browning within the 100/0 titration when compared to the other titrations. The CO packaging represented the least (P < 0.05) browning over all other MAP.

The values for the hue angle showed no difference (P > 0.05) for the fresh samples for both the titrations and MAP (Figure 4.6). The CO had the lowest (P < 0.05) hue value for the beginning and end of retail display. The 0/100 had the highest (P < 0.05) hue values within the OV for the beginning and end of the retail display.

There was no difference (P > 0.05) in chroma values between the MAP and grass/grain titrations for the fresh samples (Figure 4.7). The CO remained relatively constant at the beginning or d 2 of the retail display while the other MAP had decreased (P < 0.05) in chroma values. The 100/0 had the highest (P > 0.05) chroma values for all days of the retail display except for d 2 or the beginning of retail display within the HO.

Sensory

A significant difference (P < 0.05) was noted in the grass/grain titrations for initial and sustained juiciness (Table 4.1). A decrease in initial and sustained juiciness (P < 0.05) was noted when 40/60 was compared with 60/40, 0/100 and 100/0; but no difference (P > 0.05) was noted when compared to 20/80 and 80/20. A decrease (P < 0.05) in intial juiciness score was noted for 20/80 when compared to 100/0, but no significant difference (P > 0.05) when compared with 0/100, 40/60, 60/40, and 80/20. The titration for 60/40 was not significantly different (P > 0.05) from any of the other titrations for initial juiciness. For sustained juiciness, 40/60 was significantly different ($P < 0.05$) from 0/100, 100/0, and 60/40 (increased or decreased in sustained juiciness depending on the MAP); 100/0 was significantly different ($P < 0.05$) when compared with 20/80 and 80/20. The grass/grain titration did not show a significant difference ($P > 0.05$) in the remaining sensory characteristics for cohesiveness, flavor intensity, and off flavor. The modified atmosphere packaging was not significant ($P > 0.05$) for any of the sensory characteristics or cook-loss. There was no significant difference ($P > 0.05$) when the MAP and grass/grain titrations were combined.

Off Flavor

The CO packaging noted to have a less ($P < 0.05$) grassy off flavor than the overwrap packaging (Figure 4.1). Other off flavors were noted by the sensory panel to have characteristics of rancid, bloody, bitter, livery, salty, metallic, and other (data not shown).

Retail shelf-life

The CO had shown an extremely bright cherry-red visual lean color for all days of the retail display when compared with other MAP ($P < 0.05$); Figure 4.8). Visual lean discoloration was noted the least ($P < 0.05$) in the CO for all days of retail display. The OV had the highest ($P < 0.05$) discoloration scores by day 3 and day 5 (Figure 4.9). Browning occurred the most in the OV for all days of display ($P < 0.05$; Figure 4.10). The least browning ($P < 0.05$) was seen in the CO. The visual browning within the OV supports the high metmyoglobin values seen within the OV.

Lipid oxidation

Overall the HO package seemed to have the most ($P < 0.05$) thiobarbituric reactive substance values (TBARS; Figure 4.11). Even though there was no significant difference ($P > 0.05$) in the MAP*grass interaction, the 0/100 had the highest TBARS values within the LO and OV.

DISCUSSION

Initial Color

Color values for the titrations with the most grass content were not significant ($P > 0.05$) when compared with the titrations with the most grain content. All ground beef packaged in CO was bright red and had low hue values. The study by John et al. (2004) agrees with the present study pertaining to high a* (redness) values and low hue angle values that represent redness within the CO package. The redness value (a*) was maintained better in the MAP than the OV according to Houben et al. (2000) which also agrees with the present study that color was best retained in the MAP packaging. By the end of the retail display HO had lost its initial bright red color as indicated by increased hue angle values as well as a* values decreased and visual scores reported a decrease in red color ($P < 0.05$). Sorheim et al. (1999) agree with the present study in that their HO package (70% O_2/30% CO_2) resulted with an initial bright red to re color, but the color was unstable and off-odors developed rapidly.

Sensory

Forage-fed beef is noted by several researchers to have lower juiciness scores when compared to grain-fed beef (Hedrick et al., 1983; Sapp et al., 1999). There are several researchers such as Cross et al. (1978) and Bidner et al, (1981b) that reported no differences in juiciness between the two feeding systems. In the present study for ground beef as the titrations increase from 0/100 to 100/0 the initial and sustained juiciness scores decreased ($P < 0.05$). When comparing forage-fed cattle and grain-fed cattle, forage-fed cattle are known to have a less desirable flavor than cattle finished on grain (Wanderstock and Miller, 1948; Kropf et al., 1975; Bowling et al., 1977). In the present study there was no difference in off flavor ($P > 0.05$) for the grass/grain titrations. Majority of the 100/0 titrations noted a higher flavor intensity score than the 0/100 titrations but there was no significance ($P > 0.05$).

Off Flavor

Ground beef from forage-fed beef is known to result in a more intense flavor (negative rating; Bagley and Feazel, 1987). Flavor is normally associated with the fat content of the product and ground beef has a much higher fat percent than steaks (up to 30%). The higher amounts of grass in the ground beef samples from the present study is supported by Melton et al. (1982) as being less desirable in flavor with an intense dairy-milky flavor and often a soured or other off-flavor. In the present study and the study by Melton et al. (1982) all ground beef had the same amount of fat percentage (19.5) and this was not believed to be the cause of flavor differences.

Retail shelf-life

The visual lean color scores in the present study indicated that CO package maintained the bright, cherry-red color best over all other MAP. Hunt et al. (2004) stated that the addition of CO to the package formed a bright red carboxymyoglobin color when CO binds to myoglobin (Sorheim et al., 1999) and may be more stable (less likely to discolor to metmyoglobin) during retail display than the traditional packages that have oxymyoglobin formation. This statement by Hunt et al. (2004) supports the findings in the present study. The titrations with the most grass percentage tended to have more positive results when compared to the high grain titrations. Data from O'Sullivan et al. (2004) supports that higher vitamin E levels (grass) increases color stability and improves oxidative and color stability. Leakers (packages that had not sealed well or had holes in the trays) were noted in several MAP packages that may result in lower shelf-life, sensory, and TBARS scores because the modified atmosphere was not maintained.

Lipid oxidation

Lipid oxidation was lower ($P < 0.05$) for the titrations with the most percentage being grass. This demonstrates the antioxidant effect of Vitamin E. The Houben et al. (2000) study agrees with the present study that higher the amounts of grass percentage, the less lipid oxidation. The Houben et al. (2000) study also stated that the modified atmosphere package (65% O_2/25% CO_2/10% N_2) resulted with higher lipid oxidation values than the foil overwrapped trays in minced beef. The present study did not use the same gas mixtures as Houben et al. (2000), but oxidation was noted more in the HO and OV when compared to the CO and LO.

IMPLICATIONS

Implications of this study were to determine how much (0, 20, 40, 60, 80, 100%) grass-fed beef trim is needed to be added to the mixture to achieve the antioxidant properties and color stability that is provided from the vitamin E, while at the same time adding grain-fed beef trim to maintain a positive flavor. Modified atmosphere packages were used to help stabilize color and extend shelf-life of the ground beef. The packages with the higher grass concentrations and CO gas results were the best for color.

Table 4.1. Least Square Means ± SEM of Sensory Ground Beef patties from different MAP packaging treatments and six grass/grain titrations

	In. Juiciness[a]	Sus. Juiciness[a]	Cohesiveness[b]	Flav. Intensity[c]	Off Flavor[d]	Cookloss
CO[e]						
0/100[f]	5.58[hi]	5.00[hi]	4.17	5.00	1.92	28.6
20/80	5.17[gh]	4.83[gh]	4.00	5.42	2.75	30.7
40/60	5.34[g]	5.17[g]	3.84	5.83	1.59	29.3
60/40	5.59[hi]	5.33[hi]	3.75	5.25	2.17	26.8
80/20	5.59[ghi]	5.42[gh]	4.00	5.50	1.92	26.7
100/0	5.50[i]	5.17[i]	4.42	5.92	1.42	29.3
HO						
0/100	5.34	5.25	4.08	5.75	1.75	24.8
20/80	6.09	5.75	4.00	5.50	2.09	22.4
40/60	6.34	5.75	3.67	5.50	2.09	24.7
60/40	5.34	4.83	3.50	5.34	3.33	28.0
80/20	5.42	5.17	4.59	5.50	1.67	26.8
100/0	5.50	4.92	3.67	5.34	3.09	28.1
LO						
0/100	5.67	5.25	4.00	5.25	2.75	26.9
20/80	6.09	5.67	3.75	5.42	2.92	24.5
40/60	6.25	5.83	3.67	5.34	2.75	21.6
60/40	5.50	5.08	3.75	5.42	2.67	27.9
80/20	5.08	5.00	4.33	5.33	2.09	29.3
100/0	4.33	4.0	3.92	5.34	1.42	31.4
OV						
0/100	4.59	4.25	4.17	5.08	2.67	30.7
20/80	5.34	5.25	4.17	5.17	3.00	26.9
40/60	5.58	5.59	3.75	5.09	3.42	26.8
60/40	5.00	4.84	4.34	5.25	2.42	29.8
80/20	5.75	5.42	4.25	5.17	2.92	27.3
100/0	5.09	4.83	3.67	5.42	2.75	30.8
SEM	0.321	0.337	0.367	0.302	0.828	2.984
P > F						
diet	0.032	0.02	0.35	0.91	0.89	0.41
MAP	0.15	0.65	0.85	0.31	0.33	0.30
diet*MAP	0.08	0.27	0.94	0.92	0.94	0.90

[a] 5=slightly juicy, 6=moderately juicy.

[b] 5=slightly cohesive, 6=moderately cohesive.

[c] 5=slightly intense beef, 6=moderately intense beef.

[d] 5=moderate off flavor, 6=very off flavor.

[e] CO=Carbon monoxide packaging, HO=High Oxygen packaging, LO=Low oxygen packaging, OV=Over wrap packaging.

[f] 0/100=0% grass and 100% grain, 20/80=20% grass and 80% grain, 40/60=40% grass and 60% grain, 60/40=60% grass and 40% grain, 80/20=80% grass and 20% grain, 100/0=100% grass and 0% grain.

[g,h,i] Means in a column for the diet main effect with different superscripts differ ($P < 0.05$)

Figure 4.1. Least square means ± SEM for ground beef for grassy off descriptor as a percent frequency. M = modified atmosphere packaging, G = grass/grain, CO= Carbon monoxide, LO= Low oxygen, HO= High oxygen, OV= Overwrap

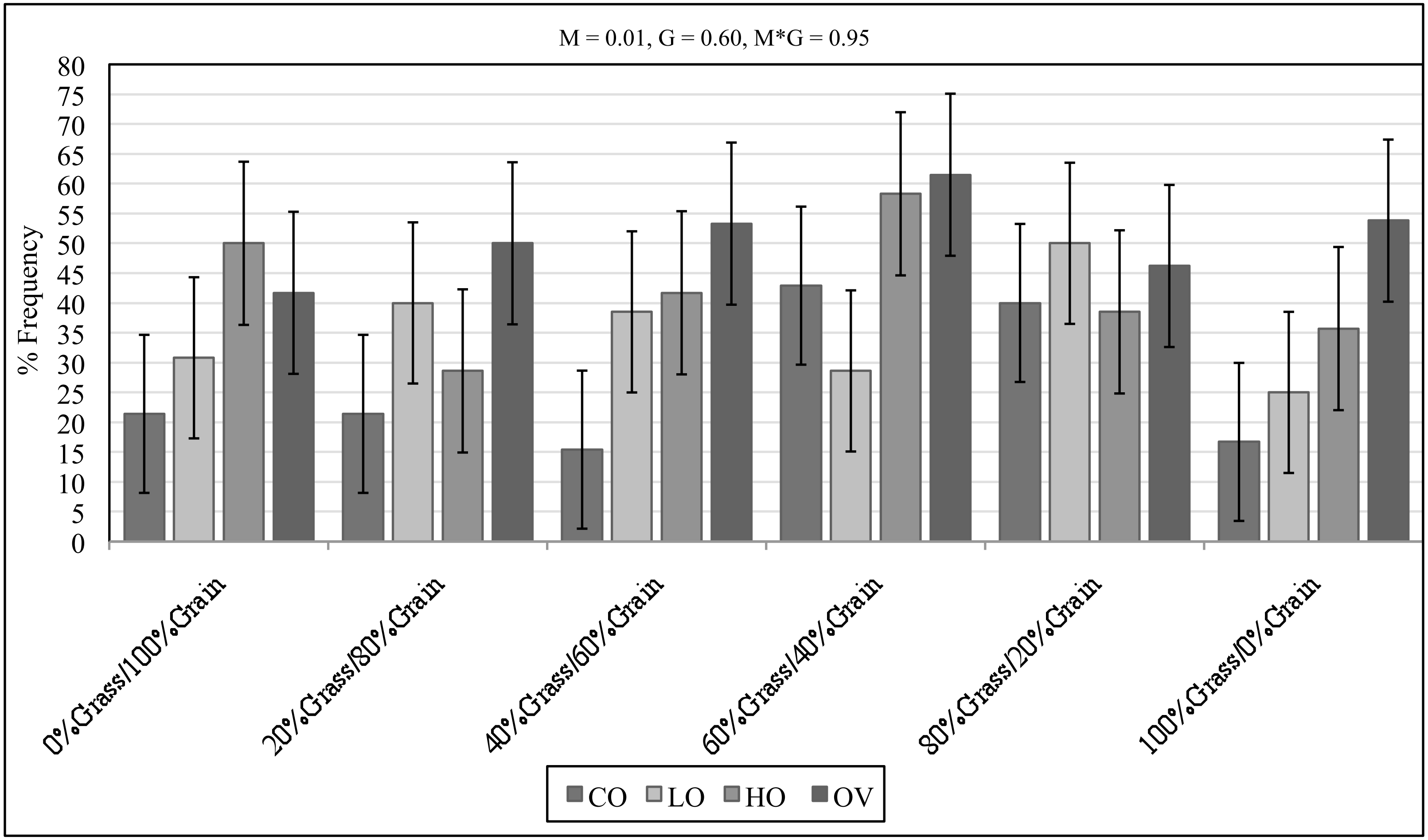


Figure 4.2. Least square means ± SEM for CIE L* instrumental values of ground beef by grass/grain titrations at the beginning and end of retail display for MAP. M = modified atmosphere packaging, G = grass/grain titration, D = day of retail display. CO = Carbon monoxide, LO = Low oxygen, HO = High oxygen, OV = overwrap packaging; [1]CIE L* Value (increasing value indicates a lighter color). Day 1 = Fresh, Day 2 = beginning of retail, Day 5 = end of retail.

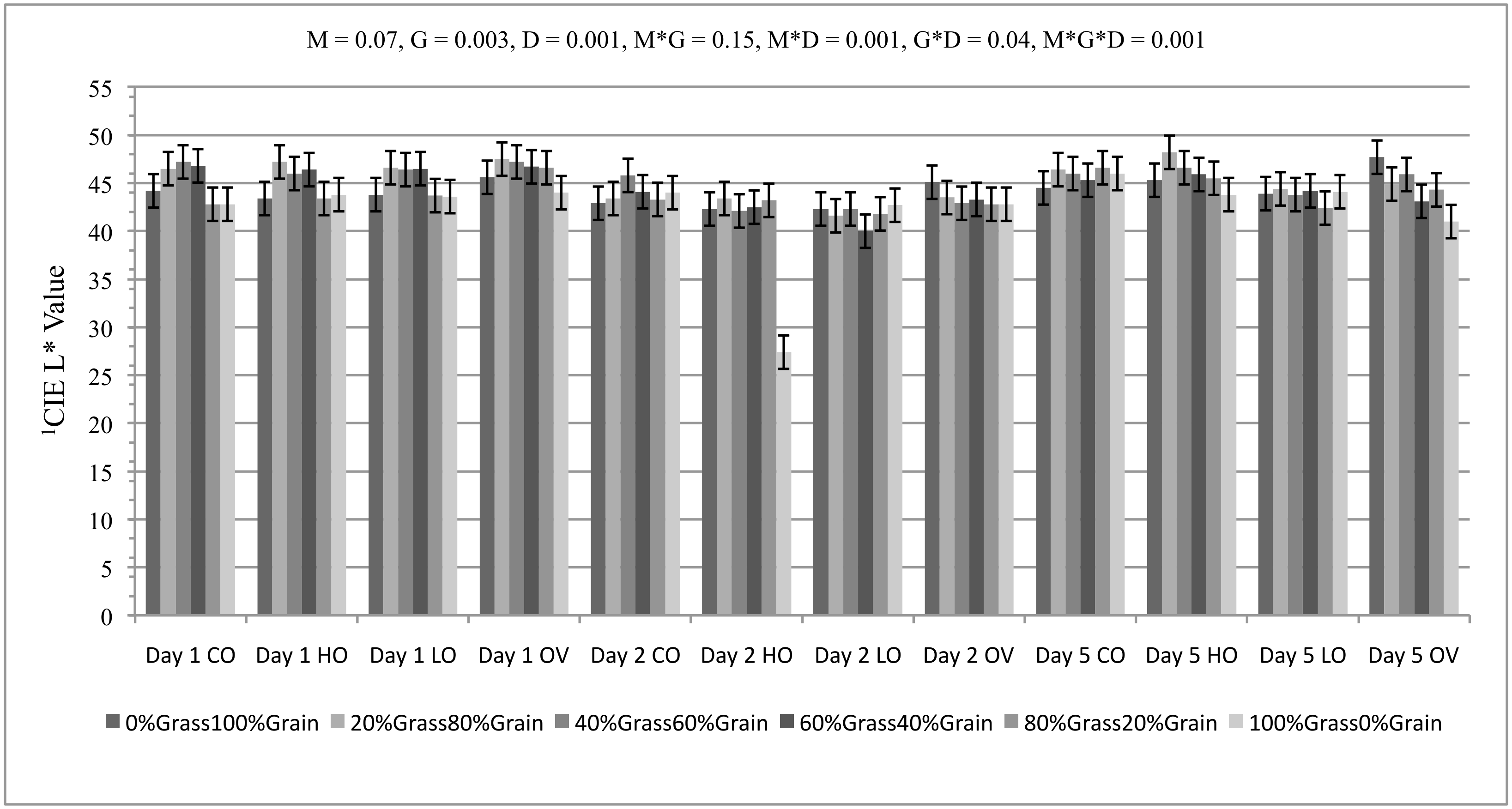


Figure 4.3. Least square means ± SEM for CIE a* instrumental values of ground beef by grass/grain titrations at the beginning and end of retail display for MAP. M = modified atmosphere packaging, G = grass/grain titration, D = day of retail display. CO = Carbon monoxide, LO = Low oxygen, HO = High oxygen, OV = overwrap packaging; [1]CIE a* Value (positive = red, 0 = neutral, negative = green). Day 1 = Fresh, Day 2 = beginning of retail, Day 5 = end of retail.

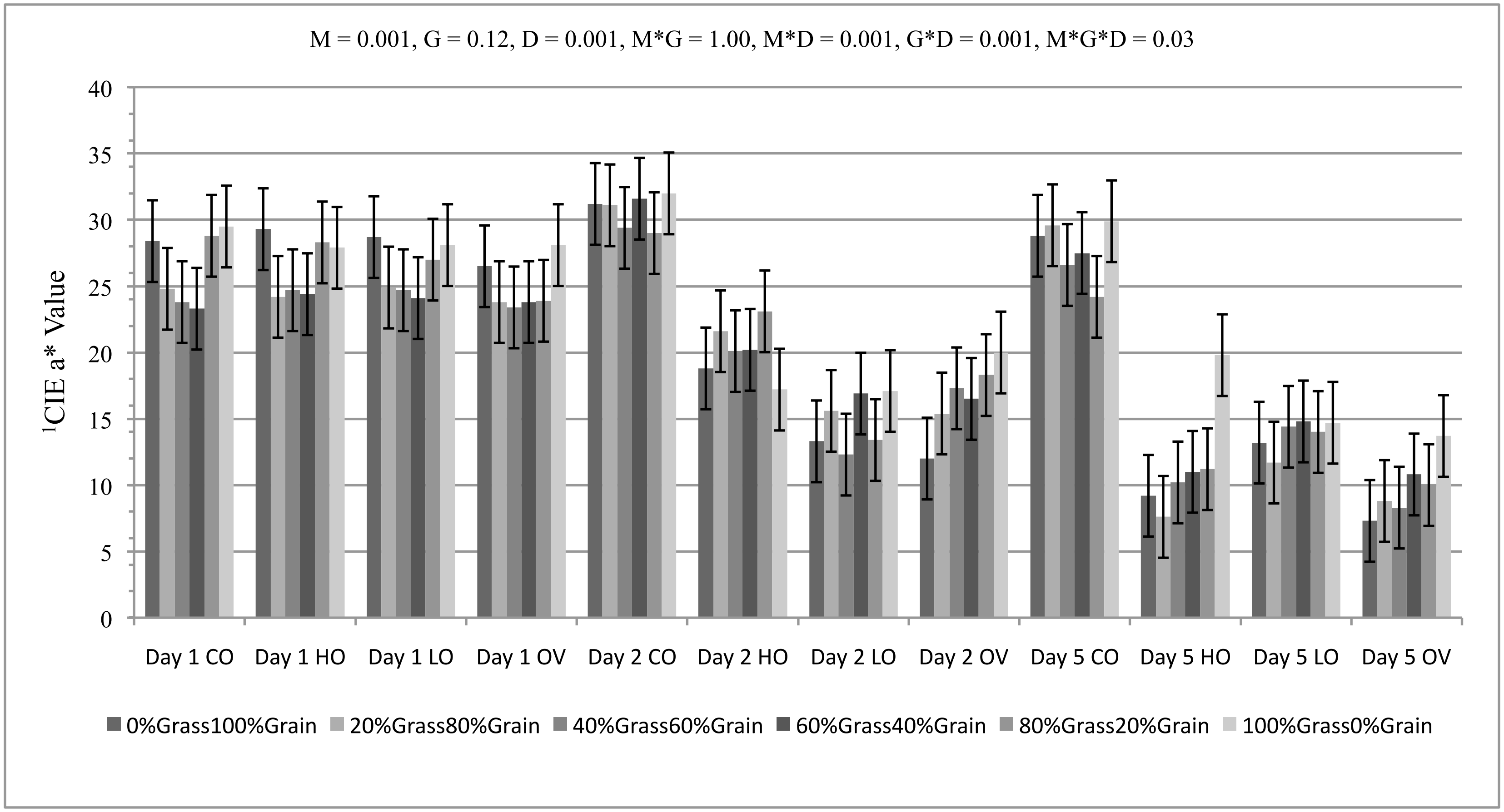


Figure 4.4. Least square means ± SEM for CIE b* instrumental values of ground beef by grass/grain titrations at the beginning and end of retail display for MAP. M = modified atmosphere packaging, G = grass/grain titration, D = day of retail display. CO = Carbon monoxide, LO = Low oxygen, HO = High oxygen, OV = overwrap packaging; ^{1}CIE b* Value (positive = yellow, 0 = neutral, negative = blue). Day 1 = Fresh, Day 2 = beginning of retail, Day 5 = end of retail.

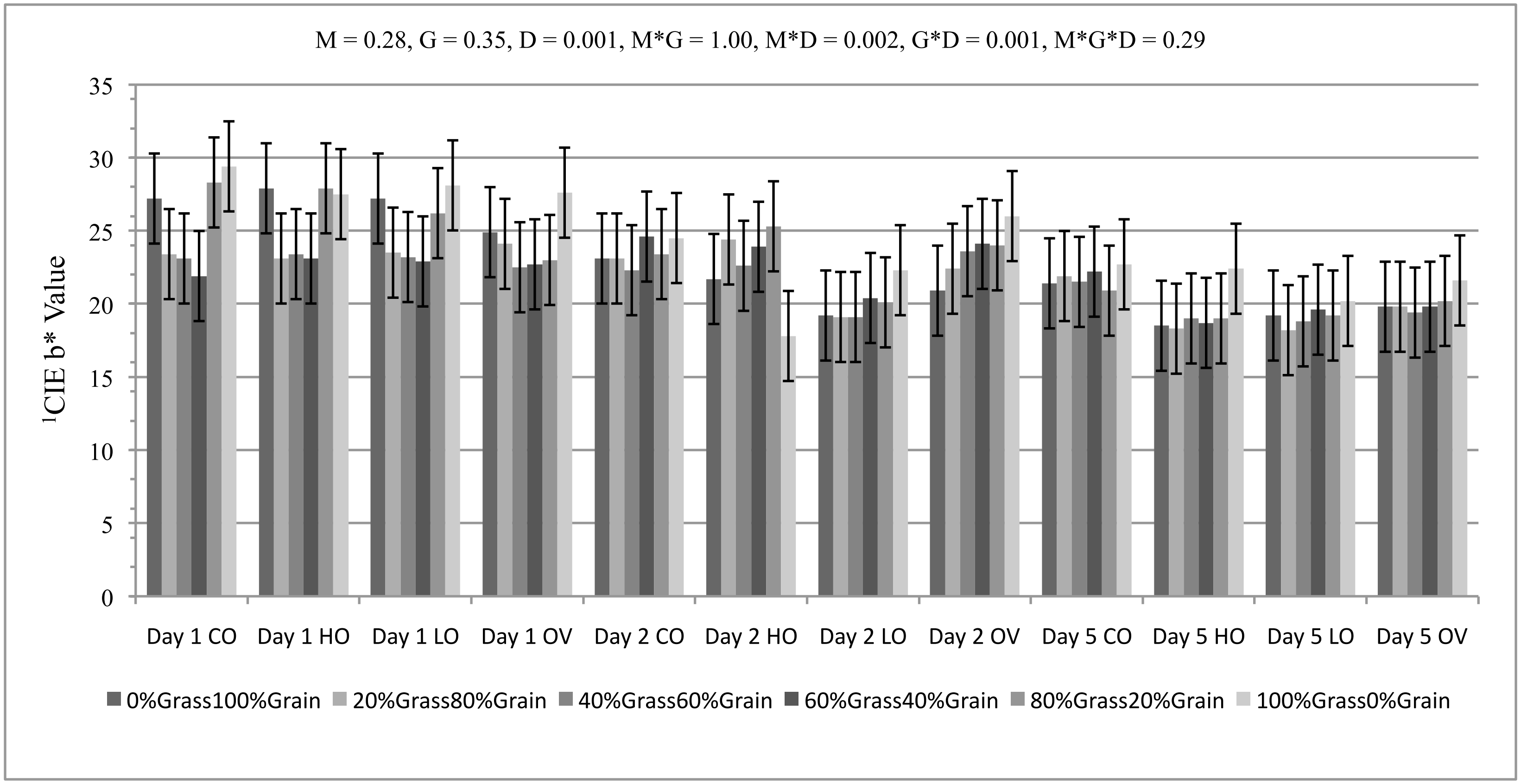


Figure 4.5. Least square means ± SEM for metmyoglobin instrumental values of ground beef by grass/grain titrations at the beginning and end of retail display for MAP. M = modified atmosphere packaging, G = grass/grain titration, D = day of retail display. CO = Carbon monoxide, LO = Low oxygen, HO = High oxygen, OV = overwrap packaging; [1]Metmyoglobin percentage (oxidized myoglobin pigment). Day 1 = Fresh, Day 2 = beginning of retail, Day 5 = end of retail.

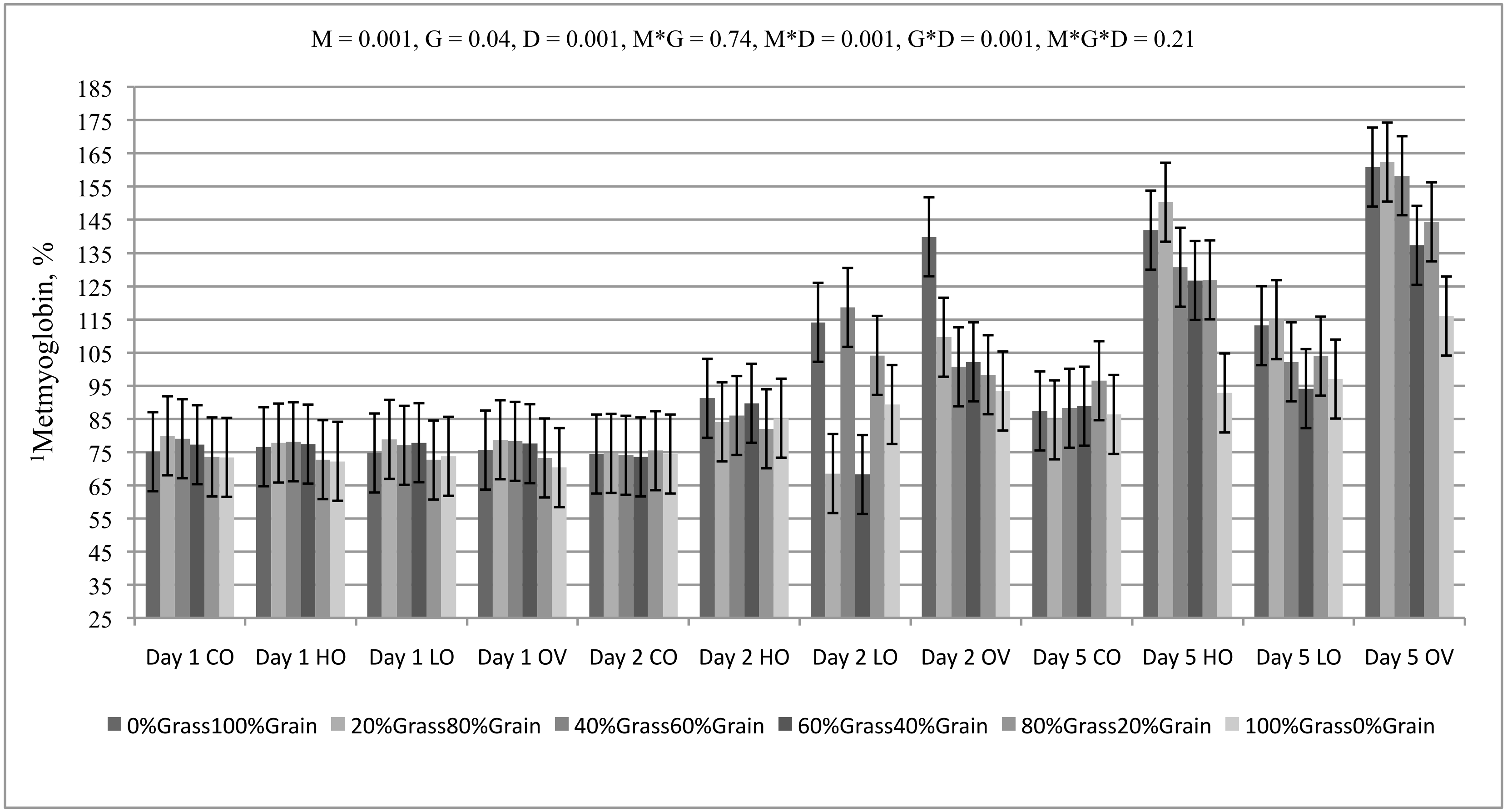


Figure 4.6. Least square means ± SEM for Hue instrumental values of ground beef by grass/grain titrations at the beginning and end of retail display for MAP. M = modified atmosphere packaging, G = grass/grain titration, D = day of retail display. CO = Carbon monoxide, LO = Low oxygen, HO = High oxygen, OV = overwrap packaging; [1] Hue value (numerically decreasing true red color). Day 1 = Fresh, Day 2 = beginning of retail, Day 5 = end of retail.

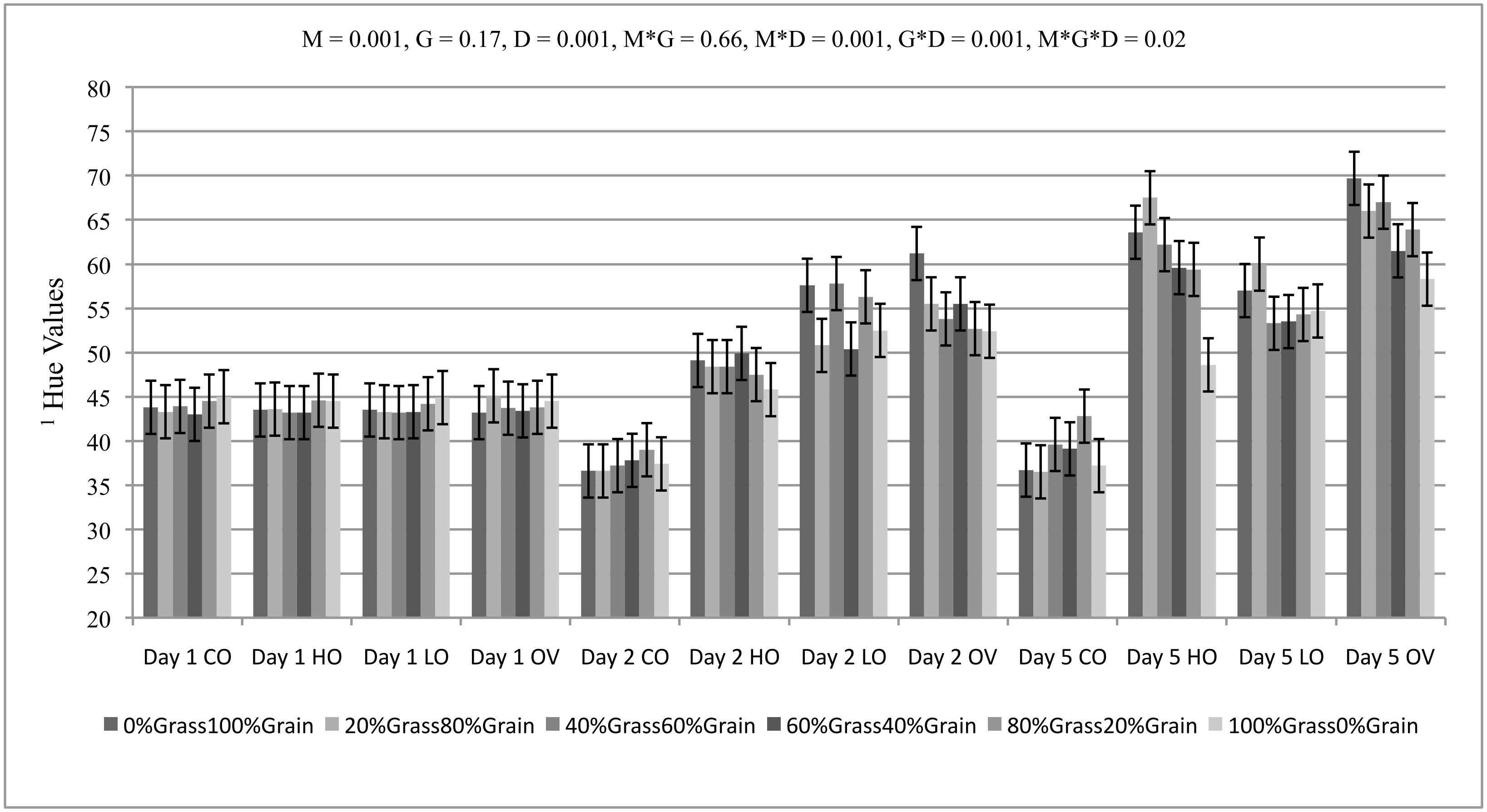


Figure 4.7. Least square means ± SEM for Chroma instrumental values of ground beef by grass/grain titrations at the beginning and end of retail display for MAP. M = modified atmosphere packaging, G = grass/grain titration, D = day of retail display. CO = Carbon monoxide, LO = Low oxygen, HO = High oxygen, OV = overwrap packaging; [1] Chroma value (numerically increasing color saturation). Day 1 = Fresh, Day 2 = beginning of retail, Day 5 = end of retail.

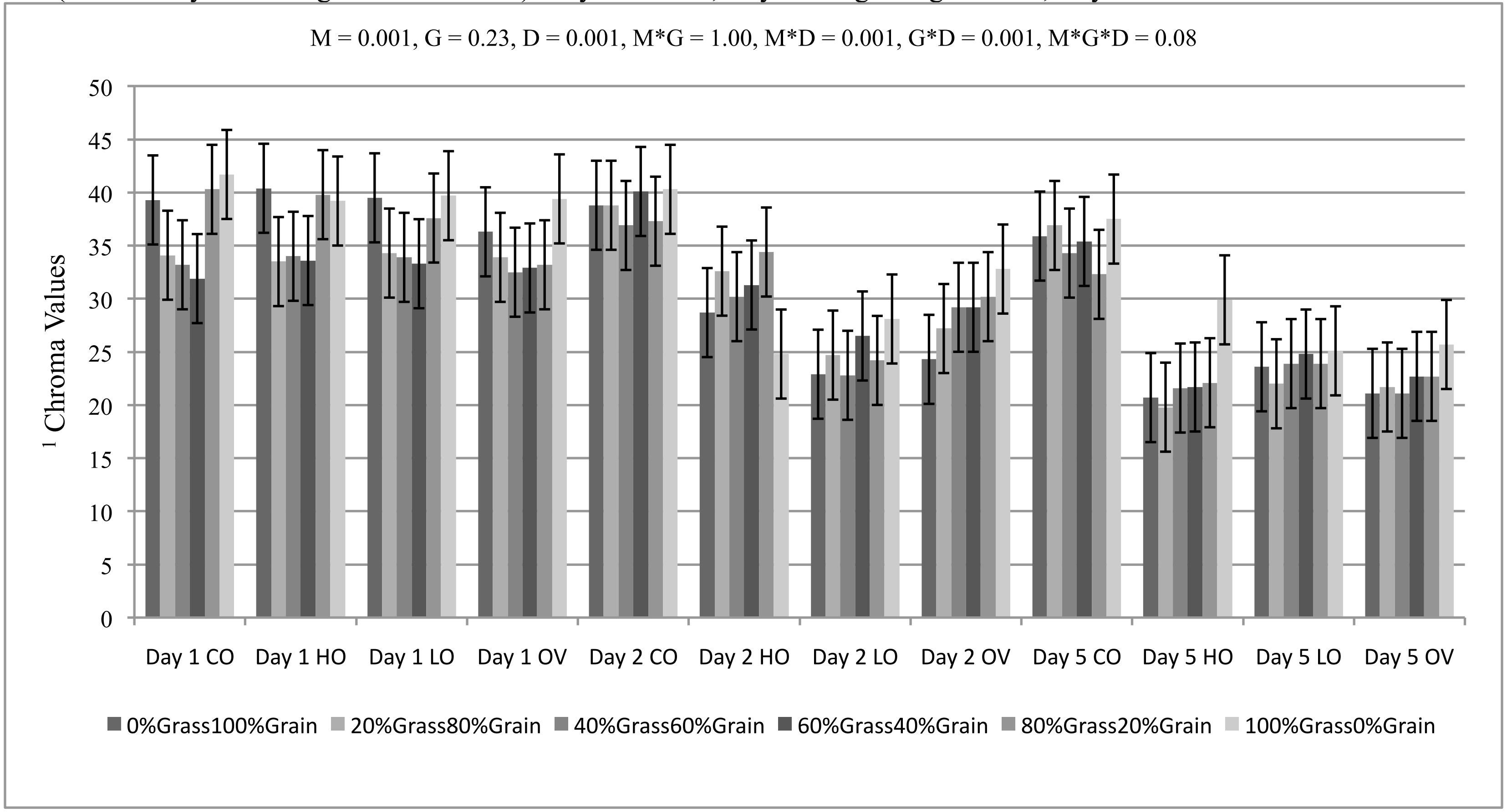


Figure 4.8. Least square means ± SEM for visual lean color of ground beef by grass/grain titrations at the beginning, middle and end of retail display for MAP. M = modified atmosphere packaging, G = grass/grain titration, D = day of retail display. CO = Carbon monoxide, LO = Low oxygen, HO = High oxygen, OV = overwrap packaging; [1] Lean color (1 = extremely dark red; 8 = extremely bright cherry-red).

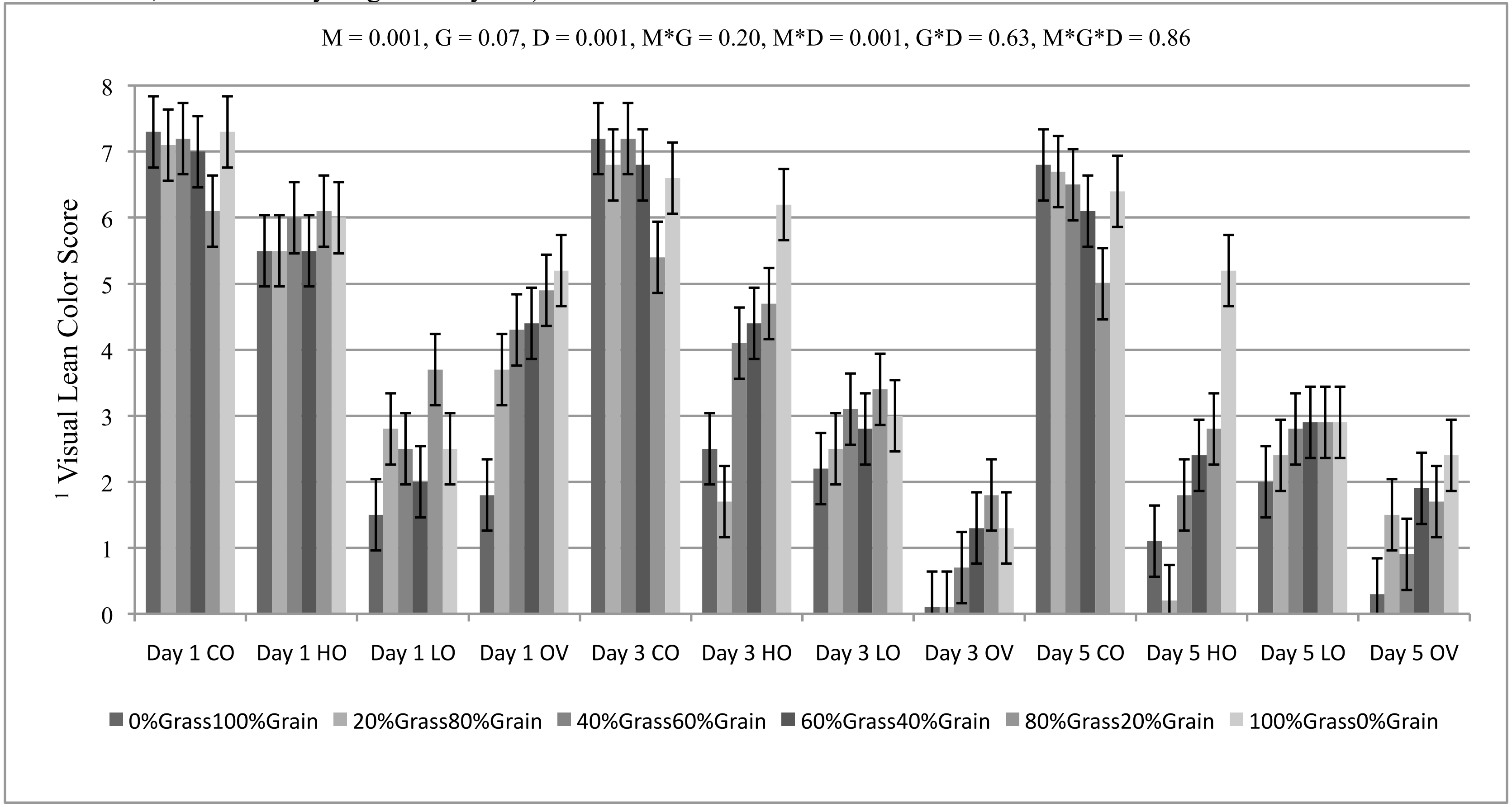

M = 0.001, G = 0.07, D = 0.001, M*G = 0.20, M*D = 0.001, G*D = 0.63, M*G*D = 0.86

Figure 4.9. Least square means ± SEM for visual lean discoloration of ground beef by grass/grain titrations at the beginning, middle and end of retail display for MAP. M = modified atmosphere packaging, G = grass/grain titration, D = day of retail display. CO = Carbon monoxide, LO = Low oxygen, HO = High oxygen, OV = overwrap packaging; [1] Lean discoloration (1 = none; 7 = total discoloration).

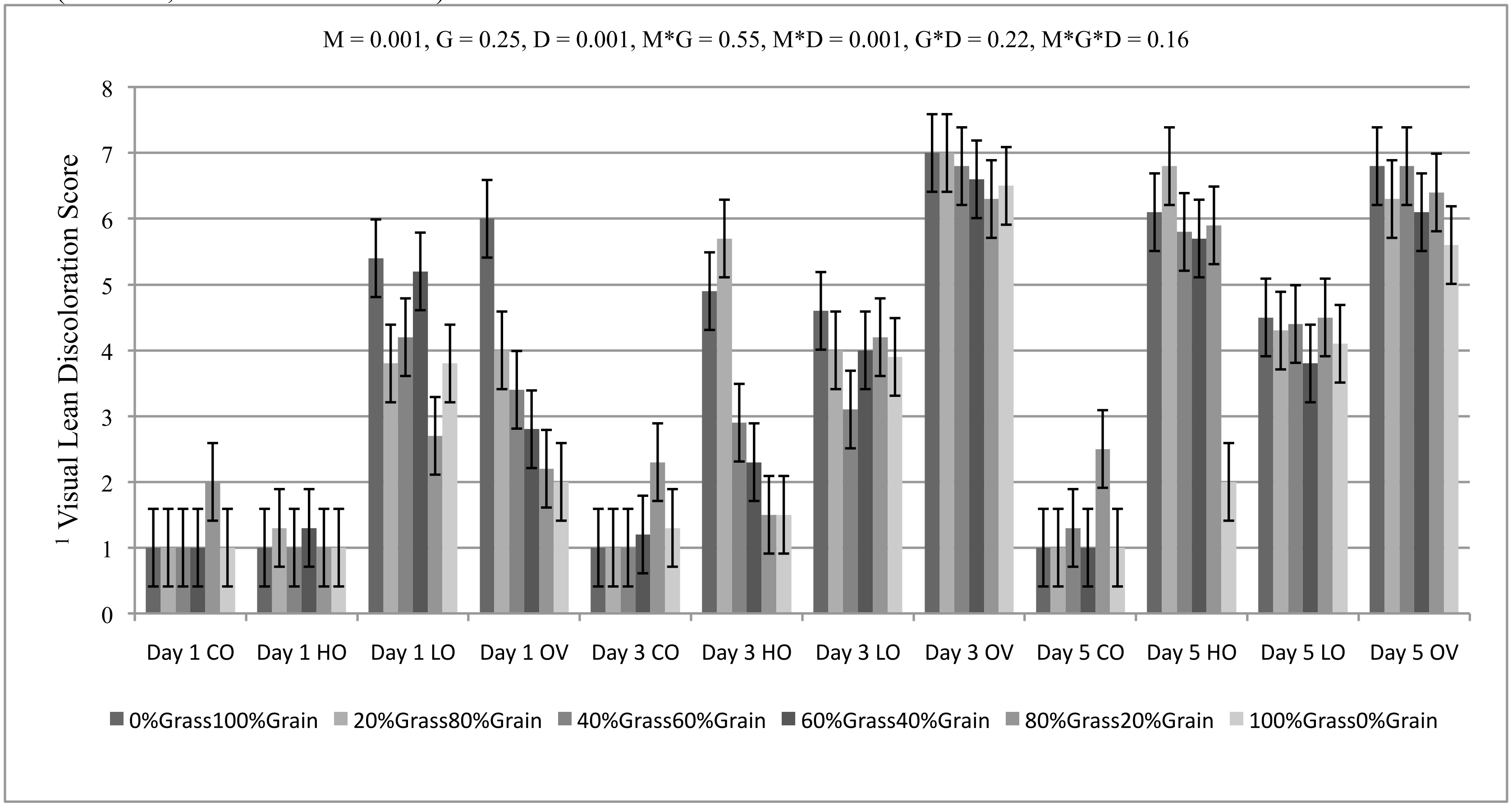
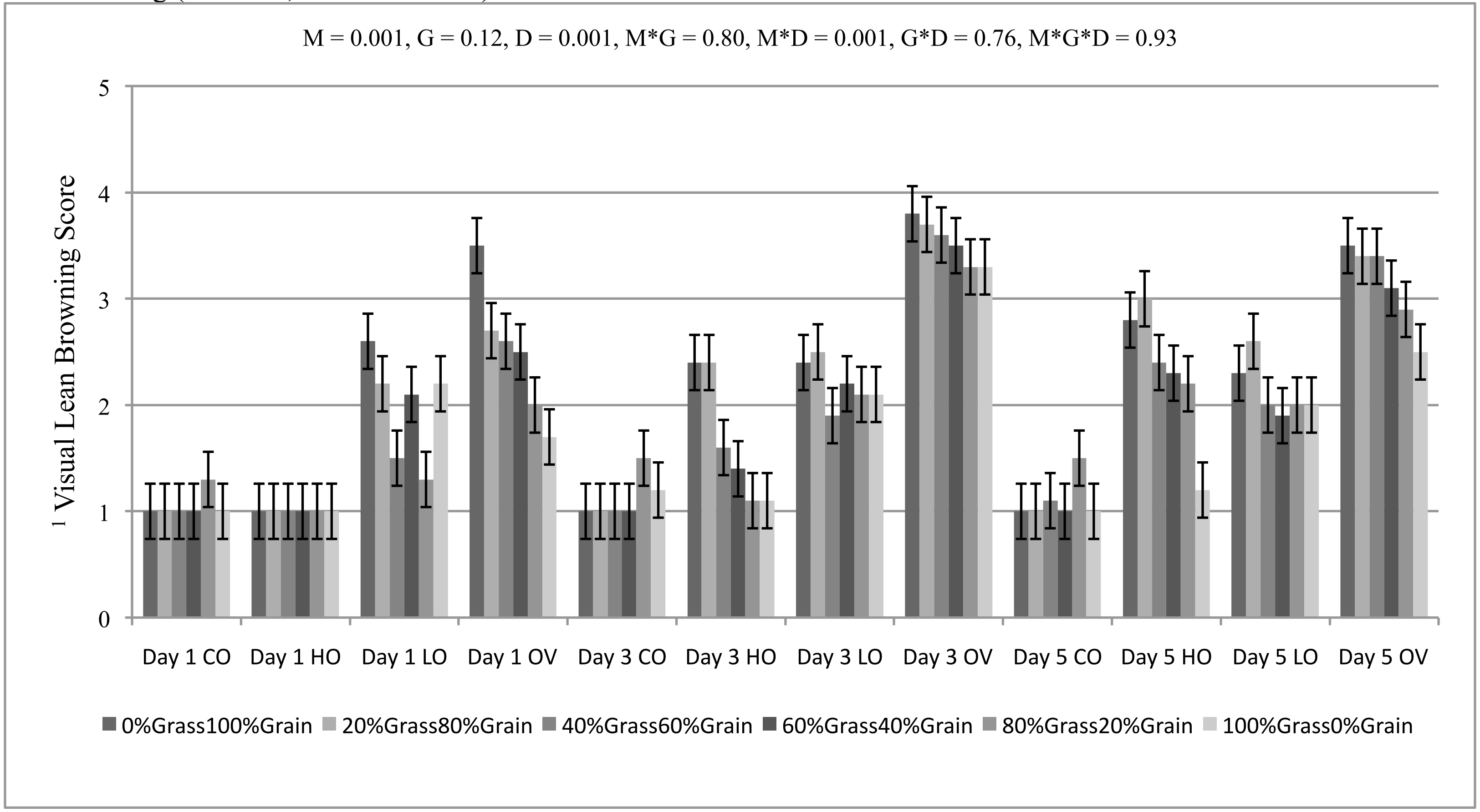
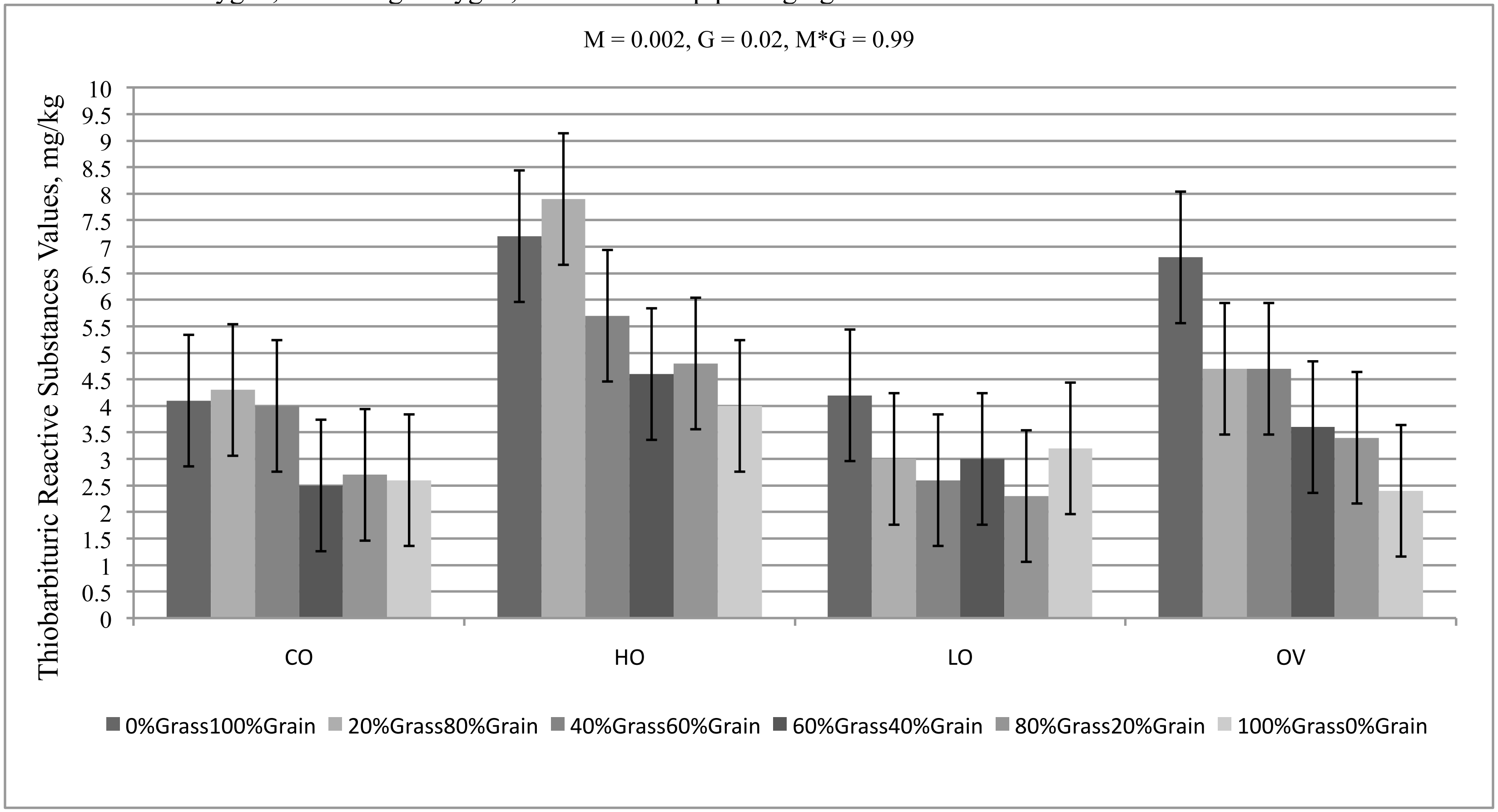


Figure 4.10. Least square means ± SEM for visual lean browning of ground beef by grass/grain titrations at the beginning, middle and end of retail display for MAP. M = modified atmosphere packaging, G = grass/grain titration, D = day of retail display. CO = Carbon monoxide, LO = Low oxygen, HO = High oxygen, OV = overwrap packaging; [1] Lean browning (1 = none; 5 = dark brown).



M = 0.001, G = 0.12, D = 0.001, M*G = 0.80, M*D = 0.001, G*D = 0.76, M*G*D = 0.93

Figure 4.11. Least square means ± SEM for thiobarbituric reactive substance values of ground beef by grass/grain titrations at the end of retail display for MAP. M = modified atmosphere packaging, G = grass/grain titration, CO = Carbon monoxide, LO = Low oxygen, HO = High oxygen, OV = overwrap packaging



M = 0.002, G = 0.02, M*G = 0.99

LITERATURE CITED

Aberle, E. D., J .C. Forrest. D. E. Gerrad, and E. W. Mills. 2001. Principles of Meat Science. Kendall/Hunt Publishing Company.

Akamittath, J. G., C. J. Brekke, and E. G. Schanus. 1990. Lipid oxidation and color stability in restructured meat systems during frozen storage. J. Food Sci. 55:1513-1517.

AMSA. 1991. Guidelines for Meat Color Evaluation. Proc. Reciprocal Meat Conference. 44.

AMSA. 1995. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. American Meat Science Association. Chicago, IL.

Arnold, R. N., K. K. Scheller, S. C. Arp, S. N. Williams, D. R. Buege, and D. M. Schaefer. 1992. Effect of long- or short-term feeding of α-tocopheryl acetate to Holstein and crossbred beef steers on performance, carcass characteristics, and beef color stability. J. Anim. Sci. 70:3055-3065.

Bagley, C. P., and J. I. Feazel. 1987. Production, economics and acceptability of forage-fed beef. La. Agric. Exp. Sta. Bull. 295-301.

Bennett, L. L., A. C. Hammond, M. J. Williams, W. E. Kunkle, D. D. Johnson, R. L. Preston, and M. F. Miller. 1995. Performance, carcass yield and carcass quality characteristics of steers finished on rhizome peanut (*Arachis glabrata*)-tropical grass pasture or concentrate. J. Anim. Sci. 66:892-890.

Bennett, R. M. 1996. People's willingness to pay for farm animal welfare. Animal Welfare. 5:3-11.

Bidner, T. D., R. E. Montgomery, and K. L. Koonce. 1981a. Increasing the palatability of forage and grain-fed beef. Livestock Producers' Day Report. 21:139-143.

Bidner, T. D., A. R. Schupp, R. E. Montgomery, and J. C. Carpenter, Jr. 1981b. Acceptability of beef finished on all-forage, forage-plus-grain or high energy diets. J. Anim. Sci. 53:1181-1187.

Bidner, T. D., R. E. Montgomery, C. P. Bagley, and K. W. McMillin. 1985. Influence of electrical stimulation, blade tenderization and postmortem vacuum aging upon the acceptability of beef finished on forage or grain. J. Anim. Sci. 61:584-589.

Bidner, T. D., A. R. Schupp, A. B. Mohamad, N. C. Rumore, R. E. Montgomery, C. P. Bagley, and K. W. McMillin. 1986. Acceptability of beef from Angus-Hereford or Angus-Hereford-Brahman steers finished on all-forage or a high-energy diet. J. Anim. Sci. 62:381-387.

Blakistone, B. A. 1998. Meats and poultry. Pages 240-290 in Principles and applications of modified atmosphere packaging of foods. 2nd ed. B. A. Blakistone, ed. Blackie Academic and Professional, London.

Boleman, S. J., S. L. Boleman, R. K. Miller, J. F. Taylor, H. R. Cross, T. L. Wheeler, M. Koohmaraie, S. D. Shackelford, M. F. Miller, R. L. West, D. D. Johnson, and J. W. Savell. 1997. Consumer evaluation of beef of known categories of tenderness. J. Anim. Sci. 75:1521-1524.

Bowling, R. A., G. C. Smith, Z. L Carpenter, T. R. Dutson, and W. M. Oliver. 1977. Comparison of forage-finished and grain-finished beef carcasses. J. Anim. Sci. 45:209-215.

Bowling, R. A., J. K. Riggs, G. C. Smith, Z. L. Carpenter, R. L. Reddish, and O. D. Butler. 1978. Production, carcass and palatability characteristics of steers produced by different management systems. J. Anim. Sci. 46:333-340.

Braden, K. W. 2006. Alternative finishing strategies: effects on animal performance, retail shelf life, sensory, fatty acid profile and lipid stability. Ph D Thesis., Auburn Univ., AL.

Brown, H. G., S. L. Melton, M. J. Riemann, and W. R. Backus. 1979. Effects of energy intake and feed source on chemical changes and flavor of ground beef during frozen storage. J. Anim. Sci. 48:338-347.

Buege, J. A. and S. D. Aust. 1978. Assay of lipid oxidation in muscle samples. Methods in Enzymol. 52:305, AP.

Callaway, T. R., R. O. Elder, J. E. Keen, R. C. Anderson and D. J. Nisbet. 2003. Forage feeding to reduce preharvest Escherichia coli populations in cattle, a review. J. Dairy Sci. 86:852-860.

Cox, R. B., C. R. Kerth, J. G. Gentry, J. W. Prevatt, K. W. Braden and W. R. Jones. 2006. Determining acceptance of domestic forage- or grain-finished beef by consumers from three southeastern USA states. J. Food Sci. 71:S542-S546.

Cox, R. B. 2004. Consumer acceptability of forage- or concentrate-finished beef in three southeastern U.S. states. M.S. Thesis., Auburn Univ., AL.

Cross, H. R., and D. A. Dinius. 1978. Carcass and palatability characteristics of beef steers finished on forage diets. J. Anim. Sci. 47:1265-1271.

Decker, E. A., C. Faustman, C. J. Lopez-Bote. 2000. Antioxidants in muscle foods. Nutritional strategies to improve quality. New York: John Wiley & Sons, Inc.

Dikeman, M. E. 1990. Genetic effects on the quality of meat from cattle. World congress on genetics applied to livestock production. 4:521-230.

Field, R. A., J. C. Williams, C. L. Ferrell, J. D. Crouse, and J. E. Kunsman. 1978. Dietary alteration of palatability and fatty acids in meat from light and heavy weight ram lambs. J. Anim. Sci. 47:858-864.

French, P., C. Stanton, F. Lawless, E. G. O'Riordan, F. J. Monahan, P. J. Caffrey, and A. P. Moloney. 2000. Fatty acid composition, including conjugated linoleic acid of intramuscular fat from steers offered grazed grass, grass silage or concentrate-based diets. J. Anim. Sci. 78:2849-2855.

French, P., E. G. O'Riordan, F. J. Monahan, P. J. Caffrey, M. T. Mooney, D. J. Troy, and A. P. Moloney. 2001. The eating quality of meat of steers fed grass and/or concentrates. Meat Sci. 57:379-386.

Gill, C. O. 1996. Extending the storage life of raw chilled meats. Meat Sci. 43:S99-S109.

Griebenow, R. L., F. A. Martz, and R. E. Morrow. 1997. Forage-based beef finishing systems: a review. J. Prod. Agric. 10:84-91.

Harper, G. C. and A. Makatouni. 2002. Consumer perception of organic food production and farm animal welfare. British Food Journal. 104:287-299.

Harrison, A. R., M. E. Smith, D. M. Allen, M. C. Hunt, C. L. Kastner, and D. H. Kropf. 1978. Nutritional regime effects on quality and yield characteristics of beef. J. Anim. Sci. 47:383-388.

Hedrick, H. B., J. A. Paterson, A. G. Matches, J. D. Thomas, R. E. Morrow, W. C. Stringer, and R. J. Lipsey. 1983. Carcass and palatability characteristics of beef produced on pasture, corn silage, and corn grain. J. Anim. Sci. 57:791-801.

Houben, J. H., A. Van Dijk, G. Eikelenboom, and A. H. Hoving-Bolink. 2000. Effect of dietary vitamin E supplementation, fat level and packaging on color stability and lipid oxidation in minced beef. Meat Sci. 55:331-336.

Hunt, M. C., R. A. Mancini, K. A. Hachmeister, D. H. Kropf, M. Merriman, G. Delduca, and G. Milliken. 2004. Carbon monoxide in modified atmosphere packaging affects color, shelf life, and microorganisms of beef steaks and ground beef. J. Food Sci. 69:FCT45-FCT52.

Jakobsen, M. and G. Bertelsen. 2000. Colour stability and lipid oxidation of fresh beef. Development of a response surface model for predicting the effects of temperature, storage time, and modified atmosphere composition. Meat Sci. 54:49-57.

Jensen, J. M., K. L. Robbins, K. J. Ryan, C. Homco-Ryan, F. K. McKeith, M. S. Brewer. 2003. Effects of lactic and acetic acid salts on quality characteristics of enhanced pork during retail display. Meat Sci. 63:501-508.

John, L., D. Cornforth, C. E. Carpenter, O. Sorheim, B. C. Pette, and D. R. Whittier. 2004. Comparison of color and thiobarbituric acid values of cooked hamburger patties after storage of fresh beef chubs in modified atmospheres. J. Food Sci. 69:C608-C614.

Jonsson, M. E., A. Aspan, E. Eriksson and I. Vagsholm. Persistence of verocytotoxin-producing *Escherichia coli* O157:H7 in calves kept on pasture and in calves kept indoors during the summer months in a Swedish dairy herd. Int. J. Food Micro. 66:55-61.

Juniper, D. T., E. M. Browne, A. V. Fisher, M. J. Bryant, G. R. Nute, and D. E. Beever. 2005. Intake, growth and meat quality of steers given diets based on varying proportions of maize silage and grass silage. Anim. Sci. 81: 159-170.

Keen, J. E., G.A. Urlich, and R.O. Elder. 1999. Effects of hay- and grainbased dies on the fecal shedding of naturally –acquired enterohemorrhagic E. coli (EHEC) 157:H7 in beef feedlot cattle. 80th Conference of Research Workers in Animal Diseases, Abstract 86. Chicago, IL.

Kerry, J. P., D. J. Buckley, and P. A. Morrissey. 2000. Improvement of oxidative stability of beef and lamb with vitamin E. Page 229 in Antioxidants in Muscle Foods, Nutritional Strategies to Improve Quality. E. Decker, C. Faustman, and C. J. Lopez-Bote, eds. John Wiley and Sons, Inc., New York.

Kerth, C. R., L. K. Blair-Kerth, and W. R. Jones. 2003. Warner-Bratzler shear force repeatability in beef longissimus steaks cooked with a convection oven, broiler, or clam-shell grill. J. Food Sci. 68:668-670.

Kerth, C. R., K. W. Braden, R. Cox, L. K. Kerth and D. R. Rankins, Jr. 2007. Carcass, sensory, subcutaneous fat color, and consumer acceptance characteristics of

Angus-cross steers finished on ryegrass (*Lolium multiflorum*) forage or on a high-concentrate diet. Meat Science. 75:324-331.

Koohmaraie, M. 1992. Role of the neutral proteinases in post mortem muscle protein degradation and meat tenderness. Proceedings of the Reciprocal Meat Conference. 45:63-74.

Kropf, D. H., D. M. Allen, and G. J. Shouvenelle. 1975. Short-fed, grass-fed and long-fed beef compared. 62nd Annu. Cattleman's Day Rep. Kansas State Univ., Manhatten. 78-87.

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

Lanier, T. C., J. A. Carpenter, R. T. Toledo, and J. O. Reagan. 1978. Metmyoglobin reduction in beef systems as affected by aerobic, anaerobic and carbon monoxide-containing environments. J. Food Sci. 43:1788-1792, 1796.

Lawrie, R. A. 2006. The eating quality of meat. Pages 302-303 in Lawrie's Meat Science. 7th ed. Cambridge, England. Woodhead Publishing Limited.

Liu, Q., K. K. Arp, S. C. Scheller, D. M. Schaefer, and M. Frigg. 1996. Colour coordinates for assessment of dietary vitamin E effect on beef color stability. J. Anim. Sci. 74:106-116.

McIntyre, B. L. and Ryan, W. J. 1984. The influence of type of diet and electrical stimulation on the eating quality of beef. Anim. Prod. Aust. 15:468-471.

Maltin, C., D. Balcerzak, R. Tilley, and M. Delday. 2003. Determinants of meat quality: tenderness. Proc. Nutri. Soc. 62:337-347.

Mandell, I. B., E. A. Gullet, J. G. Buchanan-Smith, and C. P. Campbell. 1997. Effects of diet and slaughter endpoint on carcass composition and beef quality in Charolais cross steers. Can J. Anim. Sci. 77:403-414.

Melton, S. L., N. Amiri, G. W. Davis and W. R. Backus. 1982. Flavor and chemical characteristics of ground beef from grass-, forage-grain-, and grain-finished steers. J. Anim. Sci. 55:77-87.

Melton, S. L. 1983. Effect of forage feeding on beef flavor. Food Tech. 37:239-248.

Melton, S. L. 1990. Effect of forage feeding on beef flavor: a review. J. Anim. Sci. 68:4421-4435.

Millar, S., R. Wilson, B. W. Moss, and D. A. Ledward. 1994. Oxymyoglobin formation in meat and poultry. Meat Sci. 36:397-406.

Miller, R. K., H. R. Cross, J. D. Crouse, and J. D. Tatum. 1987. The influence of diet and time on feed on carcass traits and quality. Meat Sci. 19:303-313.

Mitchell, G. E., A. W. Reed, and S. A. Rogers. 1991. Influence of feeding regimen on the sensory qualities and fatty acid contents of beef steaks. J. Food Sci. 56: 1102-1103.

Moloney, A. P., M. T. Mooney, J. P. Kerry, and D. J. Troy. 2001. Producing tender and flavoursome beef with enhanced nutritional characteristics. Proc. Nutri. Society. 60:221-229.

Monahan, F. J. 2000. Oxidation of lipids in muscle foods: fundamental and applied concerns . Page 229 in Antioxidants in Muscle Foods, Nutritional Strategies to Improve Quality. E. Decker, C. Faustman, and C. J. Lopez-Bote, eds. John Wiley and Sons, Inc., New York.

Moody, W. G. 1976. Quantitative and qualitative differences in beef from various energy regimes. Proc. 29th Annu. Reciprocal Meat Conference. 128.

Morgan, J. H. L. and G. C. Everitt. 1969. Yellow fat colour in cattle. New Zealand J. Agri. Sci. 3:10-18.

Muir, P. D., J. M. Deaker, and M. D. Brown. 1998a. Effects of forage and grain-based feeding systems on beef quality: a review. New Zealand J. Agric. Res. 41:623-635.

Muir, P. D., N. B. Smith, G. J. Wallace, G. J. Cruickshank, and D. R. Smith. 1998b. The effect of short term grain feeding on live weight gain and beef quality. New Zealand J. Agric. Res. 41:517-526.

O' Keeffe, M. and D. E. Hood. 1982. Biochemical factors influencing metmyoglobin formation on beef from muscles of differing colour stability. Meat Sci. 7:209-228.

O'Sullivan, A. K., K. O'Sullivan, K. Galvin, A. P. Moloney, D. J. Troy, and J. P. Kerry. 2002. Grass silage versus maize silage effects on retail packaged beef quality. J. Anim. Sci. 80:1556-1563.

O'Sullivan, A., K. Galvin, A. P. Moloney, D. J. Troy, K. O'Sullivan and J. P. Kerry. 2003. Effect of pre-slaughter rations of forage and/or concentrates on the composition and quality of retail packaged beef. Meat Sci. 63:279-286.

O'Sullivan, A., K. O'Sullivan, K. Galvin, A.P. Moloney, D. J. Troy, and J. P. Kerry. 2004. Influence of concentrate composition and forage type on retail packaged beef quality. J. Anim. Sci. 82:2384-2391.

Owens, F. N., and B. A. Gardner. 1999. Ruminent nutrition and meat quality. Proc. Ann. Reciprocal Meat Con. 52:25-36.

Pariza, M. 1997. Conjugated linoleic acid, a newly recognized nutrient. Chem. Indus. 12:464-466.

Pearson, A. M. 1966. Desirability of beef-its characteristics and their measurement. J. Anim. Sci. 25:843-854.

Pietrasik, Z., J. S. Dhanda, P. J. Shand, and R. B. Pegg. 2006. Influence of injection, packaging, and storage conditions on the quality of beef and bison steaks. J. Food Sci. 71:S110-S118.

Prevatt, J. W., C. R. Kerth, and D. Fields. 2006. Marketing Alabama-grown, forage-fed beef. Alabama Agric. Exp. Stat. 1-12.

Priolo, A., D. Micol, and J. Agabriel. 2001. Effects of grass feeding systems on ruminant meat colour and flavour. A review. Anim. Res. 50:185-200.

Renerre, M., and R. Labas. 1987. Biochemical factors influencing metmyoglobin formation in beef muscles. Meat Sci. 19:151-165.

Renerre, M. 1990. Factors involved in the discoloration of beef meat. Int. J. Food Sci. Technol. 25:613-630.

Resurreccion, A. V. A. 2003. Sensory aspects on consumer choices for meat and meat products. Meat Sci. 66:11-20.

Reverte, D., Y. L. Xiong, and W. G. Moody. 2003. Properties of restructured beef steaks from forage- and grain-fed cattle as affected by antioxidant and flavoring agents. Meat Sci. 65:539-546.

Robach, M. C., and M. C. Pierson. 1979. Inhibition of *Clostridium botulinum* types A and B by phenolic antioxidants. J. Food Prot. 42:858-861.

Robbins, K., J. Jenson, K. J. Ryan, C. Homco-Ryan, F. K. McKeith, and M. S. Brewer. 2002. Enhancement effects on sensory and retail display characteristics of beef rounds. J. Muscle Foods. 13:279-288.

Robbins, K., J. Jenson, K. J. Ryan, C. Homco-Ryan, F. K. McKeith, and M. S. Brewer. 2003a. Consumer attitudes towards beef and acceptability of enhanced beef. Meat Sci. 65:721-729.

Robbins, K., J. Jenson, K. J. Ryan, C. Homco-Ryan, F. K. McKeith, and M. S. Brewer. 2003b. Dietary vitamin E supplementation effects on the color and sensory characteristics of enhanced beef steaks. Meat Sci. 64:279-285.

Roberts, S. D. 2005. Forage quality, animal performance and carcass traits of steers finished on winter annual ryegrass (*Lolium multiflorum Lam.*) pasture with varying levels of corn supplementation. M. S. Thesis. Auburn Univ., AL.

Sapp, P. H., S. E. Williams and M. A. McCann. 1999. Sensory attributes and retail display characteristics of pasture- and/or grain-fed beef aged 7, 14 or 21 days. J. Food Quality. 22:257-274.

Schaake, S. L., G. C. Skelley, E. Halpin, L. W. Grimes, R. B. Brown, D. L. Cross, C. E. Thompson. 1993. Carcass and meat sensory traits of steers finished on fescue and clover, summer forage, or for different periods in drylot. J. Anim. Sci. 71:3199-3205.

Schafer, E., R. B. Schafer, G. L. Bultena, and E. O. Hoiberg. 1993. Safety of the U.S. food supply: consumer concerns and behaviour. J. Consum. Stud. Home Econ. 17:137-144.

Schroeder, J. W., D. A. Cramer, R. A. Bowling, and C. W. Cook. 1980. Palatability, shelflife and chemical differences between forage- and grain-finished beef. J. Anim. Sci. 50:852-859.

Schupp, A. R., T. D. Bidner, and N. C. Clark. 1980. Consumer acceptance of beef produced under alternative feeding systems. Southern J. Agric. Econ. 31-35.

Seideman, S. C., H. R. Cross, G. C. Smith, and P. R. Durland. 1984. Factors associated with fresh meat color: a review. J Food Quality. 6:211-237.

Simone, M., F. Carroll, and M. T. Clegg. 1958. Effect of degree of finish on differences in quality factors of beef. Food Res. 23:32-40.

Smith, G. C., T. G. Jambers, Z. L. Carpenter, T. R. Dutson, R. L. Hostetler, and W. M. Oliver. 1979. Increasing the tenderness of forage-fed beef. J. Anim. Sci. 49:1207-1218.

Sorheim, O., T. Aune, and T. Nesbakken. 1997. Technological hygienic and toxicological aspects of carbon monoxide used in modified-atmosphere packaging of meat. Trends Food Sci. Tech. 8:307-312.

Sorheim, O., H. Nissen, and T. Nesbakken. 1999. The storage life of beef and pork packaged in an atmosphere with low carbon monoxide and high carbon dioxide. Meat Sci. 52: 157-164.

Stika, J. F., Y. L. Xiong, S. P. Suman, S. P. Blanchard, and W. G. Moody. 2007. Frozen storage stability of antioxidant-treated raw restructured beef steaks made from mature cows. Meat Sci. 77: 562-569.

Tarrant, P. V. 1998. Some recent advances and future priorities in research for the meat industry. Meat Sci. 49:S1-S16.

Thompson, J. M. 2002. Managing meat tenderness. Meat Sci. 62:295-308.

Umberger, W. J., D. M. Feuz, C. R. Calkins, and K. Killinger-Mann. 2002. U.S. consumer preference and willingness-to-pay for domestic corn-fed beef versus international grass-fed beef measured through an experimental auction. Agribusiness. 18:491-504.

[USFDA] U. S. Food and Drug Administration. 2002. GRAS notice nr GRN 000083. Washington, D. C.: USFDA.

Walker, P. J., R. D. Warner, C. G. Winfield. 1990. Sources of variation in subcutaneous fat colour of beef carcasses. Proceedings of the Aust. Soci. Anim. Prod. 18:416-419.

Wanderstock, J. J. and J. I. Miller. 1948. Quality and palatability of beef as affected by method of feeding and carcass grade. Food Res. 13:291.

Weiss, M. F., F. A. Martz, C. L. Lorenzen. 2004. Conjugated linoleic acid: implicated mechanisms related to cancer, atherosclerosis, and obesity. Prof. Anim. Sci. 20:127-135.

Westerling, D. A., and H. B. Hedrick. 1979. Fatty acid composition of bovine lipids as influenced by diet, sex and anatomical location and relationship to sensory characteristics. J. Anim. Sci. 48:1343-1348.

Wood, J. D., R. I. Richardson, G. R. Nute, A. V. Fisher, M. M. Campo, E. Kasapidou, P. R. Sheard, M. Enser. 2003. Effects of fatty acids on meat quality: a review. Meat Sci. 66:21-32.

Yang, A., S. R. McLennan, J. Armstrong, T. W. Larsen, F. D. Shaw, R. K. Tume. 1993. Effect of short term grain feeding on bovine body-fat colour: a cautionary note. Aust. J. Agri. Res. 44: 215-220.

Young, O. A., and B. M. B. Baumeister. 1999. The effect of diet on the flavour of cooked beef and the odour compounds in beef fat. New Zealand J. Agric. Research. 42:297-304.

Zhao, Y., J. H. Wells, and K. W. McMillin. 1994. Applications of dynamic modified atmosphere packaging systems for fresh red meats: a review. J. Muscle Foods. 5:299-328.

APPENDICES

APPENDIX A

Retail Display Shelf-Life Visual Evaluation Setup

1. Obtain desired pumped or non-pumped fabricated 2.54cm cuts from harvest facility, package in MAP or vacuum package accordingly and store at 2 C for 21d.

2. Select postmortem days so that the first of each postmortem period fall on the first of the week.

3. At each postmortem period steaks should be placed in to simulated retail conditions.

4. In this study a Tyler (Model DMG-8, Niles, MI) retail display case (coffin) were utilized.

5. Steaks should be allowed to remain in retail display case at 2 C for 5 days and should be subjected to 24h exposure to retail display lighting (illumination intensity at surface of the steaks should be near 1,000 lx).

6. During each 5 day postmortem period steaks should be evaluated by a trained panel, consisting of at least six members, for beef color, color uniformity, surface discoloration, and lean browning according to AMSA (1991) color guidelines.

APPENDIX B

Instrumental Color Evaluation

1. Obtain desired pumped or non-pumped fabricated 2.54cm cuts from harvest facility, package in MAP or vacuum package accordingly and store at 2 C for 21d.

2. Prior to packaging the Commission Internationale de l'Eclairage (CIE) L* (muscle lightness), a* (muscle redness), and b* (muscle yellowness) values were determined from two random reading on each steak with a Hunter Miniscan XE Plus (Hunter Laboratories Model 45/0-L, Reston, VA).

3. Select postmortem days so that the first of each postmortem period fall on the first of the week.

4. At each postmortem period steaks should be placed in to simulated retail conditions.

5. In this study a Tyler (Model DMG-8, Niles, MI) retail display case (coffin) were utilized.

6. Steaks should be allowed to remain in retail display case at 2 C for 5 days and should be subjected to 24h exposure to retail display lighting (illumination intensity at surface of the steaks should be near 1,000 lx).

7. At the end of the 5d retail display the Commission Internationale de l'Eclairage (CIE) L* (muscle lightness), a* (muscle redness), and b* (muscle yellowness) values were determined from two random reading on each steak with a Hunter Miniscan XE Plus (Hunter Laboratories Model 45/0-L, Reston, VA).

APPENDIX C

Sensory Evaluation

1. Steaks should have an internal temperature of 2-5°C before cooking. It is common to thaw steaks before cooking at 2-5°C for 12 hours.

2. Take care and maintain sample identity throughout process.

3. Pre-heat sample holding containers and pans. Pans with separate suspended compartments can be utilized, with the addition of sand below to maintain temperature.

4. Internal temperature of each steak should be taken in the geometric center of the steak and recorded. Temperatures should be in the range of 2-5°C.

5. Weigh each steak in grams before cooking and record.

6. Place steak on cooking surface and cook until a medium degree of doneness. The internal temperature of steaks should be approximately 71°C.

7. Weight and temperature of each steak should be recorded immediately after cooking utilizing the same procedure as before cooking.

8. Cut all four sides of the steak in a fashion that produces a square or rectangle out of the steak, while removing fat and connective tissue.

9. Place all pieces of sample in designated sample holding containers and maintain identity.

10. Panel room should be prepared before cooking to facilitate efficient panel time and minimize period after cooking until panel evaluations.

11. Panel set-up and evaluations should be according to Cross et al., 1978.

12. Record all sensory data for analysis.

APPENDIX D

Thiobarbituric Reactive Substance (TBA) Assay

Modified from:

Buege and Aust. 1978. Methods in Enzymol. 52.302, AP

Reagent:

1. TCA/TBA stock solution: 15% TCA(w/v) and 20 mM TBA (MW 144.15) reagent in DW. **Dissolve 2.88g TBA in *warm* DDW first, add TCA (150g) and then add DW to the mark (1L).** Once liter last 100 samples in duplicate.

2. BHA: Make 10% stock solution by dissolving in 90% ethanol. Make 500ml batches.

3. TEP standard: $1*10^{-3}$ M 1, 1, 3, 3-tetra-ethoxypropane in DW. This solution can be kept for about a week if stored in the refrigerator and diluted as needed. (MW 220.31, 95% purity, d=0.918). Dilute 0.5ml TEP with 499.5 ml DW, and dilute the resulting solution 1:2.96 (TEP solution: DW) with DW.

Procedure:

1. Slice 5g of fresh meat and place in blender cup with 15ml of DW.

2. Homogenize with a blender for 2 min. (or homogenize for 10-15 sec using a polytron at speed 7-8).

3. Take 2ml of the homogenate, combine with 4ml of the TCA/TBA reagent, 100µl BHA, vortex thoroughly.

4. Heat the solution for 15 min in a boiling water bath.

5. Cool for 10 min in a cold water bath.

6. Vortex thoroughly.

7. Centrifuge at 2000G (3000RPM) for 10 min or filter using Whatman paper.

8. Read the absorbance of the supernatant at 531 nm against a blank that contains all the reagents minus sample.

Malonaldehyde standard curves ($\text{CHO-CH}^2\text{-CHO}$, MW 72.0)

1. Construct TBA standard curve using TEP.
2. Label tubes: six tubes -0 and two tubes of each- 5, 10, 20, 30, 40, and 50.
3. Add the following amounts to each tube:

	TEP	DW	Set pipettor on:
0	0µl	2000µl	1000 (twice)
5	10µl	1990µl	995 (twice)
10	20µl	1980µl	990 (twice)
20	40µl	1960µl	980 (twice)
30	60µl	1940µl	970 (twice)
40	80µl	1920µl	960 (twice)
50	100µl	1900µl	950 (twice)

4. Add 4ml TBA/TCA to each tube, vortex.

5. Heat the tubes in boiling water bath for 15 min.

6. Cool in cool water bath for 20 min.

7. Vortex.

8. Read the optical density of the standard against a blank at the same wavelength (531 nm).

APPENDIX E

GROUND BEEF TRAINED SENSORY EVALUATION FORM

Name______________ Date____________ Time: ___________ Project______________

Sample No	Initial juiciness	Sustained juiciness	Cohesiveness	Flavor intensity	Off Flavor	Off-flavor Descriptor

Juiciness	Cohesiveness	Flavor intensity	Off Flavor	Off flavor Descriptors
8=Extremely juicy	8=Extremely cohesive	8=Extremely intense beef	8=Extreme off flavor	8=Metallic
7=Very juicy	7=Very cohesive	7=Very intense beef	7=Intense off flavor	7=Salty
6=Moderately juicy	6=Moderately cohesive	6=Moderately intense beef	6=Very off flavor	6=Livery
5=Slightly juicy	5=Slightly cohesive	5=Slightly intense beef	5=Moderate off flavor	5=Grassy
4=Slightly dry	4=Slightly crumbly	4=Slightly bland	4=Modest off flavor	4=Bitter
3=Moderately dry	3=Moderately crumbly	3=Moderately bland	3=Small off flavor	3=Bloody
2=Very dry	2=Very crumbly	2=Very bland	2=Slight off flavor	2=Rancid
1=Extremely dry	1=Extremely crumbly	1=Extremely bland	1=No off flavor	1=Other – Explain

APPENDIX F

TRAINED SENSORY EVALUATION FORM

Name______________ Date____________ Time: ___________ Project______________

Sample No	Initial juiciness	Sustained juiciness	Initial tenderness	Sustained tenderness	Flavor intensity	Off Flavor	Off Descriptor

Juiciness	Tenderness	Flavor intensity	Off Flavor	Off flavor Descriptors
8=Extremely juicy	8=Extremely tender	8=Extremely intense beef	8=Extreme off flavor	8=Metallic
7=Very juicy	7=Very tender	7=Very intense beef	7=Intense off flavor	7=Salty
6=Moderately juicy	6=Moderately tender	6=Moderately intense beef	6=Very off flavor	6=Livery
5=Slightly juicy	5=Slightly tender	5=Slightly intense beef	5=Moderate off flavor	5=Grassy
4=Slightly dry	4=Slightly tough	4=Slightly bland	4=Modest off flavor	4=Bitter
3=Moderately dry	3=Moderately tough	3=Moderately bland	3=Small off flavor	3=Bloody
2=Very dry	2=Very tough	2=Very bland	2=Slight off flavor	2=Rancid
1=Extremely dry	1=Extremely tough	1=Extremely bland	1=No off flavor	1=Other – Explain

APPENDIX G

Retail Display Shelf-Life Visual Evaluation

Name: _________________________ Date: __________ Project: ________________

Beef color
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

Color Uniformity
5=Extreme two-toning
4=Moderate two-toning
3=Small two-toning
2=Slight two-toning
1=Uniform

Surface discoloration
7=100%
6=80-99%
5=60-79%
4=40-59%
3=20-39%
2=10-19%
1=0%

Browning
5=Dark brown
4=Brownish gray
3=Grayish
2=Dull
1=None

No.	Color	Uniform	Discolor	Brown	No.	Color	Uniform	Discolor	Brown