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Comparison of Color and Thiobarbituric Acid (TBA) Values of Cooked Hamburger Patties and Top Sirloin Steaks after Storage of Fresh Beef Chubs and Raw Steaks in Modified Atmospheres of 80% Oxygen or 0.4% Carbon Monoxide

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COMPARISON OF COLOR AND THIOBARBITURIC ACID (TBA) VALUES OF COOKED HAMBURGER PATTIES AND TOP SIRLOIN STEAKS AFTER STORAGE OF FRESH BEEF CHUBS AND RAW STEAKS IN MODIFIED ATMOSPHERES OF 80% OXYGEN OR 0.4% CARBON MONOXIDE

by

Liza John

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

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ABSTRACT

Comparison of Color and Thiobarbituric Acid (TBA) Values of Cooked Hamburger Patties and Top Sirloin Steaks after Storage of Fresh Beef Chubs and Raw Steaks in Modified Atmospheres of 80% Oxygen or 0.4% Carbon Monoxide

by

Liza John, Master of Science

Utah State University, 2004

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Department: Nutrition and Food Sciences

This study compared the effect of packaging method (0.4% carbon monoxide, 80% oxygen or vacuum), storage time (7, 14 and 21 days) and internal cooking temperature 49, 57, 66, 71 and 79°C) on color and thiobarbituric acid (TBA) values of top sirloin steaks and ground beef patties. Ground beef was obtained from 3 different sources (chuck, loin and trim). All samples were stored at 2°C for 7, 14 and 21 days.

All raw ground beef samples stored in 0.4% carbon monoxide remained bright red throughout the 21-day storage period. The phenomenon of premature browning (appearance of cooked color at lower than normal cooking temperatures) was observed in samples stored in high oxygen. TBA values were highest for the samples stored in 80% oxygen. Internal a* redness values were lowest for samples stored in 80% oxygen. Percent myogobin denaturation (PMD) increased with increase in internal cooking temperature and was highest for the ground beef samples stored in 80% oxygen.

The a* redness values were highest for raw steaks stored in 0.4% CO. Steaks stored in vacuum had a uniform purple color, but some browning was noticed on the surface of the samples by day 14. PMD and TBA values of cooked top sirloin steaks were highest for the samples stored in 80% oxygen.

This study confirms that high oxygen packaging promotes rancidity in ground beef and top sirloin steaks. Packaging in 0.4% carbon monoxide helps maintain a bright cherry red color in ground beef and top sirloin steaks for up to 21 days.

(118 pages)

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The completion of this thesis means a lot to my parents, Mr. John Lobo and Mrs. Viji John. So I dedicate this thesis to my parents. Finally I would like to thank my friends Sarika Paralkar and Rasmi Deshpande, who were always there to support me and build my confidence.

Liza John

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LIST OF SYMBOLS, NOTATION, DEFINITIONS

C - Celcius

CO - Carbon monoxide

CO_2 - Carbon dioxide

COHb - Carboxyhaemoglobin

DMb - Deoxymyoglobin

FDA - Federal Drug Administration

GRAS - Generally Recognized as safe

MMb - Metmyoglobin

OMb - Oxymyoglobin

PMB - Premature Browning

TBA - Thiobarbituric acid

PVC - Polyvinyl chloride

CHAPTER I

INTRODUCTION

Color of fresh meat is an important parameter determining consumer acceptance. Consumers expect the appearance of fresh beef to be bright red. The main properties by which consumers judge meat quality are appearance, texture and flavor. The most important among these is visual appearance as it is an important attribute that influences consumer's purchase decision (Kropf and others1986). It is indicated by Liu and others1995 that every year there could be a loss of over 700 million dollars in retail beef due to the problem of discoloration.

Beef color is primarily attributed to three pigments (Livingston and Brown 1981). Deoxymyoglobin (DMb) is the purple pigment found in freshly cut meat. On exposure to air, deoxymyoglobin is converted to red oxymyogobin. On further exposure to oxygen, oxymyoglobin (OMb) is converted to brown metmyoglobin (MMb) (Liu and others 1995).

Stabilization of the red color of meat has been a challenge in the area of modified atmospheric packaging (MAP) of meat. The most commonly used gases in modified atmospheric packaging include carbon dioxide (CO_2), nitrogen (N_2) and oxygen (O_2). The three packaging systems compared in this study include packaging in 0.4% CO, vacuum or 80% oxygen.

In December 2002, FDA approved the usage of 0.4% carbon - monoxide for packaging fresh cuts of case ready muscle meat and case ready ground meat to maintain wholesomeness, provide flexibility in distribution, and reduce shrinkage of the meat. Modified atmospheric packaging of meat using low levels of CO does not provide a toxic threat to consumers (Sorheim and others 1997). CO strongly binds to myoglobin in meat to form carboxymyoglobin which has a bright cherry red color. Vacuum packaging is another commonly used packaging method used in the meat industry. In the absence of oxygen, the myoglobin in meat is converted to purple deoxymyoglobin and is a cause for reduced acceptance among consumers.

The two MAP systems that are most commonly seen are a high- and low-oxygen. High-oxygen MAP uses 40-80% oxygen, 20-30% carbon dioxide, and the remainder is nitrogen (0-20%). The high partial oxygen pressure results in a deeper oxymyoglobin layer into the meat and a correspondingly appealing meat color. Because of this, high-oxygen MAP does not require additional packaging modifications before displaying in the retail case, unlike low-oxygen MAP. High-oxygen MAP results in a color-life of 7-10 days, however, high-oxygen MAP has a shorter shelf-life (8-12 days) with regard to lipid and flavor stability. Although oxygen prolongs the desirable color of meat, studies indicate that it also promotes lipid oxidation (O'Grady and others 2000; Jayasingh and others 2002).

Lipid oxidation is a major cause of deterioration in meat quality (Ashgar and others 1988). The thiobarbituric acid (TBA) test is most often used to assess lipid oxidation in meat (Gray 1978). Greene and Cumuze (1981) indicated in their study that there is a correlation between TBA numbers and consumer's detection of oxidized flavor in cooked ground beef. Panelists were able to detect an oxidized flavor in samples that had a TBA value of 0.6. The study conducted by Jayasingh and others (2002) confirmed that high oxygen packaging promoted lipid oxidation.

A food safety concern associated with cooking beef is the effect of premature browning (PMB). Recent research suggests that some ground beef patties appear well done at temperature below 160°F (the premature browning effect) (Hague and others 1994). This is a food safety concern as pathogenic bacteria could survive at these low cooking temperatures. This PMB effect was documented by visual and instrumental color measurements of the samples.

Thus the objectives of this study are as follows:

- To identify the effect of packaging method and storage time on the occurrence of PMB in cooked patties and steaks.
- To assess the color of ground beef and top sirloin steaks packaged in 0.4% CO, high oxygen or vacuum, both by visual (using a panel score) and instrumental (using a Hunter colorimeter) methods.
- To measure the TBA values of samples stored in these three MAP systems to assess the extent of lipid oxidation.
- To document the total myoglobin content, percent myoglobin denaturation and percent metmyoglobin by pigment extraction.

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CHAPTER II

LITERATURE REVIEW

BRIEF HISTORY OF MEAT PACKAGING

Packaging is an important aspect in the field of meat technology and tremendous developments are taking place in this particular area (Taylor 1996a). Prior to the 1960's carcasses used to be shipped to the retailers for breaking and cutting. In the 1960's companies started producing boxed beef where the carcass is cut into smaller parts called primals and subprimals and this boxed beef was shipped to the retailers for fabrication. Recently there has been a noticeable trend towards the production of case-ready meat (Brody 2004). In case ready packaging (also called centralized packaging), carcasses are cut, fabricated and packaged in the processing plant and this ready package is shipped to the retail outlets (Brody 2004). This method of packaging eliminates cutting, handling and processing at a store level. Case-ready meat can be sold in one of two ways: Vacuum packaging or modified atmospheric packaging.

Vacuum Packaging

Vacuum packaging involves packaging meat cuts snugly in a barrier film thus eliminating oxygen. It has been proved by Halleck and others (1958), that vacuum packaging of meat reduces the count of aerobic microorganisms. Vacuum packaging meat has a purple appearance owing to the formation of deoxymyoglobin. Vacuum packaging has been further developed into a double layer film where the outer layer is a high barrier film the inner layer is oxygen permeable. Removal of the outer layer would thus cause meat bloom, but initial studies in this system revealed irregular color on meat surfaces.

MODIFIED ATMOSPHERIC PACKAGING

A modified atmosphere can be defined as one that is created by altering the normal composition of air (78% nitrogen, 21% oxygen, 0.03% carbon dioxide and traces of noble gases) to provide an optimum atmosphere for increasing the storage length and quality of food produce (Moleyar and Narasimhan 1994). The most common gases used for modified atmospheric packaging include carbon dioxide (CO_2), nitrogen (N_2) or oxygen (O_2). CO_2 inhibits microbial growth, but has no effect on meat color (Rennere and Labadie 1993). CO_2 is soluble in muscle and fat tissue (Gill 1988). Solubilized CO_2 forms carbonic acid in the muscle tissue thus causing a slight decrease in the pH (Daniels and others 1985). Nitrogen has low solubility in meat and does not directly affect color or shelf-life. The main function of nitrogen is as a filler gas and prevents the packages from collapsing.

Usage of carbon monoxide in MAP

A recent advent in modified atmospheric packaging has been the usage of 0.4% carbon monoxide. The beneficial effect of carbon monoxide in MAP was patented over 100 years ago (Church 1994). The Norwegian meat industry initiated packaging fresh meat in carbon monoxide, the gas composition they used were 0.3-0.4% CO, 60-70% carbon dioxide and 30-40% nitrogen (Sorheim 2000). CO, even when used in very low concentrations of $< 0.2\%$ can form a stable cherry red color in meat (El- Badawi and others1964). Carbon monoxide combines with myoglobin to form carboxymyoglobin. Carboxy-myoglobin is more resistant to oxidation than oxymyoglobin (Wolfe 1980). Previous studies in MAP used CO in concentrations of 0.5-2.0% (Kropf 1980). Sorheim and others (1999) indicated in their studies that CO in concentrations of 0.3-0.4% can produce a bright red color in meat. Even in the presence of air, CO accelerates the reduction of metmyoglobin and the rate of reduction is dependent on the concentration of CO (Lanier and others 1978).

Toxicological aspects of carbon monoxide

CO binds to the iron atom of hemoglobin in red blood cells, forming carboxyhemoglobin (COHb). Hemoglobin has ~240 times higher affinity for carbon monoxide in comparison with oxygen. Breakdown of hemoproteins in the body leads to the production of a small amount of CO. The COHb thus formed is in the concentration of 0.5%. The concentration of COHb in non-smokers is in the range of 1.2-1.5% and ~ 3-4% in smokers (Aunan and others 1992). The level of CO in meat treated for 3 days in an atmosphere containing 1% CO and then cooked was ~0.1mg of CO per kg of meat. Norwegian experts on air pollution suggested in the people most susceptible to exposure of CO, the COHB levels should not exceed 1.5% (including endogenous production of CO), (Aunan and others1992). "Estimates indicate that even assuming an improbable 100% absorption of CO from the gastrointestinal tract into the blood, the consumption of meat that has been treated with 1% CO will result in COHb levels that are negligible (approximately three orders of magnitude less) compared to those resulting from exposure in the working environment to CO at an acceptable level" (Aunan and others 1992). Thus it is improbable that MAP of meat using CO in concentrations of < 0.5% will pose a toxic threat to consumers.

This research focuses on 3 main aspects:

1) Meat color,

2) Lipid oxidation,

3) The issue of premature browning.

BASIS OF MEAT COLOR

Myoglobin is the principal, but not the only pigment in meat color. Heamoglobin may constitute 20-30% of total pigment in well bled meat most of the rest is myoglobin (Fox 1996). Myoglobin, a hemoprotein found in cardiac and skeletal muscle has a molecular weight of about 17, 800 and has the main function of oxygen storage and transport (Kendrew and others 1960). Myoglobin can exist in different forms, as purple deoxy-myoglobin, bright red oxy-myoglobin or brown metmyoglobin (Broumand and others 1958). The myoglobin molecule is composed of a protein moiety (globin) and a heme prosthetic group. The heme molecule largely determines the ability of myoglobin to bind oxygen. Heme consists of a protoporphyrin ring and a central iron, Fe (II) atom (Figure 1).

Four of the six coordination sites of Fe are N_2 atoms from a planar porphyrin ring. A N_2 atom from a histidine side chain occupies the 5th coordination site. The sixth coordination site is available for binding with oxygen or other ligands. The FeO_2 center of oxymyoglobin is always subject to oxidation via nucleophilic attack of water from the surrounding solvent. Thus, myoglobin and hemoglobin have evolved with a globin moiety to protect the FeO_2 centre from easy access to water and its conjugate ions H^+ and OH^- (Shikama 1990).Metmyoglobin is formed as a result of oxidation of heme iron to ferric (Fe^{3+}) (Shikama 1990). George and Stratmann 1952 demonstrated that the maximum rate of myoglobin oxidation occurred at very low oxygen partial pressures of 6-7mm Hg. Surface browning that is observed in vacuum packaged beef could be attributed to this cause.

LIPID OXIDATION

Lipid oxidation often limits the shelf life of both raw and cooked meat (Ashgar 1988). The fat portion of meat is susceptible to lipid oxidation or degradation (Pearson and others 1977). The primary products of lipid oxidation are odorless and tasteless, but the secondary oxidation products such as aldehydes, ketones, etc are responsible for meat flavor deterioration (Tims and Watts 1958). Chicken is more susceptible to oxidative rancidity and is followed by pork, beef and lamb (Sato and Hegarty 1971). It is suggested that packaging methods that exclude oxygen from meat products can reduce warmed-over flavors. It is reported that there is a high correlation of TBA numbers with scores from sensory panels while evaluating rancidity (Tarladgis and others 1960).

Mechanism of Oxidation

Oxidation proceeds through a free radical chain reaction mechanism involving three stages:

1. Initiation – This step involves the formation of free radicals.

$$RH + O_2 \longrightarrow R\bullet + \bullet OH$$

2. Propagation – Involves a free radical chain reaction.

$$R\bullet + O_2 \longrightarrow ROO\bullet$$

$$ROO\bullet + RH \longrightarrow R\bullet + ROOH$$

$$ROOH \longrightarrow RO\bullet + OH\bullet$$

3. Termination – Step involves the formation of non-radical products.

$$R\bullet + R\bullet \longrightarrow RR$$

$$R\bullet + ROO\bullet \longrightarrow ROOR$$

$$ROO\bullet + ROO\bullet \longrightarrow ROOR + O_2$$

PREMATURE BROWNING

Premature browning is a phenomenon where meat turns brown and appears well done and cooked at lower than safe cooking temperatures (Hague and others 1994). Since consumers associate the internal color of cooked patties with the degree of doneness, this could be a food safety issue. Guidelines issued by the food safety and inspection service said that thorough cooking to an internal temperature of 160 °F kills E. coli O157:H7. E. coli O157:H7 is a strain of bacteria that produces a toxin that can cause a condition called hemorrhagic colitis.

Hunt and others (1995) found in a research study that significant numbers of ground beef patties were turning brown before reaching an internal temperature of 160°F. This study focuses on how packaging conditions of raw meat affects the occurrence of premature browning in the cooked product.

FACTORS AFFECTING MEAT COLOR

pH

Trout (1989) reported that apart from temperature and cooking time, pH is an important factor in controlling myoglobin denaturation and thus doneness. Trout's study showed that when meat with high pH values was cooked to moderately high temperatures, the interior remains pink.

The pH in living muscle is near neutral, but after death of the animal, due to glycoloysis and accumulation of lactic acid, the pH declines. Muscle pH affects cooked meat characteristics. A condition called PSE (pale soft and exudative) which results from rapid decline in meat pH makes myoglobin more heat labile. Dark firm and dry meat (DFD) conversely has a protective effect on myoglobin (Hunt and others 1995). It is reported by Appel and Brown (1971) in their studies that low pH favors myoglobin oxidation, in part due to the destabilization of the heme-protein linkages.

When meat pH is high (>6.0), mildly heated meat products have a pink or light red center as the myoglobin is more resistant to denaturation (Trout 1989). Meat with high myoglobin content and a pH > 6.4 was found to remain red even after cooking to temperatures of 71°C (Cornforth and others 1993; Moiseev and Cornfoth 1999).

Meat Source

Inter-muscular difference is an important factor while considering discoloration of meat (Hood 1980). Rennere and Labas (1987) in his study also proved that the gluteus medius muscle had poor color stability. It has been reported by O'Keefe and Hood (1982) that the biochemical factors such as oxygen consumption rate and metmyoglobin reducing activity are different for different muscles. The susceptibility to metmyoglobin formation of different muscles in beef has been reported by Ledward (1971) as follows: Biceps femoris > semimembranosus muscle > longissmus dorsi > semitendinosus.

The difference in muscle susceptibility to oxidation was also proved by Rennere and others (1992). According to this study, the psoas muscle myoglobin was more prone to oxidation than that from longissimus dorsi.

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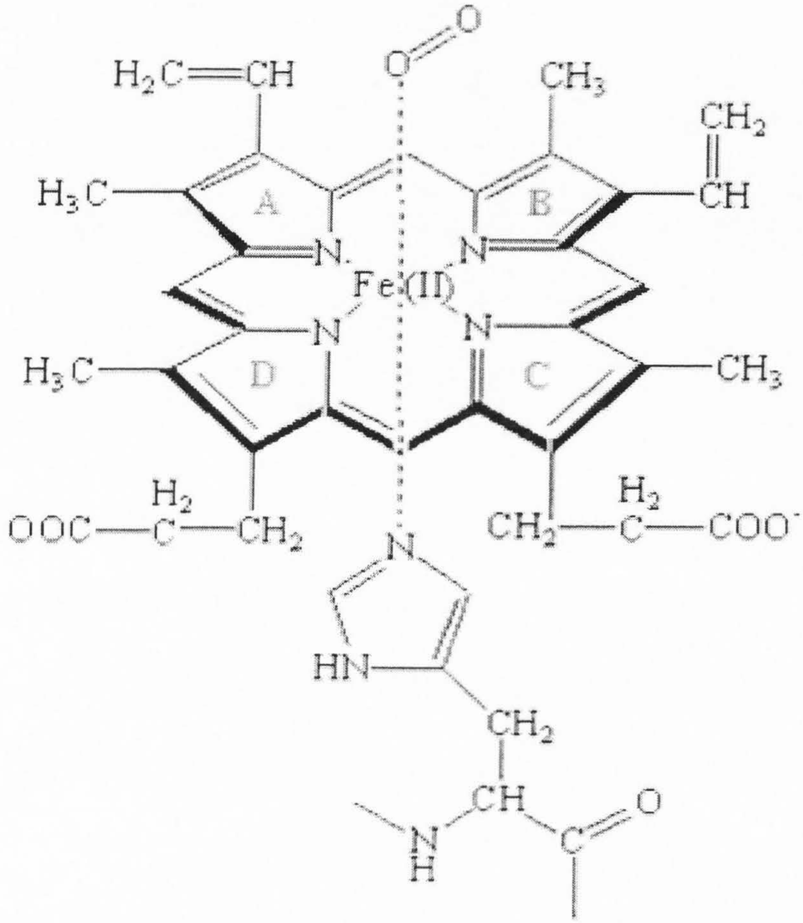

Figure 1. Structure of heme molecule.

CHAPTER III

COMPARISON OF COLOR AND THIOBARBITURIC ACID VALUES OF COOKED PATTIES AFTER STORAGE OF FRESH BEEF CHUBS IN MODIFIED ATMOSPHERES[1]

ABSTRACT: Cooked meat color is an important quality attribute for consumers. This study compared color and thiobarbituric acid (TBA) values of cooked ground beef (internal temperatures of 49-79 °C), after storage of raw product in atmospheres of 0.4% carbon monoxide (CO), or 80% oxygen, or vacuum at 2°C for 7-21 d. Premature browning (PMB), observed as a brown cooked color at internal temperatures as low as 49 °C, was found in patties made from meat stored in 80% oxygen. At all cooking temperatures, samples stored in high oxygen had less internal red color, higher myoglobin denaturation values, and were more rancid with higher TBA values than CO or vacuum packaged ground beef.

Raw ground beef held in 0.4% CO modified-atmosphere-packaging (MAP) remained bright red throughout the 21-d storage period. Premature browning and high TBA values in cooked patties was avoided by use of this packaging system. However, internal patty color remained somewhat red even at the highest internal cooking temperature of 79 °C. The persistent pink color observed in CO-treated patties cooked to 79 °C internal temperature was likely due to development of heat-denatured CO-hemochrome, rather than the presence of undenatured CO-myoglobin.

The problems of premature browning and high TBA values of cooked patties were also avoided by vacuum-packaging. However, the development of dark purple

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[1] **NOTE: CHAPTER III** has been published in Journal of Food Science 69(8):C608-14.

L. JOHN, D. CORNFORTH, C.E. CARPENTER, O. SORHEIM, B.C. PETTEE, AND D.R. WHITTIER. Comparison of Color and Thiobarbituric Acid Values of Cooked Hamburger Patties after Storage of Fresh Beef Chubs in Modified Atmospheres.

INTRODUCTION

Consumers expect good quality raw beef to be bright red, which is an indicator of freshness (Renerre and Labadie 1993). Traditionally in the USA, fresh meat is wrapped in oxygen-permeable polyvinyl chloride film allowing the meat to turn red (bloom). Red color is maintained under these conditions for about 3 days. Over the past decade, the use of case-ready modified atmosphere packaging (MAP) has increased in the US market. Carbon dioxide, nitrogen, and oxygen are the gases most commonly used in MAP. The strategy of MAP is to avoid the formation of brown metmyoglobin, because once formed, metmyoglobin is very difficult to reduce to red deoxymyoglobin or oxymyoglobin. Binding of carbon monoxide (CO) to meat pigments slows formation of metmyoglobin even in the presence of oxygen (Lanier and others 1978). Low levels of CO have been used in case-ready modified atmospheric packaged meats in Norway since 1985 (Sorheim and others 1997). The Norway MAP system uses 0.4% CO, 60% carbon dioxide, and 39.6% nitrogen. In February 2002, 0.4% carbon monoxide - MAP was approved in the USA in a master bag system during distribution. In August 2004, the FDA announced a GRAS approval of 0.4% CO for packaging of case-ready meat in the USA (www.cfsan.fda.gov/~rdb/opa-g143.html). CO used at such low levels does not present a toxic threat to consumers (Sorheim and others 1997).

Oxygen and CO both have the ability to bind to myoglobin in meat, forming the desirable bright red pigments oxymyoglobin (OMb) and carboxymyoglobin (COMb), respectively. Deoxymyoglobin (DMb) is formed in meat in the absence of oxygen (vacuum packaging). The predominant myoglobin form in raw ground beef affects the appearance of cooked meat. Hamburger with a high proportion of oxymoglobin or metmyoglobin (MMb) appears well done (gray-brown) at low internal cooking temperatures (Warren and others 1996). This premature browning (PMB) phenomenon was first identified by Hague and others (1994). Premature browning is a food safety concern (Lyon and others 2000). During cooking the meat turns brown at lower than normal temperatures, and thus appears done at temperatures where foodpoisoning organisms may survive. Warren and others (1996) concluded that PMB is related to the oxidative state of the meat. Carboxymyoglobin is more resistant to oxidation than oxymyoglobin, owing to the stronger binding of CO to the iron-porphyrin site on the myoglobin molecule (Lanier and others 1978).

Another method to achieve increased red color stability in case-ready meats is to package the product in a high-oxygen atmosphere (approximately 80% oxygen, 20% carbon dioxide), where it remains red for 7-14 d. This is the primary packaging method currently used with case-ready meats in the USA. However, the high oxygen levels may promote rancidity (Jayasingh and others, 2002) and premature browning (Hunt and others 1999).

The objective of this study was to compare 3 commonly used meat packaging systems (80% oxygen, or 0.4% CO, or vacuum) on fresh meat color stability and associated cooked meat characteristics (susceptibility to premature browning and rancidity).

MATERIALS AND METHODS

Experimental design and statistics

The experiment was a factorial design with 3 meat sources (chuck, loin, and mixed trim), 3 packaging treatments (80% oxygen - MAP, 0.4% CO – MAP, and vacuum), 3 raw meat storage times at 2 °C (7, 14, and 21 days), 5 cooked patty internal temperatures (49, 57, 66, 71, and 79 °C), and 2 replications of the entire experiment. Treatment means (main, 2-way and 3-way interactions) were calculated by analysis of variance (ANOVA) using Statistica^{TM} (Statistica, 1984). Significant differences between means were determined by calculation of Fisher's least significant difference (LSD) values, when appropriate. Significance was defined at $p < 0.05$.

Packaging

Fresh (48 hours postmortem), boneless vacuum-packaged USDA Select grade beef chuck shoulder clods, USDA Select boneless loins, or coarsely ground beef chubs (mixed trim, 4,5 kg / package) were purchased from a local packer and transported the same day to the USU meat laboratory for fabrication into ground beef. Ground beef was prepared by cutting the primals into 3-cmthick strips that were then passed through a coarse grinder plate (0.6 cm pore size; Model 4152: Hobart Mfg. Co., Troy, OH) followed by a fine grind through a plate with 0.32 cm pore diameter. Coarsely ground mixed trim was also finely ground. The fat content of hamburger was 19.6 ± 1.5% as determined by solvent extraction (AOAC, 1990) of triplicate samples for each replicate. The bulk hamburger was divided into 3 portions (2100 g per packaging treatment) and 1) vacuum packaged (using a Hollymatic Corp LV 20G vacuum packaging machine), or placed in modified atmosphere packages of 2) 0.4% CO, 30.3% CO_2, and 69.3% nitrogen; or 3) 80% oxygen + 20% carbon dioxide. The bulk hamburger was loosely placed in pouches to a thickness of < 2 cm. This facilitated penetration of carbon monoxide or oxygen, allowing the formation of a single predominant myoglobin form at the end of 7, 14 or 21 days storage. Thus bulk ground beef stored in 0.4% CO, 80% oxygen or vacuum was uniformly converted to carboxymyoglobin, oxymyoglobin or deoxymyoglobin respectively. The pouches (25 x 35 cm; Koch, Kansas City, MO) used for packaging were of 3 mil thickness (0.75 gauge nylon, 2.25 gauge polyethylene), with an oxygen permeability of 0.6 cm^3 / 100 m^2 / 24 h at 0 °C and a water vapor transmission rate of 0.6 g / 100 m^2 / 24 h at 38 °C and 100% relative humidity. The gas cylinders were obtained from Praxair Distribution (Salt Lake City, UT) and certified to be within ± 0.5% of the indicated mixtures. Treatments were held at 2 °C.

Raw bulk ground beef measurements

On storage days 7, 14, and 21, the color of the bulk ground beef for each treatment (vacuum, 80% oxygen, 0.4% carbon monoxide) was visually assessed by a 3-member panel and also instrumentally measured with a Hunter color meter in duplicate on each package. Visual color scores of uncooked ground beef were determined using a 5point scale (Hunt and others 1999), where 1= purple-red (DMb), 2= reddish-purple, 3= bright red (OMb), 4= reddish-tan or brown, 5 = tan or brown (MMb). Samples were scored to the nearest 0.5. Visual and Hunter color measurements were made while the bulk treatments remained in the treatment packaging. Color measurements were not taken on raw patties. However, it was noted that patties made from vacuum packaged ground beef turned bright red due to myoglobin oxygenation (bloom). Patties made from 0.4% CO or high oxygen treated ground beef did not change appreciably in color compared to the appearance of the ground beef in MAP. The residual oxygen in the MAP packages was measured using an oxygen gas analyzer (model 3500; Illinois Instruments, Ingleside, IL). For each replication, raw meat samples (~100g) were wrapped and frozen for later measurement of pH and fat content.

Patty making and cooking

After color measurements were made on the treatments as described above, the bulk hamburger was removed from packaging. Patties (112 g, 12 cm diameter x 1 cm thick; 5 patties / treatment) were manually formed with a Hollymatic mold (Park Forest, IL). Patties were grilled within one hour of patty making. The patties (5 / treatment) were grilled to internal temperatures of 49, 57, 66, 71, and 79 °C using a

Circulon (Hong Kong, ROC) Teflon coated grill set to 163 °C. The patties were held for 2 min, then flipped every 1.5 –2 min until the desired internal temperature was achieved. Internal temperature during cooking was measured using a VERSATUFF 396 digital thermometer with micro-needle probe (Atkins Technical, Inc., Gainesville, FL). After cooking, patties were sliced in half through the horizontal center. One half of each patty was photographed immediately (results not shown). The other half of the cooked patty was rapidly covered with Saran Wrap (S. C. Johnson & Son, Inc., Racine, WI) to minimize fading. Hunter color (CIE L*, a*, b*) values were measured within 30 s Concurrent with Hunter color measurement, the investigators (3-member panel) scored the internal color of cooked patties under cool-white fluorescent light (1600 to 1900 lux), using a 5-point scale to the nearest 0.5 where 1= dark red to purple (uncooked appearance), 2= bright red, 3= very pink, 4= slightly pink, and 5= tan with no evidence of pink (Hunt and others 1999). The Ground Beef Patty Cooked Color Guide (Marksberry and others 1993) was used as a photographic reference where scores 2-5 of the scale were equal to scores 1-4 of the photographic color guide. After visual and instrumental color assessment, one half of each patty was used for measurement of undenatured myoglobin content and TBA values. The other half was wrapped in plastic wrap and butcher wrap, labeled, and frozen at –20 °C for later measurement of pH and oxidation-reduction potential (ORP).

Hunter color measurement

Hunter color lightness, redness, and yellowness (CIE L*, a*, b*) values were measured on raw or cooked samples using a Hunter Lab Miniscan portable colorimeter with a 5 mm aperture (Reston, VA, U.S.A.). The instrument was set for illuminant D-65 and 10° observer angle, and standardized using white and black standard plates.

TBA number

Thiobarbituric acid-reactive substances (TBARS) assay was performed as described by Buege and Aust (1978), as modified by Lee and others (1999). Duplicate meat samples (0.5 g) were mixed with 2.5 mL of stock solution containing 0.375% TBA (Sigma Chemical Co., St. Louis, MO), 15% trichloroacetic acid (TCA Mallinckrodt Baker Inc., Paris, KY), and 0.25 N HCl. The mixture was heated for 10 min in a boiling water bath (100 °C) to develop a pink color, cooled in tap water, and then centrifuged (Sorvall Instruments, Model RC 5C; DuPont, Wilmington, DE) at 5500 rpm for 25 min. The absorbance of the supernatant was measured spectrophotometrically (Spectronic 21D; Milton Roy, Rochester, NY) at 532 nm against a blank that contained all the reagents minus the meat. The malonaldehyde (MDA) concentration was calculated using an extinction coefficient of $1.56x10^5 M^{-1} cm^{-1}$ for the pink chromogen (Sinnhuber and Yu 1958). The MDA concentration was converted to TBA number (mg MDA/kg meat sample) as follows;

1) TBA number (mg / kg) = Sample A_{532} X (1 M chromogen / 1.56 X 10^5) X [(1 mole /L) / M] X (0.003 L / 0.5 g meat) X (72.07 g MDA / mole MDA) X (1000 mg / g) X (1000 g / kg), or

2) TBA Number (ppm) = Sample A_{532} X 2.77

Undenatured myoglobin

Myoglobin was extracted from raw or cooked samples in cold (2 °C) 0.04 M phosphate buffer, pH 6.8 (Warriss 1979). Total myoglobin and metmyoglobin (% of total) was calculated based on absorbance of clarified extract at 525, 572, and 700 nm (Krzywicki 1979) using a Model UV-2100 UV-VIS recording spectrophotometer (Shimadzu Co., Kyoto, Japan). Total myoglobin (Mb), metmyoglobin (MetMb, % of total), and percent Mb denatured during cooking (PMD) were calculated using the following formulas (Trout 1989):

Mb (mg/g) = $(A_{525} - A_{700}) \times 2.303 \times$ dilution factor (1)

Where Mb = deoxyMb + $Mb0_2$ + MetMb.

% Metmyoglobin = $\{1.395 - [(A_{572} - A_{700}) / (A_{525} - A_{700})]\} \times 100$ (2)

PMD = [1- (Mb conc after heating / Mb conc before heating)] x 100 (3)

pH

Duplicate meat samples (10 g) were blended with 90 mL distilled water for 1 min with a polytron homogenizer (Brinkman Instruments, Westbury, NY). The pH of the filtrate was measured with a pH meter model 610A (Fisher Scientific Co., Houston, TX) calibrated to pH 4.0 and 7.0.

Oxidation-reduction potential

Oxidation-reduction potential (ORP) was measured in meat homogenates as described by Nam and Ahn (2003). Meat samples (5 g), 15 mL de-ionized water, and 50 μL butylated hydroxytoluene (7.2% in ethanol) were placed in 50-mL test tubes and were homogenized using a probe-type homogenizer (Ultra-Turrax T 25, Janke and Kunkel, Staufen, Germany) for 15 s at high speed. The ORP values of homogenates were determined using a pH meter (model 610 A; Fisher Scientific Co., Houston, TX, calibrated to pH 4.0 and 7.0) equipped with a platinum electrode filled with an electrolyte solution (4 M KCl saturated with AgCl).

RESULTS AND DISCUSSION

Oxygen measurement in MAP

Modified atmosphere package headspace oxygen measurements were taken immediately after packaging and again before opening samples on days 7, 14, and 21.

Oxygen levels in the 0.4% CO-MAP samples were always less than 0.1% after packaging and the subsequent storage period. Mean oxygen levels in 80% O_2-MAP were 79-82% after packaging. Oxygen levels at 7 and 14 days storage were 81-82% and 78-82%, respectively, but decreased to 60.5-76% at 21 days.

Raw meat color

Raw ground beef color (pooled for all meat sources) was affected ($p < 0.05$) by packaging method (0.4% CO, 80% O_2, or vacuum; Table 1). Meat source (chuck, loin, or mixed trim) also affected ($p < 0.05$) raw ground beef color. Visual color score was affected by storage time of ground beef before cooking because a surface browning was observed on some vacuum packaged beef at 14 and 21 days storage (Data found in Appendix A). However, storage time before cooking had no significant effects on Hunter color values, (Table 1) because Hunter color values were taken at locations without surface brown discoloration to more accurately represent the color of the bulk ground beef. Replication had a significant effect on the Hunter b* (yellowness) values, but did not affect other color measurements. The interaction between packaging method and meat source had no affect on Hunter color values (Table 1). The interaction of packaging method and storage time affected a* values, hue angle, and panel color score. The interaction of storage time and meat source only affected Hunter color b* values. The 3-way interaction of packaging x meat source x day had no significant effects on raw ground beef color (Table 1).

Means for the interaction of packaging method, meat source, and storage time on color of raw ground beef are shown in Table 2. All ground beef packaged in CO was bright red (visual score =3) at all storage times (7, 14, 21 days). Ground beef packaged in CO had high a* (redness) values ranging from 14.4 to 20.3, and low hue angle values of 30.7 to 37.8, where low hue angles are indicative of redness. The a* values of CO-packaged ground chuck and trim did not change during storage. However, mean a* values of ground loin increased significantly from 14.4 on day 7 to 18.6 after 14 days of storage (Table 2). Ground beef packaged in 80% oxygen was initially bright red (data not shown) but by day 7 the bright red color was beginning to fade, as indicated by visual scores near 4.0 (reddish tan). For all meat types in high oxygen, a* values decreased from 10-13 on day 7 to 4-5 on day 21 of storage, and hue angle values increased from 48 on day 7 to 70 on day 21, indicating a color change from red to brown. Most vacuum -packaged ground beef was uniformly dark purple (visual score = 1) after 7 days of storage, but browning was observed on the surface of some ground chuck and loin samples after 7 - 14 days of storage (visual score = 5). The mean values of 3.0-3.5 for vacuum packaged ground loin at 14 and 21 days of storage (Table 2) do not indicate bright red color. Rather these means indicate that some samples turned brown (visual score = 5), while other samples remained purple (visual score = 1). The brown color in some vacuum-packaged samples was found only on the surface in contact with the package. The bulk of the vacuum-packaged meat was purple. Redness (a*) values of vacuum-packaged ground beef were low, ranging from 4.3-7.5, indicative of deoxymyoglobin as the predominant myoglobin form. The partial browning and metmyoglobin formation in some vacuum packages was probably due to residues of oxygen in the finely ground meat or a small amount of leakage during storage. Low oxygen partial pressure favors metmyoglobin formation (Sorheim and others 1997). The raw beef color changes observed in this study during storage are supported by the previous findings of Sorheim and others (1999), Jayasingh and others (2001), and Hunt and others (2004).

Cooked meat color

Packaging method (0.4% CO, 80% oxygen or vacuum) significantly affected a*, hue angle, visual score, thiobarbituric acid (TBA), and oxidation-reduction potential (ORP) values of cooked ground beef (Table 3). Meat source affected all cooked ground beef measurements except visual score, percent myoglobin denaturation (PMD), percent metmyogobin, and thiobarbituric acid values. Storage time (7, 14, or 21 days at 2 °C) of the bulk ground beef significantly affected b*, TBA, ORP, and pH values. Internal cooking temperatures (49, 57, 66, 71, or 79°C) affected all parameters except percent metmyogobin and TBA values (Table 3). The 2-way interaction between packaging method and cooking temperature significantly affected all measures of color in cooked patties (Tables 3 - 5 and Figures 2-4). The remaining 2-, 3- and 4-way interactions in general had no significant effects on internal color of cooked patties (Table 3).

At all cooking temperatures, myoglobin denaturation was higher for ground beef packaged in 80% oxygen, compared to samples stored in 0.4% CO or vacuum (Figure 2). The premature browning effect was prominently observed in ground beef stored in 80% oxygen (Appendix D). In this study samples stored in 80% oxygen turned gray and appeared well done at cooking temperatures as low as 49 °C, with a mean color score of 4.7 (Table 4). Samples packaged in 80% oxygen appeared medium well done (visual score of 4.3) at the lowest internal cooking temperature of 49 °C (Table 4). No differences were observed in myoglobin denaturation between vacuum and CO-MAP-packaged ground beef (Figure 2). In agreement with the visual color scores, high-oxygen-treated patties had low Hunter redness values (a* < 6) at all cooking temperatures (Figure 3). The interior of CO-treated patties had higher redness values (Figure 3), and lower hue angle values (Table 4), indicating more red color in CO-treated patties than other treatments at all cooking temperatures. Even at the highest cooking temperature, CO-treated patties had a slight pink internal appearance that faded rapidly after slicing. This persistent pinking effect could be explained by the formation of denatured globin CO haemochrome (Tappel, 1957). In agreement with the instrumental color measurements, visual cooked color scores were lower than for other treatments, indicating that CO-treated patties had a more red interior color after cooking than patties from high-oxygen or vacuum-packaging treatments (Table 4). In agreement with results of this study, Hunt and others (1999) also reported more rapid browning of cooked patties previously stored in a high-oxygen atmosphere compared to vacuum packaged patties. Sorheim and others (2001) have previously reported similarities in the cooked color of vacuum-and low-CO-packaged meats.

It is well known that beef muscles differ in color stability. The tenderloin muscle (psoas major) has very poor color stability while the top-loin (longissimus dorsi) and bottom-round (biceps femoris) muscles have good color stability (Ledward and others 1977; Hood 1980). Thus it is likely that ground beef obtained from different anatomical locations may differ in susceptibility to premature browning during cooking. In this study cooked patties from ground chuck tended ($p < 0.068$) to have lower visual color scores, indicative of more red internal color for patties cooked to 49-66 °C (Table 5), compared to patties from ground loin or mixed trim.

In agreement with previous reports (Jayasingh and others 2002), TBA values were higher for ground beef held in a high-oxygen environment for 7 days or more, compared to ground beef stored anaerobically before cooking (Figure 3). Oxidation-reduction potential values tended to be higher in high-oxygen-treated samples (Table 4). The ORP values were uniformly lower ($p < 0.05$) in cooked ground beef compared to raw, high-oxygen or CO-treated ground beef (Table 4). pH increased ($p < 0.05$) from 5.5 - 5.6 in raw ground beef to 5.8-5.9 in cooked patties (Table 4).

SUMMARY AND CONCLUSIONS

Raw ground beef held in 80% oxygen maintained desirable red color from 7-10 days but began to darken by day 14 and lost all red color by day 21. Thus this study confirmed that high-oxygen packaging of ground beef maintained acceptable red color for at least 7 days, compared to 3 days of acceptable appearance for ground beef wrapped in the traditional oxygen-permeable polyvinyl chloride film wrap. However, ground beef stored in high-oxygen MAP was very susceptible to premature browning during cooking. High oxygen-treated ground beef developed a brown cooked appearance when cooked to internal temperatures as low as 49°C. High oxygen-treated, cooked ground beef also had TBA values of 2.0 or higher, compared to TBA values of less than 1 for ground beef stored in 0.4% CO or vacuum. Previous studies have shown a correlation between high TBA values and rancid flavor in cooked ground beef (Jayasingh and others 2002). High-oxygen packaging is also associated with bone darkening of bone-in retail cuts. Thus antioxidant treatments are recommended for high-oxygen-treated retail beef in conjunction with a "sell-by" dating system to ensure that products do not remain on shelves beyond 10 days.

Raw ground beef held in 0.4% CO remained bright red throughout the 21-day storage period. Premature browning and high TBA values in cooked patties was avoided by use of this packaging system. However, internal patty color remained somewhat red even at the highest internal cooking temperature of 79 °C. Myoglobin denaturation during cooking was no different than the control vacuum-packaged samples. Thus the persistent pink color observed in CO-treated patties cooked to 79 °C internal temperature was likely due to development of heat-denatured CO-hemochrome, rather than the presence of undenatured CO-myoglobin.

The problems of premature browning and high TBA values of cooked patties were also avoided by vacuum-packaging. However, the development of dark purple color associated with vacuum-packaging of raw beef limits the use of this packaging method for products in retail display.

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Table 1. Main and interaction effects (total n = 108) of packaging method, meat source, and storage time on visual and hunter color values of raw ground beef

Effect	n	L*	A*	b*	Hue angle	Panel score[4]
Packaging[1]	36	*	*	*	*	*
Meat source[2]	36	*	*	*	*	*
Days of storage[3]	36	NS	NS	NS	NS	*
Replication	54	NS	NS	*	NS	NS
Packaging x source	12	NS	NS	NS	NS	*
Packaging x day	12	NS	*	NS	*	*
Day x source	12	NS	NS	*	NS	NS
Packaging x source x day	4	NS	NS	NS	NS	NS

* Significant at $p < 0.05$.

[1] Samples were vacuum-packaged or modified-atmosphere-packaged in either 0.4% carbon monoxide or 80% oxygen.

[2] Ground beef was from beef shoulder (chuck), top loin, or mixed trim.

[3] Bulk ground beef (700 g per package) was stored at 2 °C for 7, 14, or 21 days.

[4] After 7, 14, or 21 days of storage, bulk ground beef color was evaluated by a 3-member panel, using a 5-point scale where 1 = purple-red (DMb), 2 = reddish-purple, 3 = bright red (OMb), 4 = reddish tan or brown, 5 = tan or brown (MMb).

Table 2. Interaction means ± standard error of the mean (n=4) of packaging method[1], meat source[2], and storage time[3] on color[4] of raw ground beef.

Packaging	Meat source	Storage (days)	L*	a*	b*	Hue angle	Visual score4
CO	Chuck	7	38.9±1.4	19.0±0.7	13.0±0.6	34.3±0.7	3.0±0.0
CO	Chuck	14	41.7±1.4	20.3±0.8	13.9±0.6	34.3±0.5	3.0±0.0
CO	Chuck	21	38.0±1.3	18.6±0.8	12.0±0.3	32.9±0.8	3.0±0.0
CO	Loin	7	40.6±1.4	14.4±1.5	10.8±1.3	36.8±1.4	3.0±0.0
CO	Loin	14	37.3±6.4	18.6±5.0	14.0±2.7	37.8±2.5	3.0±00.
CO	Loin	21	39.4±1.5	17.5±0.8	13.6±1.2	37.8±1.9	3.0±0.0
CO	Trim	7	42.6±3.4	18.5±1.1	11.7±0.6	32.5±2.6	3.0±0.0
CO	Trim	14	46.6±2.1	15.9±1.3	11.4±0.7	35.6±1.7	3.0±0.0
CO	Trim	21	40.3±0.8	17.8±1.0	10.7±1.6	30.7±2.5	3.0±0.0
O2	Chuck	7	43.6±2.4	13.1±0.4	14.8±0.9	48.4±1.5	4.0±0.0
O2	Chuck	14	43.3±4.9	7.9±1.2	13.3±0.8	59.4±3.9	4.0±0.0
O2	Chuck	21	44.4±0.8	4.2±0.4	12.2±1.1	70.6±2.0	5.0±0.0
O2	Loin	7	42.2±3.0	10.3±0.4	13.2±1.8	51.5±4.2	3.5±0.0
O2	Loin	14	38.3±5.0	8.4±1.2	15.8±1.6	62.0±4.4	3.8±0.2
O2	Loin	21	43.1±1.1	5.1±1.6	14.1±2.2	69.5±7.3	4.5±0.4
O2	Trim	7	42.4±0.9	12.2±0.9	13.4±1.3	47.5±1.9	3.5±0.0
O2	Trim	14	42.5±1.8	9.8±1.3	12.9±0.9	53.0±4.4	4.0±0.0
O2	Trim	21	46.8±3.7	4.5±0.9	11.4±1.1	68.6±4.1	4.5±0.4
Vac	Chuck	7	37.4±1.9	7.5±0.4	11.0±0.7	55.6±2.8	1.0±0.0
Vac	Chuck	14	37.5±2.9	7.4±0.6	10.0±0.9	53.1±4.5	1.3±0.2
Vac	Chuck	21	35.9±1.3	6.5±0.6	10.4±0.6	58.0±4.1	3.0±0.8
Vac	Loin	7	38.6±5.1	4.3±0.8	8.4±1.1	62.3±6.3	1.5±0.4
Vac	Loin	14	36.2±5.2	6.9±2.1	12.3±2.2	61.5±2.9	3.0±1.6

Vac	Loin	14	36.2±5.2	6.9±2.1	12.3±2.2	61.5±2.9	3.0±1.6
Vac	Loin	21	36.2±2.2	5.9±0.6	11.9±1.7	63.4±1.3	3.5±1.2
Vac	Trim	7	37.8±3.0	6.0±0.5	8.4±1.0	54.2±5.3	1.0±0.0
Vac	Trim	14	42.7±2.2	4.8±0.1	9.1±1.8	61.1±4.5	1.5±0.4
Vac	Trim	21	41.7±4.7	5.1±0.6	8.8±1.3	59.3±6.0	1.3±0.2
LSD 0.05[5]			8.9	4.0	3.9	10.4	1.3

[1] Samples were vacuum-packaged or modified-atmosphere-packaged in either 0.4% carbon monoxide or 80% oxygen.

[2] Ground beef was from beef shoulder (chuck), top loin, or mixed trim.

[3] Bulk ground beef (700 g per package) was stored at 2 °C for 7, 14, or 21 days.

[4] Hunter color L* = lightness, a* = redness. b* = yellowness, and hue angle = arctan (b* / a*). Higher hue angle values indicate less redness. Visual color score 1 = purple-red (DMb), 2 = reddish-purple, 3 = brightred (OMb), 4 = reddish tan or brown, 5 = tan or brown (MMb).

[5] LSD = Least significant difference. Means within a column are significantly different ($p < 0.05$) if the difference between mean values is greater than the LSD for that column.

Table 3. Main effects (n= 324) of packaging method (PKG), meat source (MS), days of storage (DS), and cooking temperature (CT)on color[1], thiobarbituric acid (TBA) values, oxidation reduction potential (ORP) and pH of cooked ground beef.

Effect	N	L*	a*	b*	Hue Angle	VisualScore[6]	Mb	PMD	MetMb	TBA	ORP	pH
PKG [2]	108	NS	*	NS	*	*	*	*	*	*	*	NS
MS [3]	108	*	*	*	*	NS	*	NS	NS	NS	*	*
DS	108	NS	NS	*	NS	NS	NS	NS	NS	*	*	*
CT [5]	54	*	*	*	*	*	*	*	NS	NS	*	*
Replication	162	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS
PKG x MS	36	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
PKG x DS	36	NS	NS	NS	*	NS	NS	NS	NS	*	NS	NS
PKG x CT	36	*	*	*	*	*	*	*	*	NS	NS	NS
MS x DS	36	*	NS	*	NS	NS	NS	NS	NS	NS	*	*
MS x CT	36	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CT x DS	36	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

PKG x MS x DS	12	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
PKG x MS x CT	6	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
MS x DS x CT	6	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
DS x CT x PKG	6	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
PKG x MS x DS x CT	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1] L* = lightness, a* = redness, b* = yellowness. Mb = Total soluble myoglobin, PMD = % myoglobin denaturation, MetMb = metmyoglobin % of total myoglobin.

[2] Samples were vacuum-packaged or modified-atmosphere-packaged in either 0.4% carbon monoxide or 80% oxygen.

[3] Ground beef was from beef shoulder (chuck), top loin, or mixed trim.

[4] Bulk ground beef (700 g per package) was stored at 2 °C for 7, 14, or 21 days.

[5] Patties were cooked to internal temperatures of 49, 57, 66, 71, or 79 °C.

[6] After cooking, ground beef color was evaluated by a 3-member panel, using a 5-point scale where 1 = dark red (raw), 2 = bright red, 3 = very pink, 4 = slightly pink, 5 = tan (no pink).

* Significant at $p < 0.05$; NS = not significant.

Table 4. Interaction effects of packaging method[1] and cooking temperature on color[2], oxidation-reduction potential (ORP), and pH of cooked ground beef. Values in table are means ± standard error of the mean (n = 18).

Packaging	Cook temp (°C)	L*	b*	Hue angle	Color score	Mb (mg/g meat)	Met Mb (%)	ORP (mv)	pH
CO	Raw	41.0±1.1	12.0±0.5	35±0.7	3.0±0.0	4.4±0.2	12.6±8.5	132±5.7	5.6±0.0
CO	49	56.5±0.7	13.9±0.4	48±1.8	1.7±0.1	4.6±0.2	08.8±1.3	104±4.3	5.8±0.0
CO	57	58.7±0.6	14.8±0.4	51±1.5	2.4±0.1	4.0±0.2	07.8±0.7	99±4.3	5.9±0.1
CO	66	59.4±1.1	14.7±0.4	56±1.5	2.6±0.1	3.3±0.2	10.7±1.6	95±3.5	5.9±0.0
CO	71	58.4±0.8	14.9±0.4	58±1.1	3.3±0.1	2.2±0.2	12.7±1.1	94±3.5	5.9±0.0
CO	79	56.9±0.7	13.6±0.3	66±1.0	4.1±0.1	0.8±0.1	26.2±2.6	94±3.4	5.9±0.0
OXY	Raw	43.0±1.0	13.0±0.4	59±2.1	4.0±0.1	3.9±0.2	54.6±7.5	137±5.3	5.6±0.0
OXY	49	57.4±0.8	14.0±0.4	69±1.1	4.3±0.2	3.6±0.5	78.7±3.8	108±4.6	5.9±0.1
OXY	57	57.3±0.8	14.0±0.4	71±1.0	4.7±0.1	2.0±0.3	75.0±3.0	106±3.5	5.9±0.1
OXY	66	56.6±1.0	13.3±0.4	72±0.7	4.8±0.1	0.9±0.3	69.3±5.5	103±3.0	5.9±0.0
OXY	71	55.9±1.0	13.6±0.3	73±0.6	5.0±0.0	0.4±0.1	74.6±3.7	103±2.7	5.9±0.1
OXY	79	55.7±0.9	13.9±0.3	73±0.5	5.0±0.0	0.30±0.1	72.1±5.1	103±2.5	5.9±0.0
VAC	Raw	39.0±1.1	10.0±0.6	60±1.4	2.0±0.3	4.2±0.2	13.4±2.2	106±6.2	5.5±0.0
VAC	49	55.7±0.9	13.9±0.4	62±1.2	1.1±0.1	4.2±0.2	18.2±1.9	96±3.8	5.9±0.1
VAC	57	57.5±0.7	15.1±0.4	64±1.0	2.1±0.2	3.6±0.2	17.4±3.4	99±3.9	5.9±0.1
VAC	66	58.7±0.7	16.0±0.4	67±1.0	3.1±0.2	3.1±0.2	13.3±1.9	95±3.3	5.9±0.1
VAC	71	57.5±0.9	16.0±0.3	67±0.9	3.8±0.1	2.6±0.2	16.8±2.4	94±3.3	5.9±0.0

VAC	79	58.1±1.0	14.8±0.3	72±0.7	4.6±0.0	0.9±0.1	24.2±2.8	95±3.0	5.8±0.0
LSD $_{.05}$[3]		2.5	1.1	3.3	0.4	0.6	9.1	11.0	0.2

[1] Samples were vacuum-packaged or modified-atmosphere-packaged in either 0.4% carbon monoxide or 80% oxygen.

[2] Mb = Total soluble myoglobin; MetMb = % metmyoglobin; L* = lightness; b* = yellowness; Hue angle = arctan (b*/a*), where higher values are less red. Cooked ground beef internal color was evaluated using a 5-point scale where 1= dark red (raw), 2 = bright red, 3 = very pink, 4 = slightly pink, 5 = tan (no pink).

[3] LSD = Least significant difference. Means within a column are significantly different ($p < 0.05$) if the difference between mean values is greater than the LSD for that column

Table 5. Means ± standard error of the mean (n= 6) for the interaction of meat source and cook temperature on patty internal redness (a*) and visual color scores of cooked ground beef stored in 80% oxygen for 7 – 21 days prior to cooking.

Cook temp (°C)	Chuck		Loin		Trim	
	Redness (a*)	Visual score[1]	Redness (a*)	Visual score	Redness (a*)	Visualscore
49	6.3±0.7	4.2±0.2	4.9±1.1	4.3±0.2	5.1±0.6	4.3±0.6
57	5.7±0.5	4.5±0.1	4.4±1.1	4.7±0.2	4.5±0.2	4.8±0.2
66	4.9±0.2	4.6±0.3	3.8±0.6	4.8±0.1	4.1±0.1	5.0±0.0
71	4.7±0.2	4.9±0.1	3.7±0.7	4.8±0.2	4.0±0.1	5.0±0.0
79	4.7±0.2	5.0±0.0	3.8±0.2	4.9±0.1	4.2±0.1	5.0±0.0
p – value	NS	0.068	NS	0.068	NS	0.068

[1] Cooked ground beef color was evaluated using a 5-point scale where 1= dark red (raw), 2= bright red, 3 = very pink, 4 = slightly pink, 5 = tan (no pink).

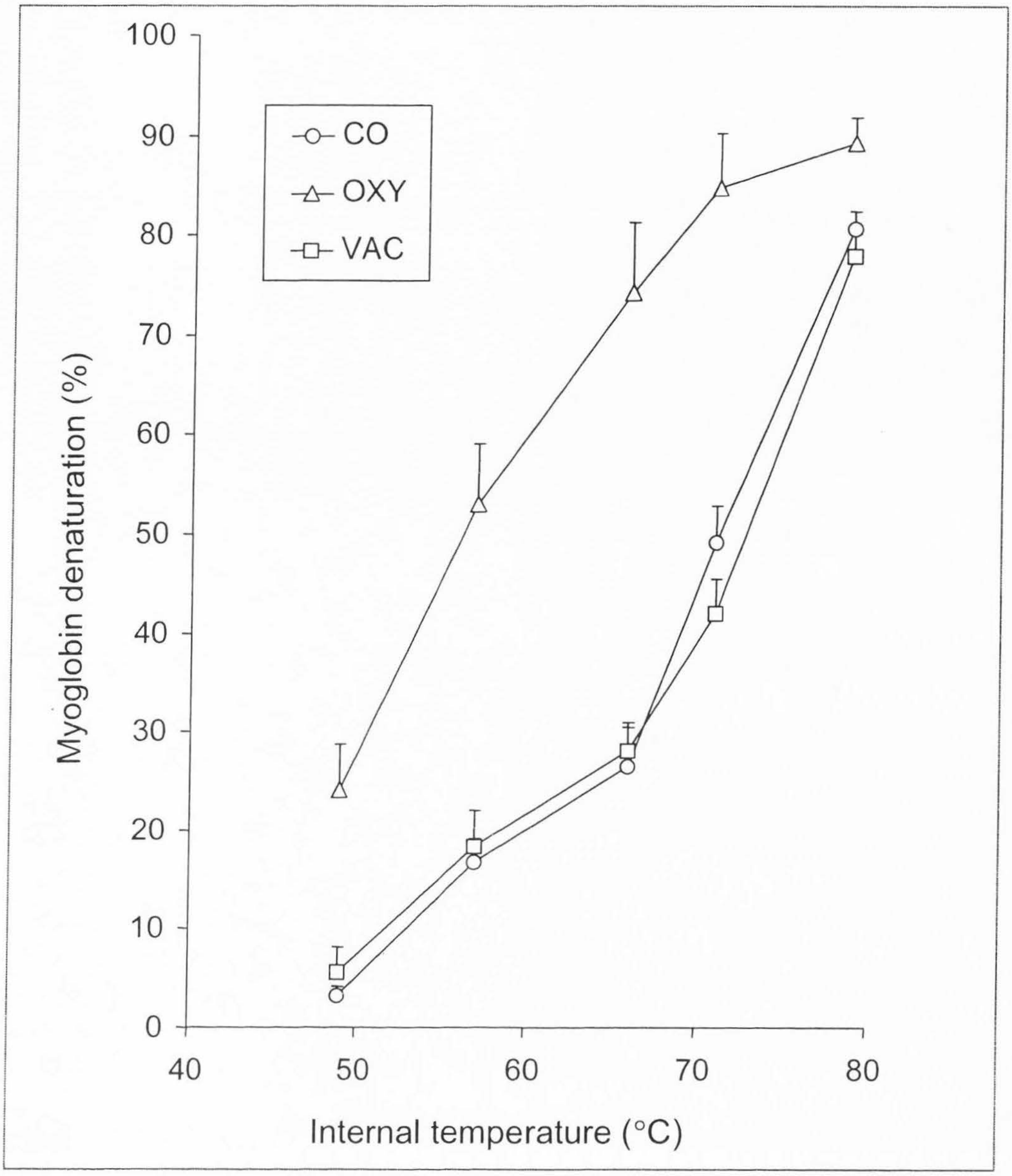

Figure 2. Percent myoglobin denaturation of cooked ground beef interior as affected by raw meat packaging method and internal cooking temperature. Means (n=18) were pooled for meat source (chuck, loin, trim), storage time before cooking (7, 14, 21 days), and replication.

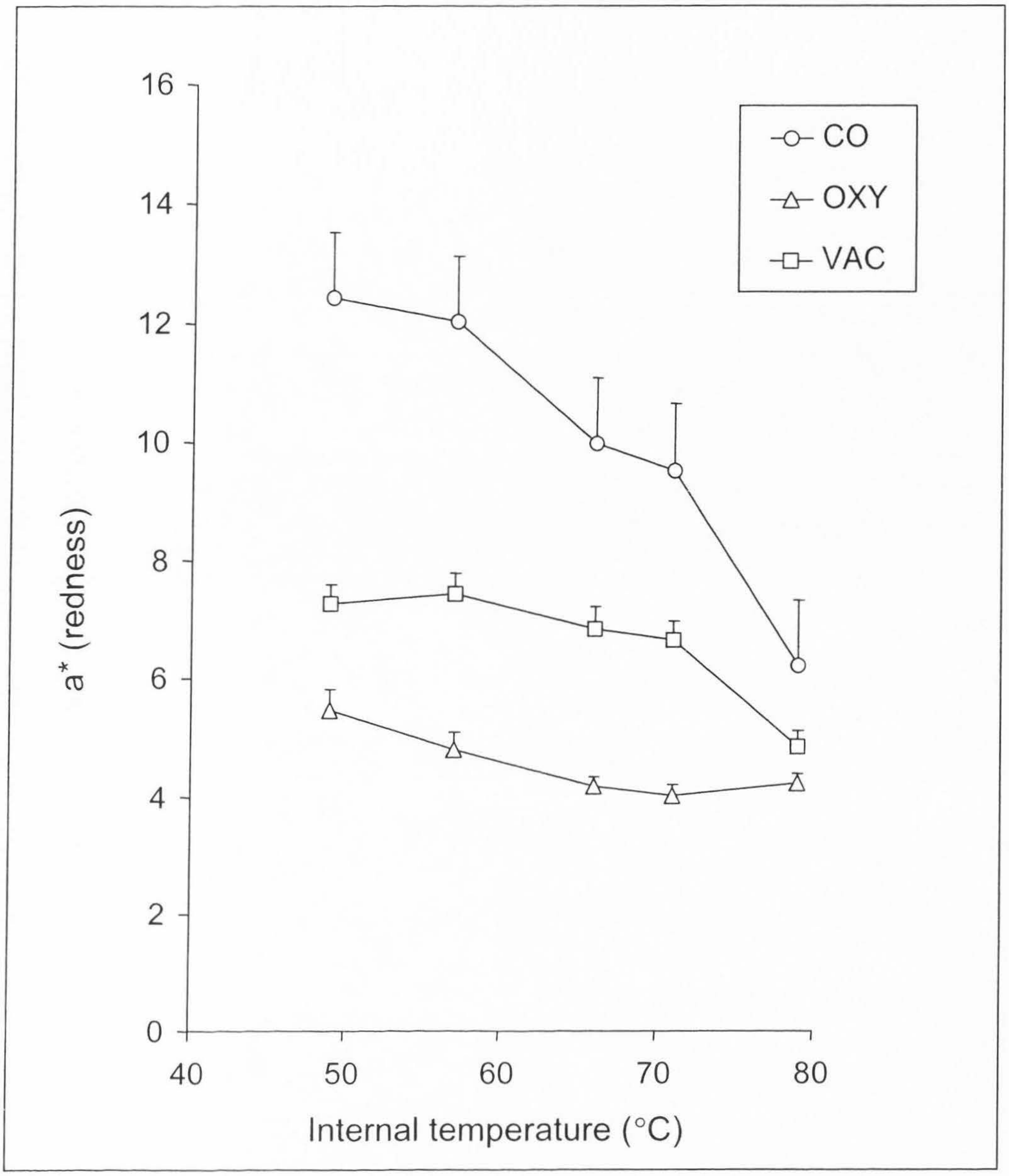

Figure 3. Mean Hunter color redness (a*) values of cooked ground beef interior as affected by raw meat packaging method and internal cooking temperature. Means (n=18) were pooled for meat source (chuck, loin, trim), storage time before cooking (7, 14, 21 days), and replication.

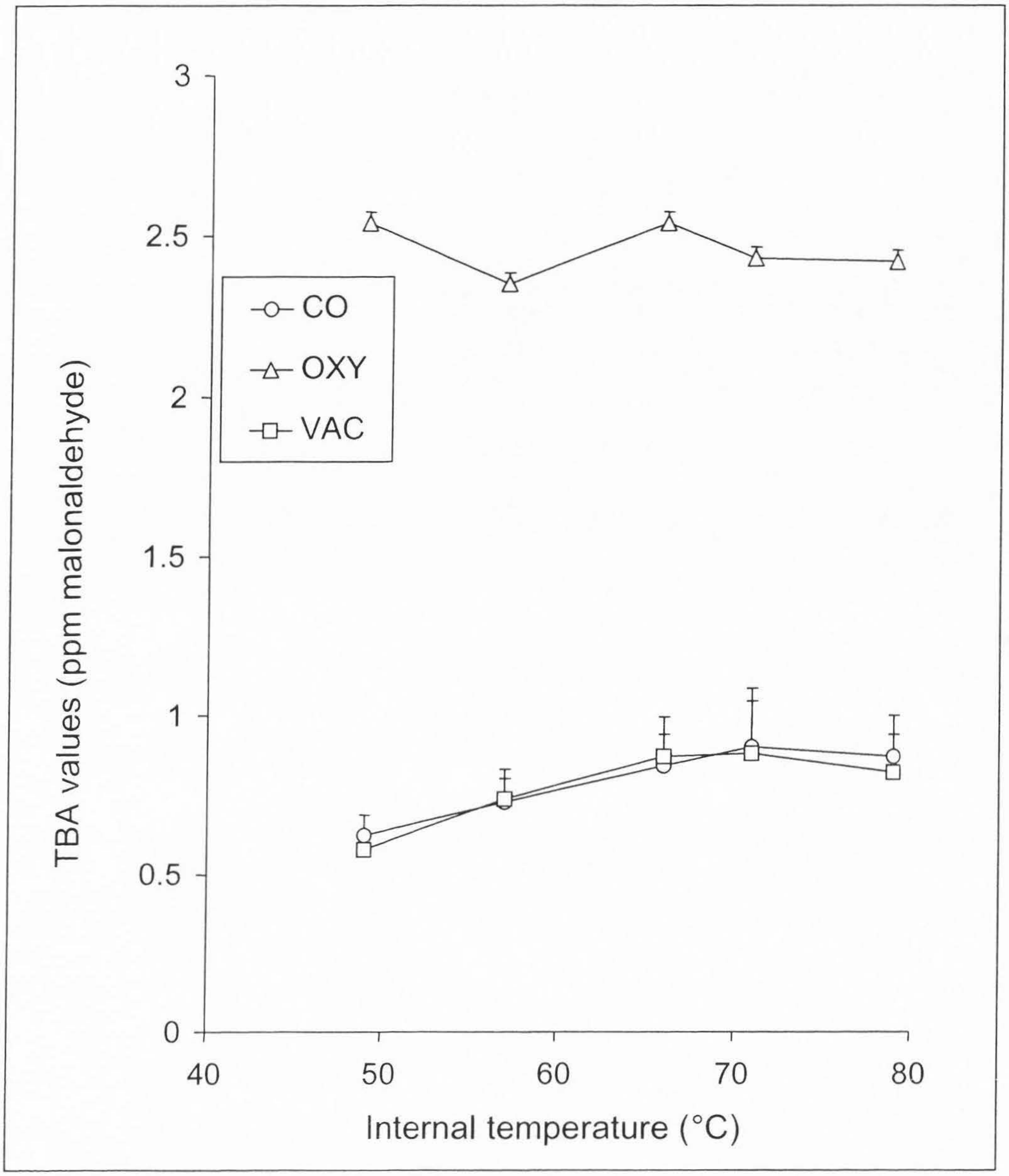

Figure 4. Mean thiobarbituric acid (TBA) values of cooked ground beef interior as affected by raw meat packaging method and internal cooking temperature. Means (n=18) were pooled for meat source (chuck, loin, trim), storage time before cooking (7, 14, 21 days), and replication.

CHAPTER IV

COLOR AND THIOBARBITURIC ACID VALUES OF COOKED TOP SIRLOIN STEAKS PACKAGED IN MODIFIED ATMOSPERES OF 80% OXYGEN, OR 0.4% CARBON MONOXIDE OR VACUUM [1]

Abstract

Case-ready fresh beef is typically packaged in a modified-atmosphere with approximately 80% oxygen and 20% carbon dioxide. Recently, USDA approved distribution of fresh meats in a master bag system using 0.4% carbon monoxide (CO). This study compared effects of packaging system (vacuum, 80% oxygen, 0.4% carbon monoxide), fresh meat storage time (7-21 days) and cooking temperature (49–79°C) on extent of myoglobin denaturation, color and rancidity in cooked top sirloin steaks.

Steaks packaged in 80% oxygen or CO retained desirable red color for 14 and 21 days storage, respectively. Steaks stored in 80% oxygen exhibited the greatest TBA values and myoglobin denaturation at all storage times and cooking temperatures. Steaks stored in high oxygen developed brown interior color at internal temperatures as low as 57°C, the premature browning effect. Premature browning and rancidity associated with steaks packaged in 80% oxygen was prevented by packaging in 0.4% CO or vacuum.

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[1] **NOTE: CHAPTER IV** has been accepted for publication in Meat Science (in press)

L.JOHN, D. CORNFORTH, C.E. CARPENTER, O. SORHEIM, B.C. PETTEE, AND D.R. WHITTIER. Color and Thiobarbituric Acid Values of Cooked Top Sirloin Steaks Packaged in Modified Atmospheres of 80% Oxygen or 0.4% Carbon Monoxide or Vacuum.

1. Introduction

Color of fresh meat is an important quality attribute and a major factor influencing retail purchase decisions. Case-ready modified atmosphere packaging (MAP), where the meat is packaged at the packing plant, can reduce the costs of fabrication and packaging at retail outlets. Gases commonly used in MAP include carbon dioxide (CO_2), oxygen (O_2) and nitrogen (N_2). CO_2 has anti-microbial properties while elevated levels of oxygen improve the red color stability of fresh meats. Nitrogen functions as a filler gas (Manu-Tawiah, Ammann, Sebranek, and Molins, 1991).

In the USA in February 2002, the USDA and FDA jointly approved the use of 0.4% carbon monoxide (CO) in an anaerobic MAP master-bag system along with 30% CO_2 and the balance as N_2. CO binds with myoglobin to form carboxymyoglobin which gives meat a stable cherry red color (El-Badawi, Cain, Samuels, and Anglemeier, 1964). Ground beef or top loin steaks stored in 0.5% CO maintained a desirable red color for up to 28 days of storage at 2°C (Jayasingh, Cornforth, Carpenter, and Whittier, 2001). Low CO/high CO_2, packaging has also been shown to improve the color and shelf life of pork (Sorheim, Nissen, and Nesbakken, 1999; Krause, Sebranek, Rust, and Honeyman, 2003). Since 1985 Norwegian meat plants have safely used 0.4% CO in MAP of fresh beef, pork and lamb. The typical MAP gas composition is 0.3-0.4% CO, 60-70% CO_2 and 30-40% N_2. About 60% of the fresh meat in Norway has been sold using this gas composition (Sorheim et al., 1999). The use of CO for MAP of meat is likely to be prohibited in Norway from 1July 2004, due to implementation of EU food regulations.

Although there is increasing interest in the use of CO-MAP for fresh beef, the most commonly used gas mixture for case-ready MAP fresh beef is 80% O_2 and 20% CO_2. The main advantage of high oxygen packaging is an increase in red color stability up to 14 days compared to 4-7 days for beef packaged in the traditional oxygen permeable polyvinyl chloride (PVC) film over-wrap. However, high oxygen MAP increases lipid oxidation of beef muscles (Jakobsen and Bertelsen, 2000) and accelerates rancid flavor development in cooked ground beef (Jayasingh, Cornforth, Brennand, Carpenter, and Whittier, 2002). Another concern of high oxygen packaging is the possible development of premature browning where the cooked product appears well done at lower than normal internal cooking temperatures (Hague et al., 1994; Warren, Hunt and Kropf, 1996; Killinger, Hunt, Campbell, and Kropf, 2000). Premature browning is a food safety concern (Lyon, Berry, Soderberg, and Clinch, 2000), because cooked product appears done at temperatures where food poisoning organisms may survive. The problems of premature browning in high oxygen MAP have also been demonstrated in enhanced beef muscles (Seyfert, Hunt, Mancini, Kropf, and Stroda, 2004).

Vacuum packaging is another common method used to distribute meat. Storage of meat in gas-impermeable packages confers to beef a purple color owing to the formation of deoxymyoglobin. The anaerobic environment delays microbial growth and improves microbial shelf life, but consumers in general prefer the appearance of bright oxygenated beef compared to the darker vacuum packaged beef products (Meischen, Huffman, and David, 1987). Previous studies have focused on the individual effects of high-oxygen or CO MAP of fresh beef. These two packaging methods have not been directly compared for packaging of intact beef steaks.

Thus the objective of this study was to compare packaging systems (80% oxygen-MAP; 0.4% CO-MAP; or vacuum package), storage time (7, 14, 21 days) and cooking temperature (49, 57, 66, 71, 79°C) on raw meat red color stability, development of premature browning and rancidity in cooked top sirloin steaks.

2. Materials and Methods

2.1. Experimental design and statistics

The experiment was a 3 x 3 X 5 x 2 factorial design with 3 packaging treatments (80% oxygen - MAP, 0.4% CO – MAP, vacuum), 3 raw meat storage times at 2°C (7, 14, and 21 days), 5 internal cooking temperatures (49, 57, 66, 71, and 79°C) and 2 replications of the entire experiment. Treatment means were calculated by analysis of variance (ANOVA) using Statistica^{TM} (Statsoft Inc., Tulsa, OK). Significant differences between means were determined by calculation of Fisher's least significant difference (LSD) values, when appropriate. Significance was defined at $p < 0.05$.

2.2. Packaging

Fresh (48 hours post-mortem), vacuum packaged select grade boneless sirloins were purchased from a local packer and transported the same day to the USU meat laboratory for fabrication. Steaks were prepared by cutting the primals into 25-mm thick steaks. Steaks (n = 18 / packaging treatment) were either 1) vacuum packaged; or placed in modified atmospheres of either: 2) 0.4% CO, 30.3% CO_2 and 69.3% nitrogen, or 3) 80% oxygen and 20% carbon dioxide. Since it was not possible to obtain enough steaks from a single butt to complete all treatments, each of three top sirloin butts were knife-cut lengthwise into three sections (proximal, medial and distal). Each section was assigned to a treatment (packaging x storage) according to a Latin square design. Thus this design considers variability between and within the top butts. A Hollymatic Corp LV 20G packaging machine was used. This machine was capable of either vacuum packaging or gas flushing and sealing of modified atmosphere packages. The gas cylinders for MAP were obtained from Praxair Distribution (Salt Lake City, UT) and certified to be within ± 0.5% of the indicated mixtures. Packaged steaks were then held at 2°C for 7, 14, or 21days. The pouches (20 x 30 cm; Koch, Kansas City, MO) used for packaging were 3 mil thickness (0.75 gauge nylon, 2.25 gauge polyethylene), with an oxygen permeability of 0.6 cm^3 / 100 m^2 / 24 h at 0°C and a water vapor transmission rate of 0.6 g / 100 m^2 / 24 h at 38°C and 100% relative humidity.

2.3. Raw steak measurements

On storage days 7, 14, and 21, the color of raw steaks for each treatment (vacuum, 80% oxygen, 0.4% carbon monoxide) was visually assessed by a 3-member panel, and instrumentally measured with a Hunter color meter. Visual color scores of uncooked ground beef were determined using a 5-point scale (Hunt, Sorheim & Slinde, 1999), where 1 = purple-red (DMb), 2 = reddish-purple, 3 = bright red (OMb), 4 = reddish-tan or brown, 5 = tan or brown (MMb). Samples were scored to the nearest 0.5. Visual and Hunter color measurements were made while the bulk treatments remained in the treatment packaging. The residual oxygen in the MAP packages was measured using an oxygen gas analyzer (Illinois Instrument, model 3500 Ingleside, IL). For each replication, raw meat samples (~100g) were wrapped and frozen for later measurement of pH and fat content.

2.4. Cooking

The top sirloin steaks (5 / treatment) were grilled to internal temperatures of 49, 57, 66, 71, and 79°C using a Circulon (Hong Kong, ROC) Teflon-coated grill set to 163°C. The steaks were held for 2 minutes, then flipped every 1.5 –2 minutes until the desired internal temperature was achieved. Internal temperature during cooking was measured using a VERSATUFF 396 digital thermometer with micro-needle probe (Atkins Technical, Inc., Gainesville, FL). After cooking, steaks were sliced in half through the horizontal center .One half of each steak was photographed immediately using a digital camera. Photographs were downloaded and stored on an IBM compatible PC. A composite color photo showing the effects of packaging treatment and internal cooking temperature on cooked steak internal color may be viewed at www.usu.edu/nfs/cookedbeef.htm. The other half of the cooked steak was rapidly covered with Saran Wrap (S. C. Johnson & Son, Inc., Racine, WI) to minimize fading. Hunter color (L*, a*, b*) values were measured within 30 sec. Concurrent with Hunter color measurement, the investigators (3 member panel) scored the internal color of cooked steaks on a 5 point scale to the nearest 0.5 where 1= dark red to purple (uncooked appearance), 2= bright red, 3= very pink, 4= slightly pink and 5= tan with no evidence of pink (Hunt et al., 1999). The Ground Beef Patty Cooked Color Guide (Marksberry, Kropf, Hunt, Hague, and Warren, 1993) was used as a photographic reference where scores 1-5 of the scale were equal to scores 1-4 of the photographic color guide. After visual and instrumental color assessment, one half of each steak was used for measurement of undenatured myoglobin content and TBA values. The other half was wrapped in plastic wrap and butcher wrap, labeled and frozen at –20°C for later measurement of pH and oxidation-reduction potential (ORP). Internal temperature was measured using a VERSATUFF 396 digital thermometer with micro-needle probe (Atkins Technical, Inc., Gainesville, FL).

2.5. Hunter color measurement

Hunter color lightness, redness and yellowness (L*, a*, b*) values were measured on raw or cooked samples using a Hunter lab Miniscan portable colorimeter (Reston, VA), using illuminant D65 and 10° observer angle. The instrument was standardized using white and black standard plates.

2.6. TBA number

Thiobarbituric acid reactive substances (TBARS) assay was performed as described by Buege and Aust (1978), as modified by Lee, Hendricks and Cornforth (1999). After cooking to the four end point temperatures, steaks were sliced horizontally and duplicate 0.5g samples were taken from the steak interior. Meat samples (0.5 g) were then mixed with 2.5 ml of stock solution containing 0.375% thiobarbituric acid (Sigma Chemical Co., St. Louis, MO), 15% trichloro-acetic acid (Mallinckrodt Baker Inc., Paris, Ky), and 0.25 N HCl. The mixture was heated for 10 min in a boiling water bath (100°C) to develop a pink color, cooled in tap water, and then centrifuged (Sorvall Instruments, Model RC 5C, DuPont, Wilmington, DE) at 5500 rpm for 25 min. The absorbance of the supernatant was measured spectrophotometrically (Spectronic 21D, Milton Roy, Rochester, NY) at 532 nm against a blank that contained all the reagents minus the meat. The malonaldehyde (MDA) concentration was calculated using an extinction coefficient of $1.56\text{x}10^5\ \text{M}^{-1}\ \text{cm}^{-1}$ for the pink TBA-MDA pigment (Sinnhuber and Yu, 1958). The MDA concentration was converted to TBA number (mg MDA/Kg meat sample) as follows:

1) TBA number (mg / kg) = Sample A_{532} X (1 M TBA chromagen / 1.56 X 10^5) X [(1 mole /L) / M] X (0.003 L / 0.5 g meat) X (72.07 g MDA / mole MDA) X (1000 mg / g) X (1000 g / Kg), or

2) TBA No. (ppm) = Sample A_{532} X 2.77

2.7. Undernatured myoglobin

Myoglobin was extracted from raw or cooked samples in cold (1°C) 0.04M phosphate buffer, pH 6.8 (Warriss, 1979). Total myoglobin and metmyoglobin (% of total) was calculated based on absorbance of clarified extract at 525, 572 and 700 nm (Krzywicki, 1979) using a Model UV-2100 UV-VIS recording spectrophotometer

(Shimadzu Co., Kyoto, Japan). Total myoglobin (Mb), metmyoglobin (MetMb, % of total), and percent Mb denatured during cooking (PMD) were calculated using the following formulas (Trout, 1989):

$$\text{Mb (mg/g)} = (A_{525} - A_{700}) \times 2.303 \times \text{dilution factor} \quad (1)$$

where $\text{Mb} = \text{deoxyMb} + \text{MbO}_2 + \text{MetMb}$.

$$\%\ \text{Metmyoglobin} = \{1.395 - [(A_{572} - A_{700}) / (A_{525} - A_{700})]\} \times 100 \quad (2)$$

$$\text{PMD} = [1 - (\text{Mb conc after heating} / \text{Mb conc before heating})] \times 100 \quad (3)$$

2.8. pH

Duplicate meat samples (10g) were blended with 90 ml of distilled water for 1 min with a polytron homogenizer (Brinkman Instruments, Westbury, NY). The pH of filtrate was measured with a pH meter model 610A (Fisher Scientific Co., Houston, TX) equipped with a combination pH electrode calibrated to pH 4.0 and 7.0.

2.9. Oxidation-reduction potential (ORP)

Oxidation-reduction potential was measured in meat homogenates as described by Nam and Ahn (2003). Meat samples (5 g), 15 ml de-ionized water, and 50 μL butylated hydroxytoluene (7.2% in ethanol) were placed in a 50 - ml test tube and were homogenized using a probe type homogenizer (Ultra-Turrax T 25, Janke and Kunkel, Staufen, West Germany) for 15 s at high speed. BHT (dissolved in ethanol) was added to minimize sample oxidation during blending. The ORP values of homogenates were determined using a pH meter set to the millivolt scale (model 610 A, Fisher Scientific Co., Houston, TX), and equipped with a platinum ORP electrode.

3. Results and Discussion

3.1. Raw meat color

Raw steak color was affected ($p < 0.05$) by packaging method (0.4% CO, 80% O2 or vacuum; Table 6). Storage time (7, 14, 21days) had no significant effect on Hunter color values. Replication also had no significant effect on color measurements of raw steaks. The interaction between packaging and storage time did not affect L* values but significantly affected all other color measurements (Table 6).

Means for the interaction of packaging method and storage time on color values of raw steaks are shown in Table 7. Steaks stored in 0.4% CO had higher mean a* values than those stored in 80% oxygen or vacuum (Table 7). Steaks stored in 0.4% CO for 7-14 days had high a* values (17.9 - 19.4), low hue angle values (34) and bright red appearance with panel scores of 3 - 3.5 (Table 7). By 21 days of storage the a* values of CO-treated steaks decreased ($p<0.05$) to 14.9 but were still acceptably red with a panel visual score of 3 (Data found in Appendix B). Similar to the CO-treated samples, steaks held in 80% oxygen for 7-14 days had high redness values (14-16), low hue angle values (37-44), and a bright red color (panel score 3.3 -3.5). After 21 days storage, however, steaks held in high oxygen had low redness values (7.6), high hue angle values (61), and a brown appearance (panel score 4.3; Table 7). Vacuum packaged steaks held for 7 days at 2°C had low redness value (7), low hue angle (43), and a dark purple appearance (Panel score 1.5; Table 7). However at 14 and 21 days storage, steak surfaces were brown as indicated by an increase in yellowness (b*) from 6 to 11. Note that the mean panel score of 3 for vacuum packaged steaks at 21 days does not indicate a bright red color. Rather, some steaks were brown with a panel score of 5 while other steaks appeared purple with a panel score of 1 yielding a mean value of

3. The partial browning and surface metmyoglobin formation on steaks in some (but not all) vacuum packages was probably due to residues of oxygen in the package. Low oxygen partial pressure favors metmyoglobin formation (George and Stratmann, 1952).

3.2. Cooked meat color

The main effects of packaging method, storage time and cook temperature on internal color and TBA values of cooked steaks are shown in Table 8. Packaging method affected most color measurements but did not significantly affect lightness, yellowness, ORP or pH values. Storage time at 2°C only affected percent metmyoglobin, TBA and ORP values. Internal cooking temperature (49, 57, 66, 71 or 79°C) significantly affected all color measurements except percent metmyoglobin. TBA values were not affected by cook temperature. Replication (1 versus 2) only affected ORP and pH measurements of cooked steaks.

The main effect means for effects of packaging method on color, TBA values, ORP and pH of cooked top sirloin steaks are shown in Table 9. Steaks packaged in 80% O_2 had significantly less soluble myoglobin and significantly higher myoglobin denaturation after cooking than steaks packaged in 0.4% CO or vacuum. Steaks packaged in CO had higher redness values and lower hue angle values in agreement with a panel score of 2.8 (bright red). Steaks packaged in high O_2 also had higher mean TBA values than other packaging treatments (Table 9).

The main effect means for effects of internal cooking temperature on color, TBA values, ORP, and pH of top sirloin steaks are shown in Table 10. As internal cooking temperature increased, soluble myoglobin content decreased with a corresponding increase in PMD. Percent myoglobin denaturation (PMD) values ranged from 0 (raw steaks) to 82% in steaks cooked to 79°C internal temperature. As cooking temperature increased, internal a* redness values decreased and hue angle values increased, indicating loss of redness. Panel color scores also indicated increased browning at higher cooking temperatures. TBA values were not affected by cooking temperature. Oxidation-reduction potential (ORP) values were significantly lower in cooked than in raw steaks, indicating that the samples had less oxidizing potential probably because cooking expels oxygen from the sample pH significantly increased from 5.6 in raw to 5.8 in steaks cooked to 79°C (Table 10).

Means for the interaction of packaging method and cooking temperature on color, ORP and pH of cooked top sirloin steaks are shown in Table 11. Myoglobin content of raw steaks was 6.1- 6.2 mg/g meat. For all packaging methods, soluble myoglobin content decreased with increasing cooking temperature. However, steaks packaged in 80% oxygen–MAP had higher myoglobin denaturation at all cooking temperatures (Fig. 5). At the higher cooking temperatures (66, 71, 79°C), steaks packaged in high oxygen had lower redness values than steaks packaged under anaerobic conditions (Fig. 6). A premature browning effect was clearly observed in steaks packaged in 80% oxygen. Steaks in high oxygen were uniformly brown when cooked to an internal temperature of 66-79°C. In comparison, steaks packaged in CO or vacuum retained some internal redness and had significantly higher a* values (Fig. 6). Even at 49°C, steaks in 80% oxygen were noticeably less red and more brown than steaks packaged in CO, but were not significantly different from steaks packaged in vacuum (Fig. 6). According to visual assessment and photography, steaks packaged in 80% oxygen were noticeably more brown, especially on exterior edges, compared to anaerobically packaged steaks cooked to 49 or 57°C. Thus premature browning was visually evident even at these low temperatures. However, premature browning was not observed at 49 or 57°C by measures of a* value (Fig. 6), because a* value measurements were taken in the center of each steak and the browning was not observed at the center of the high O_2-treated steaks until internal temperature reached 66°C.

Steaks packaged in high oxygen had higher TBA values than anaerobically packaged steaks at all cooking temperatures (Fig. 7). In Fig.7 a high variability can be observed in the TBA values of steaks packaged in the high oxygen atmosphere, because these mean values were pooled over storage time and there was a marked increase in TBA values with increasing storage time. For steaks in a high oxygen atmosphere, mean TBA values (pooled among cooking temperatures) increased from 1.02 at day 7 to 4.40 after 21 days storage. Steaks packaged in vacuum or CO did not exhibit this large variation in TBA values during storage. Informal taste panels confirmed a rancid flavor and aroma in steaks packaged in high oxygen. TBA values of high oxygen packaged steaks ranged from 0.8 (7 days storage, 49°C internal temperature) to 6.7 (21 days storage, 57°C; data not shown).

4. Conclusions

Raw top sirloin steaks packaged in high oxygen had a desirable red color on day 7 of storage, but some browning was evident by day 14, and steaks were completely brown and unappealing by day 21. Raw steaks packaged in 0.4% CO maintained a bright red desirable color throughout the 21 day storage period. Vacuum packaged raw steaks maintained a dark purplish color through day 7, but brown surface discoloration was noticeable by day 14 on some steaks possibly because of low levels of residual oxygen in the vacuum package favoring metmyoglobin formation.

The phenomenon of premature browning was evident during cooking of steaks stored in high oxygen. High oxygen-treated steaks exhibited peripheral browning during cooking to 49 and 57°C and were completely brown throughout at 66°C or higher. For comparison, steaks packaged anaerobically (0.4% CO or vacuum) did not express premature browning and retained some internal redness even at 79°C internal temperature. At all storage times (7 – 21 days), high oxygen packaging significantly increased TBA values in beef top sirloin steaks. Premature browning and increased oxidation were completely prevented by anaerobic packaging in 0.4% CO-MAP or vacuum.

Previous work has documented the problems of premature browning and rancidity in high oxygen-packaged ground beef. Results of this study show that intact steaks in high-oxygen packaging are also susceptible to these problems. To avoid these problems, processors may want to consider alternative packaging methods such as 0.4% CO or vacuum packaging.

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Table 6. Main and interaction effects of packaging method and storage time on panel and Hunter color values[3] of raw sirloin steaks.

Effect	n	L*	a*	b*	Hue Angle	Panel Score[4]
Packaging[1]	36	*	*	*	*	NS
Days of Storage[2]	36	NS	NS	NS	NS	*
Replication	72	NS	NS	NS	NS	NS
Packaging x Day	6	NS	*	*	*	*

* Significant at $p < 0.05$. NS = not significant.

1 Samples were vacuum packaged or modified atmosphere packaged in either 0.4% carbon monoxide or 80% oxygen.

2 After packaging, steaks were stored at 2°C for 7, 14, or 21 days

3 L* = lightness; a* = redness; b* = yellowness; hue angle = arctan(b*/a*).

4 After 7, 14, or 21 days storage, color was evaluated by a three member panel, using a 5 point scale where 1= purple - red (DMb), 2= reddish - purple, 3= bright – red (OMb), 4= reddish tan or brown, 5 = tan or brown (MMb).

Table 7. Means ± standard error of the mean (n=6) for the interaction of packaging method and storage time on color values[1] of raw sirloin steaks.

Packaging	Days of Storage	L*	a*	b*	Hue Angle	Panel Score[2]
CO	7	34.4±2.0	19.4±0.5	13.2±1.1	34.1±2.9	3.5±0.0
CO	14	34.6±4.1	17.9±2.1	12.0±1.1	34.0±4.9	3.0±0.0
CO	21	34.3±2.3	14.9±1.3	11.5±1.4	37.7±1.3	3.3±0.4
O2	7	36.3±1.7	16.1±1.5	15.9±1.5	44.6±1.1	3.5±0.0
O2	14	34.6±1.7	13.7±0.9	14.5±1.1	46.7±1.7	3.8±0.3
O2	21	36.6±1.5	7.6±4.1	13.1±0.7	61.1±12.3	4.3±0.9
Vac	7	26.5±1.0	7.0±0.9	6.5±0.4	43.2±2.3	1.5±0.6
Vac	14	32.0±3.8	8.5±1.3	11.3±2.0	53.0±4.0	4.5±0.0
Vac	21	31.9±3.8	8.2±0.5	11.0±2.2	52.7±5.0	3.0±1.2
$LSD_{0.05}$[3]		NS	3.8	2.9	10.8	1.1

[1] L* = lightness; a* = redness; b* = yellowness; hue angle = arctan(b*/a*).

[2] 1= purple-red (DMb), 2= reddish-purple, 3= bright –red (OMb), 4= reddish tan or brown, 5 = tan or brown (MMb).

[3] LSD = Least significant difference among means in columns. Any two means within a column are different ($p < 0.05$) if the value obtained upon subtraction is equal to or greater than the LSD value. .

Table 8. Main effects (total n = 108) of packaging method (Pkg), storage time (Day) and cooking temperature (Temp) on color[1] and thiobarbituric acid (TBA) values of cooked top sirloin steaks.

Effect	N	L*	a*	b*	Hue Angle	Panel Score[5]	Mb[6]	PMD[6]	MetMb[6]	TBA	ORP[7]	pH
Pkg [2]	36	NS	*	NS	*	*	*	*	*	*	NS	NS
Day[3]	36	NS	NS	NS	NS	NS	NS	NS	*	*	*	NS
Temp[4]	18	*	*	*	*	*	*	*	NS	NS	*	*
Replication	54	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*
Pkg x Day	12	NS	NS	*	NS	NS	NS	NS	NS	*	NS	NS
Pkg x Temp	6	*	*	*	NS	NS	*	*	NS	NS	NS	NS
Day x Temp	6	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pkg x Day x Temp	2	NS	NS	*	NS	*	NS	NS	NS	NS	NS	NS

* Significant at $p < 0.05$. NS = not significant.

1 L* = lightness; a* = redness; b* = yellowness; hue angle = arctan(b*/a*).

2 Samples were vacuum packaged or modified atmosphere packaged in either 0.4% carbon monoxide or 80% oxygen.

3 After packaging steaks were stored at 2°C for 7, 14, or 21 days.

4 Steaks were cooked to internal temperatures of 49, 57, 66, 71 or 79°C.

5 1= dark red (raw), 2= bright red, 3= very pink, 4= slightly pink, 5 = tan (no pink).

6 Mb = Total extractable myoglobin; PMD = % myoglobin denatured during cooking; MetMb = % metmyoglobin of total Mb.

7 ORP = Oxidation-reduction potential (millivolts).

Table 9. Main effect means ± standard error of the mean (n =36) for effects of packaging method (0.4% CO, 80% oxygen, vacuum) on measures of myoglobin concentration[1], internal color[2], thiobarbituric acid (TBA) values, oxidation-reduction potential (ORP), and pH of cooked top sirloin steaks. Means are pooled among cooking temperatures (49-79°C), storage days (7-21) and replications.

Package	Mb[1] (mg/g meat)	PMD[1] (%)	MetMb[1] (%)	L*	a*	b*	Hue Angle	Panel Score[3]	TBA (ppm)	ORP	pH
CO	4.8±0.4	27±5.3	15.3±2.8	50.1±1.4	9.5±0.6	13.2±0.2	55±1.8	2.8±0.2	0.7±0.1	177±3.7	5.7±0.03
OXY	3.0±0.4	50±5.8	47.7±7.3	48.8±1.1	7.4±0.6	12.8±0.3	62±1.5	3.9±0.2	2.3±0.3	181±4.2	5.7±0.02
VAC	4.6±0.3	26±4.8	14.3±2.8	50.0±1.6	7.2±0.3	13.3±0.4	61±1.4	3.0±0.2	0.4±0.0	174±3.5	5.8±0.03
LSD $_{.05}$[4]	1.0	14.9	13.6	NS	1.5	NS	4.4	0.6	0.6	NS	NS

1 Mb = Total extractable myoglobin; PMD = % myoglobin denatured during cooking; MetMb = % metmyoglobin of total Mb

2 L* = lightness; a* = redness; b* = yellowness; hue angle = arctan(b*/a*).

3 Panel score 1 = dark purple, 2 = bright red, 3 = very pink, 4 = slightly pink and 5 = tan.

4 LSD = Least significant difference among means in columns. Any two means within a column are different ($p < 0.05$) if the value obtained upon subtraction is equal to or greater than the LSD value.

Table 10. Main effect means ± standard error of the mean (n =18) for effects of cooking temperature (49, 57, 66, 71, 79°C) on measures of internal color[1], thiobarbituric acid (TBA) values, oxidation-reduction potential (ORP) and pH of cooked top sirloin steaks. Means were pooled among packaging method (0.4% CO, 80% oxygen, vacuum), cooking temperatures (49 -79°C), storage days (7-21) and replications.

Cook temp (°C)	Mb[2] (mg/g meat)	PMD[2] (%)	MetMb[2] (%)	L*	a*	b*	Hue Angle	Panel Score[3]	TBA (ppm)	ORP (mV)	pH
Raw	6.2±0.3	0.0±0.0	24.2±6.7	33.5±0.8	12.2±1.1	12.1±0.6	46.0±2.3	3.4±0.2	0.7±0.3	202.8±6.6	5.6±0.02
49	6.0±0.3	10.5±3.4	21.7±4.8	48.0±1.2	9.2±0.6	12.1±0.4	53.1±1.9	1.6±0.2	1.0±0.4	185.5±3.9	5.8±0.04
57	4.9±0.3	22.3±4.2	19.4±5.5	53.0±0.6	7.8±0.4	13.3±0.3	59.8±1.1	2.5±0.2	1.2±0.4	175.2±4.5	5.9±0.05
66	4.2±0.4	33.7±6.9	19.5±6.0	54.4±0.8	7.0±0.5	14.1±0.4	64.0±1.3	3.4±0.2	1.2±0.3	171.0±4.5	5.7±0.04
71	2.6±0.3	57.8±5.6	23.1±6.1	55.6±0.7	6.2±0.3	13.9±0.4	66.0±1.0	4.1±0.2	1.4±0.4	166.9±3.4	5.8±0.03
79	1.1±0.1	82.2±2.1	47.3±11.9	53.2±0.7	6.0±0.4	13.2±0.3	66.1±1.1	4.5±0.1	1.4±0.4	164.9±3.7	5.8±0.04
LSD $_{.05}$[4]	0.9	12.3	NS	2.3	1.7	1.2	4.3	0.5	NS	12.7	0.1

[1] L* = lightness; a* = redness; b* = yellowness; hue angle = arctan(b*/a*).

[2] Mb = Total extractable myoglobin; PMD = % myoglobin denatured during cooking; MetMb = % metmyoglobin of total Mb.

[3] 1= dark red (raw), 2= bright red, 3= very pink, 4= slightly pink, 5 = tan (no pink).

[4] LSD = Least significant difference among means in columns. Any two means within a column are different ($p < 0.05$) if the value obtained upon subtraction is equal to or greater than the LSD value.

Table 11. Means ± standard error of the mean (n=6) for the interaction of packaging method[1] and cooking temperature on color[2], oxidation-reduction potential (ORP) and pH of cooked top sirloin steaks.

Packaging	Cook temp (°C)	Mb (mg/g meat)	Met Mb (%)	L*	b*	Hue Angle	Panel score	ORP (mv)	pH
CO	Raw	6.1±0.8	10.8±13.6	34.5±2.1	12.0±1.1	35.6±2.9	3.2±0.3	203.2±36.0	5.6±0.0
CO	49	7.0±1.2	13.2±8.3	46.5±5.7	11.9±1.4	49.4±7.3	1.3±0.4	185±12.1	5.8±0.1
CO	57	6.0±0.3	8.6±4.9	54.4±2.4	13.1±0.6	58.0±3.2	1.8±0.4	178.0±14.4	5.8±0.1
CO	66	5.5±0.6	7.5±3.0	56.2±2.0	14.2±0.5	61.1±5.3	2.9±0.6	169.8±18.4	5.7±0.3
CO	71	3.6±1.0	15.3±12.3	56.8±2.0	14.5±1.5	62.6±5.6	3.4±0.8	165.3±14.4	5.7±0.2
CO	79	1.2±0.5	34.8±29.8	54.0±2.4	13.6±0.9	61.6±4.4	4.3±0.3	164.7±11.3	5.7±0.2
OXY	Raw	6.2±0.8	39.2±37.3	35.9±1.2	14.5±1.4	50.9±10.5	3.8±0.6	211.6±23.2	5.6±0.7
OXY	49	4.7±1.2	39.4±28.6	49.2±5.2	12.7±2.1	55.2±7.1	2.3±1.2	186.1±23.9	5.8±0.2
OXY	57	3.7±0.6	41.2±30.9	51.0±1.1	13.1±1.1	58.5±5.5	3.2±1.3	176.8±23.1	5.9±0.1
OXY	66	1.9±1.1	43.7±36.1	52.5±2.4	12.8±1.1	66.7±4.2	4.4±0.5	175.4±23.5	5.7±0.1
OXY	71	1.0±0.8	44.1±38.5	52.9±2.4	12.2±0.7	67.6±2.9	4.9±0.2	170.1±15.4	5.8±0.1
OXY	79	0.7±0.4	78.5±78.8	51.4±3.2	11.8±1.2	70.1±1.3	4.8±0.4	167.4±19.3	5.8±0.2
VAC	Raw	6.2±1.6	20.5±28.4	30.2±3.5	9.7±2.5	49.8±5.9	3.0±1.5	193.8±26.8	5.6±0.1
VAC	49	6.2±0.9	12.5±7.2	48.4±4.3	11.9±2.1	54.7±9.1	1.3±0.3	184.8±14.8	5.7±0.1
VAC	57	5.0±0.7	6.7±3.4	53.7±3.2	13.9±1.3	62.5±4.1	2.4±0.6	171.4±20.3	6.0±0.3
VAC	66	5.1±0.4	7.4±4.9	54.5±5.1	15.2±1.7	64.1±6.4	3.0±0.3	167.7±17.9	5.8±0.1
VAC	71	3.4±0.7	10.0±6.9	57.1±2.2	15.1±0.9	67.8±2.1	4.0±0.0	165.2±15.8	5.7±0.7

VAC	79	1.4±0.4	28.5±23.3	54.3±2.1	14.3±0.9	66.5±2.8	4.4±0.2	162.6±17.8	5.8±0.2
LSD $_{.05}$[3]		1.0	NS	3.7	1.6	NS	NS	NS	NS

[1] Packaging method: CO = 0.4% CO, 60% CO_2. 39.6% N_2 modified atmosphere packaging (MAP); OXY= 80% O_2, 20% CO_2-MAP; VAC = Vacuum packaging.

[2] Mb = Total soluble myoglobin; MetMb = % metmyoglobin; L* = lightness; b* = yellowness; Hue angle = arctan (b*/a*), where higher values are less red. Cooked ground beef panel color score 1= dark red (raw), 2= bright red, 3= very pink, 4= slightly pink, 5 = tan (no pink).

[3] LSD = Least significant difference among means in columns. Any two means within a column are different ($p < 0.05$) if the value obtained upon subtraction is equal to or greater than the LSD value.

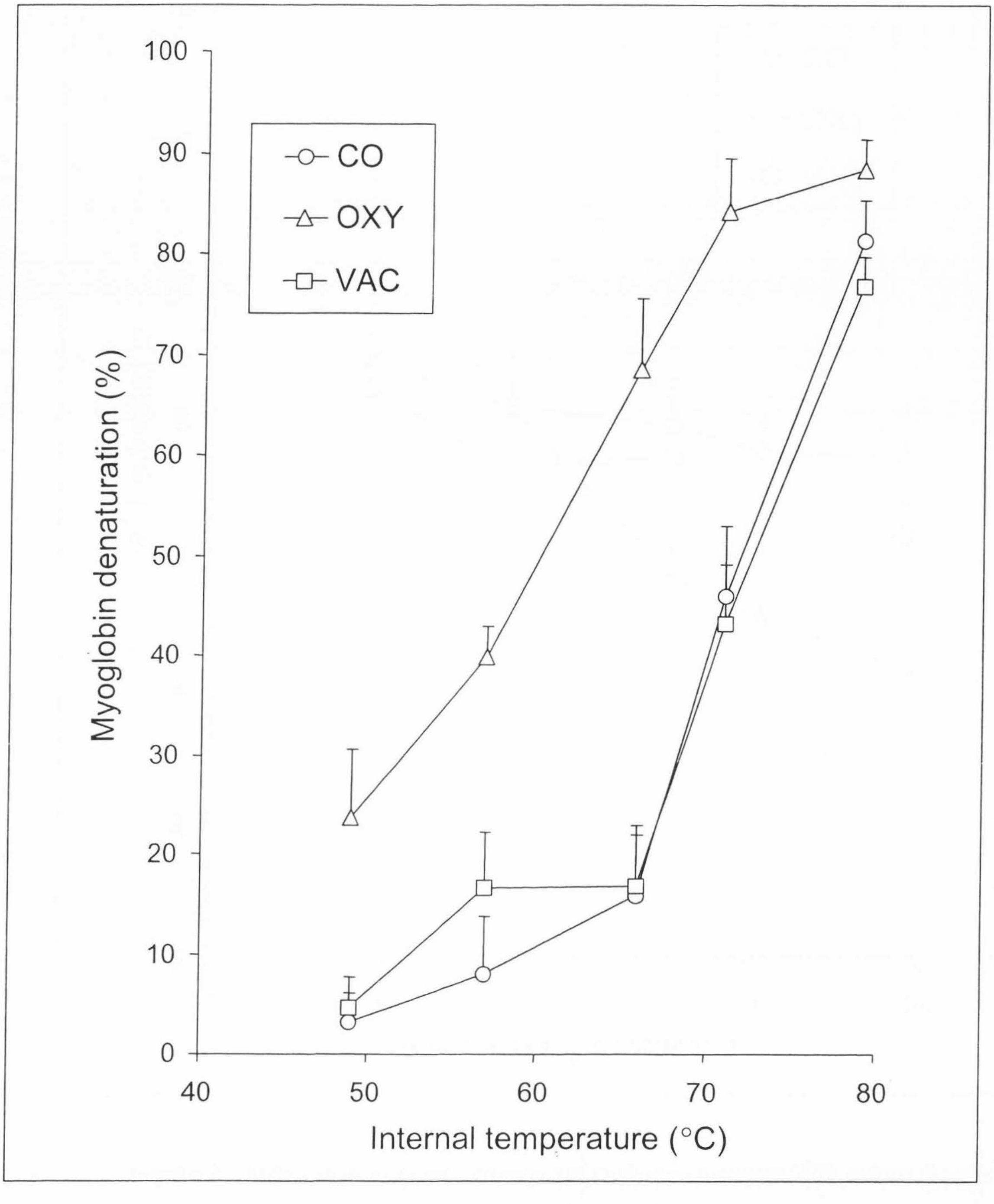

Figure 5. Percent myoglobin denaturation (PMD) of cooked top sirloin steaks as affected by raw meat packaging method and internal cooking temperature. Means (n=6) were pooled for storage time before cooking (7, 14, 21 days), and replication.

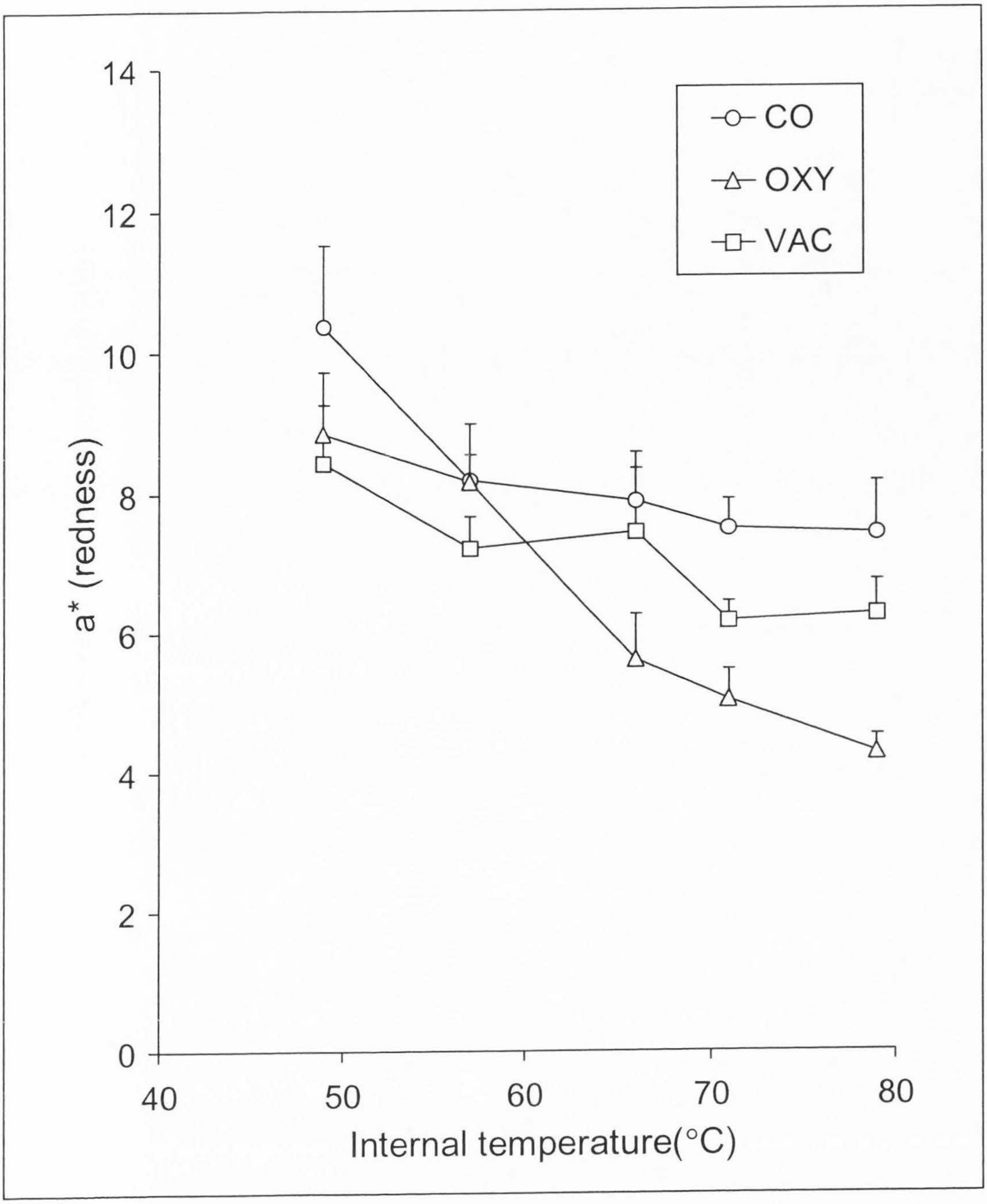

Figure 6. Mean Hunter color redness (a*) values of cooked top sirloin steaks as affected by raw meat packaging method and internal cooking temperature. Means (n=6) were pooled for storage time before cooking (7, 14, 21 days), and replication.

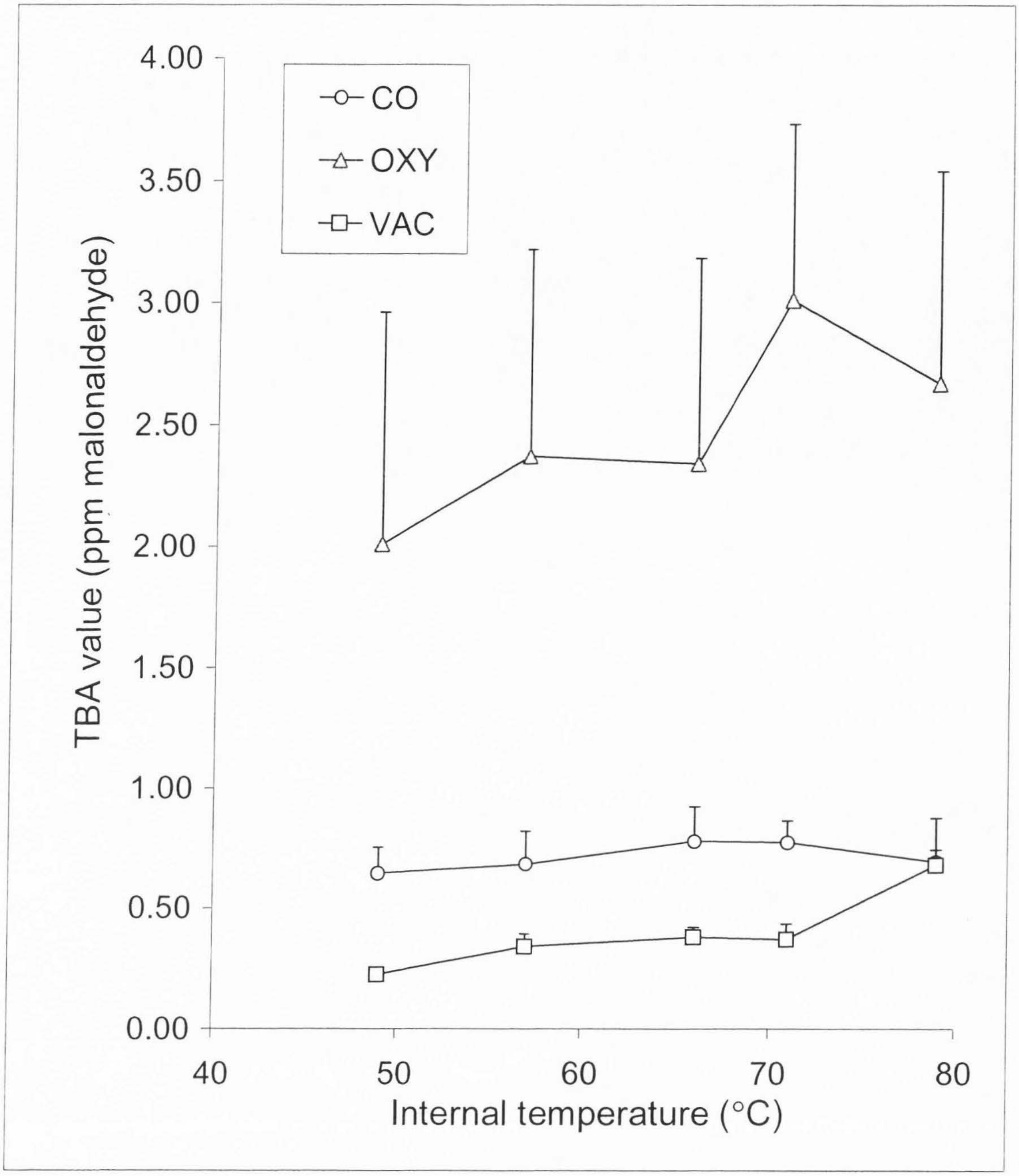

Figure 7. Mean thiobarbituric acid (TBA) values of cooked top sirloin steaks as affected by raw meat packaging method and internal cooking temperature. Means (n=6) were pooled for storage time before cooking (7, 14, 21 days), and replication.

CHAPTER IV

CONCLUSIONS

This study clearly demonstrates that modified atmospheric packaging with 0.4% CO was effective in prolonging the desirable red color of raw ground beef or top sirloin steaks. At all storage times a* redness values of samples stored in 0.4% CO were higher than samples stored in high oxygen or vacuum. Modified atmospheric packaging in high oxygen could effectively maintain desirable red color in meat samples up to 7 days of storage at 2°C, but browning was evident in samples by day 14.

The phenomenon of premature browning was also clearly demonstrated while cooking ground beef and top sirloin steaks stored in 80% oxygen MAP. In high oxygen treated ground beef and steaks, the effect of premature browning could be observed at an internal cooking temperature as low as 49°C. TBA values of samples stored in high oxygen were significantly higher than those samples stored in 0.4% CO or vacuum. This study clearly demonstrated that high-oxygen packaging promotes rancidity.

Vacuum packaging prevented the problems of premature browning and lipid oxidation. However the development of a dark purple color in raw vacuum packaged beef is a major drawback that reduces consumer acceptance.

Even at cooking temperatures as high as 79°C, the internal color of ground beef patties and steaks packaged in 0.4% carbon monoxide remained red. This persistent redness at the higher temperatures could be explained by the formation of heat denatured CO-hemochrome.

In summary MAP has the advantage that the products are case-ready eliminating fabrication and packaging at the retail store level. Packaging in 80% oxygen MAP has the advantage of extended color stability compared to meat packaged in PVC. Also beef packaged in 80% oxygen never has the problem of PMB. However, beef packaged in 80% oxygen MAP has two disadvantages; higher rancidity and pronounced PMB during cooking. Packaging in 0.4% CO also has the advantage of maintaining a desirable red appearance for prolonged times of at least 21 days after packaging. The most serious disadvantage of this packaging method appears to be the problem of persistent pinking, even though this pink color fades rapidly upon exposure to air.

In conclusion, if beef is packaged in high oxygen, the inclusion of antioxidants in the product could reduce the effect of lipid oxidation. Packaging beef in 0.4% carbon monoxide maintains a desirable red color, but consumers should be educated that the phenomena of persistent pinking in products packaged in CO is not a health concern. This study showed that the pinking remains even at temperatures above 71°C where all vegetative bacteria are killed. Consumers need to be informed of this phenomenon. Consumers always rely on color for their first impression of doneness. However the thermometer should be the final indicator of doneness. Consumer education about the effects of cooking meat packaged in 0.4% CO could thus increase the acceptability of this new packaging method.

APPENDIXES

APPENDIX A

Data for chapter III

Cummulative data ground chuck

Rep	Day	Tmt	Cking Temp	525	572	700	Mb	PMD	%MetMb	L*	a*	b*	Hue	TBA	ORP	pH
1	7	CO	Raw	0.482	0.625	0.061	5.81	0.0	5.5	40.37	18.78	12.55	33.756			5.72
1	7	CO	49°C	0.449	0.566	0.030	5.79	0.5	11.4	52.82	14.41	16.43	48.751	0.673	138.7	5.98
1	7	CO	57°C	0.400	0.501	0.024	5.20	10.6	12.7	52.67	14.91	17.09	48.901	0.920	108.3	7
1	7	CO	66°C	0.363	0.466	0.033	4.55	21.7	8.3	57.55	11.00	14.64	53.084	0.985	101.8	6.03
1	7	CO	71°C	0.266	0.331	0.040	3.11	46.4	10.8	54.18	12.71	16.11	51.732	1.063	95	6.54
1	7	CO	79°C	0.082	0.086	0.024	0.80	86.3	33.4	54.21	6.57	15.04	66.407	1.717	96.7	6.11
1	7	O_2	Raw	0.390	0.412	0.029	4.99	0.0	33.4	40.98	13.89	16.3	49.568			5.68
1	7	O_2	49°C	0.331	0.247	0.029	4.17	16.4	67.3	54.54	8.05	15.07	61.895	0.408	86.2	6.71
1	7	O_2	57°C	0.358	0.257	0.071	3.96	20.5	74.7	57.65	5.36	13.64	68.552	0.452	99.1	6.56
1	7	O_2	66°C	0.089	0.065	0.025	0.88	82.3	77.9	56.99	4.73	12.53	69.324	0.467	92.3	6.21
1	7	O_2	71°C	0.054	0.038	0.014	0.56	88.8	78.5	53.93	4.18	13.38	72.656	0.763	85.6	6.5
1	7	O_2	79°C	0.029	0.021	0.008	0.30	94.1	77.8	54.9	4.57	13.43	71.213	0.845	90.3	6.09
1	7	VAC	Raw	0.403	0.508	0.033	5.12	0.0	11.3	37.22	7.23	10.59	55.682			5.74
1	7	VAC	49°C	0.458	0.541	0.053	5.60	-9.4	18.9	55.9	7.48	14.07	62.008	0.699	97.5	7.34
1	7	VAC	57°C	0.427	0.504	0.053	5.16	-0.8	18.7	54.9	7.98	14.50	61.179	0.890	96.2	6.35
1	7	VAC	66°C	0.358	0.427	0.034	4.47	12.7	18.1	56.5	7.02	16.10	66.446	0.899	96	6.82
1	7	VAC	71°C	0.267	0.337	0.022	3.38	34.0	10.8	56.2	6.27	15.82	68.385	1.360	95.5	6.34
1	7	VAC	79°C	0.057	0.060	0.002	0.76	85.1	34.4	54.3	4.17	15.81	75.23	1.247	102.4	5.97
2	7	CO	Raw	0.650	0.764	0.224	5.88	0.0	12.8	38.64	18.8	13.21	35.097			5.71
2	7	CO	49°C	0.633	0.771	0.172	6.37	0.0	9.6	50.8	17.80	13.00	36.145	0.166		
2	7	CO	57°C	0.444	0.597	0.030	5.72	2.7	2.7	56.0	14.17	13.79	44.225	0.316	132.9	6.17

2	7	CO	66°C	0.364	0.462	0.044	4.43	24.7	9.1	58.0	9.45	14.94	57.69	0.436		
2	7	CO	71°C	0.262	0.321	0.045	3.00	49.0	12.3	59.7	8.69	13.89	57.973	0.463		
2	7	CO	79°C	0.260	0.319	0.042	3.02	48.7	12.4	58.4	6.89	11.05	58.06	0.011		
2	7	O_2	Raw	0.445	0.512	0.010	6.01	0.0	24.1	46.61	12.64	13.73	47.37			
2	7	O_2	49°C	0.368	0.280	0.001	5.07	15.6	63.4	53.8	7.32	12.10	58.832	1.922		
2	7	O_2	57°C	0.367	0.259	0.016	4.84	19.4	70.4	54.8	7.54	12.96	59.814	1.688	131.2	6.23
2	7	O_2	66°C	0.139	0.132	0.039	1.38	77.0	46.1	56.2	5.36	14.26	69.405	2.535		
2	7	O_2	71°C	0.100	0.106	0.035	0.90	85.0	30.3	57.2	4.44	13.18	71.388	2.018		
2	7	O_2	79°C	0.039	0.031	0.021	0.24	96.0	85.7	53.9	4.38	12.26	70.345	1.787		
2	7	VAC	Raw	0.506	0.658	0.063	6.12	0.0	5.1	39.42	7.19	11.56	58.124			
2	7	VAC	49°C	0.438	0.575	0.030	5.63	7.9	5.8	55.1	6.59	11.99	61.21	0.105		
2	7	VAC	57°C	0.438	0.551	0.036	5.55	9.2	11.4	54.5	6.59	11.91	61.048	0.514	128.5	6.19
2	7	VAC	66°C	0.461	0.569	0.110	4.85	20.8	8.8	57.4	9.49	15.77	58.966	0.412		
2	7	VAC	71°C	0.240	0.302	0.009	3.19	47.8	12.9	58.4	7.20	15.99	65.764	0.194		
2	7	VAC	79°C	0.058	0.068	0.003	0.77	87.4	22.8	56.4	5.83	14.46	68.047	0.017		
1	14	CO	Raw	0.433	0.578	0.022	5.69	0.0	4.4	42.83	19.02	12.98	34.314		153.4	
1	14	CO	49°C	0.407	0.533	0.017	5.39	5.3	7.3	49.7	14.70	13.02	41.535	0.725	100	5.94
1	14	CO	57°C	0.331	0.420	-0.003	4.61	19.0	12.7	58.1	14.50	15.54	46.986	1.108	97.6	5.92
1	14	CO	66°C	0.263	0.332	-0.007	3.74	34.4	14.0	56.8	13.50	16.06	49.953	1.158	83.2	6.03
1	14	CO	71°C	0.224	0.276	-0.010	3.23	43.3	17.0	57.5	9.22	15.73	59.628	1.089	69.9	6.01
1	14	CO	79°C	0.075	0.092	-0.019	1.30	77.1	22.2	54.5	7.02	14.22	63.73	0.695	85.3	5.95
1	14	O_2	Raw	0.384	0.238	0.025	4.95	0.0	80.1	43.33	6.91	12.66	61.378		151.2	
1	14	O_2	49°C	0.360	0.200	0.043	4.39	11.4	90.0	54.7	6.20	14.02	66.149	0.522	147.8	5.94

1	14	O_2	57°C	0.144	0.090	0.005	1.93	61.1	78.6	53.0	5.20	12.73	67.786	0.742	96.2	5.87
1	14	O_2	66°C	0.027	0.013	-0.013	0.55	88.8	74.2	51.9	4.26	10.56	68.035	0.706	92.6	5.99
1	14	O_2	71°C	0.028	0.017	-0.018	0.64	87.0	63.4	53.8	5.18	14.28	70.067	0.609	91.2	6.03
1	14	O_2	79°C	-0.016	-0.026	-0.038	0.30	93.9	85.0	51.4	5.42	14.22	69.141	0.776	92.2	5.87
1	14	VAC	Raw	0.400	0.494	0.032	5.09	0.0	14.0	35.99	7.64	9.04	49.801		141	
1	14	VAC	49°C	0.353	0.377	-0.005	4.95	2.7	33.0	54.4	8.14	14.46	60.628	0.693	86.2	5.91
1	14	VAC	57°C	0.304	0.304	0.003	4.17	18.1	39.5	58.9	5.99	15.22	68.522	1.330	90.9	5.84
1	14	VAC	66°C	0.216	0.219	-0.002	3.02	40.6	38.3	60.8	5.28	14.38	69.843	1.080	81.6	5.93
1	14	VAC	71°C	0.199	0.196	-0.019	3.01	40.7	40.9	53.8	7.62	15.32	63.559	0.748	80.7	5.92
1	14	VAC	79°C	-0.033	0.035	-0.034	0.02	99.6	0.0	52.8	4.97	13.60	69.931	0.554	84.9	5.91
2	14	CO	Raw	0.611	0.753	0.174	6.04	0.0	7.2	42.4	20.65	14.73	35.504		80.2	5.51
2	14	CO	49°C	0.584	0.741	0.166	5.78	4.4	2.0	55.5	14.56	12.65	40.988	1.247	82.3	5.83
2	14	CO	57°C	0.488	0.609	0.147	4.71	22.0	4.1	57.5	13.90	15.56	48.229	1.252	79	5.79
2	14	CO	66°C	0.412	0.487	0.172	3.31	45.2	8.3	57.7	9.53	15.07	57.696	2.144	79.7	6.04
2	14	CO	71°C	0.421	0.515	0.144	3.83	36.7	5.6	50.3	13.78	15.60	48.548	3.352	89.1	5.97
2	14	CO	79°C	0.307	0.344	0.150	2.17	64.0	15.9	54.5	6.66	14.60	65.484	2.133	109.2	5.97
2	14	O_2	Raw	0.612	0.381	0.179	5.98	0.0	92.7	46.81	7.19	12.52	60.136		114.2	5.53
2	14	O_2	49°C	0.335	0.248	0.147	2.61	56.4	85.6	52.1	6.09	14.93	67.814	1.371	99.3	5.84
2	14	O_2	57°C	0.374	0.267	0.150	3.10	48.2	87.0	54.5	6.09	14.43	67.123	2.161	90.6	5.85
2	14	O_2	66°C	0.178	0.161	0.140	0.53	91.2	85.2	53.8	5.39	12.97	67.438	1.357	92.9	6.04
2	14	O_2	71°C	0.176	0.166	0.152	0.33	94.5	79.9	55.0	4.46	13.56	71.799	2.022	97.4	6
2	14	O_2	79°C	0.176	0.167	0.154	0.30	95.0	78.9	55.2	4.63	13.61	71.217	1.759	106.8	5.94
2	14	VAC	Raw	0.557	0.681	0.157	5.53	0.0	8.5	39.44	6.96	10.69	56.937		78.5	5.45

2	14	VAC	49°C	0.551	0.668	0.155	5.48	0.9	9.9	50.3	7.66	10.72	54.456	0.936	79.7	5.76
2	14	VAC	57°C	0.450	0.553	0.147	4.19	24.3	5.8	55.1	9.77	15.31	57.46	1.911	86.5	5.8
2	14	VAC	66°C	0.486	0.585	0.163	4.47	19.1	9.0	55.2	8.71	14.74	59.425	2.244	80.2	5.93
2	14	VAC	71°C	0.427	0.518	0.154	3.77	31.8	6.3	57.5	8.62	16.07	61.795	3.241	79.4	5.9
2	14	VAC	79°C	0.293	0.331	0.142	2.09	62.3	14.3	57.5	5.47	14.23	68.978	1.695	81	5.91
1	21	CO	Raw	0.414	0.552	0.027	5.34	0.0	3.9	39.81	19.03	12.22	32.709		120.5	5.71
1	21	CO	49°C	0.364	0.469	0.020	4.75	11.0	9.0	55.8	13.83	15.37	48.023	0.252	81	5.63
1	21	CO	57°C	0.323	0.412	0.039	3.93	26.4	8.3	58.4	15.46	15.06	44.252	0.339	84.4	5.65
1	21	CO	66°C	0.177	0.221	0.017	2.22	58.5	12.3	52.7	14.83	16.46	47.986	0.311	88.8	5.65
1	21	CO	71°C	0.178	0.214	0.018	2.20	58.8	16.5	55.8	8.83	15.84	60.867	0.292	87.6	5.8
1	21	CO	79°C	0.046	0.048	-0.001	0.64	88.1	33.4	53.6	8.10	14.41	60.664	0.283	73.3	5.7
1	21	O_2	Raw	0.389	0.331	0.041	4.81	0.0	56.2	42.73	5.24	12.25	66.846		95.9	5.73
1	21	O_2	49°C	0.150	0.114	0.009	1.94	59.6	65.3	54.3	7.09	13.69	62.625	1.331	75.8	6.29
1	21	O_2	57°C	0.103	0.096	0.018	1.17	75.6	47.3	55.5	5.88	14.47	67.89	1.584	89.4	5.94
1	21	O_2	66°C	0.051	0.044	0.006	0.62	87.2	55.2	48.3	4.88	14.78	71.733	2.508	100	5.98
1	21	O_2	71°C	0.072	0.065	0.012	0.83	82.8	51.0	49.1	4.89	13.90	70.623	1.543	87.9	6.03
1	21	O_2	79°C	0.065	0.055	0.038	0.37	92.3	77.6	53.4	4.76	15.14	72.552	2.020	91.9	6.02
1	21	VAC	Raw	0.360	0.460	0.009	4.84	0.0	10.9	37.63	5.86	11.7	63.4		75.5	5.7
1	21	VAC	49°C	0.231	0.237	0.004	3.14	35.2	36.7	52.1	8.44	13.00	57.011	0.293	84.6	5.56
1	21	VAC	57°C	0.192	0.201	0.020	2.37	51.2	33.8	51.8	10.20	17.06	59.13	0.437	88.2	5.65
1	21	VAC	66°C	0.231	0.250	0.007	3.10	36.1	31.1	58.7	4.11	14.52	74.201	0.423	84.7	5.58
1	21	VAC	71°C	0.212	0.223	0.032	2.49	48.6	33.5	54.3	5.37	15.79	71.223	0.617	79.5	5.64
1	21	VAC	79°C	0.112	0.106	0.047	0.90	81.4	49.0	53.9	4.82	13.65	70.556	0.277	75.8	5.64
2	21	CO	Raw	0.405	0.546	0.014	5.40	0.0	3.4	36.59	17.57	11.65	33.549		129.2	5.52

2	21	CO	49°C	0.373	0.493	0.011	5.00	7.4	6.3	53.2	12.64	13.61	47.12	0.571	88.3	5.84
2	21	CO	57°C	0.342	0.422	0.070	3.76	30.4	10.0	57.5	8.33	14.74	60.532	0.767	77.8	5.89
2	21	CO	66°C	0.257	0.333	0.003	3.51	35.1	9.5	51.6	8.94	14.79	58.853	0.463	87.2	5.88
2	21	CO	71°C	0.178	0.214	0.018	2.20	59.2	16.5	57.9	9.31	14.74	57.727	0.136	82.4	5.87
2	21	CO	79°C	0.016	0.023	-0.003	0.25	95.4	0.0	52.9	6.90	13.70	63.273	0.385	75.4	5.88
2	21	O_2	Raw	0.634	0.424	0.270	5.02	0.0	97.1	44.76	3.81	12.03	72.432		135.3	5.53
2	21	O_2	49°C	0.240	0.122	0.012	3.15	37.2	91.5	52.8	3.20	12.26	75.377	4.460	105.1	5.8
2	21	O_2	57°C	0.073	0.057	0.012	0.85	83.1	66.3	50.5	4.12	14.67	74.318	3.019	106.8	5.82
2	21	O_2	66°C	0.008	0.007	-0.002	0.13	97.4	46.9	50.2	4.49	13.48	71.583	3.546	108.5	5.85
2	21	O_2	71°C	-0.006	0.000	-0.003	0.00	100.0	260.3	49.6	4.86	12.97	69.464	1.922	106.7	5.81
2	21	O_2	79°C	-0.006	-0.004	-0.002	0.00	100.0	80.5	46.7	4.73	14.31	71.715	1.551	100.4	5.82
2	21	VAC	Raw	0.491	0.622	0.114	5.21	0.0	4.7	35.74	7.08	9.83	54.241		71	5.46
2	21	VAC	49°C	0.384	0.452	0.008	5.20	0.2	21.4	51.0	7.94	12.58	57.746	0.457	85.3	5.76
2	21	VAC	57°C	0.376	0.466	0.093	3.90	25.1	7.7	56.7	7.40	14.37	62.758	0.687	89	5.8
2	21	VAC	66°C	0.240	0.309	0.000	3.31	36.4	10.6	54.1	9.50	15.48	58.467	0.382	87	5.86
2	21	VAC	71°C	0.255	0.324	0.007	3.43	34.3	11.5	51.7	8.41	16.15	62.497	0.316	81.9	5.82
2	21	VAC	79°C	0.070	0.088	0.019	0.71	86.3	6.4	55.2	5.31	14.66	70.094	0.130	74.2	5.74

Cummultive data trim

Rep	Day	Trtmt	Cooking Temp	525	572	700	Myoglobin	PMD	%MetMb	L*	a*	b*	Hue	TBA Numer	ORP	pH
1	7	CO	Raw	0.371	0.492	0.035	4.647	0.000	3.550	38.810	19.580	11.210	29.79	0.73	128.60	6.05
1	7	CO	49°C	0.550	0.662	0.157	5.426	-16.947	10.776	55.860	11.760	13.080	48.05	0.96	102.40	6.08
1	7	CO	57°C	0.316	0.416	0.007	4.261	7.360	6.912	60.770	10.340	11.950	49.13	0.75	87.70	6.08
1	7	CO	66°C	0.250	0.333	0.002	3.424	26.205	5.925	58.630	6.000	12.830	64.94	1.13	82.80	6.17
1	7	CO	71°C	0.177	0.226	0.005	2.388	48.540	11.144	57.940	8.130	14.100	60.04	1.31	96.20	6.17
1	7	CO	79°C	0.070	0.088	-0.002	1.000	78.439	14.362	56.990	4.460	11.690	69.12	1.56	9308.00	6.19
1	7	O_2	Raw	0.335	0.357	0.014	4.436	0.000	32.646	41.550	12.170	12.560	45.91	1.36	134.00	5.91
1	7	O_2	49°C	0.298	0.228	0.001	4.104	7.360	62.867	58.220	7.670	14.360	61.90	1.13	98.80	6.07
1	7	O_2	57°C	0.173	0.121	0.006	2.312	47.816	70.701	58.800	5.350	14.090	69.21	1.61	97.10	6.21
1	7	O_2	66°C	0.057	0.036	0.004	0.724	83.655	78.240	55.360	4.110	12.780	72.18	1.24	86.20	6.21
1	7	O_2	71°C	0.006	0.000	-0.009	0.207	95.321	79.500	54.510	3.620	11.870	73.05	1.51	101.40	6.22
1	7	O_2	79°C	0.031	0.024	0.012	0.258	94.167	77.468	55.340	4.220	14.270	73.53	1.47	98.30	6.18
1	7	VAC	Raw	0.337	0.435	0.024	4.324	0.000	8.180	34.070	6.440	7.240	48.35	0.56	109.10	5.89
1	7	VAC	49°C	0.365	0.463	0.043	4.460	-3.251	9.203	55.220	6.970	12.730	61.30	1.07	88.40	6.09
1	7	VAC	57°C	0.252	0.327	0.000	3.486	19.299	10.011	60.580	4.470	13.090	71.15	0.83	87.10	6.21
1	7	VAC	66°C	0.244	0.320	0.006	3.287	23.905	7.386	58.420	6.110	15.940	69.03	1.53	92.70	6.12
1	7	VAC	71°C	0.181	0.234	0.008	2.400	44.440	9.103	55.630	6.040	15.010	68.09	0.77	101.20	6.22
1	7	VAC	79°C	0.071	0.092	-0.002	1.003	76.778	11.263	53.330	5.370	14.600	69.81	1.83	88.40	6.10
2	7	CO	Raw	0.357	0.486	0.020	4.662	0.000	1.355	46.430	17.310	12.280	35.36	0.24	167.40	5.60
2	7	CO	49°C	0.387	0.493	0.043	4.758	-2.093	8.597	56.690	12.780	11.780	42.67	0.68	113.10	5.96
2	7	CO	57°C	0.311	0.404	0.024	3.963	14.957	7.178	56.340	12.390	15.310	51.02	0.55	105.30	6.01

2	7	CO	66°C	0.323	0.399	0.045	3.840	17.596	12.224	59.450	9.790	14.460	55.90	0.81	110.40	5.87
2	7	CO	71°C	0.139	0.166	0.119	0.265	94.307	-104.250	55.850	9.020	14.010	57.23	0.62	104.50	5.98
2	7	CO	79°C	0.134	0.137	0.066	0.938	79.866	34.934	55.820	3.340	12.230	74.73	0.89	101.20	5.94
2	7	O_2	Raw	0.357	0.403	0.045	4.314	0.000	24.894	43.290	12.230	14.150	49.17	1.07	158.30	5.83
2	7	O_2	49°C	0.382	0.332	0.067	4.357	-0.852	55.643	58.690	6.000	12.390	64.17	1.20	110.80	5.99
2	7	O_2	57°C	0.264	0.203	0.038	3.115	27.903	66.341	57.000	4.680	13.480	70.86	1.46	111.60	5.93
2	7	O_2	66°C	0.132	0.096	0.042	1.249	71.085	79.212	54.500	4.230	10.780	68.58	1.39	111.60	5.80
2	7	O_2	71°C	0.066	0.055	0.026	0.553	87.206	67.250	53.560	3.950	12.930	73.02	1.42	107.30	5.87
2	7	O_2	79°C	0.081	0.070	0.052	0.397	90.820	76.085	54.410	3.860	12.170	72.41	1.62	106.60	5.89
2	7	VAC	Raw	0.365	0.466	0.040	4.484	0.000	8.190	41.480	5.600	9.620	59.80	0.43	109.60	5.36
2	7	VAC	49°C	0.362	0.453	0.028	4.615	-3.018	12.314	47.900	11.530	15.170	52.77	0.41	104.20	5.96
2	7	VAC	57°C	0.340	0.416	0.033	4.244	5.279	14.557	56.630	6.050	13.280	65.51	0.55	108.40	6.21
2	7	VAC	66°C	0.290	0.375	0.030	3.594	19.775	6.859	55.480	8.300	16.950	63.91	0.87	107.00	5.89
2	7	VAC	71°C	0.189	0.231	0.018	2.360	47.319	15.203	56.740	6.180	15.340	68.06	0.51	105.00	5.88
2	7	VAC	79°C	0.131	0.141	0.063	0.942	78.965	24.691	59.224	4.090	14.040	73.76	0.86	98.80	5.95
1	14	CO	Raw	0.354	0.467	0.045	4.279	0.000	3.110	48.900	14.510	11.170	37.59	0.71	131.00	5.72
1	14	CO	49°C	0.310	0.409	0.021	3.989	6.575	5.104	58.250	12.860	13.420	46.22	0.48	86.80	6.06
1	14	CO	57°C	0.275	0.358	0.038	3.275	23.305	4.352	56.500	14.130	14.240	45.23	0.64	82.50	5.98
1	14	CO	66°C	0.267	0.337	0.033	3.229	24.373	9.675	53.690	9.860	14.830	56.39	0.83	83.00	6.09
1	14	CO	71°C	0.136	0.165	0.022	1.579	63.012	13.778	59.260	9.220	13.400	55.47	0.83	80.20	5.91
1	14	CO	79°C	0.105	0.112	0.048	0.788	81.554	28.272	57.110	4.810	12.690	69.25	0.64	80.40	5.81
1	14	O_2	Raw	0.331	0.441	0.043	3.981	0.000	1.145	43.660	8.570	12.940	56.49	2.45	136.10	5.70
1	14	O_2	49°C	0.292	0.176	0.042	3.449	13.342	86.054	59.430	4.280	12.110	70.54	2.96	93.80	5.93

1	14	O_2	57°C	0.235	0.156	0.042	2.659	33.201	80.456	58.820	4.060	14.040	73.88	2.78	89.80	5.93
1	14	O_2	66°C	0.067	0.051	0.028	0.535	86.564	82.136	56.510	3.770	12.480	73.20	2.07	93.00	5.99
1	14	O_2	71°C	0.122	0.104	0.073	0.673	83.092	75.640	55.370	3.880	13.480	73.95	1.66	92.10	5.84
1	14	O_2	79°C	0.048	0.040	0.027	0.298	92.501	78.389	52.190	3.950	13.120	73.25	1.32	90.10	5.74
1	14	VAC	Raw	0.336	0.344	0.030	4.224	0.000	36.850	40.990	4.650	7.170	57.04	0.15	80.60	5.51
1	14	VAC	49°C	0.387	0.464	0.067	4.430	-4.978	15.451	59.790	5.820	13.080	66.02	0.52	83.30	5.95
1	14	VAC	57°C	0.326	0.391	0.048	3.836	9.089	16.067	53.070	9.760	17.450	60.79	0.71	78.90	5.88
1	14	VAC	66°C	0.270	0.344	0.038	3.214	23.837	7.858	55.630	8.000	16.800	64.54	0.70	83.50	5.99
1	14	VAC	71°C	0.234	0.280	0.042	2.657	37.033	15.735	56.340	6.950	16.449	67.10	0.65	79.80	5.84
1	14	VAC	79°C	0.135	0.148	0.041	1.306	69.057	26.061	57.150	5.760	15.060	69.07	0.84	86.40	5.80
2	14	CO	Raw	0.378	0.514	0.018	4.974	0.000	1.750	44.400	17.280	11.520	33.69	0.24	133.40	5.87
2	14	CO	49°C	0.332	0.443	0.014	4.391	11.643	4.541	57.350	12.830	12.830	45.00	0.33	108.00	5.96
2	14	CO	57°C	0.274	0.363	0.017	3.553	28.519	4.728	62.240	10.410	12.130	49.37	0.40	98.10	6.03
2	14	CO	66°C	0.378	0.514	0.018	4.974	-0.090	1.750	59.480	6.610	13.580	64.05	0.51	111.20	6.10
2	14	CO	71°C	0.234	0.276	0.053	2.504	49.621	15.990	60.100	10.330	14.070	53.72	0.49	107.80	6.13
2	14	CO	79°C	0.143	0.171	0.048	1.314	73.560	10.793	60.090	8.180	14.150	59.97	0.19	107.90	6.27
2	14	O_2	Raw	0.311	0.247	0.021	4.000	0.000	61.434	41.390	10.880	12.820	49.68	3.01	144.60	5.79
2	14	O_2	49°C	0.217	0.119	0.020	2.717	32.085	89.144	59.280	4.570	12.340	69.68	3.04	100.20	6.00
2	14	O_2	57°C	0.116	0.060	0.009	1.490	62.760	91.448	55.070	4.510	13.910	72.04	3.07	108.00	5.97
2	14	O_2	66°C	0.042	0.027	0.008	0.466	88.358	84.010	55.960	4.110	12.800	72.20	3.74	115.00	6.05
2	14	O_2	71°C	0.041	0.032	0.019	0.305	92.366	81.129	57.180	4.222	12.930	71.92	3.68	113.60	6.02
2	14	O_2	79°C	0.024	0.017	0.008	0.218	94.542	83.171	55.610	4.320	14.030	72.89	3.06	110.10	6.10
2	14	VAC	Raw	0.371	0.470	0.044	4.527	0.000	9.372	44.600	4.930	11.030	65.92	0.18	106.40	5.78

2	14	VAC	49°C	0.375	0.478	0.039	4.633	-2.504	8.543	56.920	6.030	12.940	65.02	0.26	91.10	5.91
2	14	VAC	57°C	0.284	0.383	0.011	3.774	16.511	3.359	58.150	7.120	13.360	61.95	0.38	105.20	5.98
2	14	VAC	66°C	0.289	0.381	0.013	3.811	15.686	6.360	60.020	5.470	14.270	69.03	0.36	110.50	6.06
2	14	VAC	71°C	0.251	0.334	0.019	3.200	29.198	3.533	54.610	8.330	16.160	62.73	0.42	111.80	6.06
2	14	VAC	79°C	0.148	0.170	0.033	1.582	64.996	20.199	59.470	4.600	14.790	72.73	0.25	104.10	6.14
1	21	CO	Raw	0.365	0.048	0.045	4.427	0.000	138.298	41.080	18.280	11.770	32.78	0.49	93.20	5.70
1	21	CO	49°C	0.373	0.491	0.048	4.492	-1.634	3.296	57.870	14.000	12.080	40.79	0.36	89.10	5.90
1	21	CO	57°C	0.408	0.533	0.034	5.169	-16.953	5.980	59.360	11.400	12.550	47.75	1.10	80.70	5.85
1	21	CO	66°C	0.264	0.338	0.026	3.294	25.470	8.628	57.810	10.240	13.560	52.95	0.58	81.10	6.28
1	21	CO	71°C	0.199	0.235	0.030	2.338	47.104	18.223	57.730	9.600	13.500	54.59	0.07	82.10	6.11
1	21	CO	79°C	0.083	0.088	0.018	0.901	79.617	31.218	57.180	7.250	11.700	58.22	0.53	81.30	5.87
1	21	O_2	Raw	0.355	0.242	0.065	4.007	0.000	78.431	42.450	5.610	11.600	64.20	4.35	108.10	5.89
1	21	O_2	49°C	0.209	0.118	0.035	2.407	39.823	91.911	58.660	4.090	14.260	74.00	4.17	92.60	5.90
1	21	O_2	57°C	0.140	0.072	0.010	1.796	55.092	91.885	57.010	4.070	14.180	73.99	4.90	92.80	5.83
1	21	O_2	66°C	0.054	0.037	0.018	0.495	87.633	85.869	54.444	4.500	14.160	72.38	4.78	91.40	6.27
1	21	O_2	71°C	0.037	0.028	0.016	0.282	92.953	83.127	50.530	4.460	15.200	73.65	4.22	96.40	5.89
1	21	O_2	79°C	0.030	0.020	0.011	0.267	93.333	88.205	52.190	4.120	12.800	72.16	3.66	91.10	5.95
1	21	VAC	Raw	0.342	0.441	0.021	4.430	0.000	8.496	37.470	5.520	7.230	52.64	0.35	124.20	5.55
1	21	VAC	49°C	0.321	0.388	0.028	4.046	8.670	16.515	57.490	7.620	14.220	61.82	0.95	91.60	5.69
1	21	VAC	57°C	0.279	0.346	0.019	3.598	18.776	14.039	58.430	7.320	14.240	62.80	0.54	80.90	5.72
1	21	VAC	66°C	0.225	0.287	0.010	2.975	32.844	10.657	59.390	7.010	15.910	66.23	0.18	83.30	6.01
1	21	VAC	71°C	0.175	0.206	0.016	2.193	50.498	19.903	57.060	7.110	15.680	65.61	1.08	87.90	5.73
1	21	VAC	79°C	0.101	0.117	0.016	1.180	73.362	21.350	57.360	3.360	13.330	75.86	0.16	89.40	5.77
2	21	CO	Raw	0.371	0.501	0.029	4.727	0.000	1.441	39.610	17.300	9.650	29.16	0.21	139.80	5.38

2	21	CO	49°C	0.459	0.573	0.086	5.149	-9.080	8.716	58.880	13.130	11.920	42.24	1.02	105.00	5.92
2	21	CO	57°C	0.423	0.508	0.114	4.273	9.480	11.945	60.560	11.040	14.090	51.92	1.17	105.50	6.02
2	21	CO	66°C	0.312	0.395	0.024	3.982	15.628	10.562	59.970	12.780	12.720	44.87	0.92	99.50	6.04
2	21	CO	71°C	0.259	0.314	0.040	3.019	36.033	14.008	60.380	10.690	13.820	52.28	1.16	100.60	6.03
2	21	CO	79°C	0.120	0.129	0.048	0.994	78.951	26.844	56.570	6.160	12.770	64.25	1.40	101.10	6.01
2	21	O_2	Raw	0.362	0.217	0.089	3.764	0.000	92.510	51.230	3.390	11.380	73.42	5.04	151.30	5.54
2	21	O_2	49°C	0.273	0.140	0.038	3.251	13.527	96.109	59.920	3.810	13.360	74.09	4.88	114.40	5.95
2	21	O_2	57°C	0.119	0.061	0.012	1.474	60.788	93.389	57.760	4.060	13.900	73.72	5.11	115.60	6.02
2	21	O_2	66°C	0.371	0.501	0.029	4.727	-25.722	1.441	58.750	3.900	13.120	73.45	4.81	110.40	6.01
2	21	O_2	71°C	0.082	0.069	0.050	0.439	88.314	79.752	56.950	3.980	12.710	72.62	4.99	107.90	5.93
2	21	O_2	79°C	0.112	0.098	0.007	1.446	61.534	52.493	53.630	4.690	13.830	71.27	5.11	109.60	5.99
2	21	VAC	Raw	0.398	0.500	0.069	4.542	0.000	8.499	46.430	4.430	10.280	66.69	0.18	108.90	5.46
2	21	VAC	49°C	0.458	0.521	0.103	4.918	-8.322	21.855	58.030	7.790	14.310	61.44	0.82	107.50	5.94
2	21	VAC	57°C	0.294	0.369	0.018	3.822	15.814	12.602	56.940	9.160	14.490	57.70	1.14	104.70	5.94
2	21	VAC	66°C	0.389	0.460	0.076	4.317	4.918	16.581	55.870	7.610	15.910	64.44	1.15	96.70	5.96
2	21	VAC	71°C	0.301	0.359	0.032	3.717	18.127	17.864	58.110	7.050	14.860	64.62	1.29	100.20	6.06
2	21	VAC	79°C	0.102	0.118	0.021	1.121	75.316	20.141	52.290	7.750	17.050	65.56	1.29	98.60	6.01

Cummulative data loin

Rep	Day	Trtmt	Cking Temp	525	572	700	Myoglobin	PMD	%MetMb	L*	a*	b*	Hue	TBA Numer	ORP	pH
1	7	CO	Raw	0.266	0.317	0.136	1.795	0.000	-0.146	40.570	15.810	12.090	37.408	0.574	143.400	5.535
1	7	CO	49°C	0.422	0.502	0.176	3.410	-90.519	7.328	60.190	9.870	14.130	55.069	0.671	119.700	5.710
1	7	CO	57°C	0.377	0.450	0.152	3.106	-73.536	6.938	63.070	7.570	16.130	64.864	0.997	100.600	5.660
1	7	CO	66°C	0.318	0.369	0.144	2.397	-33.934	10.163	65.080	9.340	14.130	56.539	0.980	101.100	5.590
1	7	CO	71°C	0.247	0.276	0.145	1.404	21.569	10.465	63.430	6.080	13.950	66.455	1.394	96.900	5.620
1	7	CO	79°C	0.160	0.160	0.136	0.336	81.241	38.265	59.230	6.500	12.840	63.155	0.723	101.200	5.645
1	7	O_2	Raw	0.257	0.288	0.136	1.665	0.000	13.774	45.880	10.140	14.970	55.892	1.537	150.100	5.495
1	7	O_2	49°C	0.375	0.361	0.145	3.177	-91.371	45.720	60.890	6.490	14.650	66.111	1.922	119.700	5.645
1	7	O_2	57°C	0.275	0.252	0.157	1.631	1.776	59.161	62.590	3.150	13.520	76.890	1.688	107.300	5.630
1	7	O_2	66°C	0.209	0.192	0.151	0.792	52.303	68.994	64.090	2.720	12.040	77.275	2.535	107.000	5.600
1	7	O_2	71°C	0.152	0.146	0.136	0.213	87.181	73.916	58.470	2.980	12.220	76.301	2.018	105.100	5.630
1	7	O_2	79°C	0.154	0.148	0.140	0.182	89.012	82.682	57.600	3.540	13.180	74.971	1.787	107.200	5.605
1	7	VAC	Raw	0.416	0.467	0.158	3.571	0.000	19.841	44.440	3.880	9.610	68.019	0.504	140.200	5.500
1	7	VAC	49°C	0.410	0.482	0.152	3.564	0.178	11.621	57.040	5.550	14.370	68.887	0.491	104.200	5.640
1	7	VAC	57°C	0.272	0.249	0.156	1.610	54.908	58.985	62.140	6.990	16.270	66.755	0.805	98.000	5.570
1	7	VAC	66°C	0.323	0.372	0.151	2.379	33.348	11.219	62.710	4.840	15.600	72.769	1.243	98.200	5.590
1	7	VAC	71°C	0.210	0.223	0.136	1.017	71.512	20.750	63.150	5.540	16.820	71.775	0.640	98.000	5.630
1	7	VAC	79°C	0.187	0.186	0.145	0.585	83.627	42.337	63.720	3.550	13.810	75.589	0.483	98.400	5.610
2	7	CO	Raw	0.352	0.455	0.066	3.953	0.000	3.743	37.610	17.300	9.650	29.155	0.358	154.800	5.375
2	7	CO	49°C	0.327	0.410	0.052	3.807	3.624	9.446	58.880	13.130	11.920	42.238	0.417	128.100	5.920
2	7	CO	57°C	0.266	0.347	0.020	3.391	14.153	6.370	60.560	11.040	14.090	51.924	0.447	126.700	6.015

2	7	CO	66°C	0.229	0.289	0.061	2.310	41.510	3.316	66.590	6.340	15.890	68.253	0.660	121.400	5.875
2	7	CO	71°C	0.210	0.246	0.039	2.371	39.970	18.987	62.180	9.600	16.850	60.333	0.625	120.500	5.870
2	7	CO	79°C	0.066	0.068	0.013	0.725	81.634	35.881	59.310	5.620	13.140	66.848	0.809	115.900	5.880
2	7	O_2	Raw	0.330	0.341	0.063	3.694	0.000	35.160	5123.000	3.390	11.380	73.417	0.995	163.000	5.540
2	7	O_2	49°C	0.192	0.148	0.021	2.364	35.928	65.450	59.920	3.810	13.360	74.088	1.037	133.700	5.945
2	7	O_2	57°C	0.130	0.091	0.011	1.635	55.700	71.960	57.760	4.060	13.900	73.723	2.677	128.600	6.020
2	7	O_2	66°C	0.054	0.043	0.022	0.437	88.167	72.095	61.080	4.280	14.860	73.938	1.886	122.100	5.960
2	7	O_2	71°C	0.052	0.042	0.021	0.435	88.204	70.929	63.910	3.700	13.840	75.038	1.778	122.900	5.825
2	7	O_2	79°C	0.068	0.058	0.041	0.373	89.889	75.796	56.140	4.110	13.170	72.674	1.978	119.700	5.840
2	7	VAC	Raw	0.309	0.397	0.039	3.735	0.000	7.166	46.430	4.430	10.280	66.692	0.234	142.200	5.455
2	7	VAC	49°C	0.310	0.369	0.063	3.408	8.646	15.534	58.030	7.790	14.310	61.442	0.465	128.700	5.940
2	7	VAC	57°C	0.272	0.343	0.025	3.421	8.275	10.905	56.940	9.160	14.490	57.705	0.710	125.300	5.940
2	7	VAC	66°C	0.234	0.292	0.028	2.851	23.575	11.337	64.340	7.490	16.150	65.124	0.568	117.600	5.890
2	7	VAC	71°C	0.219	0.264	0.030	2.607	30.095	15.441	62.020	6.410	15.440	67.459	0.328	117.200	5.840
2	7	VAC	79°C	0.065	0.069	0.011	0.738	80.218	30.511	62.550	5.700	14.800	68.942	0.838	117.400	5.875
1	14	CO	Raw	0.258	0.345	0.014	3.372	0.000	3.557	45.150	12.490	10.670	40.510	0.428	125.700	5.535
1	14	CO	49°C	0.279	0.347	0.034	3.381	-0.334	11.915	58.100	14.190	14.580	45.780	0.607	108.400	5.655
1	14	CO	57°C	0.189	0.237	0.026	2.250	33.247	10.139	58.120	14.280	16.560	49.232	0.735	93.800	5.660
1	14	CO	66°C	0.101	0.119	0.015	1.187	64.778	18.778	68.140	8.670	11.700	53.465	0.968	90.800	5.845
1	14	CO	71°C	0.122	0.153	0.008	1.577	53.216	12.857	56.500	8.300	13.400	58.230	1.192	100.100	5.760
1	14	CO	79°C	0.058	0.060	0.013	0.623	81.508	34.844	60.870	5.950	13.990	66.965	0.941	88.800	5.730
1	14	O_2	Raw	0.243	0.253	0.020	3.080	0.000	35.148	44.240	8.960	13.940	57.273	2.757	116.500	5.480
1	14	O_2	49°C	0.138	0.090	0.017	1.678	45.536	79.368	61.000	4.000	13.930	73.984	3.178	112.500	5.610

1	14	O_2	57°C	0.048	0.031	0.005	0.600	80.529	79.823	60.730	3.410	12.770	75.055	2.854	103.700	5.680
1	14	O_2	66°C	0.041	0.024	0.007	0.468	84.791	89.942	59.830	3.540	13.030	74.806	3.653	103.000	5.845
1	14	O_2	71°C	0.031	0.024	0.012	0.264	91.431	77.196	60.680	3.050	13.360	77.146	3.443	105.200	5.715
1	14	O_2	79°C	0.018	0.014	0.005	0.181	94.123	70.034	59.610	3.140	13.690	77.088	2.505	105.100	5.725
1	14	VAC	Raw	0.271	0.326	0.029	3.333	0.000	16.614	42.260	4.640	9.750	64.555	0.295	77.200	5.470
1	14	VAC	49°C	0.191	0.218	0.022	2.335	29.873	23.820	57.320	6.270	13.930	65.772	0.396	97.700	5.680
1	14	VAC	57°C	0.200	0.245	0.018	2.519	24.354	15.035	58.230	6.770	15.440	66.329	0.563	90.100	5.685
1	14	VAC	66°C	0.161	0.198	0.010	2.085	37.383	15.047	60.480	4.950	13.960	70.481	1.094	107.500	5.770
1	14	VAC	71°C	0.152	0.188	0.004	2.045	38.587	15.108	63.200	3.660	13.720	75.069	1.203	92.200	5.740
1	14	VAC	79°C	0.075	0.089	0.011	0.880	73.567	17.208	63.470	4.060	14.280	74.134	1.121	94.300	5.685
2	14	CO	Raw	0.303	0.401	0.040	3.631	0.000	2.209	29.470	24.720	17.250	34.911	0.233	167.500	5.545
2	14	CO	49°C	0.648	0.688	0.339	4.271	-17.618	26.397	53.080	8.900	17.600	63.180	0.399	134.500	5.835
2	14	CO	57°C	0.254	0.330	0.024	3.184	25.461	6.384	58.860	9.190	17.810	62.711	0.323	133.900	5.825
2	14	CO	66°C	0.277	0.339	0.065	2.920	8.290	9.779	61.270	10.360	19.150	61.591	0.316	122.400	5.795
2	14	CO	71°C	0.146	0.184	0.005	1.939	33.602	12.059	60.460	10.490	18.960	61.050	0.136	119.600	5.865
2	14	CO	79°C	0.041	0.044	0.002	0.526	72.844	31.626	55.190	6.120	17.410	70.638	0.539	118.800	5.820
2	14	O_2	Raw	0.233	0.126	0.023	2.906	0.000	90.570	32.550	7.640	17.520	66.444	3.806	177.300	5.815
2	14	O_2	49°C	0.189	0.133	0.023	2.298	20.922	73.354	52.890	5.920	18.710	72.448	4.594	140.200	5.810
2	14	O_2	57°C	0.081	0.063	0.004	1.060	53.879	62.838	55.280	6.450	19.700	71.876	2.328	137.900	5.760
2	14	O_2	66°C	0.047	0.044	0.014	0.455	57.106	47.403	59.950	4.590	17.820	75.562	2.161	131.700	5.800
2	14	O_2	71°C	0.060	0.065	0.011	0.669	-47.112	29.169	57.320	4.710	17.910	75.271	3.943	123.700	5.820
2	14	O_2	79°C	0.033	0.026	0.016	0.232	65.289	77.000	58.570	5.050	17.230	73.670	4.803	124.000	5.785
2	14	VAC	Raw	0.276	0.344	0.033	3.363	0.000	11.521	30.870	8.900	16.180	61.191	0.126	145.400	5.730

2	14	VAC	49°C	0.267	0.331	0.022	3.384	-0.715	13.326	53.760	6.280	18.410	71.170	0.227	132.500	5.755
2	14	VAC	57°C	0.247	0.328	0.017	3.168	5.700	4.001	57.490	7.530	19.640	69.028	0.224	131.000	5.815
2	14	VAC	66°C	0.171	0.221	0.016	2.133	36.503	7.117	60.440	8.630	22.210	68.771	0.213	122.000	5.810
2	14	VAC	71°C	0.175	0.225	0.024	2.080	38.107	5.945	54.470	8.000	19.760	67.964	0.244	117.000	5.735
2	14	VAC	79°C	0.059	0.066	0.010	0.667	80.137	23.765	57.550	5.370	17.210	72.676	0.481	119.600	5.745
1	21	CO	Raw	0.271	0.366	0.005	3.677	0.000	3.536	40.320	16.720	12.200	36.120	0.466	136.600	5.260
1	21	CO	49°C	0.273	0.354	0.010	3.634	0.977	8.778	59.460	11.820	14.470	50.760	0.586	93.700	5.225
1	21	CO	57°C	0.218	0.281	-0.006	3.087	15.887	11.299	59.130	13.440	14.040	46.254	0.705	85.500	5.550
1	21	CO	66°C	0.197	0.259	-0.014	2.909	20.744	10.046	64.120	11.770	15.140	52.142	0.758	75.700	5.640
1	21	CO	71°C	0.109	0.146	-0.016	1.731	52.823	10.210	64.350	7.140	14.350	63.552	0.685	72.400	5.800
1	21	CO	79°C	0.021	0.024	-0.015	0.503	86.295	31.258	62.430	5.740	12.710	65.700	0.506	80.300	5.640
1	21	O_2	Raw	0.201	0.173	-0.003	2.817	0.000	53.183	43.220	6.610	11.770	60.686	4.749	132.800	5.250
1	21	O_2	49°C	0.173	0.091	0.002	2.353	16.256	87.298	62.730	4.050	13.760	73.605	4.460	103.000	5.315
1	21	O_2	57°C	0.035	0.016	-0.009	0.614	78.167	83.419	64.770	2.970	12.810	76.952	3.669	100.300	5.495
1	21	O_2	66°C	0.011	0.002	-0.012	0.305	89.132	80.676	63.480	3.470	14.190	76.264	3.912	94.700	5.600
1	21	O_2	71°C	-0.003	-0.011	-0.019	0.220	92.181	87.299	63.720	2.350	12.360	79.241	3.502	96.800	5.525
1	21	O_2	79°C	-0.005	-0.011	-0.019	0.199	92.919	86.028	65.930	2.990	14.190	78.107	3.701	96.900	5.570
1	21	VAC	Raw	0.251	0.276	0.014	3.276	0.000	29.125	38.110	5.270	9.820	61.784	0.492	121.400	5.175
1	21	VAC	49°C	0.238	0.275	0.003	3.246	0.739	23.791	61.220	5.540	13.670	67.944	0.611	79.900	5.190
1	21	VAC	57°C	0.213	0.258	-0.005	3.012	7.880	18.720	62.650	5.970	15.650	69.125	0.506	87.300	5.380
1	21	VAC	66°C	0.148	0.174	-0.008	2.149	34.291	23.101	61.500	6.450	15.640	67.594	0.620	78.800	5.600
1	21	VAC	71°C	0.052	0.059	-0.011	0.871	73.378	27.437	64.560	4.760	16.160	73.593	0.731	77.100	5.565
1	21	VAC	79°C	0.015	0.019	-0.020	0.482	85.252	27.752	66.360	3.970	15.130	75.303	0.375	79.600	5.620
2	21	CO	Raw	0.314	0.413	0.031	3.899	0.000	4.170	38.510	18.270	15.090	39.558			

2	21	CO	49°C	0.303	0.379	0.028	3.796	2.421	11.651	61.160	10.790	14.880	54.057		173.500	5.720
2	21	CO	57°C	0.254	0.330	0.016	3.285	15.565	7.653	64.780	10.340	16.580	58.055		142.100	5.720
2	21	CO	66°C	0.158	0.198	0.020	1.912	50.838	10.960	61.990	9.490	17.710	61.820		126.300	5.710
2	21	CO	71°C	0.111	0.129	0.028	1.155	70.304	18.089	66.010	6.940	16.500	67.193		120.700	5.660
2	21	CO	79°C	0.061	0.055	0.028	0.455	88.313	57.433	62.020	6.510	16.930	68.972		124.600	5.700
2	21	O_2	Raw	0.241	0.190	0.027	2.957	0.000	63.238	42.960	3.480	16.310	77.961			
2	21	O_2	49°C	0.230	0.215	0.040	2.635	10.675	47.680	62.150	3.020	15.800	79.185		173.600	5.770
2	21	O_2	57°C	0.103	0.114	0.011	1.282	56.532	27.970	63.250	5.800	16.780	70.938		139.000	5.760
2	21	O_2	66°C	0.054	0.052	0.007	0.651	77.938	43.534	58.610	4.500	17.880	75.879		137.200	5.760
2	21	O_2	71°C	0.078	0.076	0.042	0.496	83.184	44.235	64.350	5.310	16.550	72.217		124.900	5.810
2	21	O_2	79°C	0.027	0.020	0.009	0.253	91.428	78.298	59.280	3.960	15.410	75.594		124.400	5.690
2	21	VAC	Raw	0.283	0.316	0.023	3.594	0.000	27.005	34.450	6.560	14.040	64.961			
2	21	VAC	49°C	0.303	0.375	0.045	3.564	0.734	11.660	56.850	6.800	16.860	68.040		153.300	5.665
2	21	VAC	57°C	0.214	0.275	0.013	2.782	22.519	9.445	61.260	4.950	17.350	74.082		128.500	5.750
2	21	VAC	66°C	0.176	0.227	0.013	2.252	37.261	8.580	62.450	6.700	19.430	70.980		123.600	5.715
2	21	VAC	71°C	0.061	0.082	0.004	0.797	77.791	4.491	62.450	5.290	16.300	72.025		117.900	5.635
2	21	VAC	79°C	0.057	0.062	0.014	0.594	83.449	28.105	60.530	4.220	17.170	76.197		126.000	5.595

Statistics:

Raw ground beef
Main effect treatment: Treatment

Depend. Variable	Mean Sqr Effect	Mean Sqr Error	f(df1,2) 2,105	p-level
PNLCOLOR	43.343	.69339	62.5086	.0000000
L	202.046	20.77166	9.7270	.0001332
A	1404.508	7.58368	185.2013	.0000000
B	110.800	4.55211	24.3403	.0000000
HUE	6958.482	52.69991	132.0397	.0000000

Main effect: Meat source

Depend. Variable	Mean Sqr Effect	Mean Sqr Error	f(df1,2) 2,105	p-level
PNLCOLOR	1.8148	1.4844	1.222598	.2986210
L	117.2696	22.3864	5.238420	.0067835
A	20.7087	33.9418	.610123	.5451986
B	32.9476	6.0350	5.459417	.0055508
HUE	215.6011	181.1357	1.190274	.3082077

Main effect: Storage time

Depend. Variable	Mean Sqr Effect	Mean Sqr Error	f(df1,2) 2,105	p-level
PNLCOLOR	5.8981	1.4066	4.193154	.0177013
L	.4645	24.6113	.018874	.9813066
A	48.3796	33.4147	1.447854	.2397283
B	8.4853	6.5010	1.305240	.2754695
HUE	508.8977	175.5491	2.898890	.0595055

Main effect: Replication

Depend.	Mean Sqr	Mean Sqr	f(df1,2)	
Variable	Effect	Error	1,106	p-level
PNLCOLOR	2.08333	1.4850	1.402941	.2388808
L*	11.45956	24.2798	.471980	.4935782
a*	2.11680	33.9923	.062273	.8034219
b*	25.12378	6.3627	3.948597	.0494904
HUE	69.40353	182.8401	.379586	.5391457

Interaction effect: Treatment x Meat Source

Depend.	Mean Sqr	Mean Sqr	f(df1,2)	
Variable	Effect	Error	4,99	p-level
PNLCOLOR	2.48148	.59848	4.146273	.0037925
L*	13.43774	19.11853	.702865	.5918197
a*	6.22671	7.37336	.844488	.5002823
b*	1.18311	4.11459	.287542	.8854476
HUE	30.93070	50.28854	.615065	.6527906

Interaction effect: Treatment x Storage time

Depend.	Mean Sqr	Mean Sqr	f(df1,2)	
Variable	Effect	Error	4,99	p-level
PNLCOLOR	1.6898	.54798	3.08372	.0193888
L*	29.2078	20.84106	1.40145	.2390797
a*	57.5444	4.74091	12.13785	.0000000
b*	4.2877	4.48334	.95636	.4350296
HUE	396.2730	29.60205	13.38667	.0000000

Interaction effect: Meat Source x Storage Time

Depend.	Mean Sqr	Mean Sqr	f(df1,2)	
Variable	Effect	Error	4,99	p-level
PNLCOLOR	.70370	1.4268	.493215	.7407137
L*	33.15901	22.3941	1.480706	.2137981
a*	14.61674	34.4309	.424524	.7906097
b*	16.99398	5.5427	3.065999	.0199231
HUE	6.25572	181.5801	.034452	.9976909

Interaction effect: Treatment x Meat Source x Storage time

Depend.	Mean Sqr	Mean Sqr	f(df1,2)	
Variable	Effect	Error	8,81	p-level
PNLCOLOR	.51620	.41667	1.238889	.2874905
L*	7.92650	19.49292	.406635	.9137123
a*	3.99516	3.85923	1.035222	.4168529
b*	.83905	3.68561	.227657	.9848211
HUE	24.18489	26.63180	.908121	.5140796

APPENDIX B

Data for chapter IV

Cummulative data

Day	Rep	Tmnt	Temp	Myoglobin	PMD	% met myoglobin	L	a	b	Hue	Visual score	TBA	pH	ORP
7	1	CO	Raw	9.2	0	9.2	34.10	25.63	12.43	25.87	3	0.04	5.56	
7	1	CO	49°C	7.6	17.51	7.6	42.54	9.18	10.98	50.11	1	0.75	5.73	198.7
7	1	CO	57°C	6.2	32.68	6.2	57.01	7.64	13.41	60.33	2	0.51	5.85	198.3
7	1	CO	66°C	5.5	40.14	5.5	57.61	6.66	13.67	64.03	3	0.44	5.255	143.1
7	1	CO	71°C	4.3	53.34	4.3	57.72	6.91	14.88	65.10	3.5	0.69	5.415	152.2
7	1	CO	79°C	0.9	89.81	0.9	52.33	6.48	13.58	64.50	4.5	0.54	5.58	159.9
7	1	O_2	Raw	6.5	0.00	6.5	37.41	16.35	16.57	45.39	3.5	0.08	5.48	232
7	1	O_2	49°C	6.0	8.93	6.0	51.08	8.50	13.66	58.11	2.5	0.94	5.4	154.3
7	1	O_2	57°C	3.9	40.56	3.9	50.78	10.23	14.02	53.89	3.5	1.38	5.84	146
7	1	O_2	66°C	2.7	58.83	2.7	52.49	6.78	13.77	63.79	4.5	0.87	5.56	148.5
7	1	O_2	71°C	0.4	94.64	0.4	50.09	5.22	12.03	66.55	5	1.68	5.6	153.4
7	1	O_2	79°C	0.6	92.04	0.6	49.23	5.25	13.37	68.57	5	1.33	5.455	151.7
7	1	VAC	Raw	5.3	0.00	5.3	25.80	7.76	6.81	41.27	1	0.11	5.46	192
7	1	VAC	49°C	5.6	0.00	5.6	48.23	7.51	10.24	53.75	1	0.17	5.465	184
7	1	VAC	57°C	5.3	0.00	5.3	49.65	7.85	12.52	57.92	2	0.26	6.665	145.3
7	1	VAC	66°C	5.6	0.00	5.6	57.72	6.22	14.14	66.26	3	0.39	5.685	141.2
7	1	VAC	71°C	2.3	56.75	2.3	55.73	6.23	14.91	67.33	4	0.38	5.69	155
7	1	VAC	79°C	1.5	70.69	1.5	53.27	7.15	14.60	63.91	4	1.37	5.495	147
7	2	CO	Raw	5.9	0.00	-7.5	34.49	19.37	13.20	34.28	3.5	0.04	5.56	170.4
7	2	CO	49°C	5.8	1.71	6.4	53.32	11.02	14.31	52.40	2	0.17	5.715	187
7	2	CO	57°C	5.8	1.03	4.5	56.52	7.29	12.53	59.81	1.5	0.31	5.725	161.4
7	2	CO	66°C	4.9	15.97	3.7	59.41	6.48	14.90	66.50	3.5	0.39	5.715	171.8
7	2	CO	71°C	3.2	45.48	18.2	58.27	7.61	15.57	63.96	4	0.61	5.87	160.2
7	2	CO	79°C	0.8	87.13	57.4	56.05	7.78	12.72	58.55	4.5	0.64	5.75	166.7
7	2	O_2	Raw	5.6	0.00	16.2	35.25	15.86	15.21	43.80	3.5	0.51	5.51	173.9
7	2	O_2	49°C	5.4	3.74	42.2	52.48	11.42	15.71	53.99	2	1.02	5.705	172.9

7	2	O_2	57°C	3.1	44.07	64.1	52.61	9.36	14.66	57.45	4	1.26	5.75	167.7
	2	O_2	66°C	1.9	66.82	67.9	56.56	4.65	13.06	70.41	4.5	0.82	5.865	159.2
7	2	O_2	71°C	1.0	82.47	80.6	56.23	4.21	11.51	69.91	5	1.25	5.77	165.2
7	2	O_2	79°C	0.4	92.70	84.6	52.28	4.22	11.45	69.77	5	1.17	5.84	161.5
7	2	VAC	Raw	6.1	0.00	13.1	27.17	6.18	6.19	45.05	2	0.08	5.745	166
7	2	VAC	49°C	6.4	0.00	22.6	41.25	10.94	9.10	39.76	1.5	0.33	5.86	175
7	2	VAC	57°C	4.5	26.13	10.2	50.65	8.13	12.77	57.52	3	0.51	5.87	161.3
7	2	VAC	66°C	4.8	21.19	10.7	48.89	6.86	13.26	62.65	3	0.56	5.845	161
7	2	VAC	71°C	4.2	31.35	10.9	56.69	6.58	15.33	66.77	4	0.64	5.875	160.5
7	2	VAC	79°C	1.3	78.45	45.5	55.57	5.91	13.86	66.91	4.5	1.19	5.96	149.2
14	1	CO	Raw	7.2	0.00	28.2	31.95	19.54	11.79	31.11	3	0.15	5.60	192.4
14	1	CO	49°C	8.9	0.00	27.8	38.43	8.94	10.84	50.49	1	0.68	6.02	180.1
14	1	CO	57°C	7.7	0.00	33.7	52.82	7.97	12.76	58.02	2	1.04		
14	1	CO	66°C	6.5	9.82	9.2	54.18	6.70	14.27	64.85	3.5	1.37	5.59	190.2
14	1	CO	71°C	3.9	45.16	21.9	57.87	6.44	16.06	68.15	3.5	0.91	5.69	187
14	1	CO	79°C	1.8	74.32	59.7	51.27	7.28	13.86	62.29	4.5	0.91	6.05	179
14	1	O_2	Raw	7.6	0.00	72.6	34.36	13.98	15.06	47.13	3.5	0.16	5.63	219
14	1	O_2	49°C	5.4	28.42	61.2	48.56	10.71	12.41	49.21	1.5	1.04	5.83	202
14	1	O_2	57°C	4.1	45.86	67.7	49.99	7.58	12.61	58.99	4	1.63	5.86	207
14	1	O_2	66°C	0.8	89.34	78.4	49.27	4.99	12.28	67.89	5	1.58	5.62	186.5
14	1	O_2	71°C	0.7	90.90	77.1	54.01	4.69	12.15	68.90	5	3.16	5.83	178.9
14	1	O_2	79°C	0.7	91.01	79.9	52.58	3.88	11.22	70.93	5	1.53	5.72	179.4
14	1	VAC	Raw	8.5	0.00	77.5	30.07	8.94	10.49	49.56	4.5	0.27	5.61	229
14	1	VAC	49°C	7.9	7.62	18.7	47.10	9.76	12.11	51.14	1	0.18	5.75	201
14	1	VAC	57°C	5.8	31.41	7.4	56.95	8.14	15.84	62.81	2.5	0.31	5.98	203
14	1	VAC	66°C	5.5	35.48	15.8	49.43	9.75	18.18	61.80	3.5	0.29	5.72	189.6
14	1	VAC	71°C	3.6	57.48	20.4	59.33	5.78	13.86	67.37	4	0.26	5.70	179.3

14	1	VAC	79°C	1.5	82.73	45.7	50.50	8.01	15.90	63.27	4.5	0.54	5.71	183.4
14	2	CO	Raw	5.0	0.00	7.6	37.43	16.08	12.16	37.10	3	0.54	5.54	257
14	2	CO	49°C	5.9	0.00	13.3	52.42	6.78	11.99	60.52	1.5	0.48	5.78	197
14	2	CO	57°C	5.6	0.00	9.0	51.67	7.66	13.73	60.85	1.5	0.51	5.97	186
14	2	CO	66°C	5.2	0.00	8.9	55.98	8.01	14.61	61.27	2	0.74	6.03	186.6
14	2	CO	71°C	3.9	23.05	7.7	52.92	6.64	15.43	66.72	2.5	0.68	5.88	174.1
14	2	CO	79°C	1.7	65.48	24.9	57.57	5.72	13.20	66.58	4	0.63	5.82	167.2
14	2	O_2	Raw	5.9	0.00	39.9	35.01	13.30	14.00	46.47	4	0.45	5.58	229
14	2	O_2	49°C	3.3	43.55	70.6	43.51	8.73	11.98	53.92	4.5	1.78	5.78	218
14	2	O_2	57°C	4.4	25.95	67.2	50.96	4.73	12.04	68.56	4.5	1.81	5.89	194.9
14	2	O_2	66°C	2.3	61.08	77.2	53.37	4.19	12.00	70.76	4.5	2.51	5.71	206
14	2	O_2	71°C	0.6	89.55	75.5	52.89	4.50	12.33	69.95	5	1.82	5.85	191.4
14	2	O_2	79°C	0.6	89.08	90.2	47.20	4.43	13.04	71.24	5	1.20	5.81	193.9
14	2	VAC	Raw	5.5	0.00	17.0	34.21	8.19	12.30	56.35	4.5	0.18	5.58	223
14	2	VAC	49°C	5.4	1.46	8.1	48.37	9.70	15.05	57.20	1.5	0.20	5.72	204
14	2	VAC	57°C	5.0	9.24	2.4	54.71	5.52	13.27	67.42	1.5	0.27	5.88	183.5
14	2	VAC	66°C	4.7	14.77	2.4	57.92	6.51	15.35	67.02	3	0.46	5.89	184.2
14	2	VAC	71°C	3.1	42.75	8.2	54.96	6.98	16.50	67.08	4	0.46	5.76	185.2
14	2	VAC	79°C	1.9	65.93	24.2	55.97	4.69	13.65	71.04	4.5	0.42	5.94	184
21	1	CO	Raw	6.5	0.00	19.2	33.45	13.86	10.33	36.70	3.5	1.04	5.57	175.4
21	1	CO	49°C	6.6	0.00	16.9	45.90	11.09	10.57	43.63	1.5	0.89	5.665	165.8
21	1	CO	57°C	6.1	6.18	16.8	54.57	9.28	13.19	54.88	2.5	0.95	5.755	170
21	1	CO	66°C	4.9	24.93	11.6	54.73	8.58	13.61	57.78	3	0.87	5.57	153.5
21	1	CO	71°C	1.7	74.09	35.4	55.92	9.15	12.77	54.38	4.5	0.59	5.68	148.7
21	1	CO	79°C	0.9	85.35	64.8	54.03	6.45	12.87	63.39	4	0.73	5.63	145.4
21	1	O_2	Raw	6.1	0.00	94.7	35.94	4.14	12.61	71.83	5	5.70	5.66	192.4
21	1	O_2	49°C	5.2	15.41	53.1	42.96	8.40	9.41	48.25	1.5	6.69	5.975	170.7

21	1	O_2	57°C	3.8	38.19	41.2	51.93	7.26	12.12	59.08	1.5	6.60	5.995	159
21	1	O_2	66°C	3.3	46.51	35.5	51.90	8.34	14.38	59.89	3.5	6.34	5.745	157.1
21	1	O_2	71°C	2.5	59.08	30.1	50.20	7.09	13.54	62.37	4.5	5.65	5.87	153.3
21	1	O_2	79°C	1.6	73.61	215.2	56.38	4.45	11.34	68.58	4	5.60	5.845	142.2
21	1	VAC	Raw	7.7	0.00	6.1	29.85	8.47	10.57	51.30	4	0.11	5.67	168.7
21	1	VAC	49°C	6.3	18.69	14.2	52.10	7.19	12.13	59.35	1.5	0.18	5.82	166.9
21	1	VAC	57°C	5.5	28.50	11.0	57.17	5.98	13.56	66.21	3	0.22	5.785	160.7
21	1	VAC	66°C	5.4	29.44	5.3	51.96	10.54	14.41	53.82	2.5	0.28	5.68	158.4
21	1	VAC	71°C	3.9	49.35	14.9	55.56	6.49	14.87	66.43	4	0.15	5.725	142.7
21	1	VAC	79°C	1.4	82.17	53.5	55.25	6.23	14.29	66.45	4.5	0.14	5.7	146.3
21	2	CO	Raw	6.1	0.00	6.1	35.36	15.87	12.67	38.61	3	0.65	5.59	221
21	2	CO	49°C	7.0	0.00	7.0	46.23	15.15	12.50	39.53	1	0.90	5.75	184.3
21	2	CO	57°C	6.3	0.00	6.3	52.42	9.00	12.42	54.08	1.5	1.14	5.85	174.3
21	2	CO	66°C	5.9	4.44	5.9	55.42	10.84	13.97	52.19	2.5	0.87	5.925	173.5
21	2	CO	71°C	4.0	34.19	4.0	58.22	8.14	12.54	57.02	2.5	1.17	5.81	169.5
21	2	CO	79°C	0.9	86.08	0.9	52.49	10.81	15.13	54.46	4	0.72	5.655	169.8
21	2	O_2	Raw	5.2	0.00	5.2	37.28	11.16	13.54	50.51	3.5	2.40	5.59	223
21	2	O_2	49°C	3.0	41.61	3.0	56.33	5.34	13.02	67.70	1.5	0.62	5.94	198.8
21	2	O_2	57°C	2.9	44.50	2.9	49.70	9.74	12.97	53.10	1.5	1.56	5.84	186
21	2	O_2	66°C	0.6	88.62	0.6	51.61	4.75	11.55	67.65	4.5	1.92	5.805	195
21	2	O_2	71°C	0.6	88.44	0.6	54.04	4.61	11.52	68.20	5	4.54	5.815	178.5
21	2	O_2	79°C	0.5	91.38	0.5	50.66	3.51	10.39	71.34	5	5.21	5.855	175.7
21	2	VAC	Raw	4.2	0.00	4.2	34.14	7.97	11.62	55.56	2	0.21	5.58	183.9
21	2	VAC	49°C	5.5	0.00	5.5	53.51	5.42	12.63	66.78	1.5	0.29	5.795	177.8
21	2	VAC	57°C	4.0	4.85	4.0	53.15	7.59	15.15	63.39	2.5	0.52	5.935	174.8
21	2	VAC	66°C	4.8	0.00	4.8	61.28	4.81	15.69	72.96	3	0.34	5.925	171.9
21	2	VAC	71°C	3.3	21.56	3.3	60.29	4.93	15.26	72.10	4	0.35	5.74	168.5

Raw top sirloin steaks

Main effect: Treatment

Depend.	Mean Sqr	Mean Sqr	f(df1,2)	
Variable	Effect	Error	2,33	p-level
L	106.398	8.30329	12.81397	.0000762
A	335.445	12.10103	27.72038	.0000001
B	72.139	3.81117	18.92840	.0000033
HUE	1073.827	53.75109	19.97777	.0000021
PNLSCORE	2.333	.82828	2.81707	.0742084

Main effect: Days of storage

Depend.	Mean Sqr	Mean Sqr	f(df1,2)	
Variable	Effect	Error	2,33	p-level
L	11.6601	14.04498	.830199	.4448631
A	74.6599	27.90619	2.675388	.0837927
B	2.6283	8.02397	.327550	.7230034
HUE	378.8693	95.86973	3.951918	.0289317
PNLSCORE	3.2500	.77273	4.205883	.0236014

Main effect: Replication

Depend.	Mean Sqr	Mean Sqr	f(df1,2)	
Variable	Effect	Error	1,34	p-level
L	34.20300	13.3118	2.569371	.1182020
A	2.19040	31.4128	.069730	.7933249
B	2.04014	7.8826	.258816	.6142203
HUE	4.89974	115.1924	.042535	.8378328
PNLSCORE	.44444	.9281	.478873	.4936322

Interaction effect: Treatment x Storage days

STATISTICA	INTERACTION: 1 x 2			
GENERAL	1-TMT, 2-DAYS			
MANOVA				
Depend.	Mean Sqr	Mean Sqr	f(df1,2)	
Variable	Effect	Error	4,27	p-level
L	16.28959	6.87148	2.37061	.0775084
A	31.15270	4.64457	6.70734	.0006962
B	17.80042	1.82632	9.74662	.0000517
HUE	63.68728	28.19623	2.25872	.0890433
PNLSCORE	3.20833	.29630	10.82812	.0000228

APPENDIX C

Permission letter to reprint journal article

ELSEVIER

11 October 2004

Our Ref: HG/jj/Oct04/J215

Dr Liza John
Utah State University
Nutrition and Food Sciences
750 North 1200 East
Logan, UT 84322-8700
USA

Dear Dr Liza John

MEAT SCIENCE, (in press), John: "Color and thiobarbituric acid ..."

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Helen Gainford

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THE SOCIETY FOR FOOD SCIENCE AND TECHNOLOGY
BARBARA BYRD KEENAN, CAE / Executive Vice President

October 14, 2004

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Sincerely,

Carolw R. Hirth
Manager, Manuscript Submission & Review
JFS/JFSE/CFSFS

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Name: Liza John

Address:
Dept. of Nutrition and Food Sciences
Utah State University
750N 1200E
Logan, UT- 84322-8700

Journal Name: Meat Science

Journal Article: Color and thiobarbituric acid values of cooked top sirloin steaks packaged in modified atmospheres of 80% oxygen or 0.4% carbon monoxide or vacuum.

Authors: L.John, D. Cornforth, C.E. Carpenter. , O. Sorheim, B.C. Pette, and Whittier.

Dear Whittier,

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Address:	Dept. of Nutrition and Food Sciences Utah State University 750N 1200E Logan, UT- 84322-8700
Journal Name:	Journal of Food Science
Journal Article:	Comparison of color and thiobarbituric acid values of cooked patties after storage of fresh beef chubs in modified atmospheres
Authors:	L.John, D. Cornforth, C.E. Carpenter. , O. Sorheim, B.C. Pette, and Whittier.

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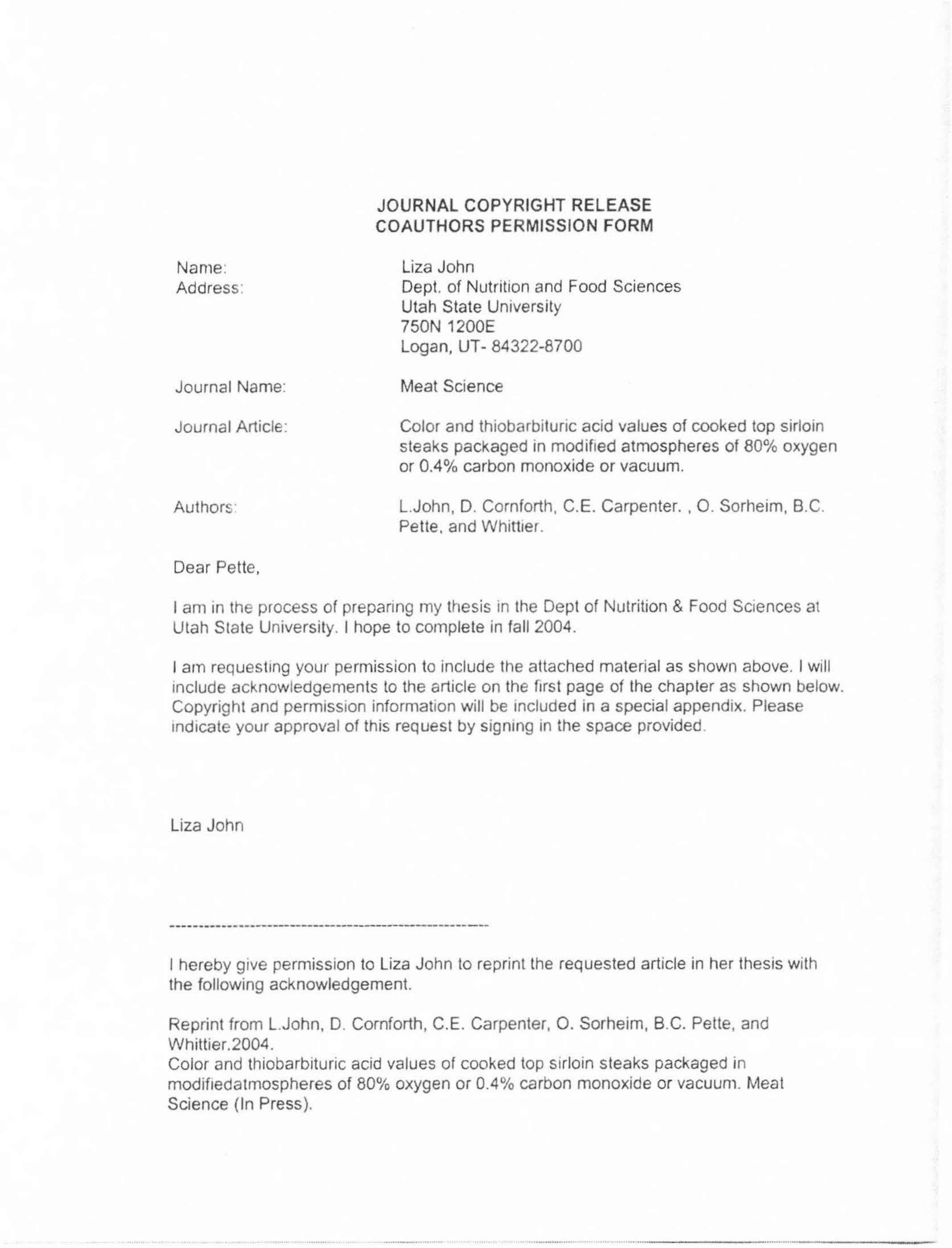
Comparison of color and thiobarbituric acid values of cooked patties after storage of fresh beef chubs in modified atmospheres. Journal of Food Science. Vol 69(8):608-614.



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Logan, UT- 84322-8700

Journal Name: Meat Science

Journal Article: Color and thiobarbituric acid values of cooked top sirloin steaks packaged in modified atmospheres of 80% oxygen or 0.4% carbon monoxide or vacuum.

Authors: L.John, D. Cornforth, C.E. Carpenter. , O. Sorheim, B.C. Pette, and Whittier.

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Journal Name:	Meat Science
Journal Article:	Color and thiobarbituric acid values of cooked top sirloin steaks packaged in modified atmospheres of 80% oxygen or 0.4% carbon monoxide or vacuum
Authors:	L.John, D. Cornforth, C.E. Carpenterr . O. Sorheim, B.C. Pette, and Whittier.

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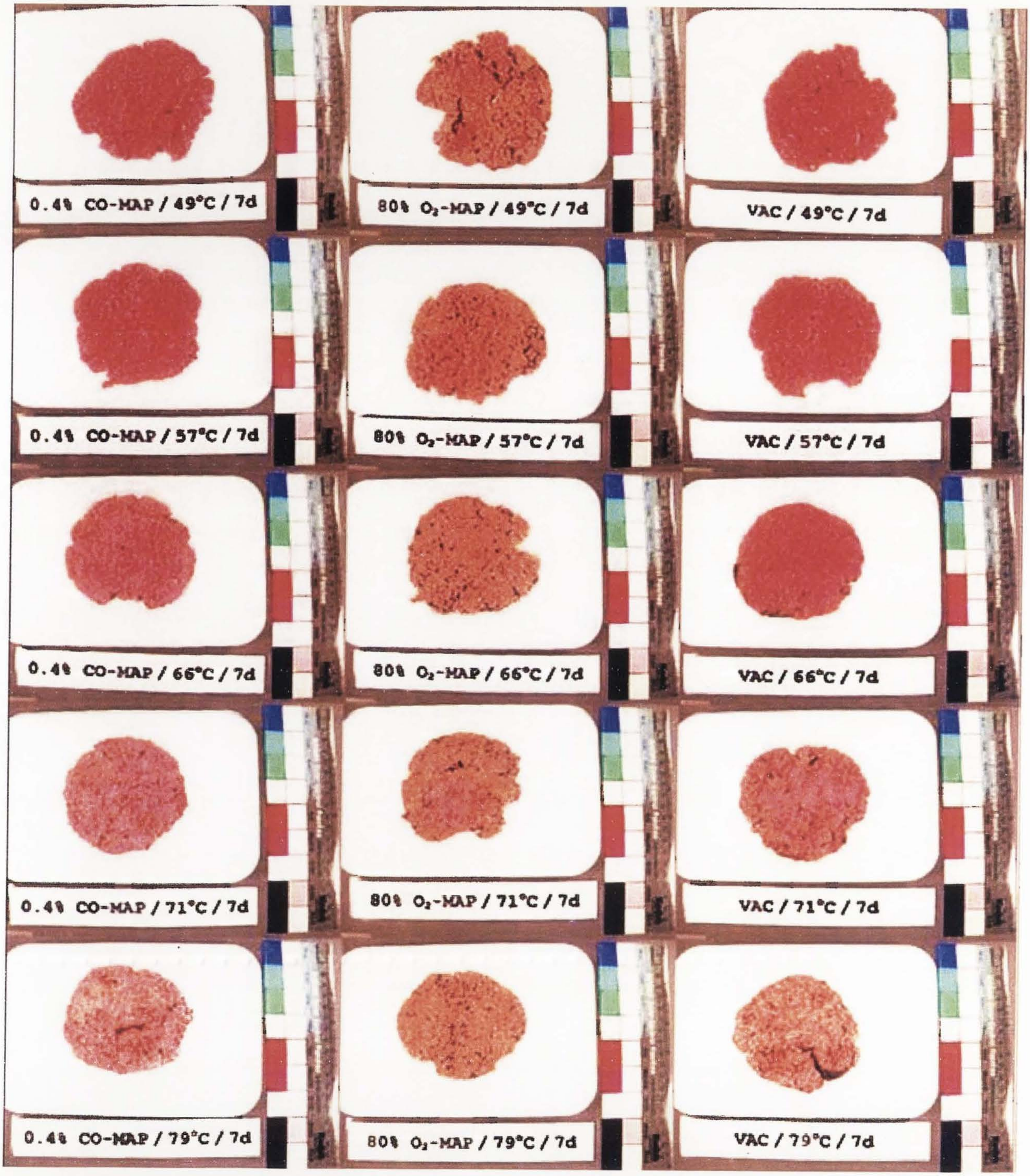
Appendix D

Composite photographs of cooked steaks and hamburger patties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VAC / 57°C / 7d
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VAC / 66°C / 7d
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80% O_2-MAP / 71°C / 7d
VAC / 71°C / 7d
0.4% CO-MAP / 79°C / 7d
80% O_2-MAP / 79°C / 7d
VAC / 79°C / 7d


0.4% CO-MAP / 49°C / 14d
80% O_2-MAP / 49°C / 14d
VAC / 49°C / 14d
0.4% CO-MAP / 57°C / 14d
80% O_2-MAP / 57°C / 14d
VAC / 57°C / 14d
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80% O_2-MAP / 66°C / 14d
VAC / 66°C / 14d
0.4% CO-MAP / 71°C / 14d
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VAC / 71°C / 14d
0.4% CO-MAP / 79°C / 14d
80% O_2-MAP / 79°C / 14d
VAC / 79°C / 14d
Kodak