EFFECTS OF SUBPRIMAL, QUALITY GRADE, AND AGING ON DISPLAY COLOR AND SENSORY PROPERTIES OF GROUND BEEF PATTIES

by

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Abstract

A factorial arrangement of treatments was used to evaluate the effects of two subprimal types (chuck roll and knuckle), two quality grades (Premium Choice and Select), and three vacuum storage aging times before processing (7, 21, and 42 d) on ground beef patty display color stability and sensory attributes. At the end of each aging time, four knuckles or two chuck rolls representing their respective quality grade categories were combined and ground to form a sample batch. After a final grind, patties were formed using a patty machine, packaged in overwrapped trays, and displayed in a coffin-type retail case under continuous fluorescent lighting. Ground beef patties from chuck roll and Premium Choice subprimals had brighter red visual color scores, less discoloration, and higher ($P<0.05$) L*, a*, b*, and chroma values than those from knuckle and Select subprimals, respectfully. With increased display time, patties became ($P<0.05$) darker red and more discolored and had decreased L*, a*, b*, a/b ratio, and chroma values and increased hue angle values. Ground beef patties from Select knuckle subprimals had greater ($P<0.05$) oxygen consumption rate (OCR) than those from Premium Choice chuck roll, Select chuck roll and Premium Choice knuckle subprimals. Patties from subprimals aged 42 d had a lower metmyoglobin reducing ability (MRA) than those from subprimals aged 7 and 21 d. Greater aging and display times had higher ($P<0.05$) aerobic and lactic acid plate counts. In addition, thiobarbituric acid reactive substances values increased ($P<0.05$) from 7 to 21 d of aging and from 0 to 24 h of display. Ground beef patties from Premium Choice subprimals had a higher MUFA:SFA ratio ($P<0.05$) than those from Select subprimals. All treatments had acceptable sensory panel results with minimal differences due to treatment. Lower ($P<0.05$) peak force values for slice shear force and Lee-Kramer were recorded for patties from chuck roll, Premium Choice, and 42 d aged subprimals than those from

knuckle, Select, and 7 d aged subprimals, respectfully. Overall, Premium Choice chuck rolls aged for fewer days would result in the most color stability and extended display life.

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Dedication

I dedicate this thesis to my husband and entire family for their endless love and support.

Chapter 1 - Introduction

Ground beef is the most commonly consumed beef product in the United States (USDA, 2009). The average American consumer eats 71 kg of red meat per year, and of this, 12.7 kg is ground beef (Haney, 2012; American Meat Institute, 2004). Historically, the source of ground beef comes from lower quality cuts, trimmings from subprimals, and subprimals from cull cows; however, alternative grinds from whole and/or premium quality subprimals are becoming more popular with consumers and creating greater demand as a distinctive menu item (Horovitz, 2009).

Consumers use color as a major criteria in selecting meat products (Kropf, 1993) and they associate the bright red color with freshness and wholesomeness (Jenkins & Herrington, 1991). Display life of ground beef is an economically important factor in the retail industry. Longer display time without discoloration results in more opportunities for sale and fewer discounts or reworks. Meat color is a complex concept with both intrinsic and extrinsic factors interacting and influencing the outcome of display color. An understanding of all the factors will result in maximizing color life of fresh retail meat products. During retail display, oxygen consumption is related to the deoxygenation of oxymyoglobin (OMb) and the further decrease of oxygen level to zero, allowing the reduction of metmyoglobin (MMb) to deoxymyoglobin (DMb) (AMSA, 2012). The deeper the OMb layer, the longer it takes for the sub-surface MMb to move upward and impact the hue and discolor the meat. Oxygen consumption rate (OCR) is also related to meat color stability. Atkinson and Follett (1973) concluded that high OCR is a defining characteristic of muscles with low color stability. Metmyoglobin reducing ability (MRA) is an inherent property of meat where a series of reactions help reduce MMb and is essential for meat color stability during display because the presence of MMb on meat surface is very undesirable to consumers (Mancini & Hunt, 2005).

Palatability of ground beef is associated with consumer satisfaction and improvement in palatability can potentially result in increased demand and opportunity. Flavor, juiciness and tenderness have been reported by various researchers as the main drivers for beef consumer acceptability (Morgan et al., 1991; Neely et al., 1998), but are affected by the chemical properties and the fatty acid composition found in beef (May, Sturdivant, Lunt, Miller, & Smith, 1993; Melton, Amiri, Davis, & Backus, 1982; Westerling & Hedrick, 1979).

Subprimals from the chuck and round are logical subprimals that could be used for ground beef production. Muscles from different subprimals can possess different properties and influence the display life of meat products. Madhavi & Carpenter (1993) found that surface MMb accumulation, MRA, and OCR were affected by muscle type in which color stable muscles (M. longissimus dorsi) had lower MMb accumulation, higher MRA, and lower OCR than color labile muscle (psoas major). Furthermore, other researchers also found that the rate of metmyoglobin accumulation on the surface of beef is muscle dependent (Hood, 1971; MacDougall & Taylor, 1975; O'Keeffe & Hood, 1980). McKenna, Miles, Baird, Pfeiffer, Ellebracht, and Savell (2005) studied the biochemical properties of 19 beef muscles and found that those with high color stability had the highest MRA while very low stability muscles had the least MRA. These researchers also suggested that the amount of MMb formed initially on the surface of the muscles was inversely related to color stability and a good or better indicator of color stability than the amount of MMb reduced over time (McKenna et al., 2005).

Subprimals representative of different fat levels may vary in ground beef palatability. Fruin and Van Duyne (1962) studied palatability differences of ground beef prepared from chucks and rounds from U.S. commercial or standard carcasses and found that sensory panelists preferred ground beef from chucks over ground beef from rounds. Beef generally becomes less palatable and satisfying as fat level is decreased (Berry and Leddy, 1984b; Cross, Berry, & Wells, 1980; Kregal et al., 1986; Law, Beeson, Clark, & Mullins, 1965; Mize, 1972), especially when fat is reduced to 5-10% (Troutt, Hunt, Johnson, Claus, Kastner, Kropf, & Stroda, 1992b). Researchers found that as percentage of fat in patties increases there was an increase in juiciness scores (Berry, 1992; Cross et al., 1980; Huffman & Egbert, 1990; Troutt et al., 1992b), beef flavor intensity (Troutt et al. 1992b), mouth coat (Cross et al. 1980; Kregal et al., 1986; Troutt et al., 1992b), tenderness (Berry, 1992; Cross et al., 1980) and patty firmness, cohesiveness, and crumbliness (Troutt et al. 1992b). As fat increased, shear force and total energy values decreased (Berry & Leddy 1984b; Troutt et al. 1992b), Instron Lee-Kramer shear values decreased (Berry & Leddy 1984b; Troutt et al. 1992b), and Instron texture profile analysis indicated lower peak forces, less springiness, and less cohesiveness (Berry & Leddy 1984b; Troutt et al. 1992b) and lower second compression peak force values (Berry & Leddy 1984b).

High quality subprimals can be used as a source of premium grind patties and are becoming more popular as a menu item (Horovitz, 2009). Researchers have reported that ground beef containing higher fat levels (>15%) have brighter red color (Kregal et al, 1986; Liu, Huffman, Egbert, McCoskey & Liu, 1991; Mancini, 2001; Shivas, Kropf, Hunt, Kastner, Kendall & Dayton, 1984; Troutt et al., 1992b) and less discoloration than higher lean (>90%) ground beef (Kregal et al., 1986; Liu et al., 1991). In addition, higher fat ground beef had greater brightness (L*) values than higher lean ground beef (Liu et al., 1991; Mancini, 2001; Troutt et al., 1992b).

Higher quality subprimals such as those grading Premium Choice are expected to have a higher percentage of intramuscular fat and a different fatty acid profile. Turk and Smith (2009) found in a survey of ground beef purchased from local retailers that product from a higher quality branded program had higher levels of oleic acid and lower levels of stearic acid resulting in a higher monounsaturated fatty acid (MUFA): saturated fatty acid (SFA) ratio than those from chub pack ground beef and ground chuck. Researchers have found that the concentration of oleic acid is positively correlated with overall palatability of beef (Waldman, Suess, & Brungardt, 1968; Westerling and Hedrick, 1979), which may be related to fat softness; and, stearic acid (18:0) is the primary determinant of fat hardness (i.e. lipid melting point; Chung, Lunt, Choi, Chae, Rhodes, & Adams, 2006; Smith, Yang, Larsen, & Tume, 1998; Woods et al., 2004;). As a result, beef palatability traits of tenderness, juiciness, and flavor intensity are influenced by the fatty acid composition (May et al., 1993; Melton et al., 1982; Westerling & Hedrick, 1979).

Vacuum-packaged subprimals can be stored for extended lengths of time and later utilized for ground beef. The time postmortem at which subprimals are ground can vary based on the accessibility and marketing of these subprimals. Madhavi & Carpenter (1993) found that surface MMb accumulation, MRA, and OCR were affected by post-mortem aging. They determined that steaks fabricated at 4 or 7 d post-mortem were more color stable than those fabricated at 0, 1, 2, 14 or 21 d post-mortem (Madhavi and Carpenter, 1993). As meat ages, it blooms better because a thicker layer of oxymyoglobin is formed because the rate of oxygen consumption is lowered as substrates in the glycolytic cycle are exhausted, which allows oxygen to penetrate faster and further into the tissue (MacDougall & Rhodes, 1972). MacDougall and Taylor (1975) reported that OCR was high in the first 2 d following harvest but declined as postmortem age increased due to decreased respiration as depletion of substrate and/or enzyme degradation occurred. This supported other studies which found that oxygen consumption rate decreased over time (Tang, Faustman, Hoagland, Mancini, Seyfert, & Hunt, 2005) up to 48 h postmortem (Lanari & Cassens, 1991). MacDougall and Rhodes (1972) suggested that as meat ages there is a faster accumulation of metmyoglobin resulting from the diminution of the meat's enzymic activity, which occurs during aging, and metmyoglobin formed in the region of low oxygen tension is no longer reduced back to myoglobin because the reducing intermediates (particularly the reduced form of nicotinamide adenine dinucleotide or NADH) are no longer being formed. Other researchers found that during display in traditional PVC packaging, discoloration increases and MRA decreases on the surface of beef steaks, whereas the interior remains deoxygenated and thus, may have somewhat different color chemistry than the surface (Sammel, Hunt, Kropf, Hachmeister, Kastner, & Johnson, 2002b; Seyfert, Mancini, Hunt, Tang, Faustman, & Garcia, 2006). Furthermore, Mancini, Hunt, Kropf, Hachmeister, Johnson and Fox (2002b) found that increased storage (0-12 d) and display time (0–48 h) of ground beef significantly increased microbial counts but lean level (7/93, 19/81, & 27/73) had no effect. McKenna et al. (2005) found that thiobarbituric acid reactive substance (TBARS) values increased with increasing days of retail display and reported that less color stable muscles have higher TBARS values. Yancey, Dikeman, Hachmeister, Chambers, and Milliken (2005) found that aging muscles longer than 21 d generally decreased beef flavor intensity.

Therefore, the objectives of this study were to determine the effects of two subprimal types (chuck rolls and knuckle representing estimated fat percentages of 20 % and 10%, respectfully), two quality grades (Premium Choice and Select), and vacuum storage aging time (7, 21, and 42 d) before processing on ground beef patty display color stability and sensory attributes.

Chapter 2 - Review of Literature

Ground Beef

Ground beef is the most commonly consumed beef product in the United States (USDA, 2009). The average American consumer eats 71 kg of red meat per year, and of this, 12.7 kg is ground beef (Haney, 2012; American Meat Institute, 2004). Historically, the source of ground beef comes from lower quality cuts, trimmings from subprimals, and subprimals from cull cows; however, alternative grinds from whole and/or premium quality subprimals are becoming more popular with consumers and creating greater demand as a distinctive menu item (Horovitz, 2009). According to United States Department of Agriculture (USDA) regulations, ground beef shall contain a maximum of 30 percent fat. The product may consist of fresh and/or frozen beef with or without seasoning. However, ground beef cannot contain added water, phosphates, binders, or extenders (Office of the Federal Register, 1987). A survey conducted by Technomic's (2009) found that 87% of 1,500 surveyed ate a burger at least once a month and 40% ate burgers at least once a week. Furthermore, more than half of the consumers surveyed (55%) said that the quality of the meat or other protein used to make a burger is more important than any other factor and an additional 20% of consumers said that the quality of the meat is the second most important attribute for burgers. Certain types or cuts of beef, such as Angus or sirloin, are considered by consumers to be higher in quality.

Consumer Purchasing Decisions

Historically, the first encounter with refrigerated retail meat cuts in self-service meat cases was with meat products packaged on Styrofoam® trays and overwrapped with polyvinyl chloride (PVC) plastic (McMillin, 2008). This packaging style allowed for oxygen to bind to the meat pigment myoglobin resulting in a process called “bloom,” a red color due to the formation of oxymyoglobin. Consequently, consumers associated the bright red color with fresh and wholesome meat items (Jenkins & Herrington, 1991). Consumers continue to use color as one of the major criteria in selecting meat products (Kropf, 1993) as they do not have methods to estimate tenderness, juiciness or flavor of packaged retail cuts on display. Meat color stability is defined as the duration of an acceptable, saleable color (Kropf, 1993). Shelf life of meat products usually ends as a result of discoloration instead of bacterial spoilage (Smith, Morgan, Sofos, Tatum, & Schmidt, 1995). Once a meat cut reaches an unacceptable percentage discoloration, consumers will choose not to purchase the product. When discoloration occurs in a meat item, the product must be discounted or discarded leading to large revenue losses up to $1 billion for retailers (Smith, Belk, Sofos, Tatum & Williams, 2000). Consumers begin rejecting products for purchase once the meat in display reaches 20 (Kropf, 1993) to 40 percent (Greene, Hsin, & Zipser, 1971) discoloration.

Consumer Ground Beef Trends

Ground beef is used extensively in fast food restaurants, school and military programs, and individual households. Ground beef accounts for almost half the beef purchased at retail and close to 70 percent of the beef eaten in foodservice. According to a survey conducted by the Cattlemen’s Beef Board and National Cattlemen’s Beef Association (2009), consumer spending on beef was $76 billion in 2008, which had grown $26.9 billion since 1999. In 2008, consumers were spending about $249 per capita for beef in retail and foodservice, which was up about $50 from 2001. Rick McCarty (2010), Vice President of Issues Analysis and Strategy of NCBA stated that ground beef is consumers’ favorite because it is a tasty, convenient, versatile, and affordable product. Ground beef is usually a young consumer’s first experience with beef. Based on recent data, 94 percent of American consumers say they eat ground beef which accounts for 48 percent of all fresh beef purchased at supermarkets and 67 percent of all beef eaten in foodservice. The November 2010 check-off survey (Beef Check-off, 2010) assessed ways in which ground beef is prepared in the home by asking consumers who were beef eaters and the primary food preparer/cook or shared the responsibility for preparing and cooking meals. Of the ground beef sold at supermarkets, lean (90 percent lean or higher) ground beef accounts for 17.5 percent. The value of leanness to consumers is evident in data reflecting that of the one-third of consumers who said they are eating lean ground beef more often, 62 percent agreed that lean ground beef is worth the cost and 59 percent agreed that ground beef can be a nutritious, low fat and affordable meal. Forty-three percent of Americans eat ground beef at home twice a week or more and 67 percent prepare a ground beef dish at least once a week. The most popular ground beef dish at home is spaghetti and meat sauce (53%) followed by burgers (46%), tacos and other Mexican dishes (38%), and chili and stews (36%). At home, browning crumbles in a skillet is the most frequently used (65%) cooking method with grilled patties (44%) being second. In summary, ground beef is a very versatile, nutritious, and affordable product which is very popular in American homes.

Factors Influencing Purchasing Decisions

Purchasing decisions are influenced more by meat color than any other quality factor because consumers associate surface discoloration with freshness (Kropf, 1993). According to Hood and Riordan (1973), discoloration, brightness, hue, and intensity account for 33% of consumer selection criteria. Hood et al. (1973) reported a positive relationship between metmyoglobin (MMb) accumulation and consumer rejection, suggesting that consumers purchased 2 times more bright red beef than beef with detectable MMb. Other characteristics such as purge, lean to fat ratio, price, weight, packaging, and display case characteristics also influenced consumer selection and purchasing decisions. Approximately 49% of consumers use odor in addition to color, which is attributed to microbial growth, as an indicator of wholesomeness (Lynch, Kastner, Kropf, & Caul, 1986). Manu-Tawiah, Ammann, Sebranek and Molins (1991) considered the "spoilage" point of ground beef packaged in oxygen permeable stretch film to occur at 7 $\log_{10}$ colony forming units per gram (CFU/g).

Premium Quality Grinds

Palatability of ground beef is important in a competitive market Value associated with consumer satisfaction can potentially result in increased demand and opportunity. Differences in quality grade and fatty acid composition could potentially alter the flavor and juiciness of ground beef. The average annually reported (USDA, 2011) 2010 price differentials between branded (upper 2/3s of choice) and Select 116A Chuck Rolls and 167A peeled knuckles were $5.31/cwt ($193.86 vs. $188.55) and $3.62/cwt ($191.02 vs. $187.40), respectively. These minimal differences allow for increased opportunity for potential value differentiation.

In an article by USA Today (Horovitz, 2009) about the McDonald's Angus Third Pounder, Scott Hume, editor of the website BurgerBusiness.com, says, "A premium burger is any burger that a restaurant can convince you is somehow better than average and in some ways even capitalize on consumer ignorance." He goes on to say that many consumers have no clue what Angus is, but they know it sure sounds special and people will buy it because fast-food chains are very good marketers. A survey by Researcher Technomic (2009) found that "premium burger" means many things to many people. About 72% of respondents said "high-quality" meat is what makes a burger premium; 71% said it's the cut of the meat, while 36% said it's the size and 30% said it's the toppings. Advertising "Angus" or "sirloin" seems to be having an effect as well because 27% of consumers said they prefer to buy restaurant burgers made with Angus beef and 19% said they prefer sirloin burgers. In conclusion, there are apparent price advantages to premium grinds, especially in the food service industry.

Fatty Acid Composition

Ground beef can be produced ranging from ≤5 to 30 percent fat and vary in its fatty acid (FA) composition. Fats are important sources of certain nutrients and food energy and also contribute to food texture and satiety after eating (Schneeman, 1987; Pearson, Asghar, Gray, & Booren, 1987).

External fat cover on carcasses is necessary to reduce cold shortening in beef and it is inevitable that most finished cattle are going to be harvested with a certain amount of unwanted external fat which will most likely be used for products such as ground beef (Smith, Dutson, Hostetler, & Carpenter, 1976). Factors that affect the level of fat deposited on the carcass are breed, sex, and nutrition (Eichhorn, Coleman, Wakayama, Blomquist, Bailey, & Jenkins, 1986; Huerta-Liedenz, Cross, Savell, Lunt, Baker, & Pelton, 1993; Melton, Amiri, Davis, & Backus, 1982; Rumsey, Oltjen, Bovard, & Priode, 1972; Zembayashi, Nishimura, Lunt, & Smith, 1995). Furthermore, age of animal, diet, and breed type influence fatty acid (FA) composition of beef. Smith, Gill, Lunt, & Brook (2009) found there were small differences in FA composition of beef from *Bos indicus* and *Bos taurus* cattle, but diet and time on feed are much more important determinants of beef fat content and FA composition than breed type. Age of animal and breed type specifically affect the concentration of monounsaturated fatty acid (MUFA) in beef by affecting stearoyl-CoA desaturase gene expression and activity, whereas diet is the sole source of the essential FA, linoleic acid and α-linolenic acid. When cattle graze pastures or are fed hay, their beef contains less marbling, much less MUFA, but contains slightly more omega-3 polyunsaturated fatty acid (PUFA). Link, Bray, Cassens, and Kauffman (1970) found that fatness and/or age altered the fatty acids present in the meat at different stages of growth. Zembayashi and Nishimura (1996) later used linear regression analyses between carcass fat percentage and FA composition, and demonstrated that leaner or younger steers contained more saturated fatty acids (SFA) in the intramuscular lipids. Chung, Lunt, Choi, Chae, Rhoades, & Adams (2006) also demonstrated that the subcutaneous adipose tissue from corn-fed steers contained more MUFA and PUFA and a higher MUFA:SFA ratios than in subcutaneous adipose tissue from hay-fed steers, which in turn contained more total SFA.

Smith, Savell, Smith, & Cross (1989) studied the FA composition of beef steaks and roasts from US Choice, Select, and Standard quality grades. Choice top loin, clod shoulder, and top round steaks were higher in total fat percentage than Select and Standard steaks. Clod shoulder steak samples cooked without external fat had a lower percentage of palmitic acid than samples cooked with 0.64 cm of external fat trim; however, this difference was not observed for the top round steaks. Clod shoulders and top round steaks had no significant differences in percentages of stearic acid or oleic acid. Cannell, Savell, and Smith (1989) used a lean source of beef top rounds and a fat source of beef plates to compare 5, 15, and 25 percent fat patties. It was discovered that as the percent fat increased, the percent of polyunsaturated FA remained about the same while the percent MUFA increased and the percent SFA decreased. Even though the values were very close, each fat level followed the same pattern of FA content from greatest to smallest amount being oleic > palmitic> stearic> palmitoleic > linoleic > myristic > myristoleic >linolenic. Turk and Smith (2009) found that the highest values for MUFA were displayed in the brisket and the highest values for SFA were displayed in the flank. The chuck had a significantly greater amount of cis-vaccenic (18:1c11) acid than the round but no difference were observed for myristic acid (14.0), palmitic (16:0), stearic (18:0) acid, myristoleic (14:1n-5), palmitoleic (16:1n-7), oleic (18:1n-9), trans-vaccenic (18:1t11), linoleic acid (18:2n-6), 18:2cis-9,trans-11, 18:2trans-10,cis-12 and the MUFA:SFA ratio.

”Premium quality grinds” have increased amounts of marbling that can contain higher levels of oleic acid, which would result in a healthier fatty acid composition. Turk and Smith (2009) found that ground beef from a branded program had higher levels of oleic acid and lower levels of stearic acid resulting in a higher MUFA:SFA ratio. The concentration of oleic acid also is positively correlated with overall palatability of beef (Waldman, Suess, & Brungardt, 1968; Westerling and Hedrick, 1979), which may be related to fat softness; however, stearic acid (18:0) is the primary determinant of fat hardness (i.e. lipid melting point; Smith, Yang, Larsen, & Tume, 1998; Woods et al., 2004; Chung, Lunt, Choi, Chae, Rhoades, & Adams, 2006). Enser and Wood (1993) showed that the relationship between stearic acid and the melting point of the lipid was highly correlated. Perry, Nicholls, and Thompson (1998) stated that variation in SFA in turn alters the firmness of fat, which affects the economics of meat processing and overall acceptance of consumers.

Beef quality attributes such as tenderness, juiciness, and flavor intensity have been shown to be affected by the chemical properties and amounts of lipids contained in a beef carcass (Dryden & Marchello, 1970; Harrison, Smith, Allen, Hunt, Kastner, & Kropf, 1978; May, Sturdivant, Lunt, Miller, & Smith, 1993; Melton, Amiri, Davis, & Backus, 1982; Westerling & Hedrick, 1979). In conclusion, the increase in the amount of intramuscular fat in meat sources affects the fatty acid profile of the meat product.

Myoglobin Chemistry

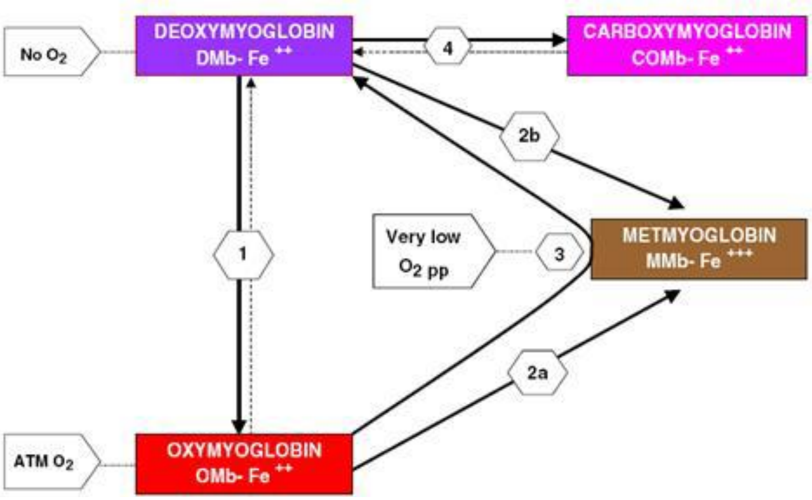
Myoglobin

Myoglobin (Mb) is the primary protein pigment associated with meat color (Mancini & Hunt, 2005). Myoglobin is a water soluble, monomeric globular heme protein with 150 amino acid residues and a molecular weight of approximately 18,000 (18 kDa) (Livingston & Brown, 1981). Myoglobin is readily found in red muscle fibers where it delivers oxygen from the sarcolemma to the mitochondria in response to increased demand for oxygen during movement or exercise (Wittenberg and Wittenberg, 2003). Myoglobin contains 8 α-helices (A–H) linked by short nonhelical sections (Mancini et al., 2005). The structure of myoglobin is composed of a single polypeptide protein or globin and the prosthetic group or heme (Stryer, 1995). The heme group consists of a planar porphyrin ring that is made up of four pyrrole rings attached to each other through methane bridges (Clydesdale & Francis, 1971). An iron atom which is centrally located in the ring has the ability to form six bonds. Four of these bonds lie in the plane and are with pyrrole nitrogens. The other two are perpendicular to the plane with the 5th coordinating with the proximal histidine-93 and the sixth remaining vacant for reversible bonding with ligands (Mancini et al. 2005; Stryer, 1995). Furthermore, a distal histidine-64 influences color dynamics by influencing the dominations of the hydrophobic pocket (Mancini et al. 2005). Meat color is a result of the ligand occupying the sixth position and the oxidation state of the iron atom.

States of Myoglobin

Meat color is derived from four forms of Mb which include oxymyoglobin (OMb), deoxymyoglobin (DMb), metmyoglobin (MMb), and carboxymyoglobin (COMb). When no ligand is present at the sixth position and the heme iron is ferrous (Fe^{2+}), a deoxygenated form of Mb exits or DMb (Figure 2.1).

This Mb state is usually observed with freshly cut muscle or vacuum packaged meat and appears purplish-red or purplish-pink in color (Mancini et al, 2005). In order to maintain meat in the DMb state, a very low oxygen tension (<1.4 mm Hg; Brooks, 1935) is required.



Rx 1 (Oxygenation): DMb + O_2 → OMb

Rx 2a (Oxidation): OMb + [oxygen consumption or low O_2 partial pressure] – e^- → MMb

Rx 2b (Oxidation): [DMb – hydroxyl ion – Hydrogen ion complex]+ O^2 → MMb + O^{2-}

Rx 3 (Reduction): MMb + Oxygen consumption + metmyoglobin reducing activty → DMb

Rx 4 (CarboxyMb): DMb + carbon monoxide → COMb

Figure 2.1 Practical depiction of the visual color and dynamics of myoglobin redox inter-conversions on the surface of meat. (Adapted from Mancini & Hunt 2005).

When Mb is exposed to oxygen and it occupies the sixth position, the formation of OMb occurs and the 'bloomed' bright red desired pigment of fresh meat develops (Figure 2.1). The iron is still in the ferrous (Fe^{2+}) state but when the distal histidine interacts with bound oxygen it alters the myoglobin’s structure and stability. Over time, the oxygen penetrates deeper beneath the meat surface resulting in a very strong OMb pigment observed on the surface. The meat temperature, oxygen partial pressure, pH, and competition for oxygen by endogenous systems can all affect the depth of oxygen penetration and thickness of the OMb layer (Mancini et al, 2005).

Browning or discoloration of meat is a reflectance of the formation of MMb on the meat surface. This pigment formation results from the oxidation of the heme iron ferrous (Fe^{2+}) to ferric (Fe^{3+}) ion. Several factors affect the formation of MMb and influence the rate of this discoloration including pH, temperature, metmyoglobin reducing ability, and oxygen partial pressure. The intensity of the browning is directly related to the thickness and depth of the sub-surface MMb located between superficial OMb and interior DMb (Mancini et al., 2005).

The oxygenation reaction is the process of DMb being exposed to oxygen and changing into the OMb form. Oxidation is the loss of an electron and the transformation of Fe^{2+} to Fe^{3+}. Mancini and Hunt (2005) describe the redox conversion of OMb to DMb as an indirect, two step process (Figure 2.1). The OMb visually appears to first convert to MMb as the muscle consumes oxygen, which creates a low oxygen partial pressure that auto-oxidizes the heme iron, which produces MMb. Then the MMb can be converted to DMb, depending upon the muscle's reducing capacity and the meat temperature (Mancini et al., 2005). In conclusion, meat Mb has four forms that are influenced by the heme iron state and the ligand occupying the sixth position.

Myoglobin Oxidation

Myoglobin is more prone to oxidation than hemoglobin (Hb) because it functions at lower oxygen pressure (George & Stratmann, 1952). Furthermore, it has been observed that DMb is more susceptible to oxidation than OMb. A conformational change occurs in the prosthetic heme due to the presence of molecular oxygen that stabilizes the electronic structure of OMb and delays Mb oxidation. The Mb can become more susceptible to oxidation after deoxygenation of the heme occurs because of factors including low pH, high temperature, and a very low oxygen partial pressure (Mancini et al., 2005; Renerre, 1990).

Myoglobin Concentration

Fresh meat color is predominantly determined by the concentration and redox status of Mb, typically distributed uniformly within muscles and varies by types of muscles (even within a muscle), species, sex, breed, and age (Lawrie, 1998). In fresh meat, the meat color portrays the most abundant Mb redox form present, even though the redox states of Mb are continuously changing (Mancini & Hunt, 2005). The total pigment concentration, along with certain properties affecting light scattering, will determine the color and acceptability of a meat product.

When comparing muscles within an animal, the differences in Mb concentration have a significant impact not only on meat color but also color stability. Red (oxidative) muscles that appear darker contain more Mb than white (glycolytic) muscles (Seideman, Cross, Smith, & Durland, 1984). Hunt and Hedrick (1977) reported that the myoglobin concentrations in beef M. longissimus (3.48 mg/g), M. gluteus medius (4.11 mg/g), and the inner (2.97 mg/g) and outer (1.95 mg/g) M. semitendinosus varied significantly from one another. Myoglobin concentration varies between different animals species. For example, the Mb concentration ranges from 2.0-5.0 mg/g wet weight in beef (Hunt and Hedrick, 1977; Rickansrud and Henrickson, 1967), 4-7 mg/g in lamb (Ledward and Shorthose, 1971), and 2.5-7.0 mg/g in pork (Topel, Merkel, & Mackinto, 1966)). The myoglobin concentration of dark meat poultry ranges from 1-2 mg/g (Nishida, 1976) and from 0.5-1.0 mg/g for light meat tuna (Brown, 1962). Meat from older animals is darker due to the increase in Mb concentration as animals age. The American Meat

Institute Foundation (1960) stated that animal age has reportedly influenced the myoglobin content in several species. For example, the myoglobin content of muscle tissue in cattle was reported as 1 to 3 mg/g of wet tissue in veal, 4 to 10 mg/g in beef, and up to 16 to 20 mg/g in old beef. Myoglobin content of pork was indicated to be about the same as veal and the content of mutton was somewhat higher than veal. In summary, Mb content differs by species, increases with age, and is greater in red versus white muscle types.

Meat Discoloration

Oxygen Consumption

Oxygen consumption is an inherent property of meat where a series of reactions, principally involving the Kreb cycle enzymes, consume (scavenge) oxygen in meat. Oxygen consumption is responsible for the deoxygenation of OMb and the further decrease of oxygen level to zero, allowing the reduction of MMb to DMb (AMSA, 2012). Oxygen consumption rate (OCR) is a measurement of the rate where oxygen consumption per unit time is calculated. Oxygen consumption rate is a major contributor to meat color stability. Color stability may be influenced by the product’s OCR as it alters the depth at which the MMb layer forms; therefore, the closer the initial MMb layer is to the surface the more rapid the color deterioration occurs (Madhavi & Carpenter, 1993). The bright red color of postmortem tissue is determined by the rate of DMb oxygenation and depth of oxygen penetration beneath the surface of meat. These two factors are regulated by many factors including partial oxygen pressure at the meat surface, rate of oxygen diffusion, oxygen consumption by muscle enzymes, and the product temperature (O'Keefe & Hood, 1982).

Mitochondria are important subcellular organelles involved in energy metabolism. Mitochondrial enzymes, particularly cytochrome c oxidase, continue to consume oxygen postmortem reducing the amount available to bind to myoglobin, which leads to deoxymyoglobin, rather than oxymyoglobin, formation (Tang, Faustman, Hoagland, Mancini, Seyfert, & Hunt, 2005). Furthermore, deoxymyoglobin is more susceptible to oxidation than is oxymyoglobin (Richards, Modra, & Li, 2002). Myoglobin and mitochondria are interrelated in living cells as Mb serves as an oxygen reservoir and oxygen transporter for mitochondria. Myoglobin's role in muscle tissues is to transport oxygen to mitochondria in cells for energy production (Wittenberg & Wittenberg, 1975). Bendall and Taylor (1972) determined that mitochondrial respiration was a main factor influencing post-rigor OCR. Muscles with weaker color stability have been linked with high mitochondrial content (Tang et al., 2005). MacDougall and Taylor (1975) reported that OCR was high in the first 2 d following slaughter but declined as postmortem age increased due to decreased respiration as depletion of substrate and/or enzyme degradation occurred. This supports other studies which found that OCR decreased over time (Tang et al., 2005) up to 48 h postmortem (Lanari & Cassens, 1991). Faster rates of pH decline and lower final pH may inhibit the respiratory activity of mitochondria (Lanari & Cassens, 1991). Muscles with a lower pH were found to have lower OCR leading to improved color stability (Lanari & Cassens, 1991; Tang et al., 2005) while increasing pH or temperature has been reported to increase tissue oxygen uptake (Urbin & Wilson, 1958). This agrees with the findings of Bendall and Taylor (1972) who reported that as the pH increased from 5.6 to 7.2 there was an increase in muscle oxygen uptake.

Lanari and Cassens (1991) found that Holstein cattle had greater OCR leading to weaker color stability in the M. longissimus dorsi and M. gluteus medias steaks compared to steaks from crossbred beef cattle breeds. Furthermore, they found color stability to be muscle dependent with the M. longissimus dorsi having greater color stability compared to the M. gluteus medias (Lanari & Cassens, 1991). MacDougall and Taylor (1975) showed that the relationship between OCR and oxygen penetration depth was greatly influenced by muscle type. Atkinson and Follett (1973) found that meat’s retail display life was inversely proportional to the oxygen uptake when beef muscle demonstrated the lowest levels of oxygen uptake and the longest display life while lamb muscle had the greatest oxygen uptake and shortest display life. King, Shackelford, Rodriguez, and Wheeler (2011b) reported that at 0 d of display color stability was negatively correlated to oxygen consumption but after 6 d of display color stability and oxygen consumption were not related. They concluded that for longissimus steaks oxygen consumption when measured at the beginning of display was related to changes in color stability, but was not related when measured at the end of display.

The oxygen tension above the meat surface greatly influences where the sub-surface MMb layer forms between the outer surface OMb and interior DMb (Atkinson & Follet, 1973). The deeper the OMb layer, the longer it takes for the sub-surface MMb to move upward and impact the hue and discolor the meat. When the mitochondria have a higher OCR, the oxygen surrounding the meat will be used up and Mb will be susceptible to becoming the brown MMb pigment (Tang et al., 2005; Lanari & Cassens, 1991). Some researchers have contended that OCR contributes more to muscle's color stability than the reducing activity (Atkinson & Follett, 1973; O'Keefe & Hood, 1982; Renerre & Labas, 1987; Lanari & Cassens, 1991). Oxygen consumption plays a very important role in color stability by impacting the display life of the product and is influenced by age and pH. As meat ages, a deeper layer of oxymyoglobin is formed beneath the surface because the rate of oxygen consumption is lowered as substrates in the glycolytic cycle are exhausted allowing oxygen to penetrate faster and further into the tissue (MacDougall & Rhodes, 1972).

Metmyoglobin Reduction Ability

Metmyoglobin reducing ability (MRA) is essential for meat color life because the presence of MMb on meat surface is very undesirable to consumers (Mancini & Hunt, 2005). Metmyoglobin reducing ability is an inherent property of meat where a series of reactions help reduce MMb. In addition, this trait is directly related to color stability where as the higher the MRA, the more stable the meat product (AMSA, 2012). Many indigenous factors including muscle's oxygen scavenging enzymes, reducing enzyme systems, and the NADH (reduced form of nicotinamide adenine dinucleotide) pool, help give the muscle the ability to reduce from the MMb form and return to DMb (Mancini et al., 2005). The dominance of MMb as a pigment in a meat product is regulated by MRA which is unique to each muscle (Ledward, Smith, Clarke, & Nicholson, 1977). Metmyoglobin reduction ability is the enzymatic pathway of reducing the iron molecule in MMb back to the Fe^{2+} state in the presence of the NADH (Renerre, 1990). The ability to reduce iron in MMb has been reported to be more dependent on the availability of NADH than MRA (Bekhit, Geesink, Ilian, Morton, & Bickerstaffe, 2003).

The major components required for the enzymatic reduction of MMb are the enzyme (NADH-cytochrome b5 MMb reductase), the intermediate (cytochrome b5) and the cofactor NADH (Bekhit and Faustman, 2005). Several investigators have suggested that the discoloration due to surface or sub-surface MMb can be reduced and retarded by regenerating the postmortem NADH pool and that this postmortem pool of NADH will reduce formed MMb via enzymatic or non-enzymatic pathways (Saleh & Watts, 1968; Brown & Snyder, 1969; Arihara, Itoh, & Kondo, 1996; Bekhit et al., 2003; Mancini & Hunt, 2005).

Faustman and Cassens (1991) found that nicotinamide adenine dinucleotide (NAD) concentrations in post-mortem muscle varied with breed (Holstein had higher NADH than crossbred) and muscle type (M. longissimus dorsi > M. gluteus medius) and that NADH concentration decreased with storage time during storage at 4ºC. While NAD concentration was negatively and highly correlated with MMb accumulation in the Holstein breed animals tested, no significant correlation was observed with crossbred animals. Sammel, Hunt, Kropf, Hachmeister, and Johnson (2002a) and Sammel, Hunt, Kropf, Hachmeister, Kastner, and Johnson (2002b) reported that NAD and NADH concentrations were location dependent in the M. semimembranosus muscle (external vs. internal location). The external portion of the muscle contained higher NAD and lower NADH concentrations and higher OCR. They attributed the location dependent differences to differences in relative chilling (i.e. the outer portion would cool faster and not result in rapid depletion of metabolites). In addition, NADH concentration has been reported to decrease during vacuum storage (Sammel et al., 2002b).

Bekhit et al. (2003) reviewed the dynamics of the enzymes that reduce MMb to DMb. They observed an apparent loss of endogenous reducing capacity in beef patties during storage and concluded that the availability of a sufficient amount of NADH is crucial for the full expression of the MMb reductase enzyme. MacDougall and Rhodes (1972) suggest that as meat ages there is a faster accumulation of metmyoglobin resulting from the diminution of the meat's enzymic activity which occurs during aging, and metmyoglobin formed in the region of low oxygen tension in no longer reduced back to myoglobin because the reducing intermediates (particularly NADH) are no longer being formed.

McKenna, Miles, Baird, Pfeiffer, Ellebracht, and Savell (2005) studied the biochemical properties of 19 beef muscles and found that those with high color stability had highest MRA while muscles with very low stability had the least MRA. The researchers also suggested that the amount of MMb formed initially on the surface of the muscles was inversely related to color stability and that the initial amount was as good as or a better indicator of color stability than the amount of MMb reduced over time.

Madhavi and Carpenter (1993) studied the effects of aging and processing on muscle color and MRA and found that surface MMb accumulation, MRA, and OCR were affected by muscle type, post-mortem aging and fabrication method. They reported that color labile muscle (M. psoas major) appears to have higher MMb accumulation, lower MRA, and greater OCR than color stable muscle (M. longissimus dorsi). Other researchers also found that the rate of MMb accumulation on the surface of beef is muscle dependent (Hood, 1971; MacDougall & Taylor, 1975; O'Keeffe & Hood, 1980). In addition, the effect of temperature on MRA is pH dependent. Reddy and Carpenter (1991) reported that enzyme activity was highest at pH 6.4 and 30ºC, compared to pH 5.8 or 7 and 4ºC.

During display in traditional polyvinyl chloride (PVC) packaging, discoloration increases and MRA decreases on the surface of beef steaks, whereas the interior remains deoxygenated and thus, may have somewhat different color chemistry than the surface (Sammel et al., 2002b; Seyfert, Mancini, Hunt, Tang, Faustman, & Garcia, 2006). King et al. (2011b) observed that at 0 and 6 d of display lean color stability was correlated with all MRA measurements. In addition, they found that steaks with stable lean color retained greater ability to reduce the nitric oxide metmyoglobin after 6 d of display than those with more labile lean color (King et al., 2011b). They concluded that initial levels of MRA are important in determining color stability, but differences in the ability to maintain MRA is important in regulating color stability.

Lean Source

Ground beef is produced using a variety of lean sources from nearly any portion of a beef carcass. However, for economic reasons, higher priced cuts such as M. longissimus dorsi or M. psoas muscles are usually not utilized as ground beef. Instead, ground beef is usually manufactured from lower priced, less tender cuts such as plates, flanks, lean trimmings, and fat trimmings from carcass fabrication operations. O'Keefe and Hood (1982) speculated that muscles containing lower Mb content were less color stable because their Mb was oxidized at a greater frequency to maintain normal cellular respiration. McKenna et al. (2005) found that steaks from muscles that were lower in Mb content had the highest L* values.

McKenna et al. (2005) used (K/S)572/(K/S)525 reflectance values to measure MMb formation on the surface on several muscles. These muscles were then grouped according to objective color measures of discoloration. ''High'' color stability muscles included M. longissimus lumborum, M. longissimus thoracis, M. semitendinosus, and M. tensor fasciae latae. ''Moderate'' color stability muscles included M. semimembranosus, M. rectus femoris, and M. vastus lateralis. ''Intermediate'' color stability muscles included M. trapezius, M. gluteus medius, and M. latissimus dorsi. ''Low'' color stability muscles were M. triceps brachi – long head, M. biceps femoris, M. pectoralis profundus, M. adductor, M. triceps brachi – lateral head, and M. serratus ventralis. ''Very low'' color stability muscles included M. supraspinatus, M. infraspinatus, and M. psoas major. Usually, "high" color stability muscles had high resistance to induced MMb formation, nitric oxide reducing ability, and oxygen penetration depth (OPD) and low OCR, myoglobin content, and oxidative rancidity. In contrast, muscles of low color stability had high MRA, OCR, myoglobin content, and oxidative rancidity and low resistance to induced MMb formation, nitric oxide metmyoglobin reducing ability, and OPD. McKenna et al. (2005)

concluded that discoloration differences between muscles are associated to the amount of reducing activity relative to the OCR.

Reddy and Carpenter (1991) reported that MRA for five muscles was M. tensor fasciae latae > M. longissimus lumborum > M. gluteus medius > M. semimembranosus = M. psoas major. Lanari and Cassens (1991) found the M. gluteus medius had greater MRA and was less color stable than the M. longissimus lumborum. As was found in this study, Renerre and Labas (1987) noted no differences in MRA between M. psoas major and M. tensor fasciae latae even though M. psoas major had much greater discoloration during retail display.

Atkinson and Follett (1973) concluded that high OCR is a defining characteristic of muscles with low color stability. Likewise, Renerre and Labas (1987) described muscles having the poorest color stability as having the highest oxidative activities. Sammel et al. (2002a) concluded that a very high or very low OCR could have a negative impact on color stability. In the case of low OCR, they speculated that low OCR would result in low mitochondrial generation of NADH, limiting the amount of reduction that could occur. Bendall and Taylor (1972) determined that the order of OCR for five muscles was M. biceps femoris > M. longissimus lumborum > M. tensor fasciae latae > M. vastus lateralis > M. rectus femoris. O’Keefe and Hood (1982) reported that M. psoas major had higher initial and residual OCR than M. longissimus lumborum/M. longissimus thoracic during display.

Oxygen penetration depth (OPD) is the depth of oxygen penetration into a piece of meat. It is governed by the partial pressure of the gas of the surface, the rate of oxygen consumption by the tissue, and the diffusion constant. O’Keefe and Hood (1982) and McKenna et al. (2005) observed that the most color stable muscles (i.e., M. longissimus lumborum, M. longissimus thoracis, M. semitendinosus, and M. tensor fasciae latae) showed incremental increases in OPD with increasing days of retail display. In addition, the total change in OPD from 0 to 5 d was greater in the traditionally color stable muscles than the total change observed in less color stable muscles. However, OPD appears to play a less important role in low color stability muscles (M. psoas major and M. adductor) which were intermediate in terms of OPD. O'Keefe and Hood (1982) also reported incremental increases in OPD with increased display time, and noted that OPD was greater in muscles that had greater postmortem age. Bendall and Taylor (1972) and MacDougall and Taylor (1975) suggested that OPD values for M. psoas major were lower than those reported for M. longissimus lumborum. Bendall and Taylor (1972) concluded that OPD was important because it masked underlying MMb formation, which occurs at the MMb/OMb interface where partial pressure oxygen is optimal for OMb autoxidation. Madhavi and Carpenter (1993) found that M. psoas major steaks had greater MMb accumulation, lower MRA, and greater OCR than M. longissimus dorsi steaks; however, after grinding, color stability of muscles were similar while observing that there was an increase in OCR.

Mancini (2001) found that visual color scores and L* values indicated that as lean level increased, ground beef color was a darker red. However, changes in discoloration due to lean level were relatively small and not likely practical. Previous work also has demonstrated that ground beef containing lower lean levels had brighter red color and less discoloration than higher lean ground beef (Liu, Huffman, Egbert, McCoskey & Liu, 1991; Kregal, Prusa & Hughes, 1986). In addition, low lean ground beef had greater brightness values than higher lean ground beef (Liu et al., 1991; Troutt, Hunt, Johnson, Claus, Kastner, Kropf, & Stroda, 1992b). However, other works have noted that display color stability and a* and b* values were not affected by lean level (Govindarajan & Hultin, 1977; Troutt et al., 1992b).

Shivas, Kropf, Hunt, Kastner, Kendall and Dayton (1984) assessed color changes in PVC wrapped ground beef displayed at 2-3°C and found that ground beef containing 75 percent lean was brighter red than ground beef containing 80 percent lean. In addition, a visual panel also tended to prefer the 75 percent lean ground beef throughout the display period (Shivas et al.,1984). Conversely, Govindarajan and Hultin (1977) found that high lean patties (100 and 95 percent lean) were more preferable than low lean patties (80 and 70 percent lean). Raines, Hunt, & Unruh (2009) found that beef-type semimembranosus lean with young beef fat trim patties had the brightest initial color, but discolored rapidly. In addition, ground dairy-type M. semimembranosus lean had a MRA up to fivefold greater than ground beef-type M. semimembranosus lean as well as a longer display color shelf-life.

Chuck Roll (116A)

The 116A, beef chuck roll is fabricated from the remainder of the 113 beef chuck, square-cut with the shoulder clod, chuck tender, the thin muscle under the blade and rib fingers removed. This boneless item consists of the large muscle system of the chuck which lies under the blade bone and contains the M. longissimus dorsi, M. rhomboideus, M. spinalis dorsi, M. complexus, M. multifidus dorsi, M. serratus ventralis, M. subscapularis, and M. splenius. The weight range for this subprimal is 5.9 -6.8 kg (AMS, 2010). Madhavi and Carpenter (1993) found that M. longissimus dorsi steaks had less MMb accumulation, greater MRA, and a lower OCR than M. psoas major steaks. Lanari and Cassens (1991) found that the M. longissimus dorsi had a lower mitochondrial concentration, OCR, and MRA compared with the M. gluteus medius. McKenna et al. (2005) observed that the M. serratus ventralis early in retail display had an initial decrease in the a* values with no subsequent decreases for the remainder of retail display. The M. serratus ventralis was classified as ‘‘low’’ color stability muscles but had high

MRA values. Furthermore, the (K/S)572/(K/S)525 values for the M. serratus ventralis indicate that by 2 d of retail display enough MMb would have accumulated for the steak to be considered discolored (McKenna et al., 2005).

Peeled Sirloin Tip Knuckle (167A)

The 167A, also called the tip, sirloin tip or round tip, is a lean cut, fabricated from the 158 round, primal with the small "cap" muscle and all remaining outer fat removed. This boneless item consists of the posterior portion of the full sirloin tip which contains the M. vastus intermedius, M. vastus lateralis, M. vastus medialis, and M. rectus femoris as well as the M. tensor fasciae latae. The average weight range of this subprimal is 1.5-1.6 kg (AMSA, 2010). King, Shackelford, and Wheeler (2011a) reported mean lightness (L*) and redness (a*) values for M. rectus femoris and M. vastus lateralis steaks decreased as display time increased from 0 to 9 d. After 5 d of retail display, the M. rectus femoris and M. vastus lateralis had lower (K/S)572/(K/S)525 values indicating greater discoloration rates and were classified as ‘‘intermediate’’ color stability muscles. The M. rectus femoris was found to have one of the lowest MRA values. Likewise, Bendall and Taylor (1972) determined that the order of OCR for five muscles was M. biceps femoris > M. longissimus lumborum > M. tensor fasciae latae > M. vastus lateralis > M. rectus femoris.

Fat Source

Fat content, in addition to greatly affecting palatability attributes, is also a contributor to color stability and shelf-life. Correale, Savell, Griffin, Acuff and Vanderzant (1986) reported that U.S. Prime loin steaks had less surface discoloration than U.S. Good (now called U.S. Select) steaks when stored in the dark for 6 d in PVC overwrap packaging. King et al. (2011b) found that quality grade did not contribute to variation to any appreciable degree for any of the traits examined in this experiment. King et al. (2010) reported that breed differences in longissimus lean color stability were inversely related to differences among the same breeds in marbling score and suggested that muscles with less marbling may have greater ability to maintain reducing activity. Troutt et al. (1992b) found that compared to 20 and 30 percent fat patties, lower fat (5 to 10%) patties had: a darker red color that was equal in color stability during display; lower cooking losses; a less open, more dense cooked physical structure; longer cooking times to specified end-point temperatures; less juiciness, moisture release, beef flavor, and oily coating of the mouth; and greater patty firmness, cohesiveness, and crumbliness. Fat level did not affect the cooked patty diameter and height.

McKenna et al. (2005) concluded that product color stability is not solely determined by MRA or OCR but by the proportion of the two components. For example, muscles with low color stability may have high or low OCR, but their reducing activity is proportionally low compared to their OCR. In contrast, muscles of high color stability may have high or low OCR, but have reducing activity that proportionally exceeds their OCR (McKenna et al., 2005).

In summary, meat product’s color stability is related to the product’s MRA and OCR. These traits differ among lean sources. Research shows the chuck roll to have less MMb accumulation and, therefore, scoring as an intermediate color stable muscle; while the knuckle muscles had a greater decrease in L* and a* values during display as well as greater MMb accumulation and as a result scoring as a low color stable muscle. Amount and source of fat plays a role in the observed product color, color stability, and palatability attributes.

Meat Color Factors

Meat color is a complex concept with both intrinsic (pH, breed, diet, muscle type, areas within a muscle, muscle fiber composition, myoglobin concentration, disruption of various subcellular components related to meat color chemistry, and water holding capacity) and extrinsic (chill rate, temperature, lighting, bacteria, lipid oxidation, grinding, packaging, and postmortem age) factors interacting and influencing the outcome of display color. An understanding of all the factors will result in maximizing color life of fresh retail meat products.

Intrinsic Factors

pH

The pH of a meat product plays an important role in meat color and color stability. The pH is a measurement of the amount of hydrogen ions (H^+) in a solution. The effect of pH on meat color stability is important from the standpoint of both ultimate pH in postrigor muscle, and the rate of pH decline in the prerigor, postmortem condition (Faustman & Cassens, 1990). Factors include rate of pH decline during rigor and ultimate pH, which are affected by breed, stress, and muscle type (Renerre, 1990). High ultimate pH is more conducive to enzyme respiratory activity and darker muscle color (Renerre, 1990). Conversely, low ultimate pH and/or a rapid rate of pH decline reduces enzyme activity allowing more oxygen to be available to myoglobin, resulting in increased oxidation and MMb accumulation (Renerre, 1990). Many studies have also determined that myoglobin tended to be more susceptible to oxidation at lower pH (Gotoh & Shikama, 1974; Ledward, Dickinson, Powell, & Shorthose, 1986). Cow beef has a higher pH and, therefore, a darker lean color than young beef (Graafhuis & Devine, 1994). Ultimate carcass pH of forage-fed cattle tends to be higher than that of grain-fed cattle

(Watanabe, Sato, Tsuneishi, & Matsumoto, 1993). Due to the presence and growth of lactic acid bacteria during vacuum aging, a decrease in pH is usually observed (Davies & Board, 1998). In contrast, Sutherland, Patterson and Murray (1975) found that pH of vacuum aged M. longissimus dorsi muscles increased from 3 (5.8) to 6 (6.05) weeks of storage.

Muscle Type

Compared to fast-twitch glycolytic or fast-twitch oxidative-glycolytic muscle fibers, slow-twitch oxidative muscle fibers contain a greater amount of myoglobin, possess higher enzymatic reducing activity, and have more intact mitochondria resulting in a greater red color and increased color stability (Renerre, 1990; Echevarne, Renerre, & Labas, 1990).

Genetics

Breed and genetics of an animal affect fresh meat color (Brewer, Jensen, Sosnicki, Fields, Wilson, & McKeith, 2002; Brewer, Sosnicki, Field, Hankes, Ryan, & Zhu, 2004). For example, M. longissimus dorsi and M. gluteus medius steaks from Holstein cattle were found to have lower mitochondrial levels and greater OCR leading to weaker color stability compared to steaks from crossbred cattle (Lanari & Cassens, 1991). Furthermore, they found color stability to be muscle dependent with the M. longissimus dorsi having greater color stability compared to the M. gluteus medius. Ledward, Smith, Clarke and Nicholson (1977) suggested that autoxidation is muscle dependent due to aerobic reducing systems located within different muscles.

Diets

Animal diets can influence fresh meat color and color stability (French, Stanton, Rawless, O'Riordan, Monahan, & Caffery, 2000; Baublits, Brown, Pohlman, Johnson, Onks, & Loveday, 2004; Realini, Duckett, Britto, Dalla Rizza, & De Mattos, 2004). One example is the incorporation of vitamin E into the diets of cattle, which retarded lipid and pigment oxidation, thereby improving color stability of beef (Faustman, Cassens, Shaefer, Buege, Williams, & Scheller, 1989). In addition, it has been shown that time on feed can improve the lean color of cull cows (Matulis, McKeith, Faulkner, Berger & George, 1987; Wooten, Roubicek, Marcheool, Dryden, & Swingle, 1979; Cranwell, Unruh, Brethour, Simms, & Campbell, 1996). Cows fed concentrate displayed a brighter, redder lean color compared with forage-fed cows (Price & Berg, 1981). Furthermore, feeding a higher energy diet to cull cows prior to slaughter helped improve carcass yield and quality (Cranwell et al., 1996; Sawyer, Mathis, & Davis, 2004).

Extrinsic Factors

Aging

Understanding the effects of longer aging periods could allow for better product management and value. Aging beef is a process that has been used extensively to create unique eating experiences by using both time and temperature to alter the meat characteristics. The most significant result is that aged beef is more tender than unaged beef (Larmond, Petrasovits, & Hill, 1969; Webb, Kahlenberg, Naumann, & Hedrick, 1967; Busch, Parrish, & Goll, 1967; Doty and Pierce, 1961; Wilson, 1957). In the past, the conventional aging process was dry aging but vacuum aging has become a more popular means of enhancing whole muscles (Minks & Stringer, 1972). Ball, Clauss, & Stier (1957), Minks and Stringer (1972), Hodges, Cahill, & Ockerman (1974), and Schimidt and Keman (1974) indicated that vacuum packaging significantly reduces weight loss during processing and storing of beef. Gutowski, Hunt, Kastner, Kropf, and Allen (1979) found that vacuum aging improved taste panel tenderness, juiciness, and flavor scores; reduced Warner-Bratzler shear force values and increased total and volatile cooking losses for averages of muscles and feeding regimens. Peirson, Collins-Thompson, and Ordal (1970) reported that sensory evaluations differed little between fresh beef and beef vacuum packaged for 10 d, but non-vacuum packaged beef steaks were “unacceptable” after 4 d of storage. Minks and Stringer (1972) found palatability did not differ between steaks aged 7 to 15 d in a vacuum compared with no vacuum aging. Hodges et al. (1974) reported shortloins packaged 24 h postmortem maintained desirability through 28 d of vacuum storage.

In addition, aging time affects the display color stability of meat products. Bevvilacqua and Zaritzky (1986) demonstrated that increasing the vacuum aging period of beef cuts decreased their subsequent aerobic color shelf life. Madhavi and Carpenter (1993) found that the NAD concentration (nmoles/g fresh wt) rapidly decreased over post-mortem vacuum aging with only trace amounts present after 7 d which alined with the decrease of MRA. Stewart, Hutchins, Zipser, and Watts (1965) found that 6 d of cold storage of intact beef ribeye only minimally affected MRA while Lanari and Cassens (1991) found no significant change in MRA determined by purified beef mitochondria/mediated reduction by methylene blue over 7 d of storage. In summary, vacuum aging or storage extends product shelf-life and can improve sensory scores.

Chilling Rate

Color stability of the final meat products is affected by the rate the carcass temperature declines after harvesting (Sammel, Hunt, Kropf, Hachmeister, Kastner, & Johnson, 2002a). Interior muscles decrease in temperature at a slower rate and as a result have a faster rate of glycolysis (Sammel et al., 2002a). Most often muscles with more rapid chilling rates will have increased redness, decreased discoloration, and greater consumer appeal. If a muscle experiences a more rapid rate of glycolysis, the result is a faster pH decline which denatures proteins and opens up the muscle structure causing more light scattering which is considered a negative to meat color (MacDougall, 1982). Chilling rate differs among species with beef having the slowest when compared with lamb and pork; however, this rate can be decreased with the addition of processing innovations.

Storage Temperature

Temperature can have one of the largest impacts on meat color stability (MacDougall, 1982). The onset of discoloration in meat is delayed with low temperature storage (Butler, Bratzler, & Mallman, 1953; Rikert, Bressler, Ball, & Stier, 1957; Lanier, Carpenter, & Toledo, 1977; Hood, 1980; O'Keefe & Hood, 1980-81; Nortje et al, 1986). Cold chain management helps maintains desirable meat color (Mancini, 2001). Lowering display temperatures 3 to 5°C will retard discoloration rate by half (MacDougall & Taylor, 1975). Wavelength reflectance ratios of meat samples stored at 0, 5, and 10°C revealed a faster accumulation of MMb on the meat surface at 5°C by a factor of 4 and at 10ºC by a factor of 9 (Hood, 1980). Hood (1980) further suggested that meat discolors 2-5 times faster at 10°C than at 0°C. In addition, Lanier et al. (1977) found that M. semitendinosus steaks reached 60% MMb faster at 4.4 than at 0°C.

Mancini, Hunt, Kropf, Hachmeister, Johnson, and Fox (2002a) found storage at 0ºC minimized discoloration during display compared to storage at 4.4º and 8.9ºC, whereas fat level (7, 19, and 27 percent) did not influence discoloration. An increased temperature accelerates pigment oxidation rate by increasing the rate(s) of any pro-oxidant reactions within the tissue. Additionally, enzyme respiratory activity increases with increasing temperatures leading to increased OCR and decreased oxygen pressure (Renerre, 1990). Keeping display temperatures low suppresses enzyme activity and allows oxygen to penetrate deeper into the meat surface creating a thicker layer of OMb above the MMb layer (Renerre, 1990). Elevated temperatures shift the thin layer of MMb below the meat surface toward the surface where it becomes more visible (Renerre, 1990). Elevated storage temperature results in an increase in oxygen consumption by the tissue (Urbin & Wilson, 1958; Cheah & Cheah, 1971; Ashmore, Parker, & Doerr, 1972; Bendall, 1972; Bendall & Taylor, 1972), enhanced microbial growth (Lawrie, 1985), and accelerated lipid oxidation processes (Labuza, 1971); all of which contribute to enhanced meat discoloration.

MacDougall et al. (1975) suggested that increasing display temperature 3°C doubled MMb accumulation (discoloration). They also reported that M. psoas steaks turned brown 5 times faster when displayed at 7°C rather than 4°C. M. gluteus medius steaks followed similar trends, turning brown approximately 2 times faster at 7°C (15 h) than at 4°C (36 h). In addition, they found that compared to 7°C, M. gluteus medius steaks remained bright 3 times longer at 4°C (3 vs 10 h, respectively). Nortje et al. (1986) found that steaks displayed at 0°C had less discoloration and a more acceptable appearance compared to those displayed at 5°C. Furthermore, over a 5 d display period, overall appearance decreased faster at 5°C than 0°C. Similarly, Berry (1980a) found that as storage time (3°C, PVC) increased, ground beef surface discoloration increased regardless of lean level (84 or 72 percent). MacDougall et al. (1975) displayed (4°C) steaks wrapped in oxygen permeable film and found an increase in brown color during display was accompanied by a decrease in saturation index (approximately 3 units in the first 4 h of display) and an increase in hue angle. After 3 d of display, steak color was brown and unacceptable (MacDougall et al., 1975). Storage coolers and display cases should be cold enough to insure that meat temperature is near 2°C (Holland, 1979). Brolls (1986) suggested that meat temperatures during display be maintained between -1° and 0°C.

Ground beef consistently discolors as display time increases. Lavelle, Hunt and Kropf (1995) found that a* and saturation index of ground beef (90 percent lean) decreased during display at 0ºC, and Eckert, Maca, Miller, and Acuff (1997) found that during display at 4ºC, ground beef (81 percent lean) discoloration increased with increasing display time. Since ground beef discoloration during display is inevitable, cold chain management is crucial to minimize discoloration and maximize color life. Mancini (2001) concluded that desirable meat color and odor are critical for maximizing ground beef shelf life, consumer acceptance, and profit. There are many factors that affect ground beef color and microbiology including lean level, storage temperature, storage time, display temperature, and display time. Compared to storage at 4.5° and 8.9°C, storage at 0°C resulted in a more desirable and brighter red initial display color. Although initial bright red color inevitably deteriorated during display, ground beef stored and displayed at 0°C maintained a color life of 80 h and reduced sales loss 60 percent. Storage up to 12 d at 0°C did not increase discoloration, whereas prolonged storage time at 4.5° and 8.9°C reduced color life to less than 10 h. Audits International (1999) found in a national retail survey that the average display case temperature was 4ºC and 9 percent of display cases were greater than 7ºC. Therefore, product discoloration increases as display temperature and time increase.

Lighting

Color is affected by the presence, duration, and intensity of light exposure. Greer and Jeremiah (1980) showed that ribeye steaks displayed (4°C, oxygen-permeable film) under continuous incandescent light (344 lux) had a case life of 2.4 d, whereas steaks displayed under the same lighting for only 8 h/d and then stored in a dark cooler (16 h @ 1.3°C) had a case life of 4.9 d. Solberg and Franke (1971) stored meat slices under various wavelengths of visible light and found that no single wavelength was more detrimental than another for the range 420 nm to 632.8 nm. They reported that illuminated meat samples contained 5.5 percent more MMb than did samples stored in the dark. In general, greater pigment oxidation occurs in meat stored under light verus dark conditions (Rikert, Bressler, Ball, & Stier, 1957; Marriott, Naumann, Stinger, & Hedrick, 1967). Marriott et al. (1967) attributed this enhanced color deterioration to increased growth of microorganisms which occurred under illumination. Satterlee and Hansmeyer (1974) found that beef stored in the dark (5°C) had the lowest autoxidation rate (3.25x10^{-3} h^{1}, slowest MMb accumulation), compared to incandescent (5.46 x10^{-3} h^{1}) and soft white fluorescent light (8.20 x10^{-3} h^{1}). Zachariah and Satterlee (1973) found that fluorescent light (soft and warm white 40W) had a greater affect on autoxidation of purified bovine OMb than incandescent (100W standard white and 160W cool white flood) light. The U.S. Department of Energy (DOE) (2008) states light emitting diode (LED) lighting will provide potential cost and energy savings as it becomes more prominent in retail display meat cases. Steele (2011) found that LED lighting resulted in lower display case temperatures, lower internal product temperatures, and extended color life. Furthermore, beef M. longissimus dorsi steaks, ground beef, and the superficial portion of beef semimembranosus steaks had less visual discoloration under LED lighting than fluorescent (Steele, 2011). In summary, light exposure deteriorates color shelf life, as well as, increasing lipid oxidation, microbial growth and surface temperature.

Bacteria During Storage

Bacterial contamination of a product affects fresh meat color. Microbial contamination can be divided into two types: pathogenic and spoilage organisms (Warriss, 2000). Cold temperature is the most critical factor for suppressing microbial growth and maintaining shelf life and wholesomeness. Stringer, Bilskie, and Naumann (1969) determined that surface discoloration was a function of the number of bacteria present on meat. Mancini et al. (2002b) found that increased storage and display temperature as well as storage and display time of ground beef significantly increased microbial counts but lean level had no effect. When bacterial counts reach 7-8 $\log_{10}$ colony forming units (CFU)/g, the resulting microbial end products yield offensive odors that cause consumers to declare that the meat is spoiled and unwholesome. Considering the average retail display case temperature is 4.4ºC, aerobic bacteria count of ground beef commercially displayed for 48 h may range from 4-8 $\log_{10}$ CFU/g. Blixt and Borch (2002) studied the shelf-life of vacuum-packed beef strip loins stored at 4ºC and found that the aerobic bacteria count was 3.1, 2.4, 6, 6.8, and 7.4 $\log_{10}$ CFU/g for 0, 1, 2, 3, and 4 weeks, respectfully, and for lactic acid bacteria the count was 1, 3.3, 6, 6.8, and 7.2 $\log_{10}$ CFU/g for 0, 1, 2, 3, and 4 weeks, respectfully. Greer and Jeremiah (1980) showed that surface psychrotroph density of steaks displayed at 2°C was highly correlated ($r = 0.87$) to surface discoloration.

Under aerobic conditions, gram-negative bacteria such as *Psedomonas, Acinetobacter, Psychrobacter* and *Moraxella* due to their fast growth rates present the greatest spoilage potential for fresh meat products (Davies & Board, 1998). In addition, gram-positive organisms such as Kurthia and nontoxinogenic staphylococci also help make up the initial microbial population (Davies & Board, 1998). *Pseudomonas* accounts for the majority of spoilage microorganisms in an aerobic environment (Gill, 1982). Glucose is the preferred substrate of *Pseudomonas* and other gram negative bacteria; however, as cell density increases, the amount of glucose on the meat surface decreases and microorganisms are forced to utilize amino acids (Davies & Board, 1998; Gill, 1982). *Pseudomonas* induced spoilage is also dependent on initial contamination level (raw materials) and generation time (Greer et al., 1980; Surkiewicz, Harriss, Elliott, Macaluso, & Strand 1975; Tompkin, 1973). Perceptible changes in off-odors and slime are caused when bacterial numbers of 7 and 8 $\log_{10}$ CFU/cm^2 are reached, respectively (Ayres, 1960). Thus, the amount of time prior to microbial induced spoilage can be prolonged by low temperatures, which effectively lengthens generation time (Tompkin, 1973). Short loins inoculated with *Pseudomonas fragi* expressed greater discoloration compared to control samples (Bala, Marshall, Stringer, & Naumann, 1977). Aerobic bacteria such as *Pseudomonas, Achromobacter* and *Flavobacterium* metabolize oxygen reducing the oxygen pressure at the meat surface resulting in an increase in MMb content (Renerre, 1990). Bala et al. (1977) studied the relationship between *Pseudomonas* and MMb accumulation in meat extracts stored (1°C) in the dark. After 10 d of storage, inoculated samples (8 $\log_{10}$ after storage) had a 76 percent decrease in OMb, whereas a 45 percent decrease in OMb quantity occurred in sterile samples.

In anaerobic packaging, a high percentage (90-95%) of the microorganisms are lactobacilli (Gill, 1982; Pierson et al., 1970), which produce compounds that inhibit competitors and compete well at refrigerated temperatures (Gill, 1982). Lactic acid bacteria metabolize glucose and produce lactic, isobutanoic, isopentanoic and acetic acids resulting a sour taste and smell for the meat product (Davies & Board, 1998). Sutherland, Patterson, and Murray (1975) researched the development of the microbial flora on meat storage in vacuum bags at 0-2ºC for up to 9 wk. Although the proportion of lactic acid bacteria increased relative to the aerobic spoilage organisms, the number of the latter continued to increase throughout storage. The initial contamination of the meat before vacuum packaging was important; meat with very low initial numbers had low numbers of bacteria throughout storage for up to 9 wk and steaks cut from this product always had 1-2 d additional aerobic shelf life at 4ºC.

Berry et al. (1979) evaluated the shelf life and bacterial characteristics of ground beef as influenced by fat level and fat source and found that ground beef formulated to 28 percent fat was scored as having more off-odor than the 16 percent fat product. Interventions to control microbiological growth through the use of products such as potassium sorbate, sodium acetate, sodium tripolyphosphate, and/or tetrasodium pyrophosphate can prevent MMb formation (Renerre, 1990). In conclusion, microbial growth increases with time and temperature and is a detrimental to meat shelf life.

Lipid Oxidation

The three sensory properties by which consumers most readily judge meat quality are appearance, texture, and flavor (Liu, Booren, & Gray, 1995a). The development of oxidative off-flavors (rancidity) has long been recognized as a serious problem during the holding or storage of meat products. Gray, Gomaa, & Buckley (1996) stated that lipid oxidation is one of the primary mechanisms of quality deterioration in foods and especially in meat products. Lipid oxidation in muscle systems is initiated at the membrane level in the intracellular phospholipids fractions. The propensity of meats and meat products to undergo oxidation depends on several factors including pre-slaughter events such as stress and post-slaughter events such as early postmortem pH, carcass temperature, cold shortening, and techniques such as electrical stimulation (Buckley, Morrissey, & Gray, 1995). Furthermore, any disruption of the integrity of the muscle membranes by mechanical deboning, grinding, restructuring or cooking alters cellular compartmentalization. This facilitutes the interaction of pro-oxidants with unsaturated fatty acids resulting in the generation of free radicals and the propagation of oxidative reactions (Asghar, Gray, Buckley, Pearson, & Booren, 1988).

Lipid and Mb oxidation are interrelated in fresh meat products (Schaefer, Liu, Faustman, & Yin, 1995) and can be catalyzed from by-products of both processes (Liu, Lanari, & Schaefer, 1995b). M. gluteus medius ground beef had a correlation coefficient of 0.91 for MMb formation and thiobarbituric-acid (TBA) values (Faustman et al., 1989). The basis for this relationship is not understood. From the viewpoint of meat color, it may be that radical species produced during lipid oxidation act directly to promote pigment oxidation, and/or indirectly by damaging pigment reducing systems. Suman, Faustman, Stamer, and Liebler (2006) looked at the effect of the aldehyde lipid oxidation by-product 4-hydroxy-2-nonenal on the oxidation of OMb and found a strong correlation in beef products. Additionally, lipid peroxidation promotes MMb formation in muscle foods (Kanner, 1994). McKenna, Miles, Baird, Pfeiffer, Ellebracht, and Savell (2005) reported that thiobarbituric-acid reactive substances (TBARS) values increased with increasing days of retail display. Furthermore, they showed that on average less color stable muscles (i.e., M. psoas major and M. adductor) had higher TBARS values and more color stable muscles (i.e., M. longissimus lumborum, M. longissimus thoracis, M. semitendinosus, and M. tensor fasciae latae) had lower TBARS values. Color stability is generally enhanced by the addition of antioxidants to meat (Greene 1969; Greene et al. 1971; Govindarajan et al. 1977). Ascorbic acid is an antioxidant and its role as a meat color stabilizer has been reviewed (Bauernfeind, 1982). Ascorbic acid will act as an oxygen scavenger as well as an antioxidant with natural and synthetic antioxidants to retard lipid oxidation and prevent MMb formation (Renerre, 1990). Reduction in the formation of TBARS and MMb accumulation occurred when higher inherent levels of lipid-soluble α-tocopherol antioxidants were present in beef (Yin, Faustman, Riesen, & Williams, 1993). In summary, lipid oxidation is a process that is advanced during retail display but must be reduced in order to help preserve product quality.

Grinding

Ground beef is highly susceptible to spoilage because the grinding process disrupts muscle reducing systems, causes areas of low oxygen pressure, distributes microorganisms throughout the product, and increases lipid oxidation; all of which accelerate discoloration and microbial growth (Chestnut, Emswiler, Kotula & Young, 1977; Govindarajan et al., 1977;

Ledward et al., 1977; Kropf, 1980). Due to grinding, ground beef also is more susceptible to microbial spoilage and off-odors than steaks. Grinding distributes bacteria throughout the entire product, creating a favorable medium for microorganism growth (Chestnut et al., 1977; Duitschaever, Arnott, & Bullock, 1973). Grinding also promotes lipid oxidation by compromising the integrity of the cellular structure and combining unsaturated lipids from the membrane with catalytic oxidizing reagents (Govindarajan & Hultin, 1977). Grinding meat creates areas of low oxygen pressure which promotes the formation of MMb (Kropf, 1980). Madhavi and Carpenter (1993) found that after grinding no differences between the M. longissimus dorsi and the M. psoas major in MMb accumulation were observed due to the similar disrupted tissue in both muscles resulting in an increase of both MMb accumulation and OCR concentration. Ledward et al. (1977) found that sliced M. longissmus dorsi muscle had less MMb accumulation than minced beef. Mincing decreased NADH content (reducing system disruption) and increased oxidation catalysts, which accelerated MMb accumulation compared to uncut or sliced beef (Ledward et al., 1977). In summary, grinding meat products reduces the display life of the product.

Packaging

Packaging is a vital component of meat products as it provides protection from physical, chemical, and biological hazards as well as containing the product, communicating to consumers as a marketing tool, and providing ease of use and convenience (Yam, Takhistov, & Miltz, 2005). A variety of packaging options exist adding complexity to fresh meat color since the display color varies between packaging systems. Polyvinyl chloride (PVC) packaging with a Styrofoam® tray was the first style of packaging integrated into retail markets (McMillin, 2008). This air-permeable flexible plastic wrap allows the product to form the bright red color of OMb while providing a moisture barrier (Brody, 2002). Modified atmosphere packaging (MAP) involves the removal of air or substitution of air with a specific atmosphere encompassing the food item within sealed vapor-barrier materials (McMillin, Huang, Ho, & Smith, 1999). The pigment form of meat can be manipulated and preserved by using specific combinations of headspace gases along with high oxygen barrier packaging films. In MAP, nitrogen and carbon dioxide are essentially neutral in their effects on pigment forms and carbon dioxide is known for its antimicrobial effect (Moeller, Nannerup, & Skibstead, 2004). The use of high oxygen MAP can help maintain oxy-heme pigment forms (Georgala & Davidson, 1970; O'Sullivan & Kerry, 2010), but respiratory capacity of the meat must be considered to avoid depleting oxygen to a level that promotes formation of MMb (Bekhit & Faustman, 2005). Modified atmosphere packaging provides many benefits for meat products ranging from shelf life to meat quality. For example, high oxygen atmospheres helps maintain a bright red, fresh beef color (McMillin, 1996). After 8 d of display, visual color scores of samples packaged in PVC demonstrated they were more discolored than those packaged in high oxygen MAP (Raines, Hunt, & Unruh, 2006). Another method of packaging meat is in an impermeable bag under a vacuum which is called vacuum packaging. This method is used in the distribution of primal cuts and provides a means of prolonging the shelf life and palatability of the meat during extended periods of shipment and storage (Seideman & Durland, 1982). In addition, vacuum packaging reduces weight loss, preserves meat color, and enhances palatability due to controlled aging. Seideman and Durland (1982) found that by removing oxygen from the environment and replacing it with carbon dioxide, this packaging system is able to reduce product discoloration and retard off-odors and off-flavors; however, lactic acid bacteria generally become the predominant bacteria which can create a sour odor if stored too long. In conclusion, packaging material can be used to manipulate the Mb form and help extend product color and shelf life.

Color Measurements

The color of meat or other objects is the interaction between light, vision, the detector, and the object being viewed. For color to be detected, light must reflect off the object being viewed and return. When light strikes meat, it will be absorbed, reflected or scattered. The reflected light is what is perceived. To perceive color, a detector must be used that is capable of recognizing an object and translating the stimuli into a perception of color. A detector can be the human eye or instrument such as a colorimeter or spectrophotometer. These devices do not "see" color, but simply captures wavelengths of light reflected from an object such as meat and, in the case of the eye, relays this sensory input to the brain for interpretation (AMSA, 2012).

Visual Color Evaluation

According to the American Meat Science Association (2012), results from visual color panels are closely related to consumer perceptions of meat products. Two types of visual color panels include the consumer preference and trained descriptive evaluation. For the consumer preference, a hedonic scale is often used to evaluate how much consumers prefer the color and appearance in display. The trained descriptive evaluations use complex scales to better characterize the meat color evaluated over shelf life and/or assess the amount of discoloration. However, there are disadvantages associated with conducting visual panels. Human judgment, which is influenced by lighting, visual deficiencies of the eye, and appearance factors other than color, affects panelist repeatability leading to variability. To minimize variability, customized pictorial color standards and appropriate scales must be prepared for each color panel (AMSA, 2012).

Instrumental Color

The Meat Color Measurement Guidelines from the American Meat Science Association (1991) report that instrumental color measurements are used to provide objective results to support visual observations provide a basis for product acceptance or rejection, document color deterioration over time, and estimate the proportion of Mb states. Product color can be instrumentally measured either through pigment extraction or reflectance. The reflectance color measurement method is a more rapid approach that can be used repeatedly on the same samples. Numerous spectral ratios and differences estimate Mb derivative quantities, show pigment changes, and describe color. Instrumental data must be used to represent relative color differences as opposed to "absolute" descriptions of color. Reflectance data can be reported as CIE L*, a*, b*, values also known as L* (light), a*(red) and b*(yellow). Hue angle ($\tan^{-1}$b*/a*), a/b (a*/b*) and saturation index (($a^2 + b^2$)(½)) are calculations of instrumental data used to monitor discoloration. Lower values of a/b ratio and saturation and higher values of hue angle are indicators of discoloration (AMSA, 1991). To reduce light scatter, researchers commonly adjust reflectance data with K/S ratios. Illuminant A (average incandescent, tungstenfilament lighting, 2857 K) places more emphasis on the proportion of red wavelength and is recommended for samples where detection of redness differences between treatments is the priority. Values of a* measured for Illuminant A will be larger than those for Illuminant C (average north sky daylight, 6774 K) and Illuminant D65 (noon day light, 6500 K). Illuminant A is recommended for measuring meat color (AMSA, 2012).

Relationship of Visual and Instrumental Color

Describing and evaluating color by humans is a very subjective practice. Consumers psychologically perceive color by a mixture of stimuli from three primary colors which can be measured in physical quantities (MacDougall, 1982). One study asked panelists to categorize beef M. longissimus dorsi steaks into one of 10 reference standards using visual color and compared those results with instrumental color measurements categorizing the steaks. Using L*, a*, and b*, instrumental measurements placed the steaks in the same category as visual observations 83.3 percent of the time (Goñi, Indurain, Hernandez, & Berian, 2007). Jeremiah, Carpenter, and Smith (1972) found 19 visual color descriptors correlated with C.I.E. instrumental value and chroma at 81 percent and 73 percent, respectively. In conclusion, measuring color either by visual panel or instrumental is correlated and valuable in characterizing meat discoloration.

Ground Beef Palatability

The complexity (Bett, 1933; Chambers & Bowers, 1993) of ground beef creates both opportunities and difficulties when investigating palatability. Many properties of ground beef have been varied to determine effects on palatability (Bentleys, Reagan, & Miller, 1989; Berry, 1980b; Hanenian, Mittal, & Usborne, 1989; Troutt et al., 1992a,b). Considerable interaction occurs between processing and physical properties (Berry, 1994a; Berry & Stiffler, 1981; Li-chan, Nakai, & Wood, 1985; Ray, Parrett, VanStavern, & Ockerman, 1981).

Flavor, juiciness and tenderness had been reported by various researchers as the main drivers for beef consumer acceptability (Morgan et al. 1991; Neely et al. 1998), but both flavor and texture are major properties that include a wide range of attributes. Consumers primarily purchase beef because of its flavor and texture. Ground beef is less palatable and satisfying when fat decreases (Law, Beeson, Clark, & Mullins, 1965; Mize, 1972; Cross, Berry, & Wells, 1980; Berry and Leddy, 1984b; Kregal et al., 1986), especially when fat is reduced to 5-10% (Troutt et al., 1992b). Cross, Green, Stanfield, and Franks (1976) investigated the effects of different cut and grade combinations on the palatability of ground beef. Both grade and cut affected aspects of palatability including tenderness, flavor, connective tissue amount, and overall acceptability, but not juiciness. Fruin and Van Duyne (1962) reported palatability differences in ground beef prepared from the chuck and round from U.S. commercial or standard carcasses. Quality grade had no effect on palatability. However, panelists preferred ground beef from chucks over ground beef from rounds. In summary, consumer's acceptability of a meat product is greatly influenced by the product flavor, juiciness, tenderness, and texture.

Fat Source and Level

Fat content has been positively associated with palatability in ground beef; as fat increases, overall palatability improves. Palatability attributes studied include juiciness (Barbut & Mittal, 1995; Troutt et al. 1992a), flavor (Berry, 1994a), tenderness (Berry & Leddy, 1984a), overall desirability (in consumer panel studies)(Bowers & Engler, 1975; Chabers & Bowers, 1993), and lower shear force (Brady &Hunecke, 1985; Cross et al., 1980). However, some studies have not found differences in palatability at the fat levels studied or even reversed the normal assumptions on tenderness (Berry & Abraham, 1994). However, it is generally accepted that ground beef patties made with very low-fat (<10 percent) will be less palatable than patties made with more than 20% fat. Consumers can select ground beef with decreased levels of fat, but such leaner products are often perceived to have decreased palatability. A certain level of fat is necessary to assure texture, mouth feel, tenderness, juiciness, flavor, appearance, and overall acceptability (Cole, Ramsey, & Odom, 1960; Berry & Leddy, 1984b; Pearson et al., 1987).

Formulations with higher levels of fat tend to cook faster than formations with less fat (AMSA, 1995). Fat also helps compensate for over cooking by the consumer.

Cooking Loss

Cross et al. (1980) found that as percent fat increased in raw patties fat loss during cooking also increased; however, total cooking loss was not significantly affected by fat level. Most of the weight loss in the low fat patty was due to water loss during cooking. Many consumers pay more for extra lean assuming that the extra lean product will shrink less during cooking than the regular ground beef. However, the regular patties only appear to loose more weight because the melted fat remains in the pan while the water loss is evaporated narrowing the difference between the regular and extra lean ground beef. Kendall, Harrison, and Dayton (1974) reported similar results. Patties with a lower fat formulation had a greater decrease in moisture content occur between the raw and cooked patties (Berry, 1992). Troutt et al. (1992b) found that cooking losses were lowest for 5-20% fat patties (24.7-26.0%), intermediate for 25% fat patties (28.9%), and highest for 30% fat patties (32.1%).

Juiciness

Juiciness has been defined as the amount of perceived juice released from the product during mastication and as fat is cooked and melted, it helps lubricates the muscle fibers adding to product moisture (AMSA, 1995). Patties containing 28% fat were significantly more juicy than patties containing 16% to 20% fat (Cross et al., 1980). Cole et al. (1960) also found that patties containing 35% fat were more juicy than patties containing 25% or 15% fat. Berry and Leddy (1984b) had ratings for juiciness that were higher (more juicy) for patties formulated to have 24% fat compared to patties with 14% fat. Ground beef containing 21% and 28.5% fat before heating was judged more juicy than patties containing 9.5% fat before heating (Kregal et al., 1986). In contrast, Kendall et al. (1974), McCormick, Kinsman, Riesen, and Taki (1981), Mize (1972) and Nielsen, Hall, Monsen, and Worthington (1967) found no effects of fat level on juiciness scores for ground beef. Troutt et al. (1992b) observed that as fat increased moisture release and juiciness significantly increased. Berry (1992) found that patty juiciness increased with increases in percent fat, but had similar values between 8 and 12% fat and between 16 and 20% fat. Other researchers observed that as fat levels in beef patties increased, they received improved juiciness scores but there were no differences between 5 and 10% fat in initial or sustained juiciness (Huffman & Egbert, 1990).

Mouth Coating

Sensory panel ratings for mouth coat were more pronounced for patties with 28% fat than at 16, 20, and 24% fat. However, the magnitude of these ratings does not suggest a consumer acceptance problem (Cross et al. 1980). Kregal et al. (1986) found that patties containing 9.5% fat before heating were scored lower for mouth coating compared to patties that were formulated for 21 and 28% fat before heating. Ground beef patties formulated by Berry and Leddy (1984b) to contain 19% fat were assigned scores for a lower amount of mouth coating than ground beef formulated to have 14 and 24% fat. Troutt et al. (1992b) observed that patties containing 5-10% fat caused the least oily coating of the mouth, and 30% fat patties had the highest scores for oily coat with 15, 20, and 25% being intermediate.

Flavor

Morgan et al. (1991) stated that beef flavor was a very important factor in determining overall palatability. Any flavors present that are not normally found in fresh, wholesome beef are deemed unfavorable, and consumers also regard any beef-eating experience in which uncharacteristic or undesirable flavors are detected as an unfavorable eating experience. Meat flavor can be influenced by several factors including species, breed, sex, age, nutrition, and stress of the animal (Sink, 1979). There are hundreds (≈ 700) of volatile compounds that contribute to beef flavor and aroma and many of these compounds can be altered through storage and cooking (Calkins & Hodgen, 2007) thus making meat flavor a complex object of study. In some studies, beef flavor has been measured as "overall flavor" intensity to evaluate how different treatments affected this broad attribute (Carmack, Kastner, Hunt, Kropf, Zepeda, & Schwenke, 1997; Baublits, Pohlman, Brown, Yancey, & Johnson, 2005; Rowe, Pohlman, Brown, Baublits, & Johnson, 2009; Hayes, Stepanyan, Allen, O'Grady, & Kerry, 2010). Yancey, Dikeman, Hachmeister, Chambers, and Milliken (2005) evaluated the variability in flavor characteristics of three types of beef muscle with differing maturing levels, marbling grades, and pH levels. Aging longer than 21 d generally decreased beef flavor intensity. A small degree of marbling generally resulted in a more rancid flavor compared with slight marbling, but marbling had no other appreciable effects on the flavor profile. Aging steaks for 35 d significantly increased the metallic flavor compared with aging for only 7 and 14 d. A trained sensory panel found that fat level (15, 20, 25, & 30%) had no effect on flavor in ground beef patties (Drake, Hinnergardt, Kluter, & Prell, 1975). Cross et al. (1975, 1980), Drake et al. (1975), Cole et al. (1960), Kendall et al. (1974), Berry and Leddy (1984b) and Nieslsen et al. (1967) also found no effects of fat level in ground beef flavor intensity or desirability. In contrast, Law et al. (1965) and Mize (1972) found more desirable flavor with higher fat levels in ground beef. Berry and Leddy (1984b) reported that patties with more fat had more intense beef flavor. Troutt et al. (1992b) found that patties with 5% fat had less intense beef flavor than all other fat levels (10, 15, 20, 25,

& 30%). Viljoen et al. (2002) indicated that the M. longissimus dorsi steaks from normal pH carcasses had meatier flavor than those from dark-cutting carcasses. Huffman and Egbert (1990) found that patties ranging from 5 to 20% fat did not differ in beef flavor intensity scores.

In summary, subprimal and grade affect final product palatability. As percent fat increases, there is an increase in cooking loss, juiciness, mouth coat and overall meat palatability. Furthermore, beef's distinct flavor created during cooking are very attractive but extensive aging can have negative effects on this flavor which can be greatly undesirable.

Tenderness

Because the tenderness of the meat products consumers' purchase is an important factor of their eating experience, developing, and comparing various sensory, mechanical, physical, and chemical methods for measuring tenderness have been a priority of many investigators over the years. Grinding is used to increase tenderness of beef, especially for lower value cuts. The texture and more uniform tenderness are factors that add to the popularity of ground beef in comparison to steaks and roasts.

Sensory Panel

As pointed out by Schultz (1957), chewing a piece of meat involves cutting, shearing, tearing, grinding, and squeezing. Instruments cannot duplicate all these actions. Forrest et al. (1975) stated that intramuscular lipids in beef steaks act as a lubricant in mastication, thus improving the apparent tenderness and easing the process of swallowing. Fruin and Van Duyne (1961), Kendall et al. (1974), and Nielsen et al. (1967) have shown minimal effects of increasing fat levels in ground beef on sensory rating for tenderness and/or texture. Tenderness scores increase with fat level as samples with 28% fat were judged more tender than patties with 9 and

21% fat (Kregal, 1986). Berry and Leddy (1984b) reported higher tenderness scores for broiled ground beef patties containing 24% fat compared to patties containing 14 and 19% fat. Patties were judged more tender because of less hardness, density, and cohesiveness during initial biting. Even though a decrease in the amount of fat resulted in lower tenderness sensory panel scores, initial tenderness values were similar between the 0 and 4%, 8 and 12%, and 16 and 20% fat levels (Berry, 1992). Cross et al., (1980) found that patties formulated to 16% fat were significantly tougher than patties containing 24-28% fat. Textural properties were influenced similarly by fat level regardless which of 6 methods of cookery was used (Berry & Leddy, 1984b) with increasing fat generally improving texture. However, no differences in tenderness were found by Huffman and Egbert (1990) with patties ranging from 5 to 20% fat levels.

Instrumental

Although subjective methods are generally time-consuming and sometimes variable, they are the basis of reference for most present-day tenderness methods. At testing, samples should all be at the same temperature. Room temperature is usually what is chosen as it is impractical to shear hot samples. Cold samples are slightly (5%) tougher than hot samples (Warriss, 2000). The most popular device used by present investigators is one developed by Warner (1928) and later tested by Bratzler (1932). The apparatus now known as the Warner-Bratzler shear, has been used by many investigators to measure tenderness of meat. Troutt et al. (1992) found that Instron Warner-Bratzler shear force and total energy values were highest for patties containing 5% fat. Other researcher showed that lower fat ground beef patties resulted in higher shear force values (Berry & Leddy 1984b).

Another mechanical apparatus was developed by Kramer (1951) for measuring tenderness of fruits and vegetables. This was a machine that used hydrolic pressure to force a series of metal plates through products held in a metal block. Refinement of the shear press called the L.E.E. Kramer shear press, has a sensitive dial pressure indicator that registers through providing ring placed between piston and plunger plates. Shannon et al. (1957) reported a correlation of 0.86 between Kramer shear press values and organoleptic panel scores of poultry meat. Wise (1957) reported a correlation of 0.89 between results obtained by a chew panel and Kramer shear values; while Baily et al. (1962) only found a 0.74 correlation between shears and sensory tenderness values. Patties with 25 and 30% fat had the lowest total energy values during shearing. Instron Lee-Krammer shear values were highest for patties with 5% fat. As fat increased, shear values decreased. Total energy values were highest in 5% fat patties and those values also decreased as fat increased (Berry & Leddy 1984b). Sharrah, Kunze, & Pangborn (1965) correlation coefficient between and within subjective and objective measurements showed that sensory scores for tenderness were slightly more highly correlated with the Warner-Bratzler than with either the conventional or modified Lee-Kramer instruments. Troutt et al. (1992b) reported that Warner-Bratzler and Lee-Kramer shear forces decreased as percentage of fat increased. Instron texture profile analysis also indicated greater peak forces, springiness, and cohesiveness for low-fat patties.

Hyldig and Nielsen (2001) defined texture as a sensory parameter only a human being can perceive, describe, and quantify. However, texture profile analysis is an instrumental texture assessment made by means of a texturometer, which allows the measurement of tissue resistance to both shearing and compression through the graphing of a double compression cycle. Hardness is the peak force during the first compression cycle (“first bite”). Cohesiveness is the ratio of the peak force area during the second compression to the peak force area during the first compression (Area2 / Area1). Springiness (originally elasticity) is the height that the food recovers during the time elapsed between the first compression and the start of the second compression. Gumminess is the product of hardness and cohesiveness. Chewiness is the product of gumminess and springiness (Bourne, 1978). Instron texture profile analysis indicated patty hardness was higher for 5 and 10% fat levels than for 15% fat or higher. Second compression peak force values also were higher in patties formulation for 5% fat. Patties containing 25 and 30% fat had lower springiness values than all other patties. Those containing 5% fat were more cohesive than all other patties which were similar in cohesiveness (Berry & Leddy 1984b). In addition, Troutt et al. (1992b) found that for texture profile analysis patties lower in fat had greater peak forces, springiness, and cohesiveness.

In conclusion, the measurement and understanding of tenderness differences in meat is one of the most important palatability factors scientists try to understand because of its direct impact on consumer’s eating experience. Sensory panels are very valuable at scoring the tenderness and palatability traits of different meat products; however, this method is restricted by panel limitations and fatiguing during sampling. Instrumental tenderness can also be used as an objective to measure and compare differences between samples.

Chapter 3 - Effect of Subprimal, Quality Grade, and Aging on Display Color of Ground Beef Patties

Abstract

A factorial arrangement of treatments was used to evaluate the effects of two subprimal types (chuck roll and knuckle), two quality grades (Premium Choice and Select), and three vacuum storage aging times before processing (7, 21, and 42 d) on ground beef patty display color stability and sensory attributes. At the end of each aging time, four knuckles or two chuck rolls representing their respective quality grade categories were combined and ground to form a sample batch. After a final grind, patties were formed using a patty machine, packaged in overwrapped trays, and displayed in a coffin-type retail case under continuous fluorescent lighting. Ground beef patties from chuck roll and Premium Choice subprimals had brighter red visual color scores, less discoloration, and higher ($P<0.05$) L*, a*, b*, and chroma values than those from knuckle and Select subprimals, respectfully. With increased display time, patties became ($P<0.05$) darker red and more discolored and had decreased L*, a*, b*, a/b ratio, and chroma values and increased hue angle values. Ground beef patties from Select knuckle subprimals had greater ($P<0.05$) oxygen consumption rate (OCR) than those from Premium Choice chuck roll, Select chuck roll and Premium Choice knuckle subprimals. Patties from subprimals aged 42 d had a lower metmyoglobin reducing ability (MRA) than those from subprimals aged 7 and 21 d. Greater aging and display times had higher ($P<0.05$) aerobic and lactic acid plate counts. In addition, thiobarbituric acid reactive substances values increased ($P<0.05$) from 7 to 21 d of aging and from 0 to 24 h of display. Overall, Premium Choice chuck rolls aged for fewer days would result in the most color stability and extended display life.

Introduction

Ground beef is the most commonly consumed beef product in the United States (USDA, 2009). The average American consumer eats 71 kg of red meat per year, and of this, 12.7 kg is ground beef (Haney, 2012; American Meat Institute, 2004). Historically, the source of ground beef comes from lower quality cuts, trimmings from subprimals, and subprimals from cull cows; however, alternative grinds from whole and/or premium quality subprimals are becoming more popular with consumers and creating greater demand as a distinctive menu item (Horovitz, 2009).

Consumers use color as a major criteria in selecting meat products (Kropf, 1993) and they associate a bright red color with freshness and wholesomeness (Jenkins & Herrington, 1991). Display life of ground beef is an economically important factor in the retail industry. Longer display life without discoloration results in more opportunities for sale and fewer discounts and/or reworks. Oxygen consumption is an inherent property of meat where a series of reactions, principally involving the Kreb cycle enzymes, consume (scavenge) oxygen in meat. During retail display, oxygen consumption is related to the deoxygenation of oxymyoglobin (OMb) and the further decrease of oxygen level to zero, allowing the reduction of metmyoglobin (MMb) to deoxymyoglobin (DMb) (AMSA 2012). The deeper the OMb layer, the longer it takes for the sub-surface MMb to move upward and impact the hue and discolor the meat. Oxygen consumption rate (OCR) is also related to meat color stability. Atkinson and Follett (1973) concluded that high OCR is a defining characteristic of muscles with low color stability. Metmyoglobin reducing ability (MRA) is an inherent property of meat where a series of reactions help reduce MMb and is essential for meat color stability during display because the presence of MMb on meat surface is very undesirable to consumers (Mancini & Hunt, 2005).

Muscles from different subprimals can possess different properties and influence the display life of meat products. Madhavi & Carpenter (1993) found that surface MMb accumulation, MRA, and OCR were affected by muscle type in which a color stable muscle (M. longissimus dorsi) had lower MMb accumulation, higher MRA, and lower OCR than a color labile muscles (psoas major). Furthermore, other researchers also found that the rate of metmyoglobin accumulation on the surface of beef is muscle dependent (Hood, 1971; MacDougall & Taylor, 1975; O'Keeffe & Hood, 1980). McKenna, Miles, Baird, Pfeiffer, Ellebracht, and Savell (2005) studied the biochemical properties of 19 beef muscles and found that those with high color stability had the highest MRA while very low stability muscles had the least MRA. These researchers also suggested that the amount of MMb formed initially on the surface of the muscles was inversely related to color stability and a good or better indicator of color stability than the amount of MMb reduced over time (McKenna et al., 2005).

Higher quality subprimals such as Premium Choice subprimals have increased intramuscular fat and differences in fatty acid composition (Turk and Smith, 2009). Researchers have reported that ground beef containing higher fat levels (>15%) have brighter red color (Mancini, 2001; Troutt et al., 1992b; Shivas, Kropf, Hunt, Kastner, Kendall and Dayton, 1984; Liu, Huffman, Egbert, McCoskey & Liu, 1991; Kregal, Prusa & Hughes, 1986) and less discoloration than higher lean (>90%) ground beef (Liu et al., 1991; Kregal et al., 1986). In addition, higher fat ground beef had greater brightness (L*) values than higher lean ground beef (Mancini, 2001; Liu et al., 1991; Troutt, Hunt, Johnson, Claus, Kastner, Kropf, & Stroda, 1992b).

Vacuum-packaged subprimals can be stored for extended lengths of time and later utilized for ground beef. The time postmortem at which subprimals are ground can vary based on the accessibility and marketing of these subprimals. Madhavi and Carpenter (1993) found that surface MMb accumulation, MRA, and OCR were affected by post-mortem aging. They determined that steaks fabricated at 4 or 7 d postmortem were more color stable than those fabricated at 0, 1, 2, 14 or 21 d postmortem (Madhavi & Carpenter, 1993). As meat ages, it blooms to a greater extent because a thicker layer of oxymyoglobin is formed and the rate of oxygen consumption is lowered as substrates in the glycolytic cycle are exhausted, which allow oxygen to penetrate faster and further into the tissue (MacDougall & Rhodes, 1972). MacDougall and Taylor (1975) reported that OCR was high in the first 2 d following slaughter but declined as postmortem age increased due to decreased respiration as depletion of substrate and/or enzyme degradation occurred. This supports other studies which found that oxygen consumption rate decreased over time (Tang et al., 2005) up to 48 h postmortem (Lanari & Cassens, 1991). MacDougall and Rhodes (1972) suggest that as meat ages there is a faster accumulation of metmyoglobin resulting from the diminution of the meat's enzymic activity which occurs during aging. Metmyoglobin formed in the region of low oxygen tension is no longer reduced back to myoglobin because the reducing intermediates (particularly reduced form of nicotinamide adenine dinucleotide or NADH) are no longer being formed. Other researchers found that during display in traditional polyvinyl chloride (PVC) packaging, discoloration increases and MRA decreases on the surface of beef steaks, whereas the interior remains deoxygenated and thus, may have somewhat different color chemistry than the surface (Sammel et al., 2002b; Seyfert, Mancini, Hunt, Tang, Faustman, & Garcia, 2006). Furthermore, Mancini et al. (2002b) found that increased storage (0-12 d) and display time (0–48 h) of ground beef significantly increased microbial counts but lean level (7/93, 19/81, & 27/73) had no effect. McKenna et al. (2005) found that thiobarbituric-acid reactive substances (TBARS) values increased with increasing days of retail display and reported that less color stable muscles have higher TBARS values.

Therefore, the objective of this study was to determine the effects of two subprimal types (chuck rolls and knuckles representing estimated fat percentages of 20 % and 10%, respectfully), two quality grades (Premium Choice and Select), and vacuum storage aging time (7, 21, and 42 d) before processing on ground beef patty display color stability.

Material and Methods

Product Selection and Manufacture

A total of 72 Chuck Roll (116A) and 144 Peeled Sirloin Tip Knuckle (167A) subprimals from Select and Premium Choice (upper 2/3's of Choice) quality grade categories were obtained from a commercial processing facility. The experiment was conducted in two equal replications from product randomly selected from two different days of production. Upon arrival at the Kansas State University meat laboratory, subprimals for each replication were then randomly assigned to an aging time of 7, 21, or 42 days post-packaging and remained in their individual vacuum bag until the end of the aging period (0 ± 1ºC). Abnormal cuts or leaking bags were eliminated from the study. Each treatment combination [subprimal types (n=2) × quality grades (n=2) × aging times (n=3)] was replicated 6 times. At the end of each aging time, four knuckles (16.10 ± 1.81 kg) or two chuck rolls (19.87 ± 1.76 kg) representing their respective quality grade categories were combined and ground to form a sample batch. Each sample batch was weighed on an Ohaus Scale (Ohaus Corporation, Model T51P, Pin Brook, NJ) before being ground using a Hobalt Grinder (Hobalt MFG, Co. Troy, Ohio Serial 1865825 Model 4732) through a 0.95

cm grinding plate followed by a fine grind using a 0.32 cm grinding plate. Samples weighing approximately 200, 125, and 30 g were removed and placed into sterile bags (Whirl pack, Nasco, Modesta, CA) for proximate analysis, initial thiobarbituric acid reactive substances (TBARS), and myoglobin concentration, respectfully. Ground beef patties were made using a Hollimatic patty machine (Patty Maker, Super model 54 Food Portioning Machine, Hollymatic Corporation, Countryside, IL, Serial 61281) to form 0.11 kg patties that were 10.8 cm in diameter and 1.3 cm thickness.

Nine patties per sample were randomly selected, individually placed on 12.7 × 12.7 × 1.3 cm Styrofoam trays (1S, Cryovac Sealed Air, Duncan, SC), and wrapped with an oxygen permeable PVC overwrap (Prime Source, oxygen transmission rate 0.6g/254cm^2/24 h at 0ºC; water vapor transmission rate 0.6cc/254cm^2/24 h at 0ºC and 0% relative humidity).

Retail Display

Ground beef patties in overwrapped trays were placed in display for visual color and instrumental color and 24 h TBARS, metmyoglobin reducing ability (MRA), oxygen consumption rate (OCR), and microbiology sampling. Ground beef patties were placed into a coffin-type retail display case (Unit Model DMF8, Tyler Refrigeration Corp., Niles, MI) under continuous fluorescent lighting (3500K, 2,140 lux and CRI=85, Bulb Model F32T8 / ADV830 / Alto, Phillips, Bloomfield, NJ) at 2°C. Cases were defrosted two times per day at 12 h intervals. Case temperatures were monitored throughout the study using OMEGA RD-Temp-XT loggers (Stamford, CT). Four temperature loggers were placed in each case on the far left, far right, center top, and center bottom. Temperatures were recorded every 10 min throughout the study. During the study, display case temperature averaged 2.23 ± 1.08ºC. The location of the packaged patties was rotated daily within the case to minimize case-location effects.

pH

The meat pH of each sample was measured on 0 d by inserting a standardized pH probe (Hanna Instruments; H199163; Woonsocket, RI) attached to an Accumet Basic pH Meter (Fisher Scientific, Pittsburgh, PA) into the sample at two locations.

Myoglobin Concentration

Myoglobin concentration was measured using the methods by Warriss (1979) and Krzywicki (1982), and calculations were made using equations from Tang, Faustman, and Hoagland (2004). Eight total composite samples were created for measuring total pigment (Premium Choice chuck rolls, Select chuck rolls, Premium Choice knuckles, and Select knuckles from each replication). Samples were submersed into liquid nitrogen, pulverized in a Waring commercial blender (model 51BL32, Waring commercial, Torrington, Connecticut), poured into a clean sample bag (Whirl-Pak, Nasco, Modesta, CA), and stored at -80°C until the analyes were completed (with in 30 d).

Duplicate 5 g samples were suspended in 25 mL of ice cold phosphate buffer (pH 6.8, 0.04 M) in 50 mL centrifuge tubes. The samples were mixed, held in ice (0 – 4°C) for 1 h, and centrifuged (Beckman Coulter, model J2-21, Brea California) at 15,000 × g for 30 min at 5°C. A 3 mL sample was removed and filtered through a 0.45 nm filter (Nalge Nunc International, Rochester, NY) into a spectrophotometer cuvette (Fisher Scientific Disposable Plastic Cuvette, Pittsburg, PA , Semimicro Style Methacrylate, 10mm lightpath,1.5 mL). Individual absorbances were taken at 503, 525, 557, 582, and 700 nm using a Hitachi spectrophotometer (U-2010, Schaumburg, Illinois) against a blank that contained only the phosphate buffer. Total myoglobin (mg/ml) and myoglobin concentration (mg/g meat) were calculated.

Proximate Analysis

Proximate analysis samples (200 g) were pulverized in a Waring commercial blender (model 51BL32, Waring commercial, Torrington, Connecticut), placed into a clean sample bag (Whirl-Pak, Nasco, Modesta, CA), and stored at -80°C until the analyes were completed. Moisture and fat content were determined by following the AOAC Official Method PVM-1:2003 using the CEM automatic fat extractor and CEM automatic volatility computer (Instrument: CEM SmarTrac System, Matthews, NC). Protein was determined following the AOAC Official Method 990.03 with a Leco protein analyzer (LECO FP-2000, St. Joseph, MI).

Visual Color Evaluation

All visual panelists were selected from those who passed the Farnsworth-Munsell 100-Hue Test for color blindness and their ability to detect differences in hue. Panelists were oriented prior to the initiation of the study to the scoring ballot and trained with ground beef patty samples and pictorial references. A minimum of 6 trained color panelists evaluated patty color to the nearest 0.5 using 8-point scales. Panelists evaluated the patties initial color, visual color, and discoloration. Initial ground beef color was evaluated on d 0 using a scale of 1 to 8 with: 1 = Very light red; 2 = Moderately light red; 3 = Light red; 4 = Slightly bright red; 5 = Bright red; 6 = Slightly dark red; 7 = Moderately dark red; and 8 = Dark red. Visual color and discoloration of ground beef patties were evaluated after 0, 1, 2, and 3 d of display using a scale of 1 to 8 with: 1 = Extremely bright cherry-red; 2 = Bright cherry-red; 3 = Moderately bright cherry-red; 4 = Slightly bright cherry-red; 5 = Slightly dark cherry-red; 6 = Moderately dark red; 7 = Dark red; and 8 = Extremely dark red for visual color and 1 = Very bright red; 2 = Bright red; 3 = Dull red; 4 = Slightly dark red; 5 = Moderately dark red; 6 = Dark red to tannish red; 7 = Dark reddish tan; and 8 = Tan to brown for visual discoloration. Daily display color scores from panelists were averaged for statistical analysis.

Instrumental Color

One ground beef patty package from each sample was analyzed for CIE L*, a*, and b*, and for reflectance from 400 to 700 nm using a HunterLab MiniScan™ EZ (Model 4500; MSEZ0115; Reston, VA) with Illuminant A, with an aperature of 31.8 mm and a 10° Observer. Three measurements were taken and averaged for each patty. Hue angle, saturation index and a/b ratios were calculated from $\tan^{-1} b/a$, $(a^2 + b^2)^{1/2}$, and a/b, respectfully. Measurements were taken at 0 h of display and every 8 h thereafter until 88 h of display.

Oxygen Consumption Rate

Oxygen consumption rate (OCR) was determined according to a modified procedure of Madhavi and Carpenter (1993). Two, 5.1 cm diameter core samples were removed from the ground beef patty and placed in a 5.1 cm diameter × 1.3 cm deep circular form. The duplicate samples were then placed in a 15.2 × 30.5 cm vacuum bag Prime Source Vacuum Pouch (Prime Source Vacuum Pouches; 3mil, STP Barrier, Nylon/PE Vacuum Pouch; oxygen transmission rate 0.04g/254cm2/24 h at 0ºC; water vapor transmission rate 0.2cc/254cm2/24h at 0ºC at 0% relative humidity) sealed down the center with a seal bar and vacuum sealed with a GS Multivac (Multivac Inc., Kansas City, MO Model A-300-116). Immediately after vacuum packaging, three color measurements were taken per duplicate sample for reflectance from 400 to 700 nm using a HunterLab MiniScan™ EZ (Model 4500; MSEZ0115; Reston, VA) with Illuminant A, with an aperature of 31.8 mm and a 10° Observer. The samples were placed in a Boekel incubator (Boekel Industries, Model 132000, Feasterville, PA) set at 25ºC and were rescanned at

20 min time intervals for 1 h. Color standards were made following the AMSA Color Guidelines (2012) and used to calculate percent oxymyoglobin, decrease in percent oxymyoglobin over 20, 40, and 60 min, and rate of reduction of oxymyoglobin per minute.

Metmyoglobin Reduction Ability

Metmyoglobin reducing ability (MRA) was determined according to Watts et al. (1966) as modified by Sammel et al. (2002b). Two, 5.1 cm diameter core samples were removed from each ground beef patty and placed in a 5.1 cm diameter × 1.3 cm deep circular form. The samples were then placed in a metal mesh screen and submerged in a 0.3% $NaNO_2$ solution for 20 min. The duplicate samples, still in their circular form, were placed in a 15.2 × 30.5 cm vacuum bag (Prime Source Vacuum Pouches; 3mil, STP Barrier, Nylon/PE Vacuum Pouch; oxygen transmission rate 0.04g/254cm2/24 h at 0ºC; water vapor transmission rate 0.2cc/254cm2/24h at 0ºC at 0% relative humidity), sealed down the center with a seal bar, and vacuum sealed with a GS Multivac machine (Multivac Inc., Kansas City, MO Model A-300-116). Immediately after vacuum packaging, three color measurements were taken per duplicate sample for reflectance from 400 to 700 nm using a HunterLab MiniScan™ EZ (Model 4500; MSEZ0115; Reston, VA) with Illuminant A, with an aperature of 31.8 mm and a 10° Observer. Samples were placed in a Thelco incubator (Percision scientific, Model 31488, GCA Corporation, Chicago, IL) set at 30ºC and rescanned at 60 and 120 min. Color standards were made following the AMSA Color Guidelines (2012) and used to calculate percent metmyoglobin, decrease in percent metmyoglobin over 60 and 120 min, and rate of reduction of metmyoglobin per minute.

Color Standards for Metmyoglobin Reducing Ability and Oxygen Consumption Rate

Color standards for each subprimal type × quality grade combination were created at 48 h after grinding using AMSA Color Guidelines (2012). These standards were used in the formulas for MRA and OCR. To form deoxymyoglobin, ground beef patties were left in a vacuum package for 48 h and then scanned using a HunterLab MiniScan™ EZ (Model 4500; MSEZ0115; Reston, VA) with Illuminant A, with an aperature of 31.8 mm and a 10° Observer. For oxymyoglobin, the ground beef samples were left in high oxygen packaging (99.8% oxygen) for 24-48 h and then scanned. Finally, the metmyoglobin was formed by submerging the patties into a 1.0% potassium ferricyanide solution for 1 min, removed from the solution and blotted the surfaces of the patties with a paper towel. Patties were then placed on a 12.7×12.7 cm Styrofoam tray, covered with an oxygen-permeable film, held at 2-4ºC for 24 h and scanned. Before color measurements were taken, the HunterLab MiniScan™ EZ was standardized with a 15.2 × 30.5 cm Prime Source Vacuum Pouches used for both the MRA and OC procedures.

Microbial analysis

Microbial samples were evaluated at 0 and 24 h of display. Packages were aseptically opened and 25 g of the ground beef patty was removed, placed in a filter bag (FILTRA-BAG, no. 01-002-57, Fisher Scientific, Pittsburg, PA), and stomached (Stomacher 400 Lab Blender, Seward Medical, London, UK) with 225 mL of 0.1% peptone diluents (Bacto Laboratories Pty Ltd; Mt Pritchard, NSW, Australia 2170) for 1 min. Each sample was serial diluted in 0.1% peptone water and dilutions were plated in duplicate. Populations were determined using Aerobic Plate Count (APC) Petrifilm^{TM} (3M Microbiology Products, St. Paul, MN). In addition, to determine anaerobic lactic acid population, a second set of duplicate APC Petrifilms were plated for each sample and placed in an acrylic medium canister (Main Stays Home, Walmart

Stores, Inc Bentonville, AR) with a AGS CO_2 gas producing pack (OXOID Atmosphere generation system, McCurtain Hill, Clonakilty, Co. Cork, Ireland). All plates for APC populations were incubated (VWR symphony, Radnor, PA) at 35ºC for 48 h prior to enumeration.

Thiobarbituric Acid Reactive Substances (TBARS)

Lipid oxidation was measured using thiobarbituric acid reactive substances (TBARS) values according to the method of Siu and Draper (1978). The top layer (0.32 cm) of the sample was removed, frozen in liquid nitrogen, pulverized in a Waring commercial blender (model 51BL32, Waring commercial, Torrington, Connecticut), and placed into a clean sample bag (Whirl-Pak, Nasco, Modesta, CA) and stored at -80°C until the TBARS analysis were completed within 30 d of grinding. The reagent used was a TBA stock solution containing 0.375% thiobarbituric acid, 15% trichloroacetic acid, and 0.25N HCl (Fisher Scientific, Pittsburg, PA). Duplicate 0.5 g pulverized samples and 2.5 mL of the TBA stock solution were placed in a 15 ml centrifuge tube and placed in a boiling water bath for 10 min. Tubes were cooled in tap water and centrifuged (Beckman Coulter, model J2-21, Brea California) at 5,000 × g for 10 min to obtain a clear supernatant. The clear supernatant was removed and filtered through a Whatman syringeless filter device (.45µm, Nalge Nunc International, Rochester, NY) into a spectrophotometer cuvette (Fisher Scientific Disposable Plastic Cuvette, Pittsburg, PA, Semimicro Style Methacrylate, 10 mm lightpath,1.5 mL). The absorbance was then measured at 532 nm using a Hitachi spectrophotometer (U-2010, Schaumburg, Illinois) against a blank that contained all the reagents minus the sample.

Statistical Analysis

The basic experimental design was a completely randomized block design with 12 treatments (n=6) arranged in a 2 × 2 × 3 factorial with two subprimal types (chuck roll and knuckle), two quality grades (Premium Choice and Select), and three aging times (7, 21, and 42 d) with replications (n=2) as the block. This model was used to analyze pH, myoglobin concentration, proximate analysis, and initial color. For visual color, instrumental color, microbiology, TBARS, OCR, and MRA data, display time was used as a repeated measure.

All sets of data were analyzed using the PROC MIXED procedure in SAS (SAS 9.2, Institute Inc., Cary, NC). The Satterthwaite method in MIXED was used to calculate the denominator degrees of freedom. The model statement included the measured trait and all possible interactions among subprimal type, quality grade, and aging time as well as display time when applicable. Tests were conducted at a significance level of $P<0.05$ and main effect and interaction means were separated by least significant difference (LSMEANS) when their respective F-tests were significant ($P<0.05$). Linear and quadratic effects were determined using PROC GLM for appropriate interaction means when the display time interaction was significant. Selected correlations were performed using the PROC CORR procedure of SAS to evaluate relationships among microbiology, TBARS, OCR, MRA, and visual and instrumental color variables measured on ground beef patties over display time.

Results and Discussion

Subprimal Characteristics

pH

Main effect means for subprimal type, quality grade, and aging time are reported in Table 3.1. A subprimal type × quality grade interaction ($P<0.05$) was observed for the percentages of moisture and fat (Table 3.2). Ground beef patty pH values were similar ($P>0.05$) for subprimal type and quality grade, but pH at 42 d of aging was higher ($P<0.05$) than at 7 and 21 d of aging. Recorded values were slightly higher than those found by Troutt et al. (1992) who recorded the pH of lean knuckles to be approximately 5.5 and did not differ among different fat levels. In addition, Anderson et al. (2012) found muscle pH at 24 h postmortem to be 5.61 for the longissimus dorsi, 5.53 for the vastus lateralis, and 5.77 for the vastus intermedius. Sutherland, Patterson and Murray (1975) found that pH of vacuum aged M. longissimus dorsi muscles increased from 3 (5.8) to 6 (6.05) weeks of storage.

Myoglobin Concentration

Ground beef patties from chuck roll subprimals had lower ($P<0.05$) myoglobin concentrations and lower ($P<0.05$, lighter) initial color scores than patties from knuckle subprimals. However, ground beef patties from Premium Choice (Modest marbling or higher) subprimals had similar ($P>0.05$) myoglobin concentration and ($P<0.05$) lower initial color scores (lighter red) than those from Select (Slight marbling) subprimals. In addition, ground beef patty initial color was highest ($P<0.05$, brighter red) at 42 d of aging and lowest at 21 d of aging. McKenna at. el. (2005) identified that muscles with high color stability had low myoglobin content and those with low color stability had high myoglobin content. Furthermore, Troutt et al. (1992) reported that as fat level decreased the patties initial color score was darker.

Proximate Analysis

As expected, percentages of moisture, fat and protein were similar (P>0.05) among the three aging times. However, ground beef patties from knuckle subprimals had a greater (P<0.05) percentage of protein than those from chuck roll subprimals and ground beef patties from Select subprimals had a greater (P<0.05) percentage of protein than those from Premium Choice subprimals. In a subprimal type × quality grade interaction (P<0.05), ground beef patties from knuckle and Select subprimals had (P<0.05) higher percentages of moisture and lower percentages of fat than those from chuck roll and Premium Choice subprimals, respectfully. Troutt et al. (1992) reported similar results in which percent moisture decreased as the fat level increased, percent fat increased as the fat level increased, and percent protein decreased as the fat level increased.

Color Panel Scores

Visual Color

Main Effect. For visual color, ground beef patties from Premium Choice subprimals (5.0) had lower visual color scores (brighter red) than those from Select subprimals (5.5, SE = 0.06).

Subprimal type × Aging time × Display time. A subprimal type × aging time × display time interaction (P<0.05) was observed (Figure 3.1) for visual color with all subprimal type × aging time treatments linearly (P<0.05) increasing (becoming darker red) over display time. When comparing hours of display, the ground beef patties at 0 h of display had the lowest

($P<0.05$, bright red) visual color scores and at 72 h of display the color scores were the highest ($P<0.05$, dark red). In addition, ground beef patties from chuck roll subprimals aged 21 and 42 d and knuckle subprimals aged 42 d had lower ($P<0.05$, brighter red) color scores at 24 h of display than at 48 h of display.

At 0, 24, and 48 h of display, ground beef patties from chuck roll subprimals at all aging times (7, 21, and 42 d) were brighter ($P<0.05$) red than those from knuckle subprimals at all aging times. Also, at 0 h of display, ground beef patties from chuck roll subprimals aged 7 d had a brighter ($P<0.05$) red color than those from subprimals aged 21 and 42 d and patties from knuckle subprimals aged 7 and 21 d had a brighter ($P<0.05$) red color than those from subprimals aged 42 d. At 24 h of display, ground beef patties from chuck rolls subprimals were similar ($P>0.05$) among all aging times and brighter ($P<0.05$) red than patties from knuckles subprimals which were similar ($P>0.05$) among all aging times. At 48 h of display, ground beef patties from chuck roll subprimals aged 7 d were the brightest ($P<0.05$) red color and those at 42 d were ($P<0.05$) the darkest. In addition, at 48 h of display, ground beef patties from knuckle subprimals aged 7 and 21 d were brighter ($P<0.05$) red than those from subprimals aged 42 d. At 72 h of display, ground beef patties from chuck roll subprimals aged 7 and 21 d had the brightest ($P<0.05$) red color and patties from knuckle subprimals aged 21 and 42 d and the darkest ($P<0.05$) red color.

Summary. Overall, patties from chuck roll subprimals were brighter than those from knuckle subprimals. Furthermore, for the chuck roll, patties from subprimals aged 42 d were darker than those from subprimal aged 7 and 21 d later in display.

Discoloration

Main Effect. For discoloration, ground beef patties from Premium Choice subprimals (4.4) had lower discoloration scores (less discoloration) than those from Select subprimals (5.1, SE = 0.12).

Subprimal type × Aging time × Display time. A subprimal type × aging time × display time interaction ($P<0.05$) was observed (Figure 3.2) for discoloration with all subprimal type × aging time treatments linearly ($P<0.05$) increasing (becoming more discolored) over display time. When comparing hours of display, ground beef patties at 0 h of display had the lowest ($P<0.05$, least discolored) scores and ground beef patties displayed 72 h had the highest ($P<0.05$) discoloration scores. In addition, patties from chuck roll subprimals aged 21 and 42 d and knuckle subprimals aged 7, 21, and 42 d had ($P<0.05$) less discoloration at 24 h of display than those displayed 48 h.

At 0 h of display, ground beef patties from chuck roll subprimals aged 7 d had the least ($P<0.05$) discoloration and patties from knuckle subprimals aged 21 and 42 d had the most ($P<0.05$) discoloration. In addition, patties from the chuck roll subprimals aged 21 d had less ($P<0.05$) discoloration than patties from knuckle subprimals aged 7 d. At 24, 48, and 72 h of display, ground beef patties from chuck roll subprimals at all aging times (7, 21, and 42 d) had less ($P<0.05$) discoloration than those from knuckle subprimals at all aging times. Also, at 24 h of display, ground beef patties from chuck roll subprimals aged 7 d had less ($P>0.05$) discoloration than those aged 42 d and discoloration of ground beef patties from knuckle subprimals. At 48 h of display, ground beef patties from chuck roll subprimals aged 7 d had the least ($P<0.05$) discoloration and those aged 42 d the most ($P<0.05$) discoloration. Also, at 48 h of display patties from knuckle subprimals aged 7 d were less ($P<0.05$) discolored than those from subprimals aged 42 d. At 72 h of display, ground beef patties from chuck roll subprimals aged 7 d had the least ($P<0.05$) discoloration and those from subprimals aged 42 d had ($P<0.05$) the most discoloration. Ground beef patties from knuckle subprimals aged 7 d were less ($P<0.05$) discolored than those from subprimals aged 21 and 42 d.

Summary. Overall, patties from chuck roll subprimals were less discolored than those from knuckle subprimals. Furthermore, for the chuck roll, patties from subprimals aged 42 d were less discolored than those from subprimal aged 7 and 21 d later in display.

Relationship of visual color and discoloration

Overall, patties from chuck roll subprimals were brighter and less discolored than those from knuckle subprimals. Furthermore, for the chuck roll patties from subprimals aged 42 d were darker and less discolored than those from subprimal aged 7 and 21 d later in display. Previous work has demonstrated that ground beef containing lower lean percentages had brighter red color (Mancini, 2001; Troutt et al., 1992b; Shivas, Kropf, Hunt, Kastner, Kendall and Dayton, 1984; Liu, Huffman, Egbert, McCoskey & Liu, 1991; Kregal, Prusa & Hughes, 1986) and less discoloration than higher lean ground beef (Liu, Huffman, Egbert, McCoskey & Liu, 1991; Kregal, Prusa & Hughes, 1986). However, Mancini (2001) found visual color score changes in discoloration due to lean level were relatively small and not likely practical and others reported that display color stability was not affected by lean level (Govindarajan & Hultin, 1977; Troutt et al., 1992b).

If a visual and discoloration score of 5 was set as the threshold of consumer acceptability, patties from chuck roll subprimal aged 7 and 21 d would have 48 more hours of shelf life than patties from knuckle subprimals from all aged times (which passed the threshold after 24 h of display) and 24 more hours of shelf life than patties from chuck roll subprimals aged 42 d (which passed the threshold after 48 h of display). Discoloration of meat products leads to discounting or discarding the products resulting in large revenue losses, therefore, profit can be increased by extending the time product can be on the shelf (Smith, Belk, Sofos, Tatum & Williams, 2000).

A relationship was observed in which visual color and discoloration for ground beef patties were correlated for the chuck roll at 0 and 24 h of display and the knuckle at 0 and 24 h of display (0.84, 0.84, 0.77, and 0.77, respectfully). Furthermore, initial color was correlated with visual color for ground beef patties from chuck roll and knuckle subprimals at 0 h of display (0.67 and 0.81, respectfully). A negative correlation was found for discoloration for ground beef patties from knuckle subprimals at 0 h of display (-0.62).

Instrumental Color

For instrumental color, a subprimal type × aging time × display time interaction ($P<0.05$) was detected for a* and chroma. In addition, subprimal type × display time and aging time × display time interactions ($P<0.05$) were observed for L*, b*, a/b ratio, and hue angle. A quality grade × display time interaction was detected for b*, a/b ratio, and hue angle. Therefore, data are presented as subprimal type × aging time × display time and quality grade × display time means.

*CIE L**

For L* (lightness), subprimal type × aging time × display time and quality grade × display time means are presented in figures 3.3 and 3.4, respectfully.

Subprimal type × display time. In a subprimal type × display time interaction ($P<0.05$), ground beef patties from chuck roll subprimals had higher ($P<0.05$, lighter) L* values than those from knuckle subprimals at all display times.

Ground beef patties from both subprimal types displayed a quadratic ($P<0.05$) relationship indicating higher values early in display followed by minimal change thereafter. For chuck roll subprimals, ground beef patties at 0 h of display had the highest ($P<0.05$) L* values followed by those at 8 h of display. In addition, ground beef patties at 16 and 32 h of display had higher ($P<0.05$) L* values than those at 24 and 72 h of display. For knuckle subprimals, ground beef patties also had the highest ($P<0.05$) L* values at 0 h of display followed by those at 8 h of display. In addition, ground beef patties at 32 h of display had higher ($P<0.05$) L* values than those at 16 and 64 h of display and patties at 24 h of display had the lowest ($P<0.05$) L* values.

Aging time × display time. In an aging time × display time interaction ($P<0.05$), ground beef patties from subprimals aged 21 d at 0 h of display had higher ($P<0.05$) L* values than those from subprimals aged 7 or 42 d. At 8 and 16 h of display, ground beef patties from subprimals aged 21 d had higher ($P<0.05$) L* values than those from subprimals aged 7 d. In addition, at 24, 32, 56, and 64 h of display, ground beef patties from subprimals aged 21 and 42 d had higher ($P<0.05$) L* values than those from subprimals aged 7 d. At 40 h of display, ground beef patties from subprimals aged 42 d had the highest ($P<0.05$) L* values and those from subprimals aged 7 d had the lowest ($P<0.05$) L* values. Furthermore, at 48 and 80 h of display ground beef patties from subprimals aged 42 d had higher ($P<0.05$) L* values than those from subprimals aged 7 and 21 d.

Ground beef patties from all aging times displayed a quadratic ($P<0.05$) relationship indicating higher values early in display followed by no subsequent change thereafter. For subprimals aged 7 d, ground beef patties had the highest ($P<0.05$) L* values at 0 h of display followed by those at 8 h of display. In addition, ground beef patties at 48 h of display had higher ($P<0.05$) L* values than those at 40 h of display and patties at 16, 32, 40, 48, 56, 72, and 80 h of display had higher ($P<0.05$) L* values than those at 24 h of display. For subprimals aged 21 d, ground beef patties had the highest ($P<0.05$) L* values at 0 h of display followed by the values at 8 h of display. In addition, ground beef patties at 32 h of display had higher ($P<0.05$) L* values than those at 24, 40, 48, and 80 h of display. Furthermore, ground beef patties at 16 and 56 h of display had higher ($P<0.05$) L* values than those at 24, 48, and 80 h of display. For subprimals aged 42 d, ground beef patties at 0 h of display had higher ($P<0.05$) L* values then those at 16, 24, 48, 56, 64, and 72 h of display. In addition, ground beef patties at 8 and 80 h of display had higher ($P<0.05$) L* values than those at 16, 24, and 56 h of display. Ground beef patties at 32 and 40 h of display had higher ($P<0.05$) L* values than those at 16 h of display.

Main Effect. For quality grade, ground beef patties from Premium Choice subprimals had higher ($P<0.05$) L* values than those from Select subprimals (Figure 3.4).

Summary. In summary, ground beef patties from chuck roll subprimals had higher L* values than those from knuckle subprimals and patties from Premium Choice subprimals had higher L* values than those from Select subprimals. In general, the effects of aging time were inconsistent on L* values, but L* values decreased from 0 h to 16 h of display and then remained relatively constant thereafter.

CIE a*

For a* (redness), subprimal type × aging time × display time interaction means and quality grade × display time means are presented in figures 3.5 and 3.6, respectfully.

Subprimal type × aging time × display time. In the subprimal type × aging time × display time interaction ($P<0.05$), ground beef patties from chuck roll subprimals at all aging times had higher ($P<0.05$; more red) a* values from 0 to 56 h of display than those from knuckle subprimals. For chuck roll subprimals at 0 h of display, ground beef patties aged 21 d had the highest ($P<0.05$) a* values and those aged 42 d had the lowest ($P<0.05$) a* values. At 16 h of display, ground beef patties from chuck roll subprimals aged 7 d had higher ($P<0.05$) a* values than those aged 42 d. At 24, 32, 40, and 48 h of display, ground beef patties from chuck roll subprimals aged 7 and 21 d had higher ($P<0.05$) a* values than those aged 42 d. At 56 h of display, the ground beef patties from chuck roll subprimals aged 7 d had the highest ($P<0.05$) a* values and those aged 42 d had the lowest ($P<0.05$). For knuckle subprimals at 0 through 56 h of display, ground beef patties from all aging times had similar ($P>0.05$) a* values at each display time. At 64 h of display, ground beef patties from chuck roll subprimals aged 7 d had the highest ($P<0.05$) a* values followed by patties from chuck roll subprimals aged 21 d. In addition, ground beef patties from chuck roll subprimals aged 42 d had higher ($P<0.05$) a* values than those from knuckle subprimals aged 21 d and patties from knuckle subprimals aged 42 d had the lowest ($P<0.05$) a* values. At 72 h of display, ground beef patties from chuck roll subprimals aged 7 and 21 d had the highest ($P<0.05$) a* values. In addition, ground beef patties from chuck roll subprimals aged 42 d and knuckle subprimals aged 7 d had higher ($P<0.05$) a* values than those from knuckle subprimals aged 21 d of aging and patties from knuckle subprimals aged 42 d had the lowest ($P<0.05$) a* values. At 80 h of display, ground beef patties from chuck roll subprimals aged 7 d had the highest ($P<0.05$) a* values. In addition, ground beef patties from chuck roll subprimals aged 21 d had higher ($P<0.05$) a* values than those from chuck roll subprimals aged 42 d and knuckle subprimals aged 7 and 21 d and ground beef patties from knuckle subprimals aged 42 d had the lowest ($P<0.05$) a* values.

Ground beef patties from all subprimal type × aging time combinations displayed a quadratic ($P<0.05$) relationship indicating higher a* values early in display with a more rapid decrease early in display than later in display. For chuck roll subprimals aged 7 d, ground beef patties had the highest ($P<0.05$) a* values at 0 h of display followed by a continuous decrease ($P<0.05$) in a* values from 0 to 40 h of display. Furthermore, at 48 h of display ground beef patties had higher ($P<0.05$) a* values than those at 64, 72, and 80 h of display and patties at 72 h of display had the lowest ($P<0.05$) a* values. For chuck roll subprimals aged 21 d, ground beef patties had the highest ($P<0.05$) a* values at 0 h of display followed by a continuous decrease ($P<0.05$) in a* from 0 to 24 h of display. Furthermore, ground beef patties at 24 and 32 h of display had higher ($P<0.05$) a* values than those at 40 and 48 h of display, which had higher ($P<0.05$) a* values than patties at 56 h of display. Ground beef patties at 64, 72, and 80 h of display had the lowest ($P<0.05$) a* values. For chuck roll subprimals aged 42 d, ground beef patties had the highest ($P<0.05$) a* values at 0 h of display followed by a continuous decrease ($P<0.05$) in a* values from 0 to 32 h of display. In addition, ground beef patties at 40 h of display had higher ($P<0.05$) a* values than those at 56 h of display, which had higher ($P<0.05$) a* values than patties at 64 h of display. Ground beef patties at 72 and 80 h of display had the lowest ($P<0.05$) a* values. For knuckle subprimals aged 7 d, ground beef patties had the highest ($P<0.05$) a* values at 0 h of display followed by the values at 8 h of display. In addition, ground beef patties at 16 and 24 h of display had higher ($P<0.05$) a* values than patties for the remainder of the display time and patties at 32 h of display had higher ($P<0.05$) a* values than those at 48 through 80 h of display. Ground beef patties at 40 h of display had higher ($P<0.05$) a* values than patties at 48, 56, 64, and 80 h of display and patties at 48 and 72 h of display had higher ($P<0.05$) a* values than those at 80 h of display. For knuckle subprimals aged 21 d, ground beef patties had the highest ($P<0.05$) a* values at 0 h of display followed by the values at 8 h of display. In addition, ground beef patties at 16 and 24 h of display had higher ($P<0.05$) a* values than patties at 32 h of display which had higher ($P<0.05$) a* values than patties for the remainder of the display times and patties at 40 h of display had higher (P<0.05) a* values than those at 56 through 80 h of display. Ground beef patties at 48 h of display had higher (P<0.05) a* values than patties at 64, 72, and 80 h of display; and patties at 56 h of display had higher (P<0.05) a* values than those at 72 and 80 h of display. For knuckle subprimals aged 42 d, ground beef patties had the highest (P<0.05) a* values at 0 h of display followed by patties at 8 h of display. In addition, ground beef patties at 16 and 24 h of display had higher (P<0.05) a* values than patties at 32 h of display which had higher (P<0.05) a* values than patties for the remainder of the display times. Ground beef patties at 40 h of display had higher (P<0.05) a* values than those at 56 through 80 h of display, patties at 56 h of display had higher (P<0.05) a* values than patties at 64, 72, and 80 h of display, and patties at 72 and 80 h of display had the lowest (P<0.05) a* values.

Main Effect. For quality grade, ground beef patties from Premium Choice subprimals had higher (P<0.05) a* values than those from Select subprimals (Figure 3.6).

Summary. In summary, ground beef patties from chuck roll subprimals had higher a* values (more red) than those from knuckle subprimals, and patties from Premium Choice subprimals had higher a* values than those from Select subprimals. For ground beef patties from chuck roll subprimals, a* values were similar among aging times until 24 h of display and then patties from subprimals aged 42 d had the lowest a* values thereafter. However, for ground beef patties from knuckle subprimals, a* values were similar among aging times until 64 h of display and then patties from subprimals aged 42 d had the lowest a* values thereafter. For display time, a* values decreased more rapidly early in the display period then during the remainder of the display time.

*CIE b**

For b* (yellow), subprimal type × aging time × display time and quality grade × display time means are presented in figures 3.7 and 3.8, respectfully.

<u>Subprimal type × display time</u>. In a subprimal type × display time interaction ($P<0.05$), ground beef patties from chuck roll subprimals had higher ($P<0.05$, more yellow) b* values than those from knuckle subprimals at all display times.

Ground beef patties from both subprimal types displayed a quadratic ($P<0.05$) relationship indicating higher values early in display followed by a continuous decrease at a declining rate (Figure 3.7). For chuck roll subprimals at 0 h of display, ground beef patties had the highest ($P<0.05$) b* values followed by a continuous decrease ($P<0.05$) in b* from 0 to 48 h of display. In addition, ground beef patties at 48 and 56 h of display had higher ($P<0.05$) b* values than those at 72 and 80 h of display. For knuckle subprimals, ground beef patties had the highest ($P<0.05$) b* values at 0 h of display followed by a continuous decrease in b* values through 16 h of display. In addition, ground beef patties at 16 and 24 h of display had higher ($P<0.05$) b* values than those for the remainder of display times and patties at 32 h of display had higher ($P<0.05$) b* values than those from 48 to 80 h of display. Furthermore, ground beef patties at 56, 64, 72, and 80 h of display had the lowest ($P<0.05$) b* values.

<u>Aging time × display time</u>. In an aging time × display time interaction ($P<0.05$), aging time did not influence ($P>0.05$) b*values at 0 through 40 h and at 56 h of display (Figure 3.7). At 48 and 80 h of display, ground beef patties from subprimals aged 7 and 21 d had higher ($P<0.05$) b* values than those aged 42 d. At 64 h of display, ground beef patties from subprimals aged 7 d had higher ($P<0.05$) b* values than those from subprimals aged 21 and 42 d

and, at 72 h of display, patties from subprimals aged 7 d had higher ($P<0.05$) b* values than those from subprimals aged 42 d.

Ground beef patties from subprimals of all aging times displayed a quadratic ($P<0.05$) relationship indicating higher values early in display followed by a more rapid decrease during early display with minimal decline later in display. For subprimals aged 7 d, ground beef patties had the highest ($P<0.05$) b* values at 0 h of display followed by 8 h of display. Ground beef patties at 16 and 24 h of display had higher ($P<0.05$) b* values than those for the remainder of the display times. In addition, ground beef patties at 32 and 40 h of display had higher ($P<0.05$) b* values than those at 48, 56, 72, and 80 h of display. For subprimals aged 21 d, ground beef patties had the highest ($P<0.05$) b* values at 0 h of display followed by the b* values at 8 h of display. In addition, ground beef patties at 16 and 24 h of display had higher ($P<0.05$) b* values than those from 32 to 80 h of display. Ground beef patties at 32, 40 and 48 h of display had higher ($P<0.05$) b* values than those at 56, 64, 72, and 80 h of display. For subprimals aged 42 d, ground beef patties had the highest ($P<0.05$) b* values at 0 h of display followed by a continuous decrease ($P<0.05$) in b* values from 0 to 24 h of display. In addition, ground beef patties at 32 h of display had higher ($P<0.05$) b* values than those from 48 to 80 h of display and patties at 40 h of display had higher ($P<0.05$) b* values than those at 48, 64, 72, and 80 h of display. Ground beef patties at 72 and 80 h of display had the lowest ($P<0.05$) b* values.

Quality grade × display time. In a quality grade × display time interaction ($P<0.05$), ground beef patties from Premium Choice subprimals had higher ($P<0.05$) b* values than those from Select subprimals at all display times (Figure 3.8). Furthermore, ground beef patties from both quality grades displayed a quadratic ($P<0.05$) relationship indicating higher values early in display followed by a more rapid decrease early in display with minimal decline thereafter. For

Premium Choice subprimals, ground beef patties had the highest ($P<0.05$) b* values at 0 h of display followed by a continuous decrease ($P<0.05$) in b* values from 0 to 32 h of display. In addition, ground beef patties at 32 and 40 h of display had higher ($P<0.05$) b* values than those from 48 to 80 h of display. Ground beef patties at 48, 56, 64, and 80 h of display had higher ($P<0.05$) b* values than those at 72 h of display and patties 72 h of display had the lowest ($P<0.05$) b* values. For Select subprimals, ground beef patties had the highest ($P<0.05$) b* values at 0 h of display followed by 8 h of display. In addition, ground beef patties at 16 and 24 h of display had higher ($P<0.05$) b* values than those for the remainder of the display times and patties at 32 h of display had higher ($P<0.05$) b* values than those for the remainder of the display times. Furthermore, ground beef patties at 48 h of display had higher ($P<0.05$) b* values than those at 72 and 80 h of display. Ground beef patties at 56 and 64 h of display had higher ($P<0.05$) b* values than those at 80 h of display.

Summary. In summary, ground beef patties from chuck roll subprimals had higher b* values (more yellow) than those from knuckle subprimals, and patties from Premium Choice subprimals had higher b* values than those from Select subprimals. In addition, aging time did not influence b* values. For display time, b* values decreased more rapidly early in the display period followed by minimal decreases for the remainder of the display time.

CIE a/b ratio

For a/b ratio, subprimal type × aging time × display time and quality grade × display time means are presented in figure 3.9 and 3.10, respectfully (greater value = greater redness and less discoloration).

Subprimal type × display time. In a subprimal type × display time interaction ($P<0.05$), for knuckle subprimals at 0 h of display ground beef patties had a higher ($P<0.05$) a/b ratio than those from chuck roll subprimals. From 8 to 24 h of display, ground beef patty a/b ratio was similar ($P>0.05$) between the subprimal types and from 32 to 80 h of display ground beef patties from chuck roll subprimals had a higher ($P<0.05$) a/b ratio than those from knuckle subprimals.

Ground beef patties from both chuck roll and knuckle subprimals had a linear decrease ($P<0.05$) in a/b ratio as display time increased. For knuckle subprimals, ground beef patties had the highest ($P<0.05$) a/b ratio at 0 h of display followed by a continuous decrease ($P<0.05$) in a/b ratio from 0 to 40 h of display. In addition, ground beef patties at 40 and 48 h of display had a higher ($P<0.05$) a/b ratio than those at 56, 64, 72, and 80 h of display. Patties at 56 h of display had a higher ($P<0.05$) a/b ratio than patties at 64, 72, and 80 h of display and patties at 80 h of display had the lowest ($P<0.05$) a/b ratio.

<u>Aging time × display time</u>. In an aging time × display time interaction ($P<0.05$), ground beef patties at 0 h of display from subprimals aged 21 d had a higher ($P<0.05$) a/b ratio than those from subprimals aged 7 and 42 d and patties from subprimals aged 7 d had a higher ($P<0.05$) a/b ratio than those from subprimals aged 42 d. At 8, 16, 24, 32, 40, and 56 h of display, ground beef patties from subprimals aged 7 and 21 d had a higher ($P<0.05$) a/b ratio than those aged 42 d. At 48, 64, 72, and 80 h of display, ground beef patties aged 7 d had a higher ($P<0.05$) a/b ratio than those from subprimals aged 21 and 42 d and patties from subprimals aged 21 d had a higher ($P<0.05$) a/b ratio than those from subprimals aged 42 d.

Ground beef patties from subprimals aged 7 and 21 d displayed a quadratic ($P<0.05$) relationship indicating a higher ratio early in display followed by a continuous decrease at a declining rate. Furthermore, ground beef patties from subprimals aged 42 d displayed a linear ($P<0.05$) decrease in a/b ratio as display time increased. For subprimals aged 7 d, ground beef patties at 0 and 8 h of display had a higher ($P<0.05$) a/b ratio than those at 16 h of display.

Ground beef patties at 16 h of display had a higher ($P<0.05$) a/b ratio than those for the remainder of the display times. In addition, ground beef patties at 24 and 32 h of display had a higher ($P<0.05$) a/b ratio than those at 40, 48, 56, 64, 72, and 80 h of display. Ground beef patties at 40 and 48 h of display had a higher ($P<0.05$) a/b ratio than those for the remainder of display. Furthermore, ground beef patties at 56 h of display had a higher ($P<0.05$) a/b ratio than those at 64, 72, and 80 h of display. Ground beef patties at 80 h of display had the lowest ($P<0.05$) a/b ratio. For subprimals aged 21 d, ground beef patties had the highest ($P<0.05$) a/b ratio at 0 and 8 h of display followed by 16 h of display. In addition, ground beef patties at 16 h of display had a higher ($P<0.05$) a/b ratio than patties from 24 to 80 h of display and patties at 24 and 32 h of display had a higher ($P<0.05$) a/b ratio than those from 40 to 80 h of display. Ground beef patties at 40 h of display had a higher ($P<0.05$) a/b ratio than those at 48, 56, 64, 72, and 80 h of display and patties at 48 and 56 h of display had a higher ($P<0.05$) a/b ratio than those at 64, 72, and 80 h of display. Ground beef patties at 64 h of display had a higher ($P<0.05$) a/b ratio than those at 72 and 80 h of display and patties at 80 h of display had the lowest ($P<0.05$) a/b ratio. For subprimals aged 42 d, ground beef patties displayed a linear ($P<0.05$) effect indicating a decrease in a/b ratio from 0 to 24 h of display and then from 40 to 80 h of display.

Quality grade × display time. In a quality grade × display time interaction ($P<0.05$), ground beef patties from Select subprimals had a higher ($P<0.05$) a/b ratio at 0 to 16 and 32 h of display than those from Premium Choice subprimals (Figure 3.10). At 24, 40, 48, 56, and 64 h of display, ground beef patties from Premium Choice and Select subprimals were similar ($P>0.05$), and at 72 and 80 h of display ground beef patties from Premium Choice subprimals had a higher ($P<0.05$) a/b ratio than those from Select subprimals.

Furthermore, ground beef patties from both Premium Choice and Select subprimals displayed a linear ($P<0.05$) decrease in a/b ratio values as display time increased.

Subprimal type × aging time. In a subprimal type × aging time interaction ($P<0.05$), ground beef patties from both chuck roll and knuckle subprimals aged 7 and 21 d had a higher ($P<0.05$) a/b ratio than those from subprimals aged 42 d. At 7 and 21 d of aging, ground beef patties from chuck roll subprimals also had a higher ($P<0.05$) a/b ratio than those from knuckle subprimals but at 42 d of aging patties from chuck roll and knuckle subprimals had similar ($P>0.05$) a/b ratios.

Summary. In summary, ground beef patties from knuckle subprimals had a higher a/b ratio (greater redness and less discoloration) than those from chuck roll subprimals at 0 h of display but after 32 h of display patties from chuck roll subprimals had a higher a/b ratio for the rest of the display period. Ground beef patties from Select subprimals had a higher a/b ratio than those from Premium Choice subprimals from 0 to 32 h of display but after 72 h of display patties from Premium Choice subprimals had a higher a/b ratio for the rest of the display period. In addition, ground beef patties from subprimals aged 7 and 21 d had a higher a/b ratio than those from subprimals aged 42 d. Ground beef patty a/b ratio decreased as display time increased.

CIE Hue Angle

For hue angle, subprimal type × aging time × display time and quality grade × display time means are presented in figure 3.11 and 3.12, respectfully (greater value = less red).

Subprimal type × display time. In a subprimal type × display time interaction ($P<0.05$), ground beef patties at 0 h of display from chuck roll subprimals had greater ($P<0.05$) hue angle values than those from knuckle subprimals. In addition, from 8 to 24 h of display, ground beef patties from chuck roll and knuckle subprimals had similar ($P>0.05$) hue angle values; however, from 32 to 80 h of display patties from knuckle subprimals had greater ($P<0.05$) hue angle values than those from chuck roll subprimals.

Ground beef patties from both chuck roll and knuckle subprimals displayed a linear ($P<0.05$) increase in hue angle as display time increased.

Aging time × display time. In a aging time × display time interaction ($P<0.05$), ground beef patties at 0, 16, 32, 48, and 56 h of display from subprimals aged 7 and 21 d had lower ($P<0.05$) hue angle values than those from subprimals aged 42 d. At 8 h of display, ground beef patties at all aging times (7, 21, and 42 d) had similar ($P>0.05$) hue angle values. At 24 h of display, ground beef patties aged 7 d had lower ($P<0.05$) hue angle values than patties from subprimals aged 21 and 42 d. At 40, 64, 72, and 80 h of display, ground beef patties from subprimals aged 7 d had the lowest ($P<0.05$) hue angle and patties from subprimals aged 42 d had the greatest ($P<0.05$) hue angle.

Ground beef patties from subprimals aged 7 and 21 d displayed a linear ($P<0.05$) increase in hue angle as display time increased. Furthermore, ground beef patties from subprimals aged 42 d displayed a quadratic ($P<0.05$) relationship indicating lower values early in display followed by a rapid increase with a continuous increase thereafter. For subprimals aged 7 d, ground beef patties showed a linear ($P<0.05$) increase in hue angle from 0 to 24 h of display, 32 to 40 h of display, 56 to 64 h of display, and 72 and 80 h of display. For subprimals aged 21 d, ground beef patties showed a linear ($P<0.05$) increase in hue angle from 0 to 24 h of display, 32 to 40 h of display, 56 to 64 h of display, and 72 and 80 h of display. For subprimals aged 42 d, ground beef patties had the lowest ($P<0.05$) hue angle values at 0 and 8 h of display. In addition, ground beef patties at 16 and 24 h of display had lower ($P<0.05$) hue angle values than patties from 32 to 80 h of display and patties at 32 h of display had lower ($P<0.05$) hue angle values than those from 40 to 80 h of display. Ground beef patties at 40 and 48 h of display had lower ($P<0.05$) hue angle values than those at 56, 64, 72, and 80 h of display and patties at 56 h of display had lower ($P<0.05$) hue angle values than those at 64, 72, and 80 h of display. Ground beef patties at 64 h of display had lower ($P<0.05$) hue angle values than those at 72 and 80 h of display and patties at 80 h of display had the highest ($P<0.05$) hue angle.

Quality grade × display time. In a quality grade × display time interaction ($P<0.05$), ground beef patties at 0 and 8 h of display from Premium Choice subprimals had greater ($P<0.05$) hue angle values than those from Select subprimals (Figure 3.12). In addition, from 16 to 64 h of display ground beef patties from Premium Choice and Select subprimals had similar ($P>0.05$) hue angle values. At 72 and 80 h of display, patties from Select subprimals had greater ($P<0.05$) hue angle values than those from Premium Choice subprimals. Ground beef patties from both Premium Choice and Select subprimals displayed a linear ($P<0.05$) increase in hue angle as display time increased.

Summary. In summary, ground beef patties from chuck roll subprimals had greater hue angle values than those from knuckle subprimals at 0 h of display but patties from knuckle subprimals after 32 h of display had greater ($P<0.05$) hue angle values (less red) than those from chuck roll subprimals for the remainder of the display period. From 0 to 8 h of display, ground beef patties from Premium Choice subprimals had greater ($P<0.05$) hue angle values than those from Select subprimals but after 72 to 80 h of display patties from Select subprimals had greater ($P<0.05$) hue angle values for the remainder of the display period. In addition, after 24 h of display ground beef patties from subprimals aged 7 and 21 d had lower hue angle values than those from subprimals aged 42 d. Furthermore, as display time increased, ground beef patty hue angle increased.

CIE Chroma

For chroma (color intensity), subprimal type × aging time × display time and quality grade × display time means are presented in figure 3.13 and 3.14, respectfully.

Subprimal type × aging time × display time. In a subprimal type × aging time × display time interaction ($P<0.05$), ground beef patties from 0 to 64 h and 80 h of display from chuck roll subprimals had higher ($P<0.05$) chroma values than those from knuckle subprimals. At 0 h of display, ground beef patties from chuck roll subprimals aged 21 d had higher ($P<0.05$) chroma values than those from chuck roll subprimals aged 7 and 42 d. At 16 h of display, ground beef patties from chuck roll subprimals aged 7 d had higher ($P<0.05$) chroma values than patties from chuck roll subprimals aged 42 d. At 24 h of display, chroma values for ground beef patties from chuck roll subprimals were similar ($P>0.05$) among aging times. In addition, at 32, 40, and 48 h of display ground beef patties from chuck roll subprimals aged 7 and 21 d had higher ($P<0.05$) chroma values than those from chuck roll subprimals aged 42 d. At 56, 64, and 80 h of display, ground beef patties from chuck roll subprimals aged 7 d had the highest ($P<0.05$) chroma values and patties from chuck roll subprimals aged 42 d had the lowest ($P<0.05$) chroma values.

Ground beef patties from all subprimal type × aging time combinations displayed a quadratic ($P<0.05$) relationship indicating higher chroma values early in display with a more rapid decline early in display. Ground beef patties from knuckle subprimals aged 7, 21, and 42 d had similar ($P>0.05$) chroma values from 0 to 56 h of display. At 64 h of display, ground beef patties from knuckle subprimals aged 7 d had higher ($P<0.05$) chroma values than those from knuckle subprimals aged 42 d. At 72 h of display, ground beef patties from chuck roll subprimals aged 7 and 21 d had the highest ($P<0.05$) chroma values and ground beef patties from knuckle subprimals aged 21 and 42 d had the lowest ($P<0.05$) chroma values. At 80 h of display, ground beef patties from knuckle subprimals aged 7 and 21 d had higher (P<0.05) chroma values than those from subprimals aged 42 d. For chuck roll subprimals aged 7 d, ground beef patties had the highest (P<0.05) chroma values at 0 h of display followed by a decrease (P<0.05) in chroma values from 0 to 24 h of display. In addition, ground beef patties at 24 of display had higher (P<0.05) chroma values than for patties over the remainder of display and patties at 32, 40, 48, and 56 h of display had higher (P<0.05) chroma values than patties at 72 and 80 h of display. Ground beef patties at 80 h of display had the lowest (P<0.05) chroma values. For chuck roll subprimals aged 21 d, ground beef patties had the highest (P<0.05) chroma value at 0 h of display followed by a decrease (P<0.05) in chroma value from 0 to 40 h of display. In addition, ground beef patties at 40 h of display had higher (P<0.05) chroma values than those from 56 to 80 h of the display and patties at 48 h of display had higher (P<0.05) chroma values than patties at 64, 72, and 80 h of display. Ground beef patties at 72 and 80 h of display had the lowest (P<0.05) chroma values. For chuck roll subprimals aged 42 d, ground beef patties had the highest (P<0.05) chroma values at 0 h of display followed by a decrease (P<0.05) in chroma values from 0 to 40 h of display. In addition, ground beef patties at 40, 48, and 56 h of display had higher (P<0.05) chroma values than patties at 64, 72, and 80 h of display and patties at 72 and 80 h of display had the lowest (P<0.05) chroma values. For knuckle subprimals aged 7 d, ground beef patties had the highest (P<0.05) chroma values at 0 h of display followed by chroma values at 8 h of display. In addition, ground beef patties at 16 and 24 h of display had higher (P<0.05) chroma values than patties for the remainder of the display times and patties at 32 h of display had higher (P<0.05) chroma values than those at 48 through 80 h of display. Ground beef patties at 40 and 72 h of display had higher (P<0.05) chroma values than those at 80 h of display. For knuckle subprimals aged 21 d, ground beef patties had the highest (P<0.05) chroma values at 0 h of display followed by chroma values at 8 h of display. In addition, ground beef patties at 16 and 24 h of display had higher ($P<0.05$) chroma values than patties for the remainder of the display times and patties at 32 and 40 h of display had higher ($P<0.05$) chroma values than those at 56 through 80 h of display. Ground beef patties at 48 h of display had higher ($P<0.05$) chroma values than patties at 64, 72, and 80 h of the display and patties at 56 h of display had higher ($P<0.05$) chroma values than those at 72 h of display. For knuckle subprimals aged 42 d, ground beef patties had the highest ($P<0.05$) chroma value at 0 h of display followed by a decrease ($P<0.05$) in chroma values from 0 to 32 h of display. Ground beef patties at 32 h of display had higher ($P<0.05$) chroma values than patties from 48 to 80 h of display. In addition, ground beef patties at 56 h of display had higher ($P<0.05$) chroma values than patties at 64 h of display and patties at 72 and 80 h of display had the lowest ($P<0.05$) chroma values.

Main Effect. For quality grade, ground beef patties from Premium Choice subprimals had higher ($P<0.05$) chroma values than those from Select subprimals (Figure 3.14).

Summary. In summary, ground beef patties from chuck roll subprimals had higher chroma values (more color intensity) than those from knuckle subprimals and patties from Premium Choice subprimals had higher chroma values than those from Select subprimals. For ground beef patties from chuck roll subprimals, chroma values were similar among aging times until 32 h of display and then patties from subprimals aged 42 d had the lowest chroma values thereafter. However, for ground beef patties from knuckle subprimals, chroma values were similar among aging times. For display time, chroma values decreased more rapidly early in the display period then during the remainder of the display time.

Relationship of Instrumental Color Measurements

In the current research, instrumental color measurements showed that ground beef patties from chuck roll subprimals had higher L*(lighter), a*(red), b* (yellow), and chroma (color intensity) values than those from knuckle subprimals and patties from Premium Choice subprimals had higher L*, a*, b*, and chroma values than those from Select subprimals. This is in agreement with other researchers who have reported that ground beef containing low lean levels had greater brightness (L*) values than ground beef with higher lean levels (Mancini, 2001; Liu et al., 1991; Troutt, Hunt, Johnson, Claus, Kastner, Kropf, & Stroda, 1992b). However, in disagreement it has also been reported that a* and b* values were not affected by lean level (Govindarajan & Hultin, 1977; Troutt et al., 1992b). Furthermore, in the current research it was recorded that L*, a*, b*, a/b ratio, and chroma decreased and hue angle increased as display time increased. This is in agreement with Troutt et al. (1992b) who found that L*, a*, b* values decreased as display time increased (0 to 3 d). In addition, Seyfert et al. (2007) found that the control ground beef patties showed a decrease in a*, b*, and chroma throughout the display period. Raines et al. (2010) observed that ground beef patties from all lean type combinations at 10 and 20% fat had a decrease in a*, a/b ratio, and saturation index values from 0 to 4 d of display. In addition, ground beef patties at 10 and 20% fat with a lean source of equal to or less than 50% high color stability muscle recorded a decrease in b* values and hue angle from 0 to 4 d of display.

For ground beef patties, initial visual color had a correlation with L* for patties from chuck roll subprimals at 0 h of display (-0.74) as well as a correlation with a* for ground beef patties from chuck roll and knuckle subprimals at 0 h of display (-0.60 and -0.61, respectfully).

Oxygen Consumption Rate Before and After 24 h of Display

Percentage of oxymyoglobin after 0 min vacuum packaged

A subprimal type × quality grade × aging time × display time interaction ($P<0.05$) was observed for percentage of oxymyoglobin (OMb) of ground beef patties at 0 min in a vacuum package measured before and after 24 h of display (Figure 3.15).

<u>Subprimal type × quality grade × aging time × display time</u>. For all subprimal type × quality grade × aging time combinations, ground beef patties at 0 h of display contained greater ($P<0.05$) OMb levels than those after 24 h of display. At 0 h of display and aging periods of 7 or 21 d, all subprimal type × quality grade means were similar ($P>0.05$). At 42 d of aging, ground beef patties from Select chuck roll subprimals had higher ($P<0.05$) percentages of OMb than those from Premium Choice chuck roll subprimals. At 0 h of display, ground beef patties from Premium Choice chuck roll subprimals aged 21 d had greater ($P<0.05$) OMb levels than those from subprimals aged 7 and 42 d. Ground beef patties from Select chuck roll subprimals aged 21 and 42 d had greater ($P<0.05$) percentages of OMb than those from subprimals aged 7 d. At 0 h of display, ground beef patties from Premium Choice knuckle subprimals had similar ($P>0.05$) OMb levels among all aging times and ground beef patties from Select knuckle subprimals aged 21 d had greater ($P<0.05$) percentages of OMb than those from subprimals aged 7 d.

At 24 h of display and 7 d of aging, ground beef patties from Select chuck roll subprimals had greater ($P<0.05$) OMb levels than those from Select knuckle subprimals and patties from Premium Choice chuck roll subprimals had the lowest ($P<0.05$) OMb levels. At 21 d of aging, ground beef patties from Select knuckle subprimals had greater ($P<0.05$) percentages of OMb than those from Premium Choice and Select chuck roll subprimals. At 42 d of aging, ground beef patties from Select chuck roll and knuckle subprimals had greater ($P<0.05$) OMb levels than those from Premium Choice knuckle subprimals. At 24 h of display, ground beef patties from Premium Choice chuck roll and Select knuckle subprimals aged 7 and 21 d had greater ($P<0.05$) levels of OMb than those from subprimals aged 42 d. Ground beef patties from Select chuck roll subprimals aged 7 d had greater ($P<0.05$) percentages of OMb than those from subprimals aged 21 and 42 d. Furthermore at 24 h of display, ground beef patties from Premium Choice knuckle subprimals aged 7 d had greater ($P>0.05$) OMb levels than those from subprimals aged 21 d and patties from subprimals aged 42 d had the lowest ($P<0.05$) percentages of OMb.

Percentage of oxymyoglobin after 20 min vacuum packaged

A subprimal type × quality grade × aging time × display time means for percentages of OMb of ground beef patties at 20 min in a vacuum package measured before and after 24 h of display are presented in figure 3.16. Subprimal type × quality grade, subprimal type × display time, quality grade × display time, and aging time × display time interactions were significant ($P<0.05$).

Subprimal type × quality grade. In the subprimal type × quality grade interaction, ground beef patties from Select knuckle (33.9%) subprimals had lower ($P<0.05$) percentages of OMb than those from Premium Choice chuck roll (40.0%), Premium Choice knuckle (40.9%) and Select chuck roll (42.7%) subprimals.

Subprimal type × display time. In the subprimal type × display time interaction, ground beef patties from knuckle subprimals displayed for 24 h (31.3%) had lower ($P<0.05$) percentages of OMb than those from chuck roll subprimals displayed 24 h (39.5%), chuck roll subprimals displayed for 0 h (43.3%) and knuckle subprimals displayed for 0 h (43.5%).

Quality grade × display time. In the quality grade × display time interaction, ground beef patties from Select subprimals displayed 0 h (44.3%) had greater ($P<0.05$) levels of OMb than those from Premium Choice subprimals displayed 24 h (38.5%) and patties from Select subprimals display 24 h (32.3%) had the lowest (P<0.05) percentages of OMb.

Aging time × display time. In the aging time × display time interaction, ground beef patties from subprimals aged 21 d at 0 h of display (50.9%) had the greatest (P<0.05) levels of OMb. In addition, ground beef patties from subprimals aged 42 d at 24 h of display (28.7%) had lower (P<0.05) percentages of OMb than from those from subprimals aged 7 d and display 0 h (41.7%) and 24 h (40.7), aged 21 d and displayed 24 h (36.7&), and aged 42 d and displayed 0 h (37.6%).

Percentage of oxymyoglobin after 40 min vacuum packaged

Subprimal type × quality grade × aging time × display time means for percentages of OMb of ground beef patties at 40 min in a vacuum package measured before and after 24 h of display are presented in figure 3.17. Quality grade × aging time and aging time × display time interactions were significant (P<0.05).

Quality grade × aging time. In the quality grade × aging time interaction, ground beef patties from Select subprimals aged 42 d (22.0%) had the greatest (P<0.05) levels of OMb, ground beef patties from Premium Choice subprimals aged 7 d (20.2%) had greater (P<0.05) percentages of OMb than Select subprimals aged 42 d (17.5%), and patties from Premium Choice subprimals aged 42 d (14.1%) had the lowest (P<0.05) levels of OMb.

Aging time × display time. In the aging time × display time interaction, ground beef patties from subprimals of all aging times had greater (P<0.05) percentages of OMb at 0 h of display than those at 24 h of display. In addition, ground beef patties at 0 h of display from subprimals aged 7 (26.3%) and 21 (25.6%) d had greater (P<0.05) levels of OMb than those from subprimals aged 42 d (23.9%). At 24 h of display, ground beef patties from subprimals aged 7 d (15.9%) had the greatest ($P<0.05$) levels of OMb and patties from subprimals aged 21 d (12.7) had greater ($P<0.05$) percentages of OMb than those from subprimals aged 42 d (7.7%).

Main effect. A subprimal type main effect was observed in which ground beef patties from knuckle subprimals (19.5%) had greater ($P<0.05$) levels of OMb than those from chuck roll subprimals (17.8%).

Percentage of oxymyoglobin after 60 min vacuum packaged

A subprimal type × quality grade × aging time × display time interaction ($P<0.05$) was observed for percentage of oxymyoglobin (OMb) of ground beef patties at 60 min in a vacuum package measured before and after 24 h of display (Figure 3.18).

Subprimal type × quality grade × aging time × display time. For all subprimal type × quality grade × aging time combinations, ground beef patties at 0 h of display contained greater ($P<0.05$) OMb levels than those after 24 h of display. At 0 h of display and aging times of 7 or 42 d, ground beef patties from Select knuckle subprimals had greater ($P<0.05$) levels of OMb than those from Premium Choice and Select chuck roll and Premium Choice knuckle subprimals. At 21 d of aging, ground beef patties from Premium Choice and Select knuckle subprimals had greater ($P<0.05$) percentages of OMb than patties from Premium Choice and Select chuck roll subprimals. At 0 h of display, ground beef patties from Premium Choice chuck roll subprimals aged 7 d had greater ($P<0.05$) levels of OMb than those from subprimals aged 42 d. Ground beef patties from Select chuck roll subprimals had similar ($P<0.05$) percentages of OMb at all aging times. At 0 h of display, ground beef patties from Premium Choice knuckle subprimals aged 7 and 21 d had greater ($P<0.05$) levels of OMb than those from subprimals aged 42 d. Ground beef patties from Select knuckle subprimals aged 7 d had greater ($P<0.05$) percentages of OMb than those from subprimals aged 21 and 42 d. At 24 h of display and 7 d of aging, ground beef patties from Select chuck roll and Premium Choice and Select knuckle subprimals had greater ($P<0.05$) OMb levels than those from Premium Choice chuck roll subprimals. At 21 d of aging, the percentages of OMb of ground beef patties were similar ($P>0.05$) among all aging times. At 42 d of aging, ground beef patties from Select knuckle subprimals had greater ($P<0.05$) OMb levels than those from Premium Choice and Select chuck roll and Premium Choice knuckle subprimals. At 24 h of display, ground beef patties from Premium Choice chuck roll and knuckle subprimals aged 7 and 21 d had greater ($P<0.05$) levels of OMb than those from subprimals aged 42 d. Ground beef patties from Select chuck roll subprimals aged 7 d had the greatest ($P<0.05$) percentages of OMb and patties from subprimals aged 21 d had greater ($P<0.05$) levels of OMb than those from subprimals aged 42 d. Furthermore, at 24 h of display, ground beef patties from Select knuckle subprimals aged 7 d had greater ($P>0.05$) levels of OMb than those from subprimals aged 21 and 42 d.

Oxygen consumption rate from 0 to 20 min in vacuum package

A subprimal type × quality grade, subprimal type × display time, and quality grade × display time interactions ($P<0.05$) were observed for the oxygen consumption rate (OCR) of ground beef patties from 0 to 20 min in a vacuum package measured before and after 24 h of display.

Subprimal type × quality grade. In the subprimal type × quality grade interaction, ground beef patties from Select knuckle (60.9%) subprimals had greater ($P<0.05$) OCR than those of Premium Choice (49.1%) and Select (49.1%) chuck roll and Premium Choice knuckle (49.9%) subprimals.

Subprimal type × display time. In the subprimal type × display time interaction, ground beef patties from chuck roll subprimals displayed 24 h (42.6%) had lower ($P<0.05$) OCR than those from chuck roll subprimals displayed 0 h (55.7%) and knuckle subprimals displayed 0 (55.5%) and 24 (55.3%) h.

Quality grade × display time. In the quality grade × display time interaction, ground beef patties from Premium Choice subprimals displayed 24 h (43.1%) had lower ($P<0.05$) OCR than those from Premium Choice subprimals displayed 0 h (56.0%) and Select subprimal displayed 0 (55.2%) and 24 (54.8%) h.

Main effect. An aging time main effect was also seen in which ground beef patties from subprimals aged 42 d (57.8%) had greater ($P<0.05$) OCR than those from subprimals aged 7 (50.5%) and 21 (48.5%) d.

Oxygen consumption rate from 0 to 40 min in vacuum package

A subprimal type × quality grade × aging time and aging time × display time interactions ($P<0.05$) were observed for the oxygen consumption rate of ground beef patties from 0 to 40 min in a vacuum package measured before and after 24 h of display.

Subprimal type × quality grade × aging time. In the subprimal type × quality grade × aging time interaction, ground beef patties from subprimals aged 7 and 21 d were similar ($P>0.05$) for all subprimal type × quality grade combinations (Premium Choice chuck roll = 76.3%, 78.2%; Select chuck roll = 74.8%, 79.3%; Premium Choice knuckle = 75.8%, 77.2%; and Select knuckle = 74.0%, 77.7% respectfully). At 42 d of aging, ground beef patties from Select knuckle (76.1%) subprimals had lower ($P<0.05$) OCR than those from Premium Choice (83.3%) and Select (83.4%) chuck roll and Premium Choice knuckle (83.4%) subprimals. Ground beef patties from Premium Choice chuck roll and knuckle subprimals aged 42 d (83.3%, 83.4%) had greater ($P<0.05$) OCR than those aged 7 (76.3%, 75.8%) and 21 (78.2%, 77.2%) d. Ground beef patties from Select chuck roll subprimals aged 42 d (83.4%) had the greatest

($P<0.05$) OCR and those aged 21 d (79.3%) which had greater ($P<0.05$) OCR than those aged 7 d (74.8%). Ground beef patties from Select knuckle subprimals aged 7 d (74.0%) had lower ($P<0.05$) OCR than those aged 21 d (77.7%).

Aging time × display time. In an aging time × display time interaction, ground beef patties displayed 24 h had greater ($P<0.05$) OCR than those displayed 0 h. At 0 h of display, ground beef patties from subprimals aged 21 (74.4%) and 42 (75.2%) d had greater ($P<0.05$) OCR than those from subprimals aged 7 d (72.1%). At 24 h of display, ground beef patties from subprimals aged 42 d (87.8%) had the greatest ($P<0.05$) OCR and patties from subprimals aged 21 d (81.8%) had greater ($P<0.05$) OCR than those aged 7 d (78.4%).

Oxygen consumption rate from 0 to 60 min in vacuum package

Subprimal type × quality grade × age time × display time. A subprimal type × quality grade × age time × display time interaction ($P<0.05$) was observed for oxygen consumption rate of ground beef patties from 0 to 60 min in a vacuum package measured before and after 24 h of display. For all subprimal type × quality grade × aging time combinations, except patties from Select chuck roll subprimals aged 21 d and Premium Choice knuckle subprimals aged 7 d, ground beef patties at 0 h of display had lower ($P<0.05$) OCR than those after 24 h of display. At 0 h of display and aging periods of 7 or 42 d ground beef patties from Select knuckle subprimals (65.0%, 70.1%, respectfully) had lower ($P<0.05$) OCR than those from Premium Choice (71.8%, 77.7%, respectfully) and Select (71.7%, 76.1%, respectfully) chuck roll and Premium Choice knuckle (70.5%, 75.9%, respectfully) subprimals. At 21 d of aging, ground beef patties from Premium Choice knuckle subprimals (70.6%) had lower ($P<0.05$) OCR than those from Premium Choice (75.7%) and Select (75.3%) chuck roll patties. At 0 h of display, ground beef patties from Premium Choice chuck roll subprimals aged 42 d (77.7%) had greater

($P<0.05$) OCR than those from subprimals aged 7 d (71.8%). Ground beef patties from Select chuck roll subprimals aged 7 d (71.7%) had lower ($P>0.05$) OCR than those from subprimals aged 21 (75.3%) and 42 (76.1%) d. At 0 h of display, ground beef patties from Premium Choice knuckle subprimals aged 42 d (75.9%) had greater ($P<0.05$) OCR than those from subprimals aged 7 (70.5%) and 21 (70.6%) d. Ground beef patties from Select knuckle subprimals aged 21 (71.8%) and 42 (70.1%) d had greater ($P<0.05$) OCR than those from subprimals aged 7 d (65.0%). At 24 h of display and 7 d of aging, ground beef patties from Premium Choice chuck roll subprimals (80.9%) had the greatest ($P<0.05$) OCR and patties from Select chuck roll subprimals (75.2%) had greater ($P<0.05$) OCR than those from Select knuckle subprimals (70.0%). At 24 h of display and 21 d of aging, ground beef patties were similar ($P>0.05$) among all subprimal type × quality grade combinations (Premium Choice chuck roll = 79.8%; Select chuck roll = 78.7%; Premium Choice knuckle = 77.4%; and Select knuckle = 78.2%, respectfully. At 24 h of display and 42 d of aging, ground beef patties from Select knuckle subprimals (77.8%) had lower ($P<0.05$) OCR than those from Premium Choice (89.4%) and Select (88.5%) chuck roll and Premium Choice knuckle (88.9%) subprimals. At 24 h of display, ground beef patties from Premium Choice (89.4%) and Select (88.5%) chuck roll and Premium Choice knuckle (88/9%) subprimals aged 42 d had greater ($P<0.05$) OCR than patties from subprimals aged 7 and 21 d (Premium Choice chuck roll = 80.9%, 79.8%; Select chuck roll = 75.2%, 78.7%; Premium Choice knuckle = 74.3%, 77.4%, respectfully). Furthermore at 24 h of display, ground beef patties from Select knuckle subprimals aged 21 (78.2%) and 42 (77.8%) d had greater ($P>0.05$) OCR than those from subprimals aged 7 d (70.0%).

Metmyoglobin Reducing Ability Before and After 24 h of Display

Percentage of metmyoglobin after 0 h vacuum packaged

Subprimal type × quality grade × aging time and aging time × display time means for percentage of metmyoglobin (MMb) before and after 24 h of display and after 0 h in a vacuum package for ground beef patties are presented in figure 3.19 and table 3.3, respectfully.

<u>Subprimal type × quality grade</u>. A subprimal type × quality grade interaction was significant ($P<0.05$) in which ground beef patties from Premium Choice chuck roll subprimals (82.7%) had the greatest ($P<0.05$) percentages of initial metmyoglobin. In addition, ground beef patties from Select chuck roll subprimals (78.7%) had greater ($P<0.05$) levels of MMb than those from Premium Choice knuckle (72.5%) subprimals. Ground beef patties from Select knuckle (70.4%) subprimal had the lowest ($P<0.05$) percentages of initial MMb.

<u>Main effect</u>. An aging time main effect was seen in which ground beef patties from subprimals aged 7 d (77.0%) had greater ($P<0.05$) percentages of MMb than those from subprimals aged 21 d (75.9%) and patties from subprimals aged for 42 d (75.4%) had the lowest ($P<0.05$) percentages of initial MMb. Furthermore, a display time main effect was observed in which ground beef patties displayed for 0 h (75.7%) had lower ($P<0.05$) percentages of MMb than those displayed for 24 h (76.6%).

Percentage of metmyoglobin after 1 h vacuum packaged

Subprimal type × quality grade × aging time and aging time × display time interaction ($P<0.05$) means for percentage of metmyoglobin (MMb) before and after 24 h of display and after 1 h in a vacuum package for ground beef patties are presented in figure 3.20 and table 3.3, respectfully.

Subprimal type × quality grade × aging time. In the subprimal type × quality grade × aging time interaction, at 7 d of aging ground beef patties from Premium Choice chuck roll subprimal had greater ($P<0.05$) percentages of MMb than those from Select chuck roll and knuckle subprimals. At 21 d of aging, ground beef patties from Premium Choice chuck roll subprimal had the greatest ($P<0.05$) percentages of MMb. At 42 d of aging, ground beef patties from Premium Choice and Select chuck roll subprimal had greater ($P<0.05$) levels of MMb than those from Premium Choice knuckle subprimals and patties from Select knuckle subprimals had the lowest ($P<0.05$) percentages of MMb. For Premium Choice chuck roll subprimals aged 42 d, ground beef patties had the greatest ($P<0.05$) levels of MMb and patties from subprimals aged 21 d had greater ($P<0.05$) percentages of MMb than those from subprimals aged 7 d. For Select chuck roll and Premium Choice knuckle subprimals aged 42 d, ground beef patties had greater ($P<0.05$) levels of MMb than those from subprimals aged 7 and 21 d. For Select knuckle subprimals aged 42 d, ground beef patties had greater ($P<0.05$) levels of MMb than those from subprimals aged 7 d.

Aging time × display time. In the aging time × display time interaction (Table 3.3), ground beef patties displayed 0 h had lower ($P<0.05$) levels of MMb than those displayed 24 h. At 0 h of display, ground beef patties from subprimals aged 42 d had greater ($P<0.05$) levels of MMb than those from subprimals aged 7 and 21 d. At 24 h of display, ground beef patties from subprimals aged 42 d had the greatest ($P<0.05$) percentages of MMb and ground beef patties from subprimals aged 21 d had greater ($P<0.05$) levels of MMb than those from subprimals aged 7 d.

Percentage of metmyoglobin after 2 h vacuum packaged

Subprimal type × quality grade × aging time and aging time × display time interaction ($P<0.05$) means for percentage of metmyoglobin (MMb) before and after 24 h of display and after 2 h in a vacuum package for ground beef patties are presented in figure 3.21 and table 3.3, respectfully.

<u>Subprimal type × quality grade × aging time</u>. In the subprimal type × quality grade × aging time interaction, at 7 d of aging ground beef patties from Premium Choice chuck roll subprimals had greater ($P<0.05$) percentages of MMb than those from Select knuckle subprimals. At 21 d of aging, ground beef patties from Premium Choice chuck roll subprimals had greater ($P<0.05$) percentages of MMb than those from Premium Choice and Select knuckle subprimals. At 42 d of aging, ground beef patties from Select chuck roll subprimals had greater ($P<0.05$) levels of MMb than those from Premium Choice knuckle subprimals and patties from Select knuckle subprimals had the lowest ($P<0.05$) percentages of MMb. For Premium Choice chuck roll and Select knuckle subprimals aged 42 d, ground beef patties had the greatest ($P<0.05$) levels of MMb and patties from subprimals aged 21 d had greater ($P<0.05$) percentages of MMb than those from subprimals aged 7 d. For Select chuck rolls and Premium Choice knuckle subprimals aged 42 d, ground beef patties had greater ($P<0.05$) levels of MMb than those from subprimals aged 7 and 21 d.

<u>Aging time × display time</u>. In the aging time × display time interaction (Table 3.3), ground beef patties displayed 0 h had lower ($P<0.05$) levels of MMb than those displayed 24 h. At 0 h of display, ground beef patties from subprimals aged 42 d had greater ($P<0.05$) levels of MMb than those from subprimals aged 7 and 21 d. At 24 h of display, ground beef patties from subprimals aged 42 d had the greatest ($P<0.05$) percentages of MMb and ground beef patties

from subprimals aged 21 d had greater ($P<0.05$) levels of MMb than those from subprimals aged 7 d.

Metmyoglobin reducing ability from 0 to 1 h in vacuum package

A subprimal type × quality grade × aging time and aging time × display time interaction ($P<0.05$) means were observed for ground beef patties' metmyoglobin reducing ability (MRA) from 0 to 1 h in a vacuum package before and after 24 h of display.

<u>Subprimal type × quality grade × aging time</u>. In the subprimal type × quality grade × aging time interaction, at 7 d of aging ground beef patties from Select chuck roll subprimals (34.2%) had greater ($P<0.05$) MRA than those from Premium Choice knuckle subprimals (27.8%). At 21 d of aging, ground beef patties from Select Premium Choice subprimal (30.7%) had greater ($P<0.05$) percentages of MMb than those from Premium Choice chuck roll (24.6%) and Premium Choice (23.0%) and Select (21.8%) knuckle subprimals. But at 42 d of aging, ground beef patties from Select knuckle subprimals (16.2%) had greater ($P<0.05$) MRA than those from Select chuck roll (10.3%) and Premium Choice knuckle (10.4%) subprimals. For Premium Choice chuck roll subprimals aged 7 d (31.9%), ground beef patties had the greatest ($P<0.05$) MRA and patties from subprimals aged 21 d (24.6%) had greater ($P<0.05$) MRA than those from subprimal aged 42 d (13.1%). For Select chuck rolls and Premium Choice knuckle subprimals aged 7 (34.2%, 27.8% respectfully) and 21 (30.7%, 23.0% respectfully) d, ground beef patties had greater ($P<0.05$) MRA than those from subprimals aged 42 d (10.3%, 10.4% respectfully). For Select knuckle subprimals aged 7 (29.0%) and 21 (21.8%) d, ground beef patties had greater ($P<0.05$) MRA than those from subprimals aged 42 d (16.2%).

<u>Aging time × display time</u>. In the aging time × display time interaction, ground beef patties displayed 0 h had greater ($P<0.05$) MRA than those displayed 24 h. At 0 h of display,

ground beef patties from subprimals aged 7 (33.4%) and 21 (33.1%) d had greater ($P<0.05$) MRA than those from subprimals aged 42 d (15.7%). At 24 h of display, ground beef patties from subprimals aged 7 d (28.1%) had the highest ($P<0.05$) MRA and ground beef patties from subprimals aged 21 d (16.9%) had greater ($P<0.05$) MRA than those from subprimals aged 42 d (9.3%).

Metmyoglobin reducing ability from 0 to 2 h in vacuum package

A subprimal type × quality grade × aging time and aging time × display time interaction ($P<0.05$) means were observed for ground beef patties' MRA from 0 to 2 h in a vacuum package before and after 24 h of display.

Subprimal type × quality grade × aging time. In the subprimal type × quality grade × aging time interaction, at 7 and 21 d of aging ground beef patties from all subprimal type × quality grade combinations were similar (Premium Choice chuck roll = 73.6%, 63.9%; Select chuck roll = 76.6%, 70.1%; Premium Choice knuckle = 73.5%, 68.6%; and Select knuckle = 80.0%, 69.2%, respectfully). At 42 d of aging, ground beef patties from Select knuckle (56.4%) subprimals had greater ($P<0.05$) MRA than those from Premium Choice (43.0%) and Select (37.5%) chuck roll and Premium Choice knuckle (43.2%) subprimals. For Premium Choice chuck roll and Select knuckle subprimals aged 7 d (73.6%, 80.0% respectfully), ground beef patties had the greatest ($P<0.05$) MRA and patties from subprimals aged 21 d (63.9%, 69.2% respectfully) had greater ($P<0.05$) MRA than those from subprimals aged 42 d (43.0%, 56.4% respectfully). For Select chuck rolls and Premium Choice knuckle subprimals aged 7 (76.6%, 73.5% respectfully) and 21 d (70.1%, 68.6% respectfully), ground beef patties had greater ($P<0.05$) MRA than those from subprimals aged 42 d (37.5%, 43.2% respectfully).

Aging time × display time. In the aging time × display time interaction, ground beef patties displayed 0 h had greater ($P<0.05$) MRA than those displayed 24 h. At 0 h of display, ground beef patties from subprimals aged 7 (78.5%) and 21 (75.6%) d had greater ($P<0.05$) MRA than those from subprimal aged 42 d (50.0%). At 24 h of display, ground beef patties from subprimals aged 7 d (73.3%) had the greatest ($P<0.05$) MRA and ground beef patties from subprimals aged 21 d (60.3%) had greater ($P<0.05$) MRA than those from subprimals aged 42 d (40.0%).

Relationship between oxygen consumption rate and metmyoglobin reducing ability

For oxygen consumption rate (OCR), the percent of oxymyoglobin after vacuum packaging decreased as time vacuum packaged increased especially in the first 20 min followed by minimal changes from 40 to 60 min. Therefore, for determining the oxygen consumption rate the change in percentage of oxymyoglobin from 0 to 20 min was the primarily rate used. At 0 min vacuum packed, ground beef patties at 0 h of display had higher percentages of oxymyoglobin than those at 24 h of display. Furthermore, ground beef patties from subprimals aged 7d had similar percentages of oxymyoglobin at 0 and 24 h of display, but patties from subprimals aged 21 and 42 d had higher percentages of oxymyoglobin at 0 h of display then those at 24 h of display.

For OCR from 0 to 20 min vacuum packaged, ground beef patties from chuck roll subprimals at 24 h of display had lower OCR than those from chuck roll subprimals at 0 h of display while patties from knuckle subprimals had similar OCR at 0 and 24 h of display. In addition, ground beef patties from Premium Choice subprimals at 24 h of display had lower OCR than those from Premium Choice subprimals at 0 h of display while patties from Select subprimals had similar OCR at 0 and 24 h of display. Furthermore, ground beef patties from subprimals aged 42 d had a higher OCR than those from subprimals aged 7 and 21 d.

Furthermore, the current data found that ground beef patties from Select knuckle subprimals had the lowest OCR. McKenna, Miles, Baird, Pfeiffer, Ellebracht, and Savell (2005) studied the biochemical properties of 19 beef muscles and identified high color stability muscles to have high oxygen penetration depth (OPD) and low OCRs, while muscles of low color stability had high OCRs and low OPD. Furthermore, Madhavi and Carpenter (1993) found that M. longissimus dorsi steaks had a lower OCR than M. psoas major steaks. Researchers have observed that increased oxygen consumption decreases color stability because less oxygen is available to bind with myoglobin, creating oxidative conditions that favor metmyoglobin formation (Ledward, 1985; O'Keefe & Hood, 1982; McKenna et al., 2005).

For metmyoglobin reducing ability (MRA), the percent of metmyoglobin after vacuum packaging decreased as time vacuum packaged increased. Therefore, for determining the MRA the change in percentages of metmyoglobin from 0 to 2 h was the primary MRA rate used. At 0 h vacuum packed, ground beef patties at 0 h of display had lower percentages of metmyoglobin than those at 24 h of display. In addition, ground beef patties from chuck roll subprimals had higher percentages of metmyoglobin than those from knuckle and ground beef patties from Premium Choice subprimals had higher percentages of metmyoglobin than those from Select subprimals. Not in agreement with the current study, McKenna et al. (2005) suggests that the amount of MMb formed initially on the surface of the muscles was inversely related to color stability and that the initial amount was as good as or a better indicator of color stability than the amount of MMb reduced over time. However, it was found in the current study that ground beef patties from subprimals aged 42 d had higher percentages of metmyoglobin than those from subprimals aged 7 d. MacDougall and Rhodes (1972) suggest that the faster accumulation of metmyoglobin subsequently result from diminution of the meat's enzymic activity which occurs during aging and metmyoglobin formed in the region of low oxygen tension in no longer reduced back to myoglobin because the reducing intermediates (particularly NADH) are longer being formed.

For MRA from 0 to 2 h vacuum packaged, ground beef patties at all aging times had greater MRA at 0 h of display than those at 24 h of display. Ground beef patties from subprimals aged 7 and 21 d had similar MRA among all subprimal type × quality grade combinations but at 42 d of aging patties from Select knuckle subprimals had the highest MRA. Madhavi and Carpenter (1993) found that M. longissimus dorsi steaks had less MMb accumulation and greater MRA than M. psoas major steaks; however, after grinding no differences between the M. longissimus dorsi and the M. psoas major in MMb accumulation were observed due to the similar disrupted tissue in both muscles resulting in an increase of both MMb accumulation and OCR concentration. Furthermore, King et al. (2010) reported that breed differences in longissimus lean color stability were inversely related to differences among the same breeds in marbling score and suggested that muscles with less marbling may have greater ability to maintain reducing activity. In the current study, this was not observed except at 42 d of display when ground beef patties from Select knuckle subprimals had a greater MRA than those from Premium Choice knuckle subprimals. In addition, McKenna et al. (2005) found that those with high color stability had the highest MRA and a high resistance to induced MMb formation while muscles with very low stability muscles had the least MRA and low resistance to induced MMb formation. Conversely, in the current study minimal differences were seen between the treatment groups and the sample with the greatest MRA also had low visual color scores and instrumental color measurements.

McKenna et al. (2005) also concluded that product color stability is not solely determined by MRA or OCR but by the proportion of the two components. For example, muscles with low color stability may have high or low OCRs, but their reducing activity is proportionally low compared to their OCRs; furthermore in contrast, muscles of high color stability may have high or low OCRs, but have reducing activity that proportionally exceeds their OCR. In summary, meat products color stability is related to the products MRA and OCR (McKenna et al., 2005).

Microbiology

Display time interactions ($P<0.05$) with subprimal type and aging time were detected for aerobic plate count (APC) and lactic acid plate count (LAPC). Therefore, subprimal type × display time and aging time × display time interaction means are presented in table 3.4 and 3.6, respectfilly.

For APC, ground beef patties from knuckle subprimals had ($P<0.05$) more colony forming units per g (CFU/g) than ground beef patties from chuck roll subprimals at both 0 and 24 h of display and patties displayed 24 h had ($P<0.05$) more CFU/g than those displayed 0 h. Ground beef patties from both quality grades had ($P<0.05$) more CFU/g after 24 h of display than those displayed 0 h. In the aging time × display time interaction for APC, at both display times the CFU/g count was ($P<0.05$) highest for ground beef patties from subprimals aged 42 d and lowest for patties from subprimals aged 7 d. Furthermore, ground beef patties from subprimals aged 7 d did not differ ($P>0.05$) in CFU/g count between display times; however, ground beef patties from subprimals aged 21 and 42 d and displayed 24 h had greater ($P<0.05$)

CFU/g than those displayed 0 h. A relationship was observed in which pH and APC for ground beef patties where correlated for the chuck roll at 0 and 24 h of display and the knuckle at 0 and 24 h of display (0.73, 0.74, 0.82, and 0.84, respectfully).

For LAPC, ground beef patties from knuckle subprimals had ($P<0.05$) more CFU/g than those from the chuck roll subprimals displayed 0 h and patties from both subprimals had ($P<0.05$) more CFU/g after 24 h of display than those at 0 h of display. Ground beef patties from both quality grades had ($P<0.05$) more CFU/g after 24 h of display than those at 0 h of display. In the aging time × display time interaction for LAPC, at both display times the CFU/g count was ($P<0.05$) highest for patties from subprimals aged 42 d and lowest for patties from subprimals aged 7 d. Furthermore, ground beef patties from subprimals aged 7 d did not differ ($P>0.05$) in CFU/g count between display times; however, ground beef patties from subprimals aged 21 and 42 d and displayed 24 h had greater ($P<0.05$) CFU/g than those displayed 0 h. A relationship was observed in which pH and LAPC for ground beef patties where correlated for the chuck roll at 0 and 24 h of display and the knuckle at 0 and 24 h of display (0.75, 0.73, 0.83, and 0.82, respectfully). Furthermore, APC and LAPC for ground beef patties where highly correlated for the chuck roll at 0 and 24 h of display and the knuckle at 0 and 24 h of display (0.99, 0.99, 0.99, and 0.99, respectfully). In addition, Rodas-Gonzalez et al. (2011) found similar APC and LAPC CFU/g when sampling vacuum packaged strip-loins and cube rolls over 20 weeks of aging.

Mancini et al. (2002b) also found that increased storage (0-12 d) and display time (0–48 h) of ground beef significantly increased microbial counts but lean level (7/93, 19/81, & 27/73) had no effect. In addition, they found that at the average retail display case temperature of 4.4ºC the aerobic bacteria count of ground beef chubs delivered to retailers contain approximately 2 to

4 $\log_{10}$ CFU/g and the count of ground beef commercially displayed for 48 h may range from 4-8 $\log_{10}$ CFU/g. Furthermore, Manu-Tawiah, Ammann, Sebranek and Molins (1991) considered the "spoilage" point of ground beef packaged in oxygen permeable stretch film to occur at 7 $\log_{10}$ CFU/g. This count to determine spoilage is supported by other researchers including Dainty and Mackey (1992) and Bell and Garout (1994).

Thiobarbituric Acid Reactive Substances

Display time interactions ($P<0.05$) with subprimal type, quality grade, and aging time were detected for thiobarbituric acid reactive substances (TBARS). Therefore, subprimal type × display time, quality grade × display time, and aging time × display time interaction means are presented in table 3.4, 3.5, and 3.6, respectfully.

For thiobarbituric acid reactive substances (TBARS), ground beef patties from knuckle subprimals had greater ($P<0.05$) TBARS than those from chuck roll subprimals after 24 h of display and ground beef patties from both subprimals had greater ($P<0.05$) TBARS after 24 h of display than those displayed 0 h. Patties from Select subprimals had ($P<0.05$) greater TBARS than those from Premium Choice subprimals after 24 h of display and patties from both quality grades had ($P<0.05$) greater TBARS after 24 h of display than those displayed 0 h. For the aging time × display time interaction for lipid oxidation, the TBARS amount was ($P<0.05$) greater for ground beef patties from subprimals aged 21 and 42 d than those aged 7 d and at all aging times patties displayed 24 h had greater ($P<0.05$) TBARS than those displayed 0 h. McKenna et al. (2005) also found that TBARS values increased with increasing days of retail display. In addition, on average McKenna et al. (2005) reported that less color stable muscles had higher TBARS values and more color stable muscles had lower TBARS values. The TBARS value (mg malonaldehyde/kg) level at which the consumer can perceive an off-flavor is an area of debate and may vary from 0.5-1.0 mg according to Tarladgis, Watts, Younathan, & Dugan (1960), approximately 2.28 mg in beef loin steaks according to Campo, Nute, Hughes, Enser, Wood, and Richardson (2006), or 0.6 - 2.0 mg according to Greene & Cumuze (1981). If an arbitrary threshold of 1 was used, aging times of 21 and 42 d at 24 h of display in the present study may be approaching possible detection. Furthermore, in this experiment a relationship was observed in which APC and TBARS for ground beef patties where correlated for the chuck roll and knuckle at 0 h of display (0.60 and 0.69, respectfully) as well as LAPC and TBARS for ground beef patties where correlated for the chuck roll and knuckle at 0 h of display (0.59 and 0.70, respectfully).

Summary

Subprimal type. Ground beef patties from chuck roll subprimals had lower (brighter red) initial color scores, brighter red visual color at 0, 24, and 48 h of display, less discoloration at 24, 48, and 72 h of display, higher L*, a*, b*, chroma values throughout display, and lower TBAR values at 24 h of display than those from knuckle subprimals.

Quality grade. Ground beef patties from Premium Choice subprimals had lower (brighter red) initial color scores, brighter red visual color, less discoloration, higher L*, a*, b*, and chroma values, and lower TBARS values at 24 h of display than those from Select subprimals. Ground beef patties from Select knuckle subprimals had greater OCR than those from Premium Choice and Select chuck roll subprimals and Premium Choice knuckle subprimals.

Aging time. Patties from chuck roll subprimals aged 42 d were darker, more discolored and had lower a* and chroma values later in display than those from subprimal aged 7 or 21 d.

In addition, patties from subprimals aged 42 d had lower MRA than those from subprimals aged 7 or 21 d. As aging time increased, patties had higher Aerobic and Lactic acid plate counts (7 d < 21 d < 42 d) and TBAR values (7 d < 21 & 42 d).

Display time. As display time increased, patties became darker red and more discolored, which was supported with decreased L*, a*, b*, a/b ratio and chroma values and increased hue angle values. In addition, displaying ground beef patties for 24 h resulted in increased Aerobic and Lactic acid plate count, TBAR values, and percentages of initial MMb formed as well as decreased percentages of surface OMb and MRA.

Conclusion

Chuck roll and Premium Choice subprimals had brighter red color, less discoloration, and higher L*, a*, b*, and chroma values throughout display than those from knuckle and Select subprimals, respectfully. Furthermore, if a visual and discoloration score of 5 was set as the threshold of consumer acceptability, patties from chuck roll subprimal aged 7 and 21 d had 48 more hours of shelf life than patties from knuckle subprimals from all aged times (which passed the threshold after 24 h of display) and 24 more hours of shelf life than patties from chuck roll subprimals aged 42 d (which passed the threshold after 48 h of display). This is further supported by data showing patties from subprimals aged 7 and 21 d had greater MRA than those aged 42 d. Lastly, for patties from subprimals aged 42 d, microbial counts became less acceptable. Therefore, Premium Choice chuck roll subprimals aged for up to 21 d would be recommended for extended display life and acceptability. Furthermore, Select Knuckle subprimals aged 21 and 42 d at 24 h of display had the highest TBAR values approaching a threshold in which consumers may detect an off-flavor; therefore, these combinations should be avoided for ground beef patties designated for retail display.

Table 3.1 Effect of subprimal type, quality grade, and aging time on pH, myoglobin concentration, initial color and percentages of moisture, fat, and protein of ground beef patties

	Subprimal type			**Quality grade**			**Aging time**			
	Chuck roll	**Knuckle**	**SE**	**Premium Choice**	**Select**	**SE**	**7 d**	**21 d**	**42 d**	**SE**
pH	5.83	5.82	0.045	5.84	5.81	0.045	5.74^{a}	5.77^{a}	5.96^{b}	0.046
Myoglobin[1]	6.04^{a}	6.58^{b}	0.142	6.40	6.22	0.142	.	.	.	.
Initial Color[2]	3.9^{a}	5.8^{b}	0.11	4.6^{a}	5.2^{b}	0.11	4.9^{b}	4.5^{a}	5.3^{c}	0.12
Moisture, %[3]	--	--	--	--	--	--	68.0	68.4	67.6	0.270
Fat, %[3]	--	--	--	--	--	--	12.0	11.5	12.7	0.360
Protein, %	18.0^{a}	19.7^{b}	0.114	18.4^{a}	19.3^{b}	0.114	18.8	19.1	18.7	0.140

[a-c] Means within a row and trait with a different letter differ ($P<0.05$).

[1] Myoglobin Concentration = mg/g meat

[2] Initial Meat Color: 1 = Very light red; 3 = Light red; 5 = Bright red; 8 = Dark red.

[3] Subprimal type × Quality grade Interaction ($P<0.05$; Table 3-2)

Table 3.2 Subprimal type × quality grade interaction means for percentages of moisture and fat of ground beef patties

	Chuck roll		**Knuckle**		
	Premium Choice	**Select**	**Premium Choice**	**Select**	**SE**
Moisture, %	62.2^{a}	66.5^{b}	70.7^{c}	72.7^{d}	0.312
Fat, %	19.8^{a}	14.3^{b}	8.5^{c}	5.8^{d}	0.415

[a-d] Means within a row with a different letter differ ($P<0.05$).

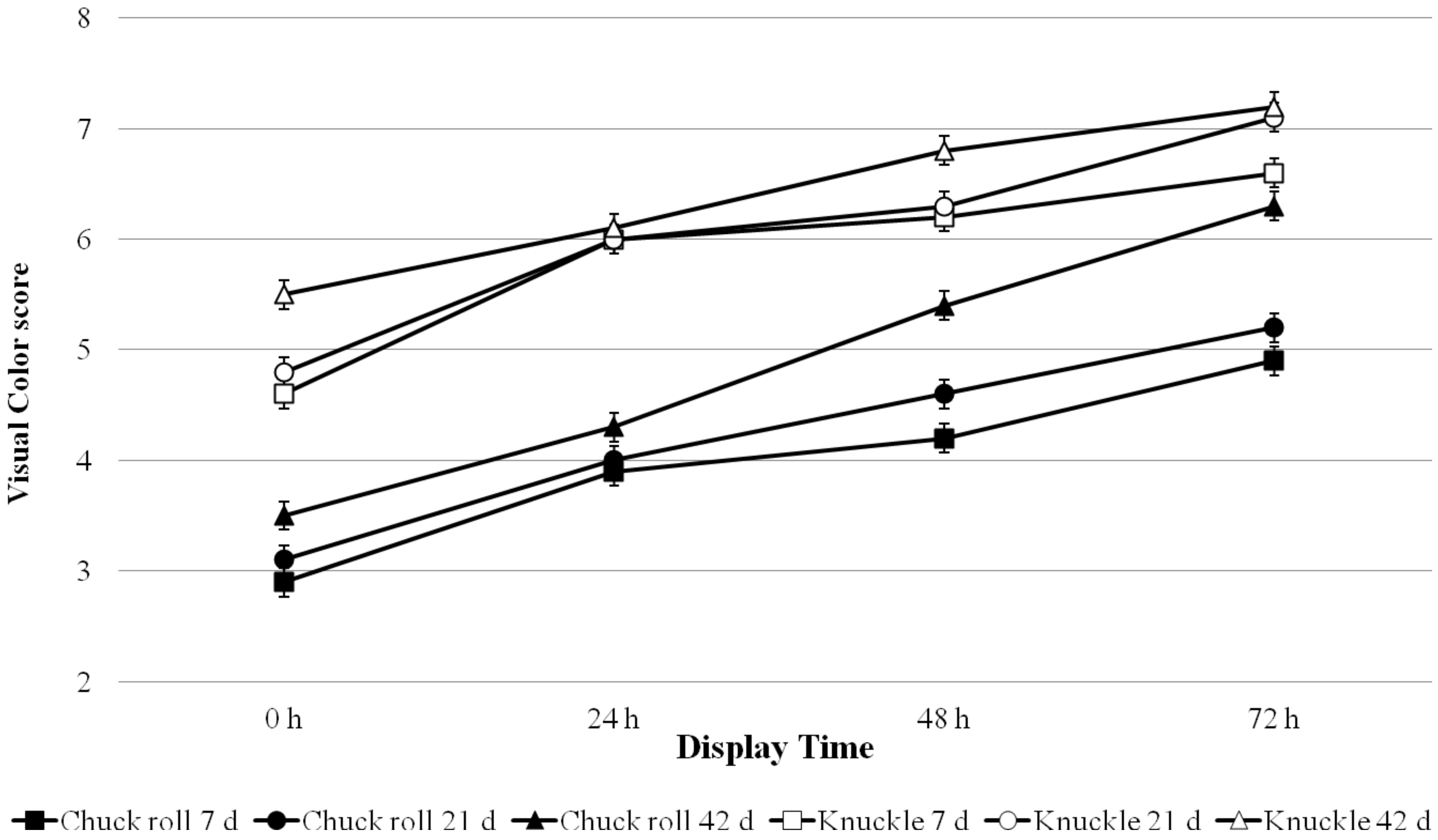


Figure 3.1. Subprimal type × aging time × display time interaction means for color panel visual color scores (2 = Bright cherry-red; 5 = Slightly dark cherry-red; 8 = Extremely dark red) of ground beef patties (SE = 0.13)

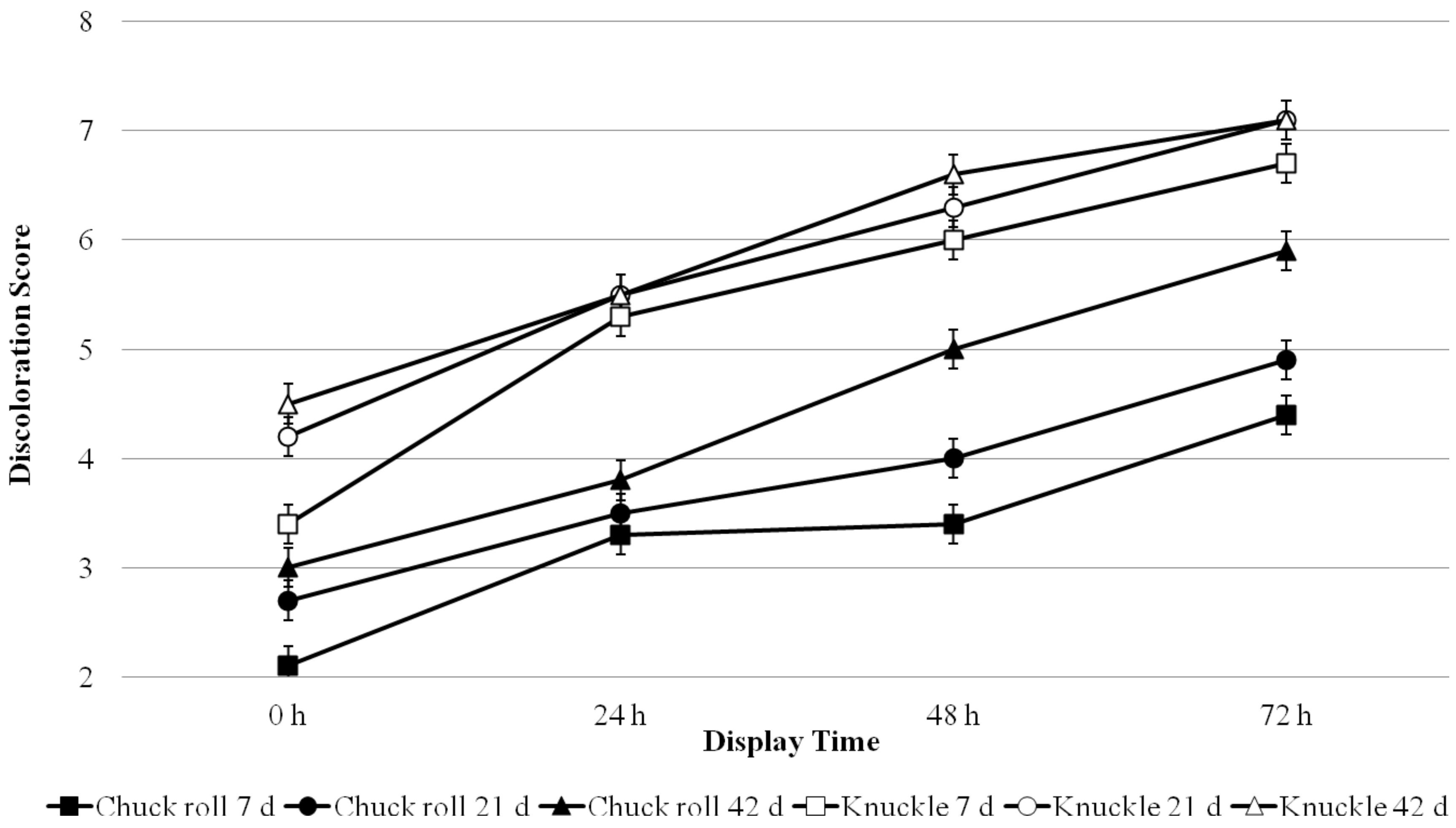


Figure 3.2. Subprimal type × aging time × display time interaction means for color panel discoloration scores (2 = Bright red; 5 = Moderately dark red; 8 = Tan to brown) of ground beef patties (SE = 0.18)

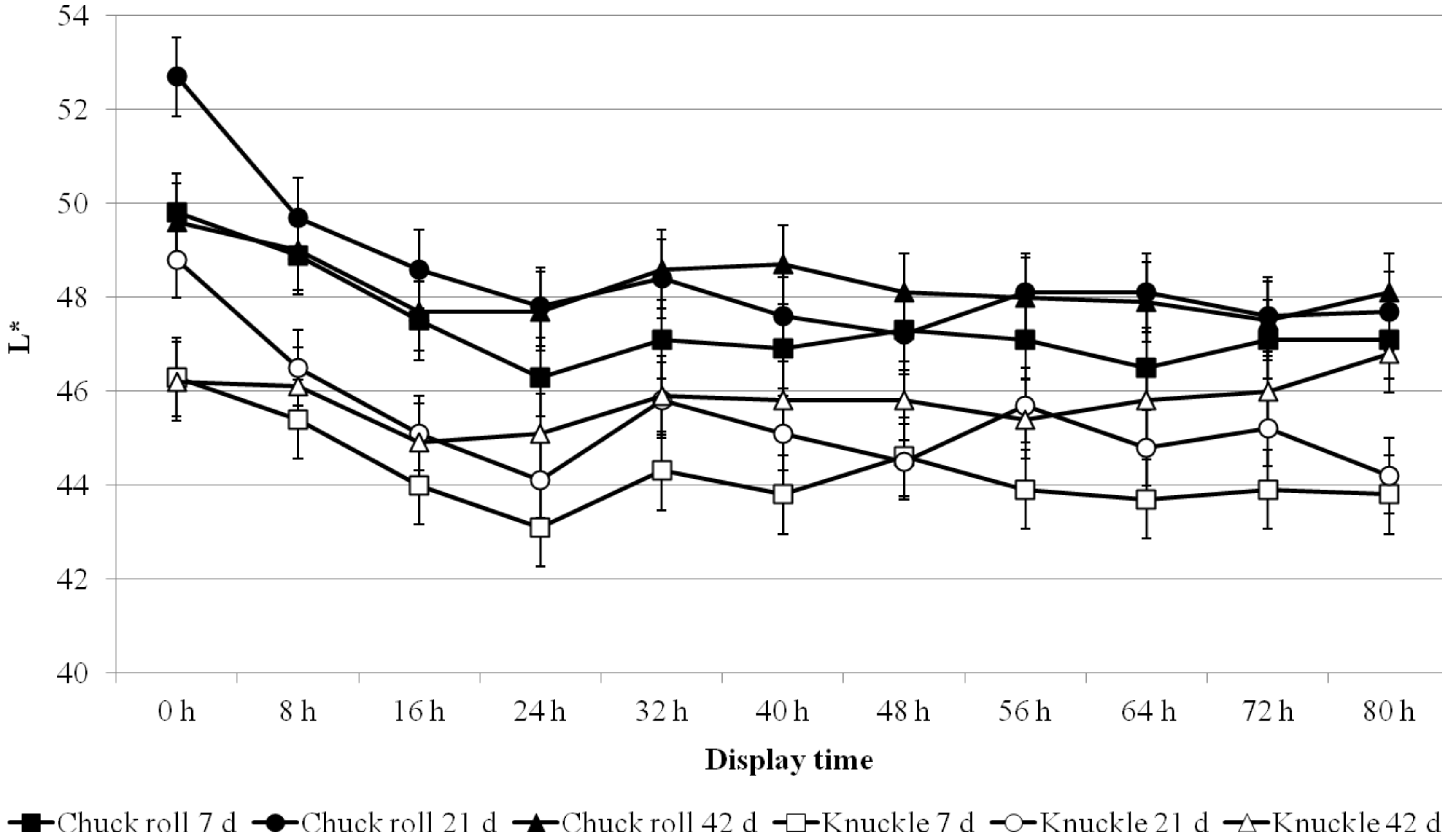


Figure 3.3 Subprimal type × aging time × display time means for L* instrumental color values for ground beef patties (SE = 0.8441)

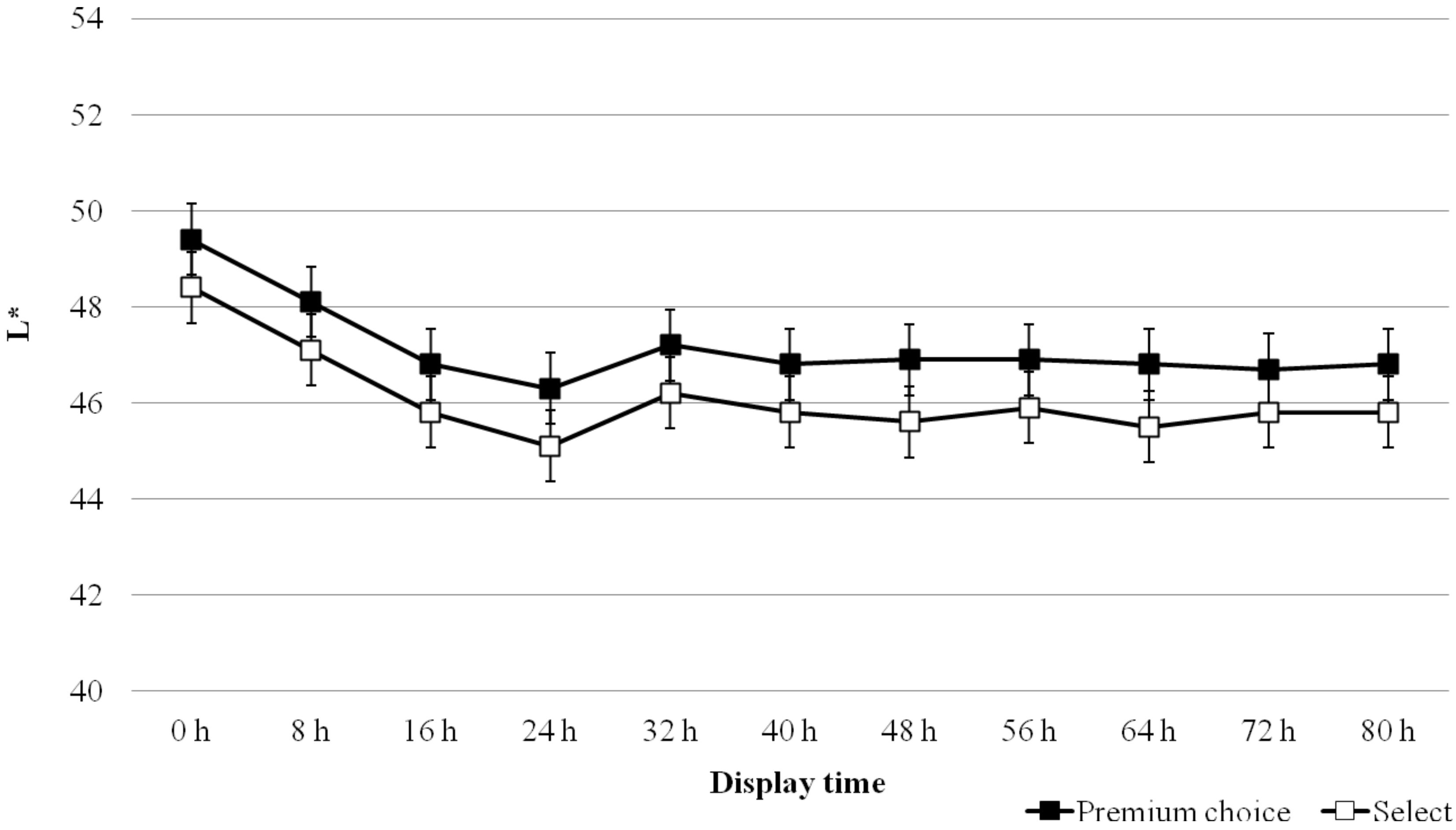


Figure 3.4 Quality grade × display time means for L* instrumental color values for ground beef patties (SE = 0.7412)

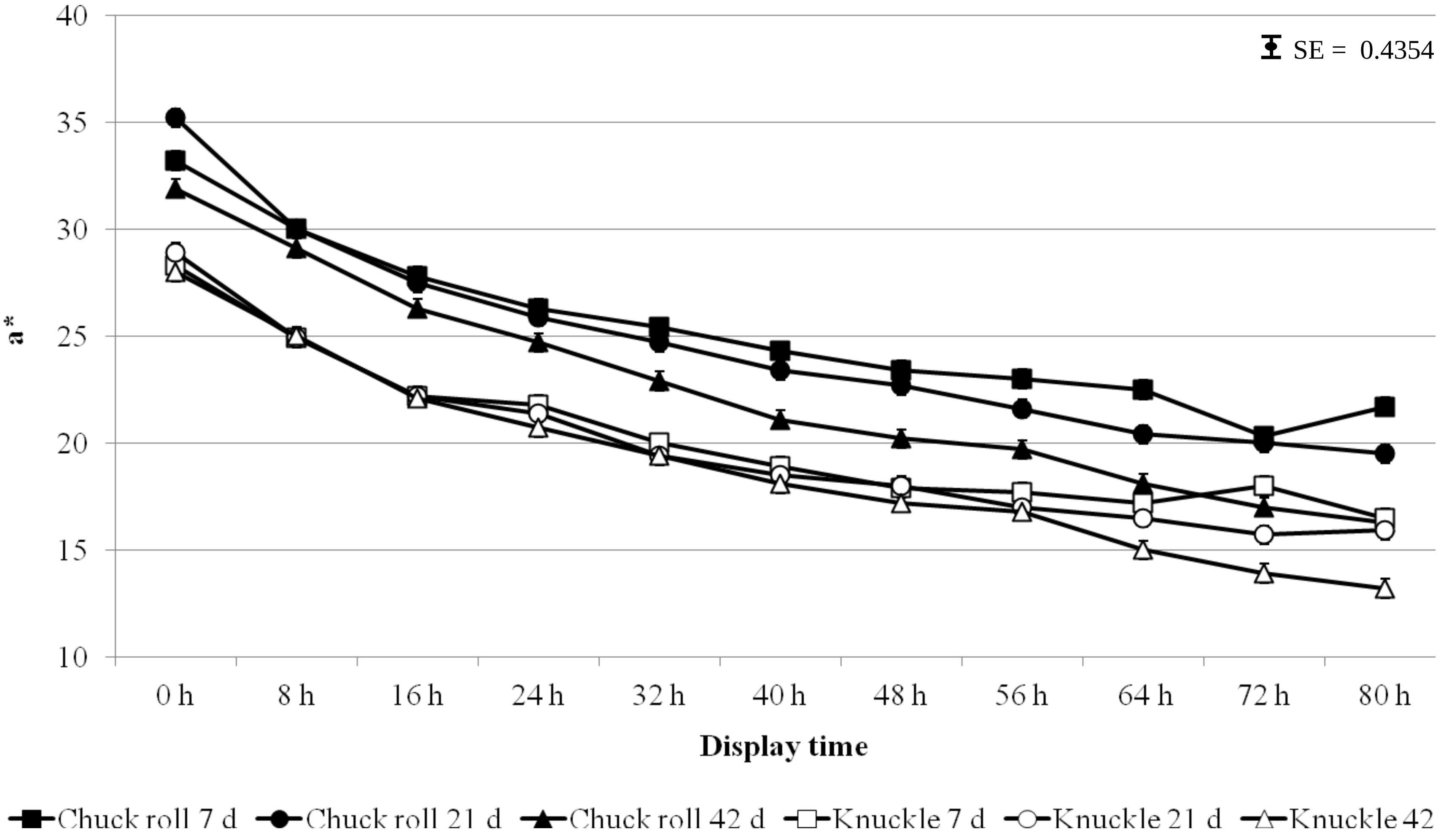


Figure 3.5 Subprimal type × aging time × display time interaction means for a* instrumental color values for ground beef patties (SE = 0.4354)

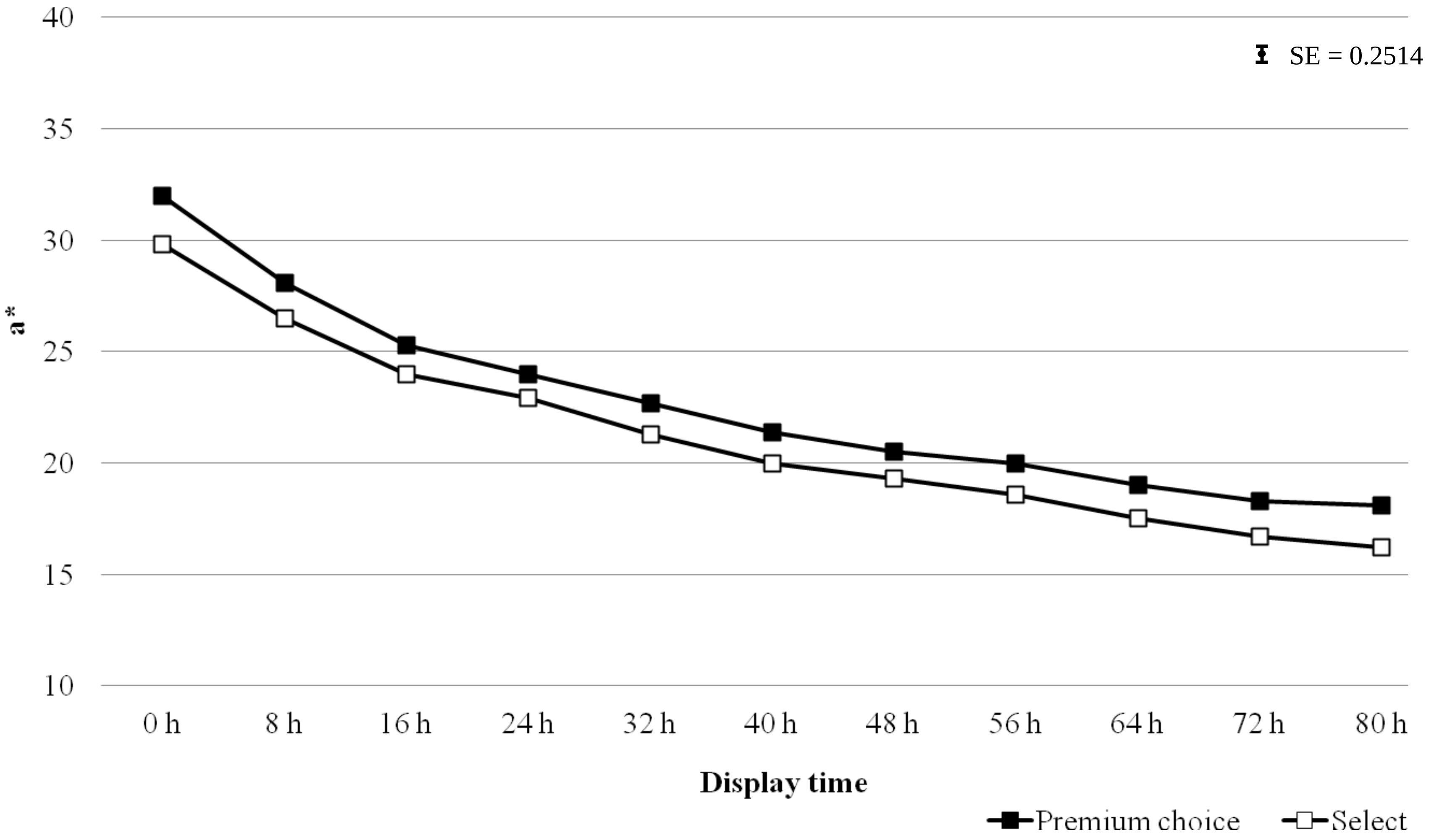


Figure 3.6 Quality grade × display time means for a* instrumental color values for ground beef patties (SE = 0.2514)

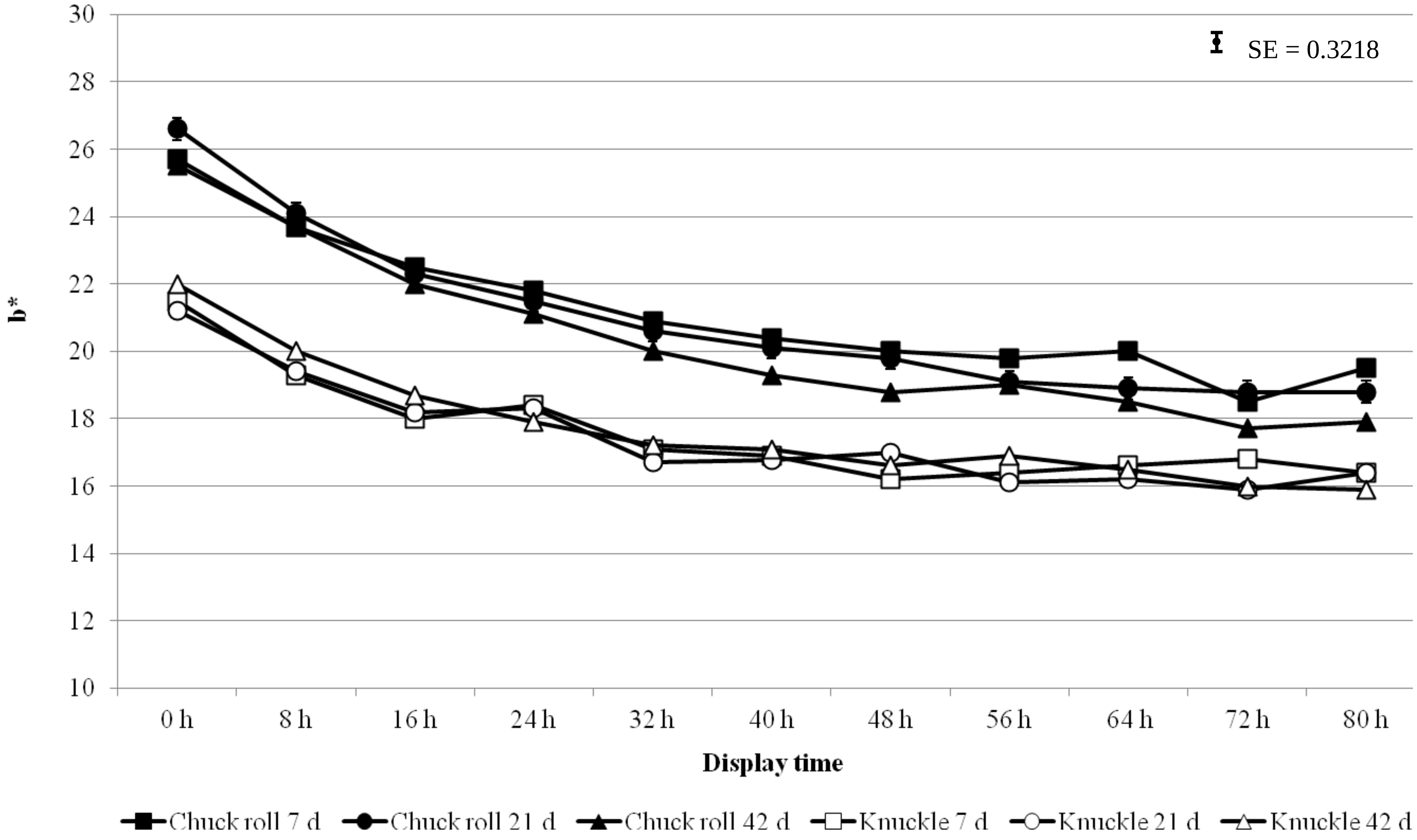


Figure 3.7 Subprimal type × aging time × display time means for b* instrumental color values for ground beef patties (SE = 0.3218)

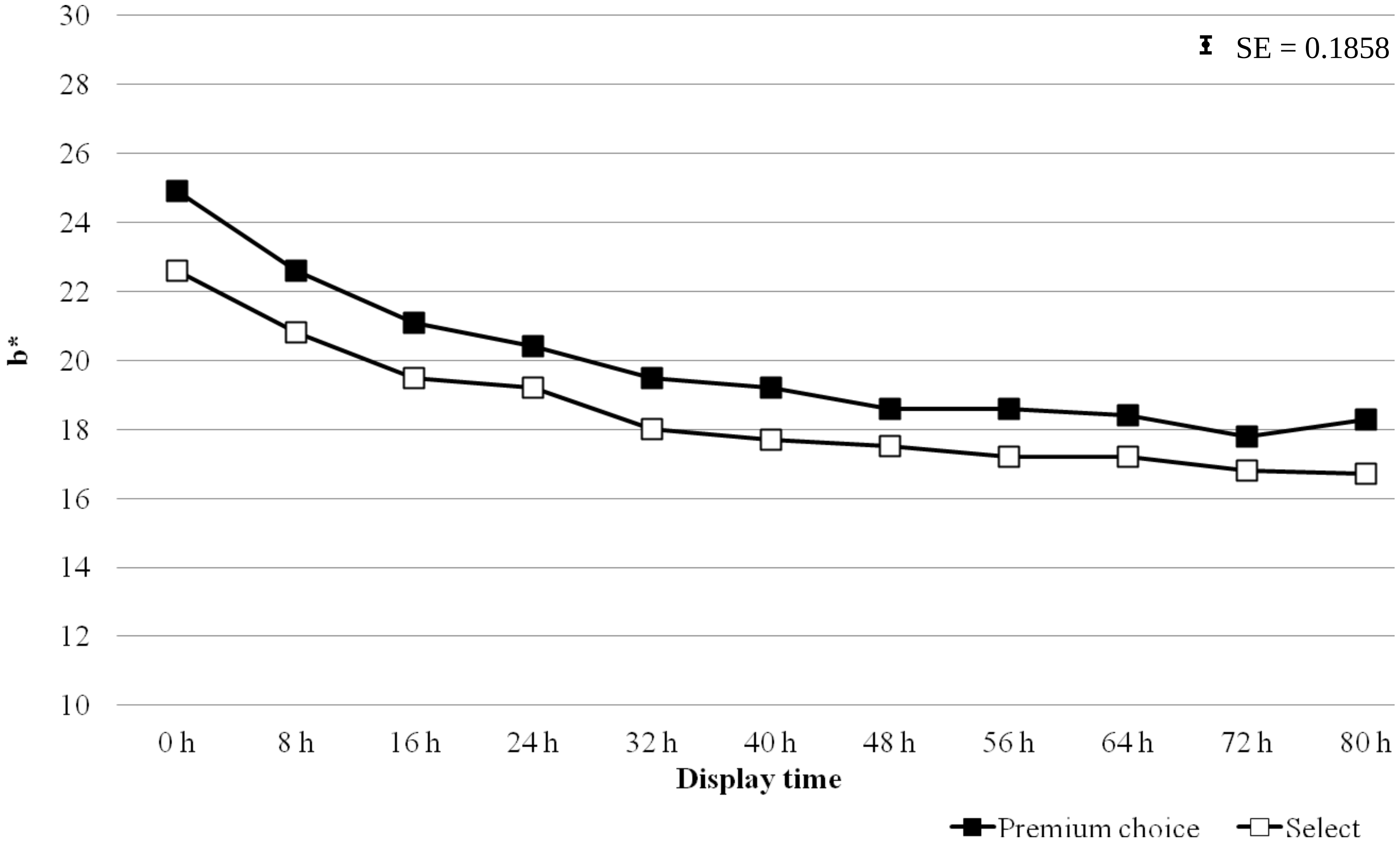


Figure 3.8 Quality grade × display time interaction means for b* instrumental color values for ground beef patties (SE = 0.1858)

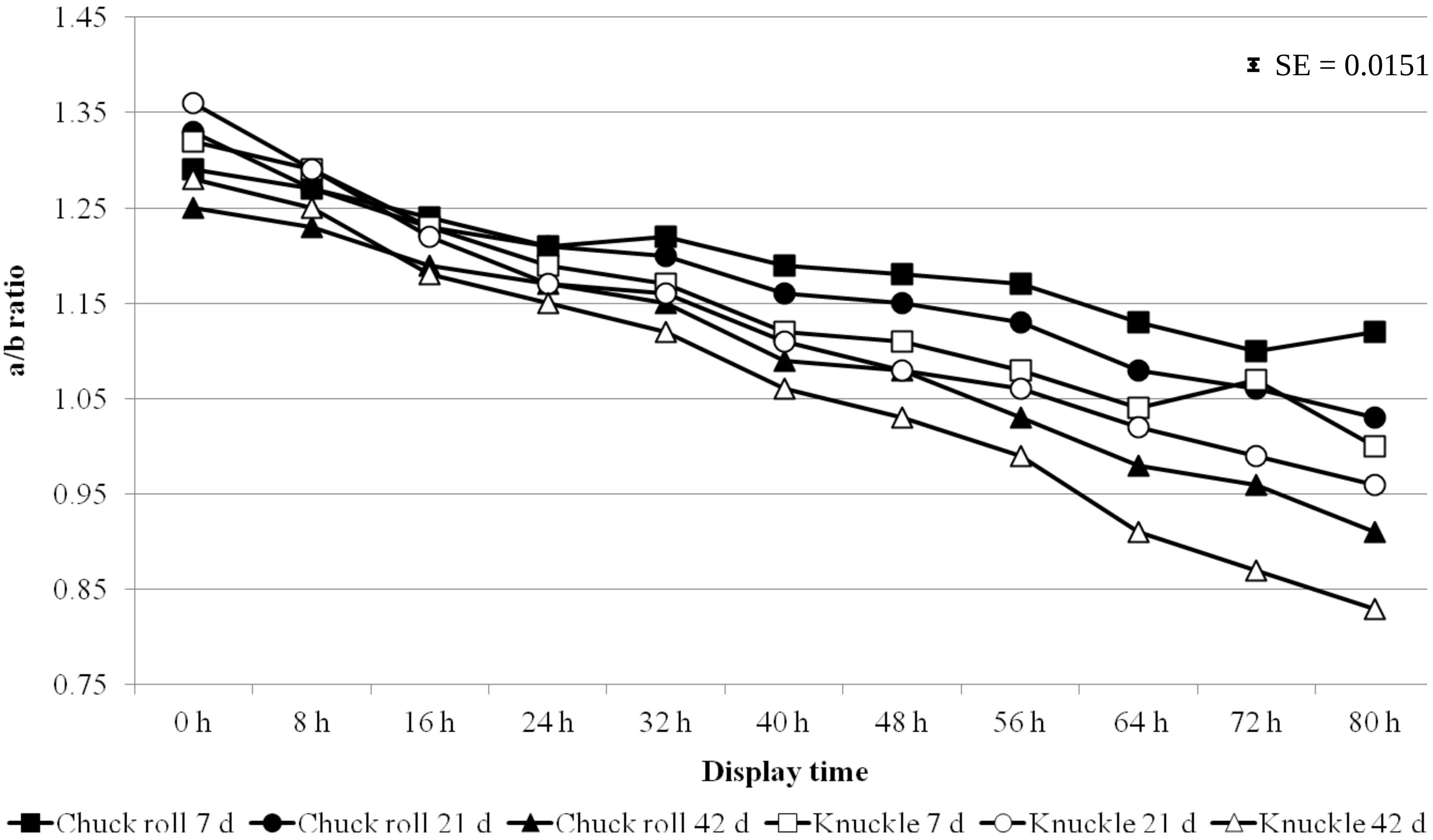


Figure 3.9 Subprimal type × aging time × display time means for a/b ratio instrumental color values for ground beef patties (SE = 0.01511)

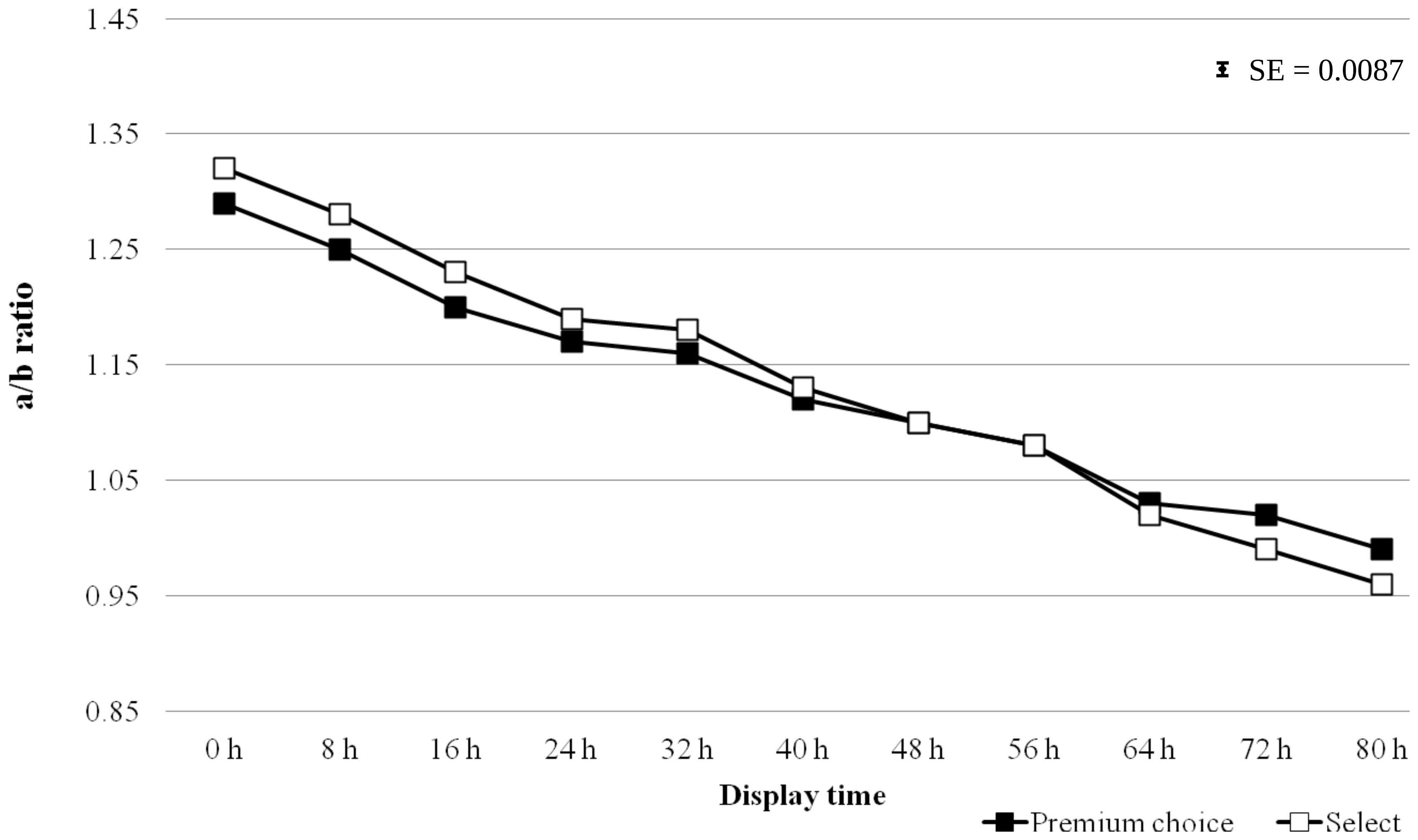


Figure 3.10 Quality grade × display time interaction means for a/b ratio instrumental color values for ground beef patties (SE = 0.0087)

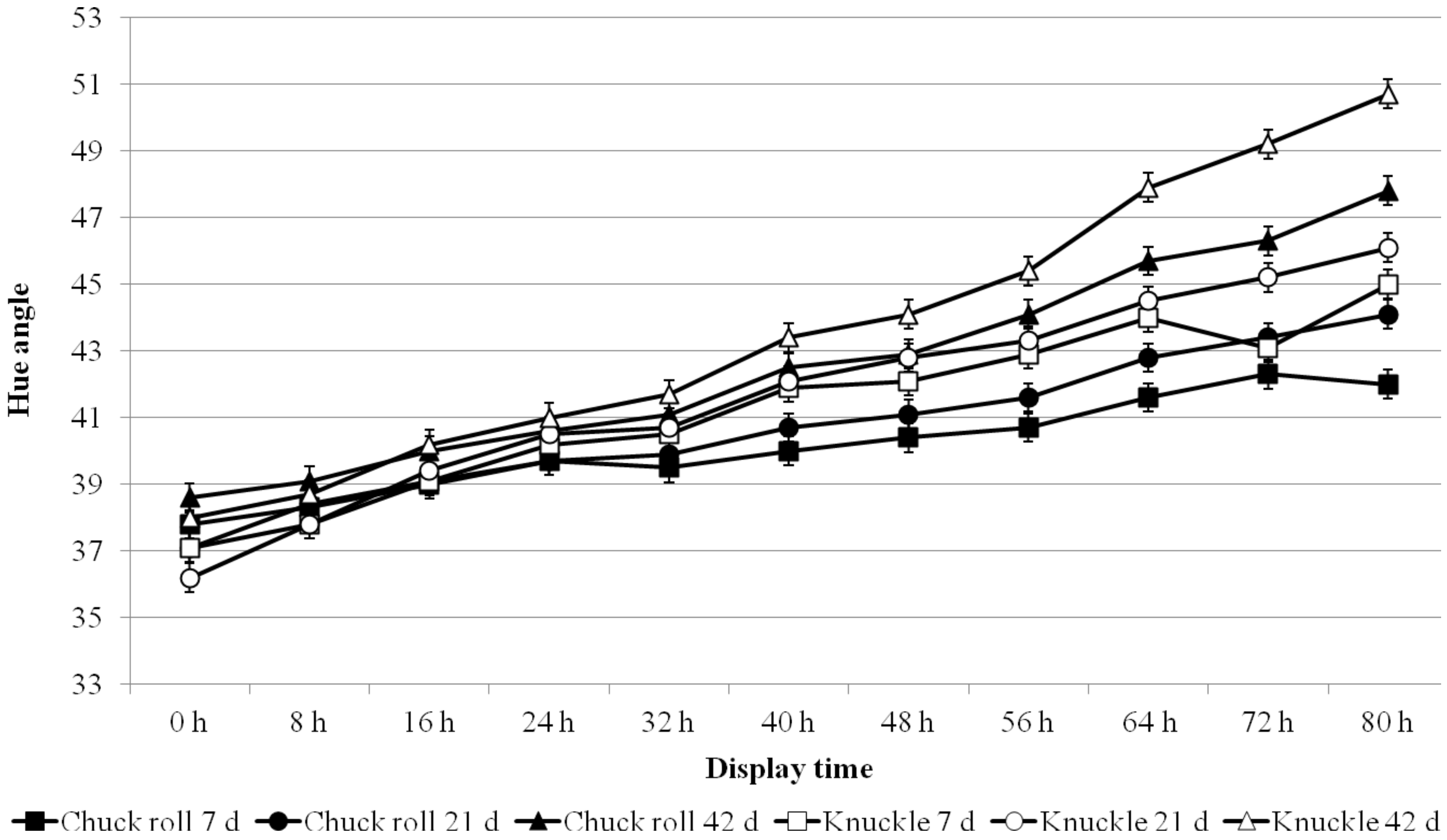


Figure 3.11 Subprimal type × aging time × display time means for hue angle instrumental color values for ground beef patties (SE = 0.4233)

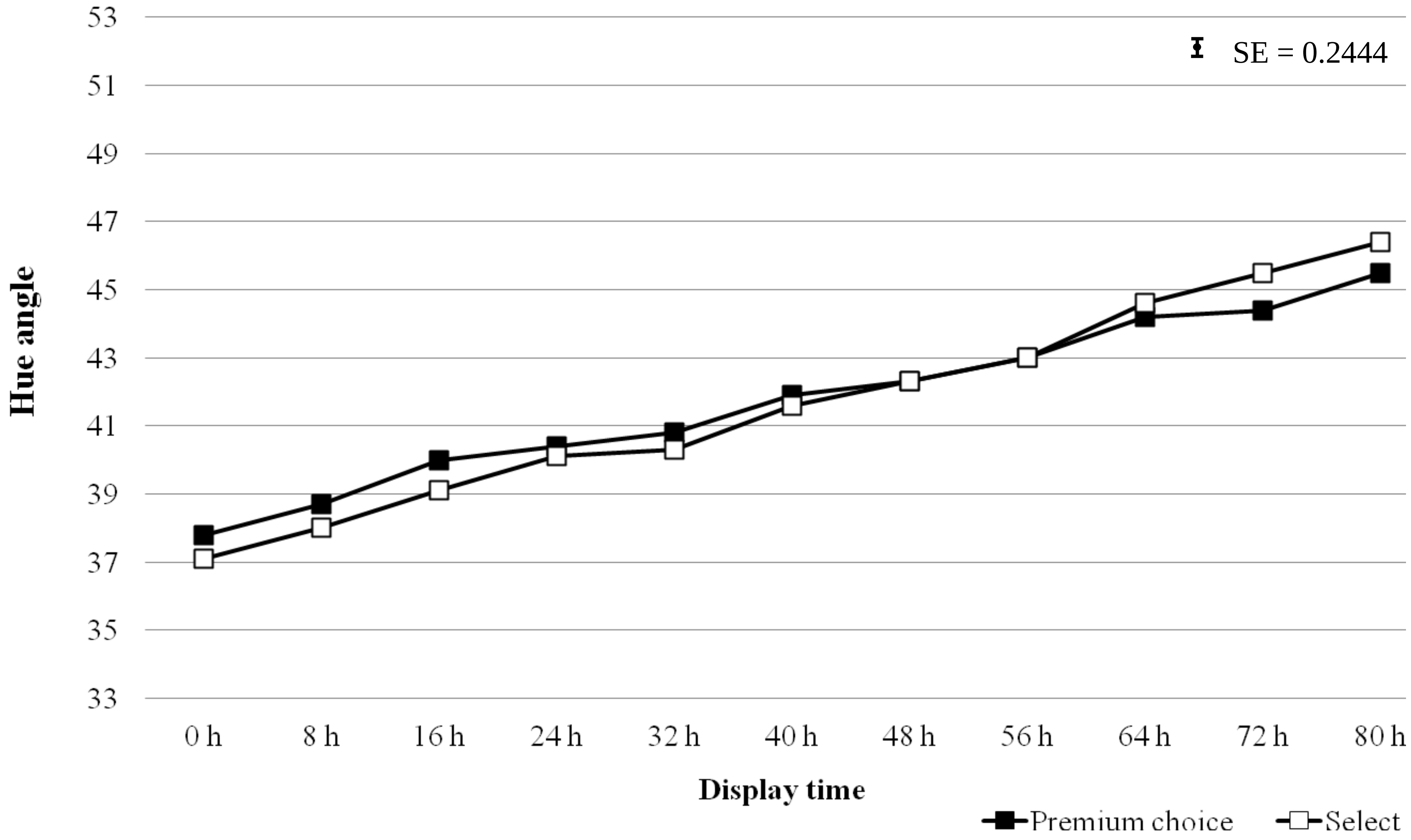


Figure 3.12 Quality grade × display time interaction means for hue angle instrumental color values for ground beef patties (SE = 0.2444)

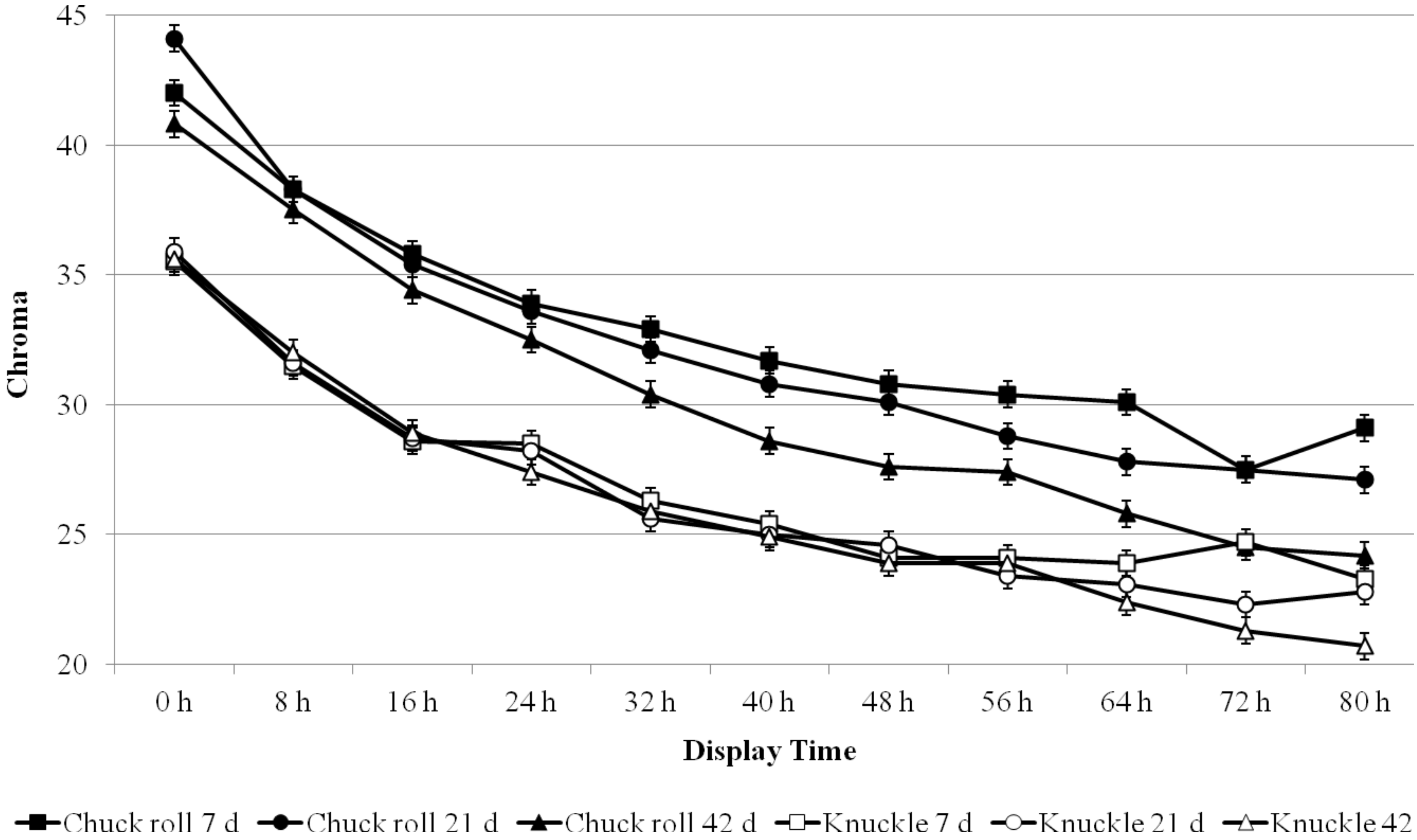


Figure 3.13 Subprimal type × aging time × display time interaction means for chroma instrumental color values for ground beef patties (SE = 0.5041)

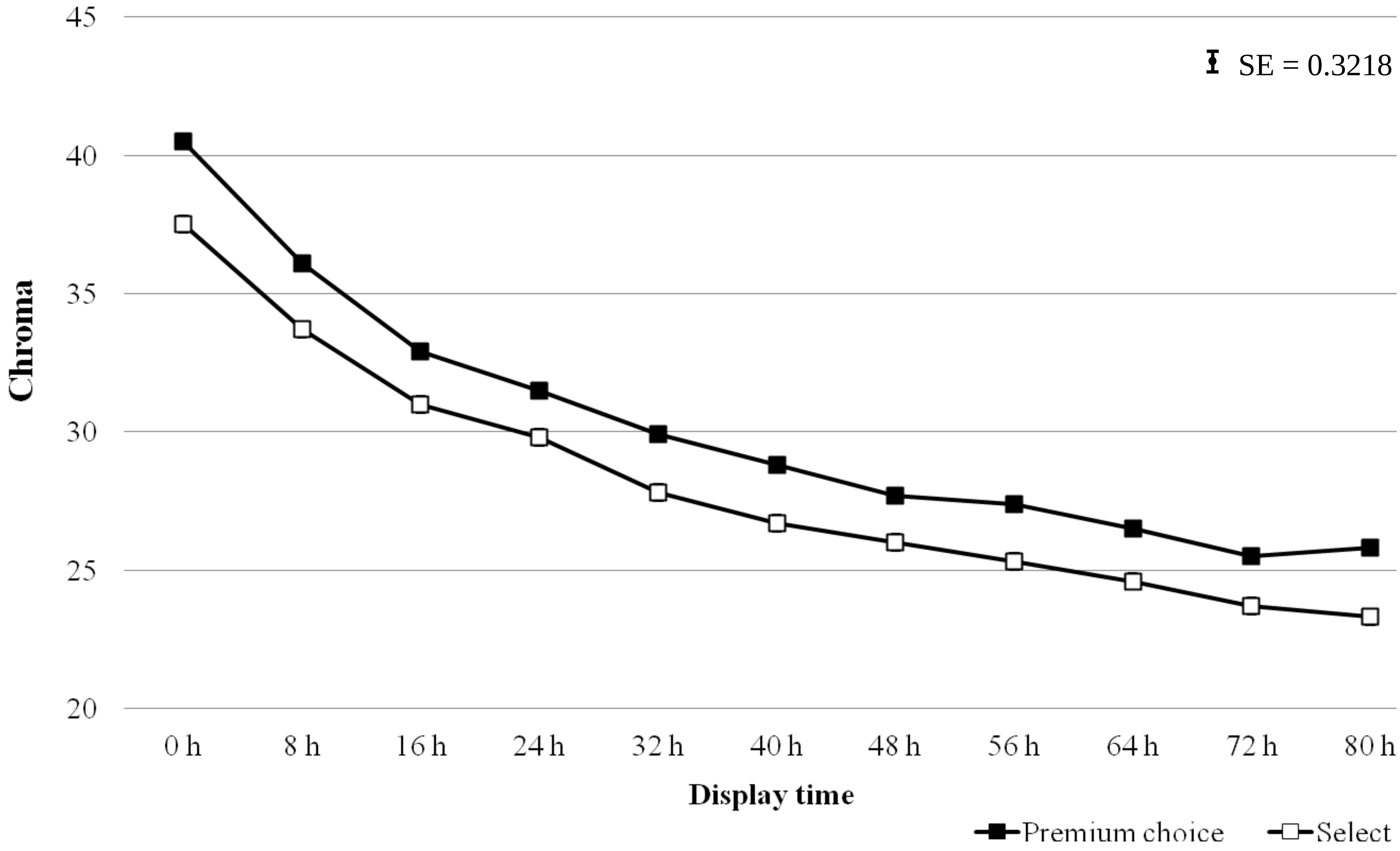


Figure 3.14 Quality grade × display time means for chroma instrumental color values for ground beef patties (SE = 0.2911)

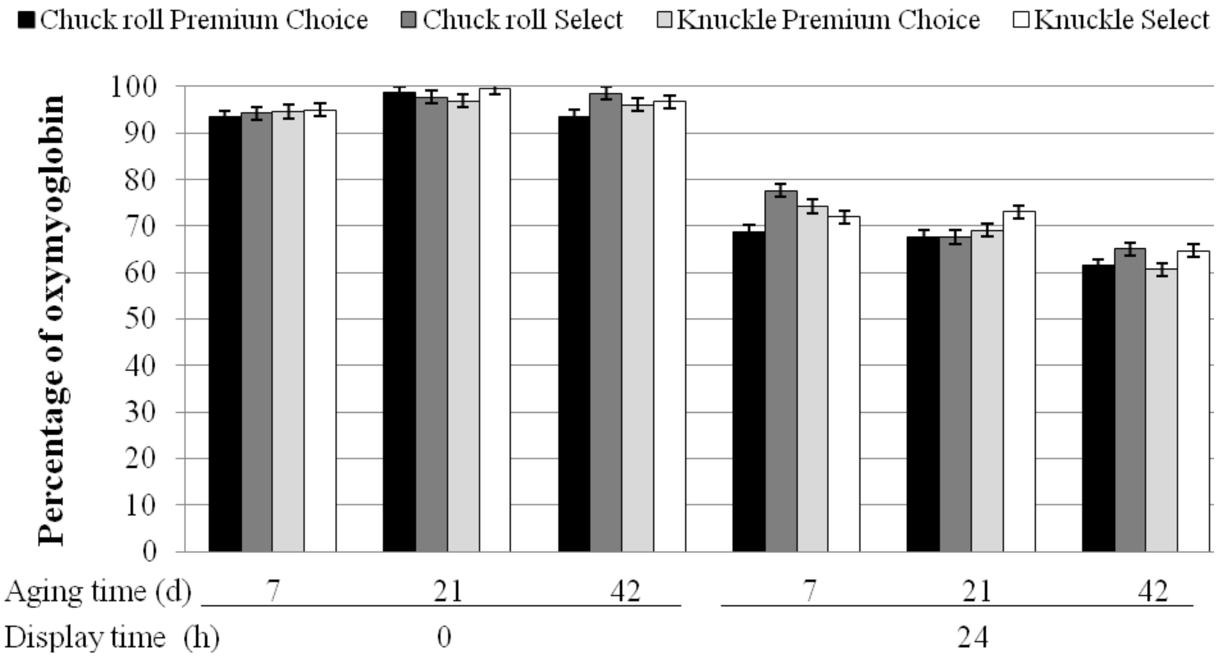


Figure 3.15 Subprimal type × quality grade × aging time × display time interaction means for percentages of oxymyoglobin before and after 24 h of display and after 0 min in a vacuum package for ground beef patties (SE = 1.44)

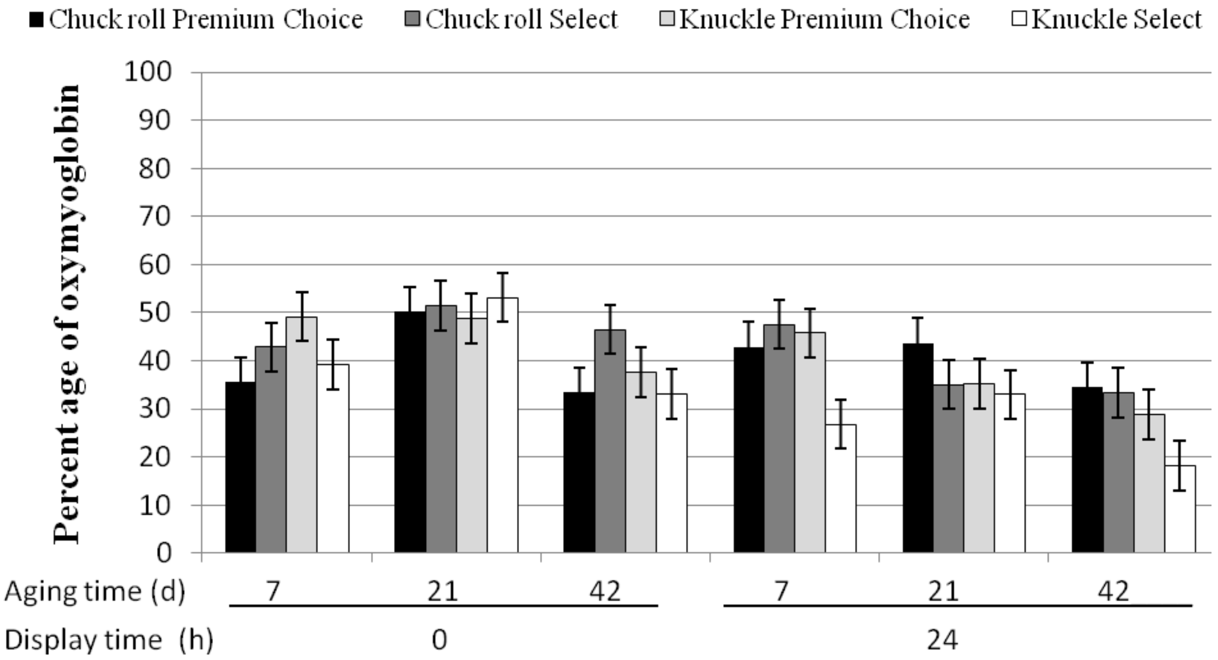


Figure 3.16 Subprimal type × quality grade × aging time × display time means for percentages of oxymyoglobin before and after 24 h of display and after 20 min in a vacuum package for ground beef patties (SE = 5.09)

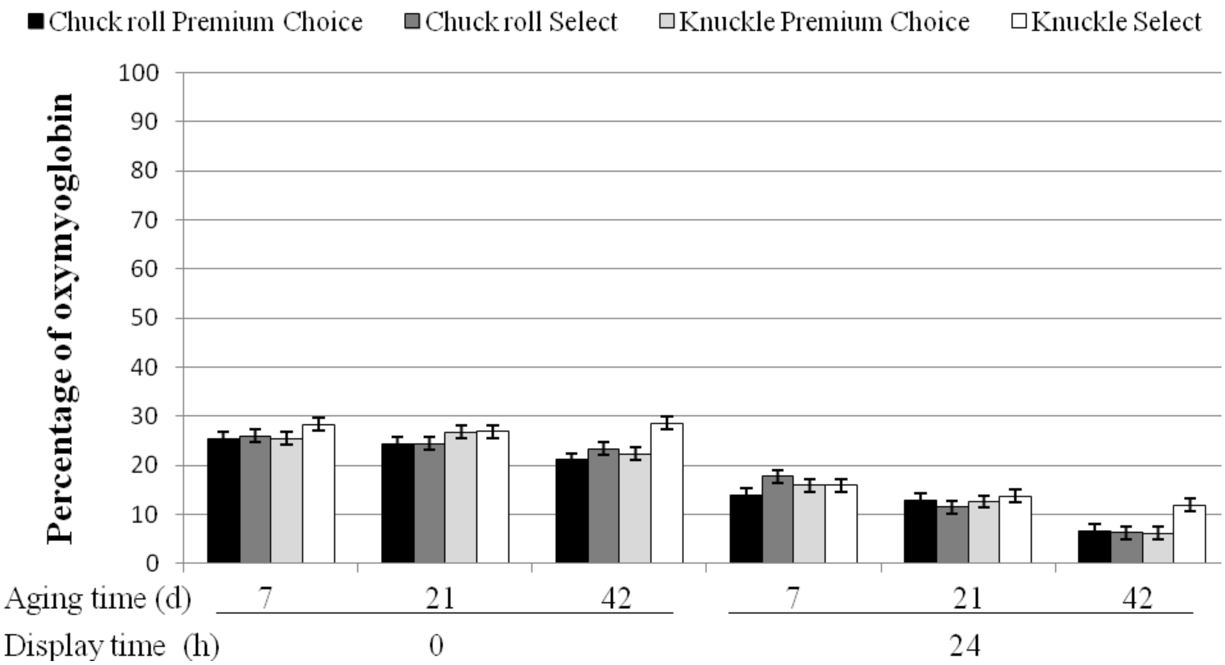


Figure 3.17 Subprimal type × quality grade × aging time × display time means for percentages of oxymyoglobin before and after 24 h of display and after 40 min in a vacuum package for ground beef patties (SE = 1.13)

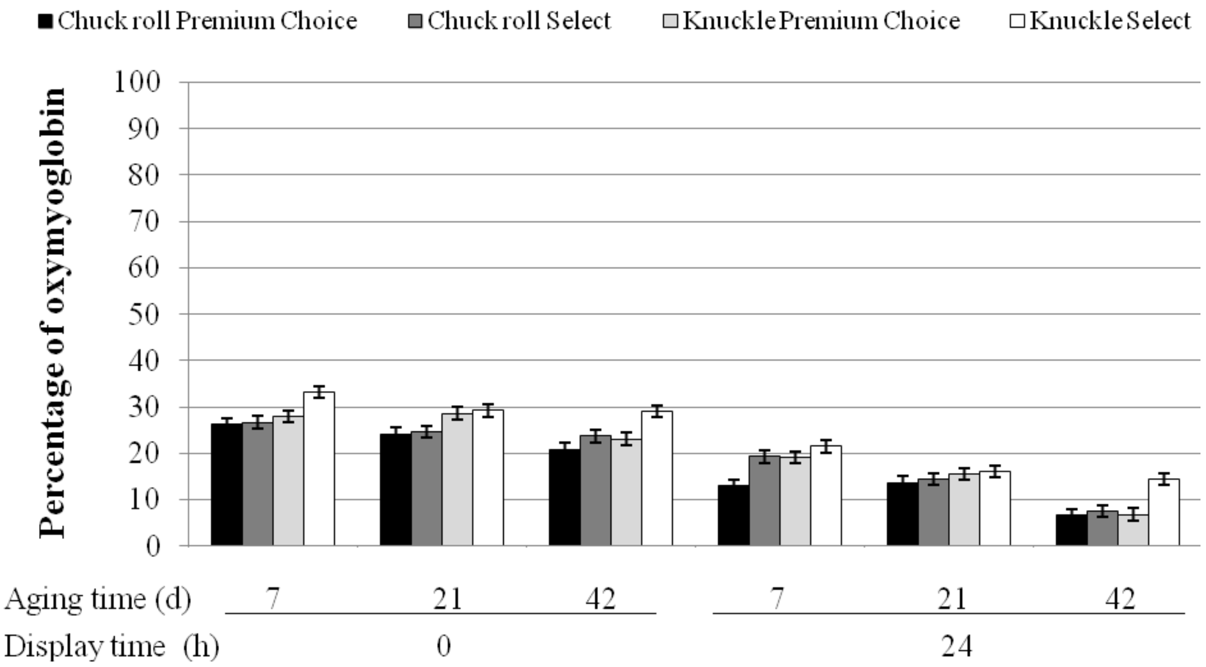


Figure 3.18 Subprimal type × quality grade × aging time × display time interaction means for percentages of oxymyoglobin before and after 24 h of display and after 60 min in a vacuum package for ground beef patties (SE = 1.262)

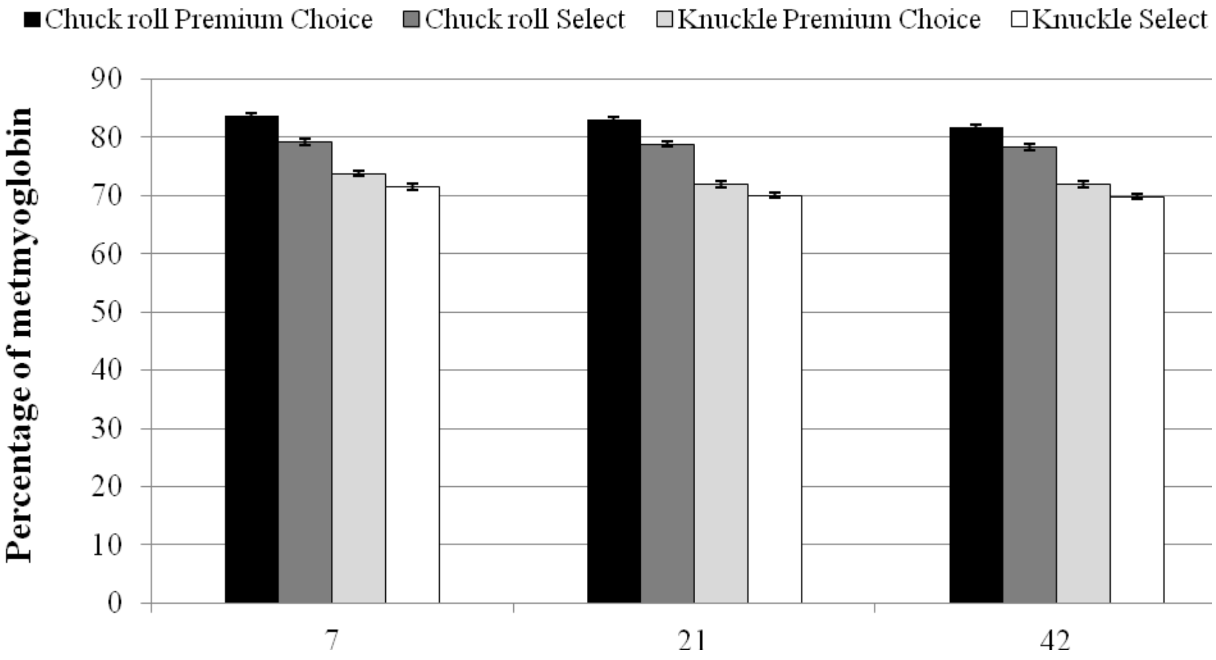


Figure 3.19. Subprimal type × quality grade × aging time means for percentages of metmyoglobin before and after 24 h of display and after 0 h in a vacuum package for ground beef patties (SE = 0.374)

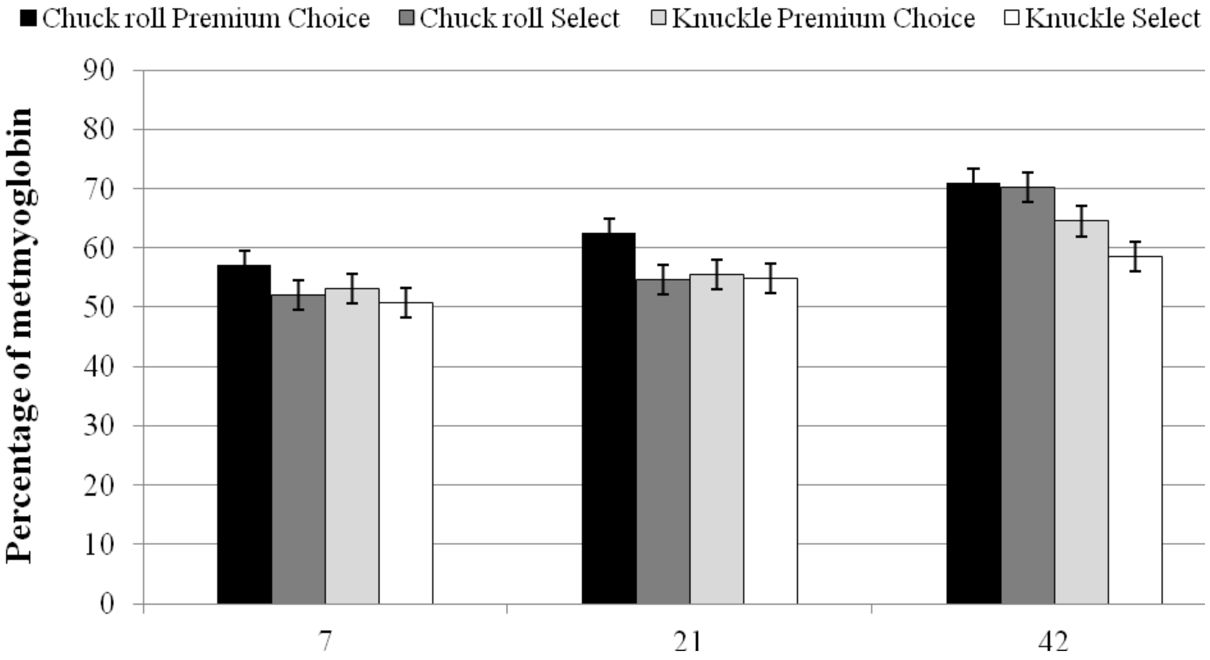


Figure 3.20 Subprimal type × quality grade × aging time interaction means for percentages of metmyoglobin before and after 24 h of display and after 1 h in a vacuum package for ground beef patties (SE = 2.500)

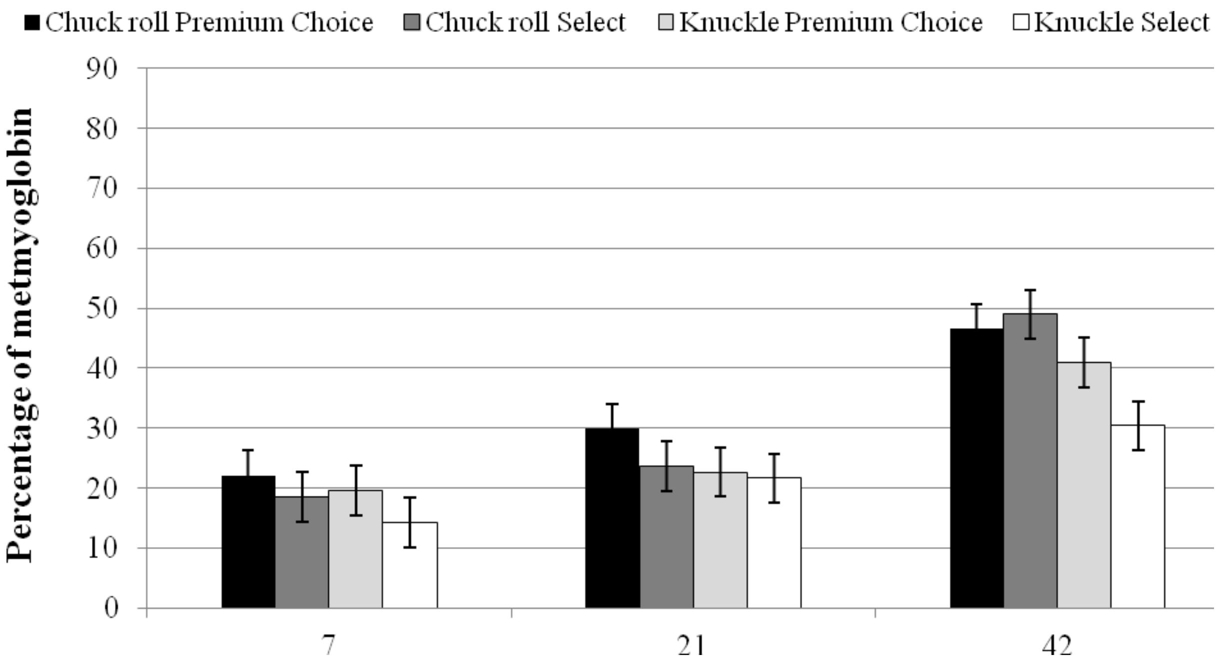


Figure 3.21 Subprimal type × quality grade × aging time interaction means for percentages of metmyoglobin before and after 24 h of display and after 2 h in a vacuum package for ground beef patties (SE = 4.110)

Table 3.3 Aging time × display time means for percentages of metmyoglobin before and after 24 h of display and after 0 h in a vacuum package and aging time × display time interaction means for percentages of metmyoglobin before and after 24 h of display and after 1 and 2 h in a vacuum package of ground beef patties

	Display Time		
	0 h	24 h	SE
MMb 0 h[1]			
7 d	76.7^{au}	77.4^{b}	0.239
21 d	75.4^{v}	76.4	
42 d	74.8^{w}	76.0	
MMb 1 h[2]			
7 d	51.0^{c}	55.6^{d}	2.092
21 d	50.4^{c}	63.4^{e}	
42 d	63.1^{e}	69.0^{f}	
MMb 2 h[3]			
7 d	16.6^{c}	20.7^{d}	3.602
21 d	18.6^{cd}	30.4^{e}	
42 d	37.6^{f}	45.8^{g}	

$^{a\text{-}b}$ Display time main effect ($P<0.05$) for MMb at 0 h : 0 h (75.7%) > 24 h (76.6%)

$^{c\text{-}g}$ Means within a trait (Aging time × display time interaction) with a different letter differ ($P<0.05$)

$^{u\text{-}w}$ Aging time main effect ($P<0.05$) for MMb at 0 h: 7 d (77.0%) > 21 d (75.9%) > 42 d (75.4%)

[1] Percentage of MMb at 0 h after vacuum packaging

[2] Percentage of MMb at 1 h after vacuum packaging

[3] Percentage of MMb at 2 h after vacuum packaging

Table 3.4 Subprimal type × display time interaction means for aerobic plate count (APC), lactic acid plate count (LAPC), and lipid oxidation (TBARS) of ground beef patties

	Subprimal type				
	Chuck roll		Knuckle		
	0 h	24 h	0 h	24 h	SE
APC[1]	4.2^{a}	4.8^{b}	4.6^{b}	5.1^{c}	0.118
LAPC[2]	4.2^{a}	4.8^{bc}	4.6^{b}	5.0^{c}	0.098
TBARS[3]	0.46^{a}	0.77^{b}	0.54^{a}	0.96^{c}	0.029

$^{a\text{-}c}$ Means within a row and trait with a different letter differ ($P<0.05$)

[1] Aerobic plate count (log CFU/g or log CFU/cm^2)

[2] Lactic acid plate count (log CFU/g or log CFU/cm^2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

Table 3.5 Quality grade × display time interaction means for lipid oxidation (TBARS) of ground beef patties

	Quality grade				
	Premium Choice		Select		
	0 h	24 h	0 h	24 h	SE
TBARS[1]	0.48^{a}	0.78^{b}	0.51^{a}	0.95^{c}	0.029

$^{a\text{-}c}$ Means within a row and trait with a different letter differ ($P<0.05$)

[1] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

Table 3.6 Aging time × display time interaction means for aerobic plate count (APC), lactic acid plate count (LAPC), and lipid oxidation (TBARS) of ground beef patties

	Aging time						
	7 d		21 d		42 d		
	0 h	24 h	0 h	24 h	0 h	24 h	SE
APC[1]	2.9^{a}	3.0^{a}	3.9^{b}	4.7^{c}	6.4^{d}	7.2^{e}	0.131
LAPC[2]	2.9^{a}	2.9^{a}	3.8^{b}	4.7^{c}	6.5^{d}	7.2^{e}	0.114
TBARS[3]	0.27^{a}	0.69^{c}	0.58^{b}	0.94^{d}	0.65^{bc}	0.96^{d}	0.035

$^{a\text{-}e}$ Means within a row and trait with a different letter differ ($P<0.05$)

[1] Aerobic plate count (log CFU/g or log CFU/cm^2)

[2] Lactic acid plate count (log CFU/g or log CFU/cm^2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

Chapter 4 - Effect of Subprimal, Quality Grade, and Aging on Sensory Properties of Ground Beef Patties

Abstract

A factorial arrangement of treatments was used to evaluate the effects of two subprimal types (chuck roll and knuckle), two quality grades (Premium Choice and Select), and three vacuum storage aging times before processing (7, 21, and 42 d) on ground beef patty display color stability and sensory attributes. At the end of each aging time, four knuckles or two chuck rolls representing their respective quality grade categories were combined and ground to form a sample batch. After a final grind, patties were formed using a patty machine, packaged in overwrapped trays, and displayed in a coffin-type retail case under continuous fluorescent lighting. Ground beef patties from knuckle subprimals had lower percentages of total fat, C18:0, and SFA resulting in a greater MUFA:SFA ratio than those from chuck roll subprimals. Furthermore, ground beef patties from Premium Choice subprimals had greater percentages of total fat, C18:1, and MUFA and lower percentages of C18:0 and SFA resulting in a greater MUFA:SFA ratio than those from Select subprimals. All treatments had acceptable sensory panel results with minimal differences due to treatment. Lower ($P<0.05$) peak force values for slice shear force and Lee-Kramer were recorded for patties from chuck roll, Premium Choice, and 42 d aged subprimals than those from knuckle, Select, and 7 d aged subprimals, respectfully. Therefore, subprimals for either quality grade or different aging times would be acceptable in palatability.

Introduction

Ground beef is the most commonly consumed beef product in the United States (USDA, 2009). The average American consumer eats 71 kg of red meat per year, and of this, 12.7 kg is ground beef (Haney, 2012; American Meat Institute, 2004). Historically, the source of ground beef comes from lower quality cuts, trimmings from subprimals, and subprimals from cull cows; however, alternative grinds from whole and/or premium quality subprimals are becoming more popular with consumers and creating greater demand as a distinctive menu item (Horovitz, 2009).

Palatability of ground beef is associated with consumer satisfaction and improvement in palatability can potentially result in increased demand and opportunity. Flavor, juiciness and tenderness have been reported by various researchers as the main drivers for beef consumer acceptability (Morgan et al. 1991; Neely et al. 1998), but are affected by the chemical properties and the fatty acid composition found in beef (May et al., 1993; Melton et al., 1982; Westerling & Hedrick, 1979).

Subprimals from the chuck and round are logical subprimals that could be used for ground beef production. Fruin and Van Duyne (1962) studied palatability differences of ground beef prepared from the chuck and rounds from U.S. Commercial or Standard carcasses and found that sensory panelists preferred ground beef from chucks over ground beef from beef rounds. Ground beef generally becomes less palatable and satisfying as fat level is decreased (Berry and Leddy, 1984b; Cross, Berry, & Wells, 1980; Kregal et al., 1986; Law, Beeson, Clark, & Mullins, 1965; Mize, 1972), especially when fat is reduced to 5-10% (Troutt et al. 1992b). Researchers found that as percentage of fat in patties increased there was an increase in juiciness scores (Berry, 1992; Cross et al., 1980; Huffman and Egbert, 1990; Troutt et al., 1992b), beef flavor intensity (Troutt et al. 1992b), mouth coat (Cross et al. 1980; Kregal et al., 1986; Troutt et al., 1992b), tenderness (Berry, 1992; Cross et al., 1980) and patty firmness, cohesiveness, and crumbliness (Troutt et al. 1992b). As fat increased, shear force and total energy values decreased (Berry & Leddy 1984b; Troutt et al. 1992b), Instron Lee-Kramer shear values decreased (Berry & Leddy 1984b; Troutt et al. 1992b), and Instron texture profile analysis indicated lower peak forces, less springiness, and less cohesiveness (Berry & Leddy 1984b; Troutt et al. 1992b) and lower second compression peak force values (Berry & Leddy 1984b). Therefore, subprimals representative of different fat levels may vary in ground beef palatability.

High quality subprimals can be used as a source of premium grind patties and are becoming more popular as a menu item (Horovitz, 2009). Higher quality subprimals such as those grading Premium Choice are expected to have a higher percentage of intramuscular fat and a different fatty acid profile. Turk and Smith (2009) found in a survey of ground beef purchased from local retailers that product from a higher quality branded program had higher levels of oleic acid and lower levels of stearic acid resulting in a higher monounsaturated fatty acid (MUFA): saturated fatty acid (SFA) ratio than those from chub pack ground beef and ground chuck. Researchers have found that the concentration of oleic acid is positively correlated with overall palatability of beef (Waldman, Suess, & Brungardt, 1968; Westerling and Hedrick, 1979), which may be related to fat softness; and, stearic acid (18:0) is the primary determinant of fat hardness (i.e. lipid melting point; Smith, Yang, Larsen, & Tume, 1998; Wood et al., 2004; Chung et al. 2006). As a result, beef palatability traits of tenderness, juiciness, and flavor intensity are influenced by the fatty acid composition (May et al., 1993; Melton et al., 1982; Westerling & Hedrick, 1979).

Vacuum-packaged subprimals can be stored for extended lengths of time and later utilized for ground beef. The time postmortem at which subprimals are ground can vary based on the accessibility and marketing of these subprimals. However, Yancey et al. (2005) found that aging muscles longer than 21 d generally decreased beef flavor intensity.

Therefore, the objective of this study was to determine the effects of two subprimal types (chuck roll and knuckle representing estimated fat percentages of 20 % and 10%, respectfully), two quality grades (Premium Choice and Select), and vacuum storage aging time (7, 21, and 42 d) before processing on ground beef patty sensory attributes.

Material and Methods

Product Selection and Manufacture

A total of 72 Chuck Roll (116A) and 144 Peeled Sirloin Tip Knuckle (167A) subprimals from Select and Premium Choice (upper 2/3s of Choice) quality grade categories were obtained from a commercial processing facility. The experiment was conducted in two equal replications from product randomly selected from two different days of production. Upon arrival at the Kansas State University meat laboratory, subprimals for each replication were then randomly assigned to an aging time of 7, 21, or 42 days post-packaging and remained in their individual vacuum bag until the end of the aging period (0 ± 1ºC). Abnormal cuts or leaking bags were eliminated from the study. Detailed product selection and ground beef manufacture are described in Chapter 3 Material and Methods. After the final grind, an approximate 200-g sample was removed and placed in sterile bags (Whirl pack, Nasco, Modesta, CA) for proximate analysis and fatty acid composition.

Fourteen patties from each sample replication, collected for sensory panel and mechanical tenderness evaluation, were placed on trays and crust frozen at -40ºC for 30 to 60 min before vacuum packaging. Patties were then vacuum packaged (Multivac model C500, Multivac Inc. Kansas City, MO) in pairs (2 per bag) in 25.4 x 30.5 cm Prime Source Vacuum Pouches (Prime Source Vacuum Pouches; 3mil, STP Barrier, Nylon/PE Vacuum Pouch; oxygen transmission rate 0.04g/254cm^2/24 h at 0ºC; water vapor transmission rate 0.2cc/254cm^2/24h at 0ºC at 0% relative humidity) and stored at -20ºC until analysis. A trained sensory panel evaluated the patties for firmness, cohesiveness, juiciness, beef flavor intensity, mouth coat, off-flavor, and desirability. Slice shear force, Lee-Kramer shear, and texture profile analysis were conducted to measure mechanical tenderness.

Fatty Acid Composition

Fatty acid composition samples (200 g) were pulverized in a Waring commercial blender (model 51BL32, Waring commercial, Torrington, Connecticut), placed into a clean sample bag (Whirl-Pak, Nasco, Modesta, CA), and stored at -80°C until the analyses were completed (3 weeks). Fatty acid analyses were conducted following the long chain fatty acids in feeds, fecals, digesta, and meats procedure with a Palm quist (Sukhija & Palmquist, 1988).

Cookery Method

Patties were thawed at 2ºC for 24 h prior to cooking and prepared for the sensory panels and mechanical tenderness measurements following the AMSA cookery guidelines (1995). Patties were cooked on a griddle (Griddle Model 106733, Walmart stores, Inc Bentonville, AR) set at 163ºC (325ºF). Each patty was heated for 1-2 min then flipped every 2 min until an internal end point temp of 71ºC (160ºF) was reached. Internal temperature was monitored by intermittently inserting an Omega hypodermic temperature probe (20 gauge) attached to a Doric Trendicator (410A Omega Engineering Inc. Sandiego, CA Model 400A Trendication).

Sensory Panel

Sensory panel procedures followed the AMSA cookery guidelines (1995). Patties were cut into eight wedge slices (patty was quartered and then each quarter was cut in half again) and evaluated by a trained sensory panel. A scale of 1 to 8 was used to evaluate firmness (1 = extremely soft, 8 = extremely firm), cohesiveness (1 = not cohesive at all, 8 = extremely cohesive), juiciness (1 = extremely dry, 8 = extremely juicy), beef flavor intensity (1= extremely bland, 8 = extremely intense), mouth coat (1 = abundant, 8 = none), off flavor (1 = were abundant, 8 = none), and desirability (1 = extremely dislike, 8 = extremely like). Trained sensory panelists were given an unscored "warm-up" sample and discussed prior to evaluation of six samples representing the quality grade x aging time treatments within subprimal types. A minimum of 6 panelists were present at each panel and their scores were averaged for statistical analysis

Slice Shear Force, Lee-Kramer Shear, and Texture Profile Analysis

Ground beef patties were analyzed using three textural analysis methods of slice shear force, Lee-Kramer shear force, and texture profile analysis. Patties were prepared following AMSA guidelines (1995) previously mentioned in cookery method. Following cooking, the patties were cooled to room temperature (approximately 30 min) before analysis.

For slice shear force, two 3 × 1 × .5-cm strips were removed from the center of each patty and each strip was sheared twice. Two patties per sample were utilized resulting in 8 measurements that were averaged for analysis. The blade was attached to the crosshead of an

Instron Model 5569 (Instron Caibration Lab Norwood, MA model 5569) with a 50 kg load cell and crosshead speed of 250 mm/min. In addition to peak force (kg) and total energy (kg x mm) values, cooking loss, cooking time and cooked patty thickness were also measured.

For the Lee-Kramer shear values, two patties from each sample were cooked and cooled to room temperature (approximately 30 min) before a 6.0 × 6.0 × .5-cm subsample was cut from each patty. Each square was weighed and sheared in the Lee-Kramer cell attached to the Instron with a 500 kg load cell and a crosshead speed of 350 mm/min. Peak force (kg) and total energy (kg x mm) were determined and divided by the weight to obtain force or energy/g. The average of the two patty measurements was used for analysis.

The procedures developed by Bourne (1978) and Montejano et al. (1985) were used for texture profile analysis. After two patties were cooked and cooled to room temperature (approximately 30 min), three 2.54 cm cores were removed from each patty. Each core was compressed 30% of its height for two cycles. The Instron was programmed for 40% load range of a 50 kg load cell and a cross head speed of 200 mm/min. Averages for hardness (peak force of first compression, kg), cohesiveness (total energy of 2nd compression ÷ total energy of the 1st compression), springiness (base width of 2nd compression ÷ base width of 1st compression), gumminess (hardness x cohesiveness) , and chewiness (gumminess x springiness) were utilized for statistical analysis.

Statistical Analysis

The basic experimental design was a completely randomized block design with 12 treatments (n=6) arranged in a 2 × 2 × 3 factorial with two subprimal types (chuck roll and knuckle), two quality grades (Premium Choice and Select), and three aging times (7, 21, and 42 d) with replications (n=2) as the block. This model was used to analyze fatty acid composition, cooking data, and instrumental tenderness. For sensory analysis, 6 treatments were arranged in a 2 × 3 factorial with two quality grades (Premium Choice and Select) and three aging times (7, 21, and 42 d). A panel term was added to the model as a blocking factor to account for sensory panel variation. The sample batch (n=6) was the experimental unit.

All sets of data were analyzed using the PROC MIXED procedure in SAS (SAS 9.2, Institute Inc., Cary, NC). The Satterthwaite method in MIXED was used to calculate the denominator degrees of freedom. The model statement included the measured trait and all possible interactions among subprimal type, quality grade, and aging time. Tests were conducted at a significance level of $P<0.05$ and main effect and interaction means were separated by least significant difference (LSMEANS) when their respective F-tests were significant ($P<0.05$). Selected correlations were performed using the PROC CORR procedure of SAS to evaluate relationships among cooking data, instrumental tenderness, and sensory analysis variables measured for ground beef patties.

Results and Discussion

Fatty Acid Composition

Fatty Acids (g/100g raw sample)

Main effect means for subprimal type, quality grade, and aging time are reported for fatty acid composition expressed as g/100g of raw sample in table 4.1. A subprimal type × quality grade interaction ($P<0.05$) was detected for total SFA, C16:0, C18:0, total MUFA, C18:1, and total percent of fatty acids and those are reported in table 4.2.

Ground beef patties from chuck roll subprimals had higher ($P<0.05$) concentrations of total PUFA than those from knuckle subprimals (Table 4.1). In addition, ground beef patties from Premium Choice subprimals had higher ($P<0.05$) concentrations of total PUFA than those from Select subprimals. As expected, aging time did not affect ($P>0.05$) fatty acid composition, except for stearic (18:0) acid and total PUFA. For stearic (18:0) acid, ground beef patties from subprimals aged 42 d had slightly higher ($P<0.05$) concentrations than those from subprimals aged 7 and 21 d. Ground beef patties from subprimals aged 21 and 42 d had higher ($P<0.05$) concentrations of total PUFA than those from subprimals aged 7 d.

In the subprimal type × quality grade interaction observed for total SFA, C16:0, C18:0, total MUFA, C18:1, and total percent of fatty acids, ground beef patties from Premium Choice chuck roll subprimals had the most ($P<0.05$) of these fatty acids, while those from Select knuckle subprimals had the least ($P<0.05$). In addition, ground beef patties from Select chuck roll subprimals had more ($P<0.05$) of these fatty acids than those from Premium Choice knuckle subprimals. In agreement, Smith, Savell, Smith, & Cross (1989) found that Choice steaks from the clod shoulder and top round were higher in total fat percentage than steaks from Select and Standard carcasses. However, they also reported that clod shoulders and top round steaks had no significant differences in percentages of stearic (18:0) or oleic (18:1) acids (Smith, et al., 1989). In addition, Turk and Smith (2009) observed no difference for palmitic (16:0), and stearic (18:0) acid, and the MUFA:SFA ratio (g/100 g total fatty acids) for ground beef from the chuck and round.

Fatty Acids (% of total fatty acids)

Main effect means for percentages of fatty acids (expressed as a percentage of total fatty acids) are reported in table 4.3. Ground beef patties from chuck roll subprimals had greater

($P<0.05$) percentages of total SFA and C18:0 than those from knuckle subprimals; but ground beef patties from knuckle subprimals had greater ($P<0.05$) percentages of total PUFA than those from chuck roll subprimals. As a result, ground beef patties from knuckle subprimals had higher ($P<0.05$) MUFA:SFA and PUFA:SFA ratios than those from chuck roll subprimals. Ground beef patties from Premium Choice subprimals had higher ($P<0.05$) percentages of total MUFA and C18:1 than those from Select subprimals; however, ground beef patties from Select subprimals had greater ($P<0.05$) percentages of total SFA, C18:0 and total PUFA than those from Premium Choice subprimals. As a result, ground beef patties from Premium Choice subprimals had higher ($P<0.05$) MUFA:SFA ratios and lower PUFA:SFA ratios than those from Select subprimals. In agreement, Turk and Smith (2009) found that ground beef from a higher quality branded program had higher levels of oleic acid (18:1) and lower levels of stearic acid (18:0) resulting in a higher MUFA:SFA ratio. Few differences were observed for aging time; however, for percentage of total PUFA and PUFA:SFA ratio, ground beef patties from subprimals aged 21 and 42 d were higher ($P<0.05$) than those from subprimals aged 7 d.

Cooking Data

Main effect means (subprimal type, quality grade, and aging time) for cooking data are presented in table 4.4. Ground beef patties from knuckle subprimals had ($P<0.05$) a greater cooked weight, less cooking loss, and greater thickness than those from chuck roll subprimals. In agreement, Troutt et al. (1992b) found that lower fat (5 to 10%) patties had lower cooking losses. However, Cross et al. (1980) found that as percent fat increased total cooking loss was not significantly affected by fat level. Ground beef patty cooking time was similar ($P>0.05$) between subprimal types.

Ground beef patties from Select subprimals had greater ($P<0.05$) cooked weights than those from Premium Choice subprimals. Ground beef patty cooking loss, thickness, and cooking time were similar ($P>0.05$) between quality grades. Troutt et al. (1992b) reported that lower fat (5 to 10%) patties had longer cooking times but fat level had no affect on cooked patty diameter and height.

Ground beef patties from subprimals aged 42 d had ($P<0.05$) the lowest raw weights and the greatest patty thickness. Furthermore, ground beef patties from subprimals aged 42 d had a longer ($P<0.05$) cooking time than those from subprimals aged 21 d. Ground beef patty cooked weight and cooking loss were similar ($P>0.05$) among all aging times.

In a subprimal type × quality grade interaction ($P<0.05$), ground beef patties from Premium Choice (116.71 g) and Select (116.76 g) knuckle subprimals had heaviest ($P<0.05$) raw weights and patties from Premium Choice chuck roll subprimals (114.82 g) had the lightest ($P<0.05$) raw weights. In agreement, Troutt et al. (1992b) reported that patties with ≤20% fat had greater raw weight than those with ≥25% fat and speculated this difference was due to potential higher density of lean since all patties were made with the same patty maker and were the same size.

Sensory Characteristics

No quality grade × aging time interaction ($P<0.05$) was detected for ground beef patties from either chuck roll or knuckle subprimals. Main effect means for quality grade and aging time are reported for chuck roll and knuckle subprimals in table 4.5.

Chuck roll

For the chuck roll, ground beef patties from Premium Choice and Select subprimals had similar (P>0.05) cohesiveness, juiciness, beef flavor, off-flavor, and desirability scores. However, ground beef patties from Select subprimals were firmer (P<0.05) and had less mouth coating (higher scores; P<0.05) than those from Premium Choice subprimals. No differences (P>0.05) in sensory traits were observed for ground beef patties form subprimals aged 7, 21, and 42 d except patties from subprimals aged 7 d had (P<0.05) the most off-flavor (lowest scores).

Knuckle

For the knuckle, ground beef patties from Premium Choice and Select subprimals had similar (P>0.05) scores for all sensory traits. In addition, no differences (P>0.05) were observed in firmness, cohesiveness, and beef flavor scores for ground beef patties from subprimals aged 7, 21, and 42 d. However, ground beef patties from subprimals aged 42 d were the most juicy (P<0.05) and had the most mouth coating (lower scores; P<0.05) while patties from subprimals aged 7 d were the least (P<0.05) juicy and had the least mouth coating (higher scores; P<0.05). Ground beef patties from subprimals aged 21 d had more (P<0.05) off-flavor than those aged 7 and 42 d. In addition, ground beef patties from subprimals aged 21 and 42 d were more (P<0.05) desirable than those aged 7 d.

<u>Correlation.</u> A relationship was observed in which firmness was correlated to cohesiveness for ground beef patties from chuck roll and knuckle subprimals (0.67 and 0.81, respectfully) and beef flavor was correlated to desirability for ground beef patties from chuck roll and knuckle subprimals (0.74 and 0.51). Furthermore, ground beef patties from knuckle subprimals had juiciness scores that were correlated to mouth coat and desirability (-0.50 and

0.66, respectfully). A relationship was observed in which mouth coat was negatively correlated to desirability for ground beef patties from knuckle subprimals (-0.67).

<u>Discussion.</u> Even though minimal differences were observed for our sensory panels, past researchers have observed differences between ground beef patties with different fat levels. For example, Troutt et al. (1992b) found that compared to 20 and 30 percent fat patties, lower fat (5 to 10%) patties had greater patty firmness and cohesiveness and less juiciness, moisture release, beef flavor, and oily coating of the mouth. In addition, other researchers have shown that sensory panel tenderness scores were lower for patties with greater fat levels with similar values seen between the 0 and 4%, 8 and 12%, and 16 and 20% fat levels (Berry, 1992), lower for patties with 28% fat than those with 9 and 21% fat (Kregal, 1986) and lower for patties with 24-28% fat than those with 16% fat (Cross et al., 1980). Other researchers found that overall as percent fat in patties increased there was an increase in juiciness scores (Troutt et al., 1992b; Berry, 1992; Huffman and Egbert, 1990; Cross et al., 1980). Yancey et al. (2005) found that aging muscles longer than 21 d generally decreased beef flavor intensity but aging steaks for 35 d significantly increased the metallic flavor compared with aging for only 7 and 14 d. Cross et al. (1975, 1980), Drake et al. (1975), Cole et al. (1960), Kendall et al. (1974), Berry and Leddy (1984b) and Nieslsen et al. (1967) found no effects of fat level in ground beef flavor intensity or desirability. Furthermore, Huffman and Egbert (1990) found that patties ranging from 5 to 20% fat did not differ in beef flavor intensity scores. However, Troutt et al. (1992b) found patties with 5% fat had less intense beef flavor than all other fat levels (10, 15, 20, 25, and 30%). Other researchers found that sensory panel mouth coat ratings were higher (less mouth coating) for patties with 28% fat than those with 16, 20, and 24% fat (Cross et al. 1980), patties containing

9.5% fat than those with 21 and 28% (Kregal et al., 1986) and patties containing 5-10% fat than those with 30% fat patties (Troutt et al., 1992b).

Instrumental Tenderness

Main effect means (subprimal type, quality grade, and aging time) for instrumental attributes are presented in table 4.6.

Slice Shear Force

For slice shear force, ground beef patties from knuckle subprimals had ($P<0.05$) greater peak force and total energy values than those from chuck roll subprimals (Table 4.6). In addition, ground beef patties from Select subprimals had greater ($P<0.05$) peak force values than those from Premium Choice subprimals. In agreement, researchers found that as fat increased Warner-Bratzler shear force and total energy values decreased (Troutt et al. 1992b, Berry & Leddy 1984b). Ground beef patties from Premium Choice and Select subprimals had similar ($P>0.05$) total energy values. Furthermore, ground beef patties from subprimals aged 7 d had ($P<0.05$) the greatest slice shear peak force and total energy values.

Lee-Kramer Shear Force

For Lee-Kramer shear force, ground beef patties from chuck roll subprimals had lower ($P<0.05$) peak force and total energy values than those from knuckle subprimals. In addition, ground beef patties from Select subprimals had greater ($P<0.05$) peak force values than those from Premium Choice subprimals and patties had similar ($P>0.05$) total energy values between quality grades. In agreement, researchers found that for Lee-Kramer shear values were highest for patties with 5% fat (Troutt et al. 1992b and Berry and Leddy 1984b). Furthermore, in my study, ground beef patties from subprimals aged 7 d had ($P<0.05$) greater shear peak force values than those from subprimal aged 21 and 42 d and had greater total energy than those from subprimals aged 42 d.

A relationship was observed in which Lee-Kramer shear force was correlated to percent total fat for ground beef patties from chuck roll and knuckle subprimals (-0.55 and -0.51, respectfully) as well as slice shear force peak force for ground beef patties from chuck roll and knuckle subprimals (0.53 and 0.43, respectfully).

Texture Profile Analysis

For texture profile analysis, ground beef patties from knuckle subprimals had ($P<0.05$) greater first compression peak force, first compression total energy, second compression peak force, second compression total energy, gumminess, and springiness than those from chuck roll subprimals. In addition, ground beef patties had similar ($P<0.05$) cohesiveness between subprimal type. Ground beef patties from Select subprimals had ($P<0.05$) greater first compression peak force, first compression total energy, second compression peak force, and second compression total energy values than those from Premium Choice subprimals. In addition, ground beef patties had similar ($P>0.05$) cohesiveness, gumminess and springiness between quality grades. Ground beef patties from subprimals aged 7 d had less ($p<0.05$) first compression peak force and second compression total energy values than those from subprimals aged 42 d. Furthermore, ground beef patties from subprimals aged 42 d had the greatest ($P<0.05$) first compression total energy. Ground beef patties from subprimals aged 7 d had the greatest ($P<0.05$) springiness and chewiness values and patties from subprimals aged 21 d had greater ($P<0.05$) springiness and chewiness values than those from subprimals aged 42 d. In addition, ground beef patties had similar ($P>0.05$) second compression peak force, cohesiveness, and gumminess values among all aging times.

In a subprimal type × quality grade interaction ($P<0.05$), ground beef patties from Premium Choice chuck roll subprimals (7.25) had lower ($P<0.05$) chewiness values than Select chuck roll (8.34) and Premium Choice (8.17) and Select (8.03) knuckle subprimals.

A relationship was observed in which texture profile analysis springiness measurements were negatively correlated to sensory juiciness scores for ground beef patties from knuckle subprimals (-0.57). Furthermore, researchers found that for texture profile analysis, patties lower in fat had greater peak forces, springiness, and cohesiveness (Troutt et al. 1992b, Berry & Leddy 1984b) and greater second compression peak force values (Berry & Leddy 1984b).

Summary

Subprimal type. Ground beef patties from chuck roll subprimals had a higher concentration of total PUFA, higher percentages of total SFA and C18:0, lower percentages of total PUFA, lower MUFA:SFA and PUFA:SFA ratios, lower raw and cooked patty weights, greater cooking loss, and thinner patties, lower peak force and total energy values for slice shear force, Lee-Kramer, and texture profile analysis first and second compression and less gumminess and springiness than those from knuckle subprimals.

Quality grade. Ground beef patties from Premium Choice subprimals had higher concentrations of total PUFA, higher percentages of total MUFA and C18:1, higher MUFA:SFA ratio, lower percentages of total SFA, C18:0, total PUFA and PUFA:SFA ratio, lower cooked weight, and lower peak force for slice shear force, Lee-Kramer, and TPA first and second compression and less total energy values for TPA first and second compression.

Furthermore, for the chuck roll ground beef patties from Select subprimals were firmer ($P<0.05$) and had less mouth coating (higher scores; $P<0.05$) than those from Premium Choice subprimals but for the knuckle ground beef patties from Premium Choice and Select subprimals had similar ($P>0.05$) scores for all sensory traits.

Aging time. As aging time increased, ground beef patty peak force and total energy values for slice shear force and Lee-Kramer decreased, TPA peak force for the first compression and total energy values for the first and second compression increased, and springiness and chewiness decreased.

Conclusion

Knuckle subprimals had lower percentages of total fat, C18:0, and SFA resulting in a greater MUFA:SFA ratio than those from chuck roll subprimals. Premium Choice subprimals had greater percentages of total fat, C18:1, and MUFA and lower percentages of C18:0 and SFA resulting in a greater MUFA:SFA ratio than those from Select subprimals. Even though the percentages of total fat and fatty acid composition varied among the patties and patties from chuck roll and Premium Choice subprimals and subprimals aged for longer periods of time had more mechanical tenderness (less peak force and energy values) than those from knuckle and Select subprimals and subprimals aged for fewer days, respectfully, sensory panelists did not detect differences in sensory traits for subprimals from the chuck roll and knuckle. Therefore, subprimals for either quality grade or different aging times would be acceptable in palatability.

Table 4.1 Effect of subprimal type, quality grade, and aging time on fatty acid composition (g/100g raw sample) of ground beef patties

	Subprimal type			**Quality grade**			**Aging time**			
	Chuck roll	**Knuckle**	**SE**	**Premium Choice**	**Select**	**SE**	**7 d**	**21 d**	**42 d**	**SE**
Total SFA (g/100g)[1,2]	---	---	---	---	---	---	5.5	5.3	5.7	0.18
C16:0 (g/100g)[1]	---	---	---	---	---	---	2.9	2.8	3.0	0.10
C18:0 (g/100g)[1]	---	---	---	---	---	---	1.7^{a}	1.7^{a}	1.9^{b}	0.07
Total MUFA (g/100g)[1,3]	---	---	---	---	---	---	5.9	5.6	6.2	0.22
C18:1 (g/100g)[1]	---	---	---	---	---	---	5.0	4.8	5.3	0.19
Total PUFA (g/100g) [4]	0.62^{b}	0.35^{a}	0.033	0.53^{b}	0.44^{a}	0.330	0.36^{a}	0.51^{b}	0.59^{b}	0.038
Total Fatty Acid (g/100g)[1]	---	---	---	---	---	---	11.7	11.4	12.5	0.348

[a-b] Means within a row and main effect with a different letter differ ($P<0.05$).

[1] Subprimal type × Quality grade interaction ($P<0.05$)

[2] Saturated Fatty Acids: C10:0, C11:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0, 21:0, C22:0, C24:0

[3] Monounsaturated Fatty Acids: C14:1, C15:1, C16:1, C17:1, C18:1n9t, C18:1n9c, C18:1n7, C18:1n11, C20:1, C24:1

[4] Polyunsaturated Fatty Acids: C18:2n6t, C18:2n6c, C18:3n3, C18:3n6, C20:2, C20:5n3, C20:3n6, C20:4n6, C22:5n3, C22:6n3, Conjugated linoleic acid (C18:2) isomers

Table 4.2 Subprimal type × quality grade interaction means for fatty acid composition (g/100g raw sample) of ground beef patties

	Chuck roll		Knuckle		
	Premium Choice	**Select**	**Premium Choice**	**Select**	**SE**
Total SFA (g/100g) [1]	9.0^{d}	6.6^{c}	3.7^{b}	2.7^{a}	0.202
C16:0 (g/100g)	4.8^{d}	3.4^{c}	2.1^{b}	1.4^{a}	0.114
C18:0 (g/100g)	2.9^{d}	2.3^{c}	1.1^{b}	0.9^{a}	0.074
Total MUFA (g/100g)[2]	9.9^{d}	6.7^{c}	4.2^{b}	2.9^{a}	0.241
C18:1 (g/100g)	8.5^{d}	5.7^{c}	3.5^{b}	2.4^{a}	0.214
Total Fatty acid (g/100g)	19.6^{d}	13.8^{c}	8.2^{b}	5.9^{a}	0.397

[a-d] Means within a row with a different letter differ ($P<0.05$).

[1] Saturated Fatty Acids: C10:0, C11:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0, 21:0, C22:0, C24:0

[2] Monounsaturated Fatty Acids: C14:1, C15:1, C16:1, C17:1, C18:1n9t, C18:1n9c, C18:1n7, C18:1n11, C20:1, C24:1

Table 4.3 Effect of subprimal type, quality grade, and aging time on the percentage of fatty acids (expressed as percentage of total fatty acids) and selected fatty acid ratios of ground beef patties

	Subprimal type			**Quality grade**			**Aging time**			
	Chuck roll	**Knuckle**	**SE**	**Premium Choice**	**Select**	**SE**	**7 d**	**21 d**	**42 d**	**SE**
Total SFA (%)[1]	46.8^{b}	45.0^{a}	0.331	45.3^{a}	46.5^{b}	0.331	46.6	45.7	45.4	0.399
C16:0 (%)	24.4	24.5	0.203	24.7	24.2	0.203	24.7	24.4	24.1	0.242
C18:0 (%)	15.7^{b}	14.2^{a}	0.219	14.1^{a}	15.7^{b}	0.219	14.8	14.8	15.1	0.267
Total MUFA(%)[2]	49.4	49.9	0.572	50.6^{b}	48.7^{a}	0.572	50.2	49.3	49.5	0.609
C18:1 (%)	42.2	41.7	0.576	42.9^{b}	41.0^{a}	0.576	42.2	41.6	42.1	0.607
Total PUFA (%)[3]	3.77^{a}	5.07^{b}	0.388	4.03^{a}	4.81^{b}	0.388	3.21^{a}	4.97^{b}	5.08^{b}	0.424
MUFA[2]:SFA[1]	1.06^{a}	1.11^{b}	0.018	1.12^{b}	1.05^{a}	0.018	1.08	1.08	1.09	0.020
PUFA[3]:SFA[1]	0.08^{a}	0.11^{b}	0.008	0.09^{a}	0.11^{b}	0.008	0.07^{a}	0.11^{b}	0.11^{b}	0.009

$^{a\text{-}b}$ Means within a row and main effect with a different letter differ ($P<0.05$).

[1] Saturated Fatty Acids: C10:0, C11:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0, 21:0, C22:0, C24:0

[2] Monounsaturated Fatty Acids: C14:1, C15:1, C16:1, C17:1, C18:1n9t, C18:1n9c, C18:1n7, C18:1n11, C20:1, C24:1

[3] Polyunsaturated Fatty Acids: C18:2n6t, C18:2n6c, C18:3n3, C18:3n6, C20:2, C20:5n3, C20:3n6, C20:4n6, C22:5n3, C22:6n3, Conjugated linoleic acid (C18:2) isomers

Table 4.4 Effect of subprimal type, quality grade, and aging time for cooking traits for ground beef patties

	Subprimal type			**Quality grade**			**Aging time**			
	Chuck roll	**Knuckle**	**SE**	**Premium Choice**	**Select**	**SE**	**7 d**	**21 d**	**42 d**	**SE**
<u>Cooking data</u>										
Raw Weight (g)[1]	---	---	---	---	---	---	116.32^{b}	116.30^{b}	115.50^{a}	0.1635
Cooked Weight (g)	82.73^{a}	86.73^{b}	0.3699	84.15^{a}	85.31^{b}	0.3699	84.35	81.87	84.97	0.4362
Cooking Loss (%)`[2]	28.38^{b}	25.71^{a}	0.3198	27.32	26.66	0.0320	27.50	27.04	26.44	0.3739
Thickness (cm)	1.40^{a}	1.46^{b}	0.011	1.43	1.43	0.011	1.41^{a}	1.42^{a}	1.47^{b}	0.013
Cooking Time (min)	6.7	6.9	0.18	6.8	6.9	0.30	6.8^{ab}	6.6^{a}	7.0^{b}	0.19

[a-c] Means within a row and trait with a different letter differ ($P<0.05$)

[1] Subprimal type × Quality grade interaction ($P<0.05$)

[2] Cooking loss = (Raw weight – Cooked Weight) / Raw weight * 100

Table 4.5 Effect of quality grade and aging time on sensory traits for ground beef patties

	Quality grade			Aging time			
	Premium Choice	**Select**	**SE**	**7 d**	**21 d**	**42 d**	**SE**
Chuck roll							
Firmness[1]	4.7^a	4.9^b	0.07	4.8	4.7	4.8	0.08
Cohesiveness[2]	4.8	4.9	0.07	4.9	4.8	4.9	0.08
Juiciness[3]	5.5	5.3	0.11	5.4	5.4	5.5	0.13
Beef flavor[4]	5.3	5.3	0.10	5.1	5.4	5.4	0.11
Mouth coat[5]	6.7^a	6.8^b	0.06	6.8	6.8	6.8	0.07
Off flavor[6]	7.6	7.6	0.10	7.3^a	7.8^b	7.8^b	0.12
Desirability[7]	5.4	5.4	0.12	5.2	5.5	5.4	0.13
Knuckle							
Firmness[1]	5.0	5.1	0.09	5.1	4.9	5.0	0.09
Cohesiveness[2]	4.9	5.0	0.07	5.0	4.9	5.1	0.08
Juiciness[3]	5.1	5.2	0.10	4.8^a	5.1^b	5.5^c	0.11
Beef flavor[4]	5.3	5.2	0.06	5.1	5.2	5.3	0.07
Mouth coat[5]	7.0	7.1	0.04	7.2^c	7.0^b	6.9^a	0.05
Off flavor[6]	7.7	7.6	0.09	7.5^a	7.8^b	7.5^a	0.09
Desirability[7]	5.2	5.0	0.11	4.8^a	5.2^b	5.3^b	0.12

[a-c] Means within a row and trait with a different letter differ ($P<0.05$)

[1] Firmness scale: 8. Extremely firm, 1. Extremely soft.

[2] Cohesiveness scale: 8. Extremely cohesive, 1. Not cohesive at all

[3] Juiciness scale: 8. Extremely juicy, 1. Extremely dry

[4] Beef flavor intensity scale: 8. Extremely intense, 1. Extremely bland

[5] Mouth coat scale: 8. None, 1. Abundant

[6] Off-flavor intensity scale: 8. None, 1. Abundant

[7] Desirability scale: 8. Extremely Liked, 1. Extremely Dislike

Table 4.6 Effect of subprimal type, quality grade, and aging time for tenderness traits for ground beef patties

	Subprimal type			Quality grade			Aging time			
	Chuck roll	Knuckle	SE	Premium Choice	Select	SE	7 d	21 d	42 d	SE
Slice Shear Force										
Peak Force (kg)	2.71^{a}	3.22^{b}	0.074	2.85^{a}	3.08^{b}	0.074	3.33^{b}	2.73^{a}	2.83^{a}	0.089
Total Energy (kg x mm)	19.64^{a}	22.49^{b}	0.8430	20.35	21.79	0.8430	23.32^{b}	19.08^{a}	20.80^{a}	0.9216
Lee-Kramer Shear Force										
Peak force (kg/g)	2.58^{a}	3.13^{b}	0.042	2.69^{a}	3.02^{b}	0.042	3.08^{b}	2.81^{a}	2.68^{a}	0.051
Total Energy (kg x mm/g)	14.97^{a}	17.61^{b}	0.4830	15.87	16.71	0.4830	17.18^{b}	16.04^{ab}	15.66^{a}	0.5404
Texture Profile Analysis										
Force Comp 1 (kg)[1]	3.55^{a}	4.05^{b}	0.465	3.66^{a}	3.93^{b}	0.465	3.69^{a}	3.74^{ab}	3.96^{b}	0.467
Total Energy FC 1[2]	5.68^{a}	7.07^{b}	0.789	6.14^{a}	6.61^{b}	0.789	5.76^{a}	6.19^{a}	7.17^{b}	0.797
Force Comp 2 (kg)	3.19^{a}	3.71^{b}	0.411	3.32^{a}	3.58^{b}	0.411	3.36	3.40	3.58	0.413
Total Energy FC 2[3]	3.06^{a}	3.83^{b}	0.421	3.30^{a}	3.59^{b}	0.421	3.29^{a}	3.41^{ab}	3.63^{b}	0.424
Cohesiveness[4]	0.55	0.67	0.090	0.66	0.56	0.090	0.56	0.55	0.72	0.110
Gumminess (kg)[5]	1.87^{a}	2.03^{b}	0.131	1.91	2.00	0.131	1.95	1.92	1.99	0.135
Springiness[6]	4.03^{a}	3.68^{b}	0.054	3.87	3.84	0.054	4.20^{c}	3.91^{b}	3.46^{a}	0.063
Chewiness (kg)[7]	---	---	---	---	---	---	8.83^{c}	8.03^{b}	6.98^{a}	1.013

[a-c] Means within a row and trait with a different letter differ ($P<0.05$)

[1] Hardness: Peak force of first compression, kg

[2] Total Energy 1st comp (kg x mm)

[3] Total Energy 2nd comp (kg x mm)

[4] Cohesiveness: Total energy of 2nd compression ÷ total energy of the 1st compression

[5] Gumminess: Hardness x cohesiveness

[6] Springiness: Height that the food recovers during the time elapsed between the end of the first compression and the start of the second compression

[7] Chewiness: Gumminess x Springiness

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Appendix A - Methodology

A-1. Total Pigment

Reagent:

1. 40 mM potassium phosphate buffer, pH 6.8
2. KH2PO4 = 4.87 g; K2HPO4 = 2.48 g; 1000 mL distilled/deionized water

Sample pulverization:

1. Cut sample into small cubes.
2. Submerge cubes in liquid nitrogen until rapid boiling of liquid nitrogen is complete.
3. Pour small amount of liquid nitrogen into Waring blender.
4. Pour meat samples into the blender and blend until a pulverized powder is created.
5. Pour pulverized sample into a Whirl-pak bag, removing as much air as possible while sealing.
6. Store sample in ultra low freezer (-80°C) until ready for use.

Procedures:

1. Grind meat through a 1/8" plate or mince into 3 mm cubes.
2. Weigh duplicate 5 g meat samples and place samples in 50 mL polypropylene tubes.
3. Add 25 mL ice cold phosphate buffer per 5 g sample (Warriss, 1979; Trout, 1989).
4. Homogenize sample for 40-45 sec at low speed, using the small diameter head of a polytron or similar probe-type homogenizer.
5. Hold the sample in ice (0 – 4°C) for 1 h.
6. Centrifuge sample at 50,000×g for 30 min at 5°C. Filter supernatant through Whatman #1 filter paper.

7. Take individual absorbances at 503, 525, 557, 582, and 700 nm (Tang et al., 2004). The values at 503, 557, and 582 are wavelength maxima for metmyoglobin, deoxymyoglobin, and oxymyoglobin, respectively. Absorbance at 525 nm (the isobestic point for the 3 forms of myoglobin) is used to calculate total myoglobin concentration.

Calculations: (according to Tang, Faustman, and Hoagland, 2004)

Total Mb (mg/ml) = (A525 − A700) × 2.229 × dilution factor.

Mb concentration (mg/g meat) = A_{525} × (1 mM Mb / 7.6) × [(1 millimole / L) / mM] × (16.949 g Mb / millimole Mb) × (0.03 L / 5 g meat; the dilution factor) × 1000 mg / g).

References:

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A-2. Microbial analysis

Reagent:

1. 0.1% peptone

Procedure:

1. Packages were aseptically opened and a 25 g sample of the ground beef patty was removed with tweezers and placed in a filter bag.

2. Between each sample, disinfect tweezers by submerging in 70% ethanol and flaming.

3. Add 225mL of 0.1% peptone diluents to the filter bag and stomach for one minute.

3. Each sample was serial diluted in 0.1% peptone water and dilutions were plated in duplicate.

4. Aerobic bacteria populations were determined using Aerobic Plate Count (APC) PetrifilmTM.

5. Anaerobic lactic acid population were determined by plating a second set of duplicate APC Petrifilms for each sample and placed in an acrylic medium canister with a AGS CO2 gas producing pack.

6. All plates for APC population were incubated at 35ºC for 48 h prior to enumeration.

Formula for calculation colony forming units (CFU) per gram:

Log CFU/g = Log_{10} (CFU/g)

CFU/g = (Average count / Volume plated) x sample dilution factor x dilution factor

Sample dilution factor = (sample weight (g) + volume of diluents (mL)) / (Sample weight (g))

Dilution factor = (1 / dilution)

Dilution: 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}

A-3. Determination of thiobarbituric acid reactive substances (TBARS)

Reagents:

1. TBA stock solution - 0.375% thiobarbituric acid, 15% trichloroacetic acid, and 0.25N HCl.
2. Stock solutions (100 mL) are sufficient for 20 individual tests. Stock solution may be stored at room temperature in the dark (foil-wrapped container).

Sample pulverization:

1. Cut sample into small cubes.
2. Submerse cubes in liquid nitrogen until rapid boiling of liquid nitrogen is complete.
3. Pour small amount of liquid nitrogen into Waring blender.
4. Pour meat samples into the blender and blend until a pulverized powder is created.
5. Pour pulverized sample into a Whirl-pak bag, removing as much air as possible while sealing.
6. Store sample in ultra low freezer (-80°C) until ready for use.

Procedure:

1. Finely chop or mince a portion of the product of interest. Weigh out duplicate 0.5 g samples.
2. Add 2.5 mL TBA stock solution to each sample, giving a dilution factor of 6. Mix well.
3. Heat samples 10 min in boiling water in loosely capped tubes (round bottom Pyrex or polypropylene centrifuge tubes). Caution: tightly capped tubes may burst during heating. Positive samples turn pink during heating.
4. Cool tubes in tap water.
5. Centrifuge at 5,000 × g for 10 min to obtain a clear supernatant.

6. Carefully pipette a portion of the supernatant to a spectrophotometer cuvette. Take care that the solution remains clear.

7. Measure supernatant absorbance at 532 nm against a blank that contains all the reagents minus the meat.

8. Calculate the TBA value expressed as ppm malonaldehyde, using 1.56 × 105/M/cm as the extinction coefficient of the pink TBA chromogen (Sinnhuber and Yu, 1958), as follows:

Calculations:

TBARS number (mg MDA/kg) = sample A 532 × (1 M TBA chromagen/156,000) × [(1mole/L/M] × (0.003 L/0.5 g meat) × (72.07 g MDA/mole MDA) × 1000 mg/g) × 1000 g/kg)

or

TBARS value (ppm) = sample A532 × 2.77

References:

Buege, J.A. and Aust, S.D. 1978. Microsomal lipid peroxidation. Methods in Enzymology 52:302-304.

Sinnhuber, R.O. and Yu, T.C. 1958. 2-Thiobarbituric acid acid method for the measurement of rancidity in fishery products. II. The quantitative determination of malonaldehyde. Food Technology 12(1):9-12.

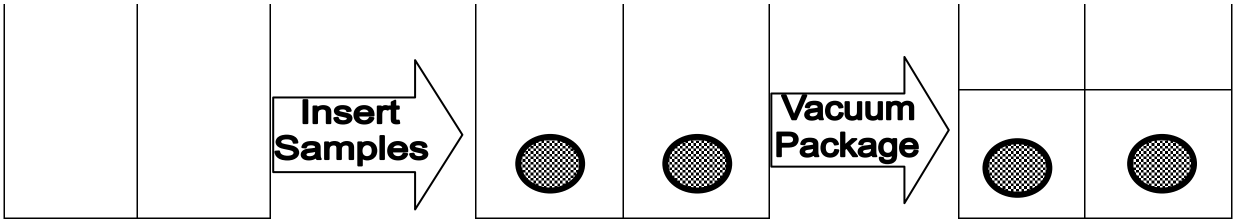
A-4. Determination of oxygen consumption rate

Procedure:

1. All pieces of meat to be assayed must be at the same temperature, such as 4^{0}C, otherwise oxygen consumption will be faster (if warmer) or slower (if colder).

2. Remove two, 5.1 cm diameter core samples from the ground beef patty and place each in a 5.1 cm diameter × 1.3 cm deep circular form. (Note: Avoid dull knives or cores, that disrupt surface structure, and excessive handling and pressing of the blooming surface of ground product.)

3. Place the duplicate samples, in a circular form then place in a 15.2 × 30.5 cm vacuum bag (Ultra Vac Solutions LLC; Kansas City, MO) sealed down the center with a seal bar.



4. Quickly vacuum package with high vacuum that is uniform from sample to sample (Note: the vacuum may slightly flatten or round the samples).

5. Immediately after vacuum packaging, take three color measurements per duplicate sample for reflectance from 400 to 700 nm using a HunterLab MiniScan.

6. Place the samples in an incubator (Boekel Industries, Model 132000, Feasterville, PA) set at 25ºC and rescan at 20 min time intervals for 1 h. (Note: Use an incubator at 25^{0}C to speed up the oxygen consuming enzymes in the meat you may also maintain samples at 4^{0}C).

7. Color standards were made following the AMSA Color Guidelines (2012) and used to calculate percent OMb, decrease in percent OMb over 20, 40, and 60 min, rate of reduction of OMb per min.

Calculations:

$$\%\text{OMb} = [\text{K/S610} - \text{K/S525 (for100\%DMb)}] - [\text{K/S610} - \text{K/S525 (sample)}] \div$$

$$[\text{K/S610} - \text{K/S525 (for100\%DMb)}] - [\text{K/S610} - \text{K/S525 (for100\%OMb)}] \quad [\times 100]$$

For each recorded interval, determine the %OMb for each recorded interval and then determine the amount of OMb remaining.

$$\text{Oxygen consumption} = [(\text{Initial \% OMb} - \text{Ending \%OMb}) \div \text{Initial \% OMb}] \times 100$$

Reference:

Madhavi, D.L. and C.E. Carpenter. 1993. Aging and processing affect color, metmyoglobin reductase and oxygen consumption of beef muscles. J. Food Sci. 58:939-942.

A-5. Determination of metmyoglobin reducing ability

Reagent:

1. 0.3% sodium nitrite solution:

   Make fresh daily. Tare a large beaker and weigh 3.0 g NaNO2 into the beaker and add distilled water to 1000 g.

Procedures:

1. Use a 1000 mL volumetric flask to mix the 0.3% solution of $NaNO_2$ before pouring into 1000 mL beakers (Note: This solution must be made VERY fresh. Prepare 15-30 min before analysis.)

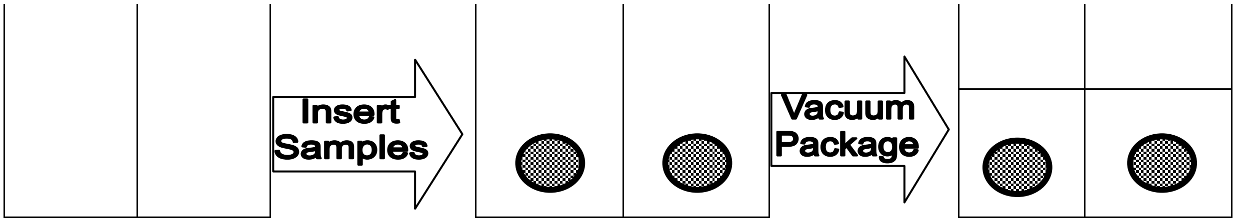
2. Removed two, 5.1 cm diameter core samples from each ground beef patty and place in a 5.1 cm diameter × 1.3 cm deep circular form.

3. Place samples in a metal mesh screen (slightly bigger than the sample and closed with a paper clip) to minimal crumbling (Note: Make sure and mark one side on the mesh screen or circular form to indicate what side of the sample was up during display; ex. purple permanent marker lines on one side of the mesh screen worked great. This is very important because this is the side of the sample you will want to scan later to collect your readings.)

4. Submerge samples in 0.3% $NaNO_2$ solution for 20 min at room temperature to induce MMb formation. (Note: Be gentle when first submerging the product. If samples are dipped too quickly, chunks may come off the product and if it is from the top of the sample the color reading will be negatively affect.)

5. Carefully remove samples from the solution, blotted with paper towel on both surfaces, and removed from the mesh screen. (Note: Blotted sample before removing the screen to help keep the sample form)

6. Place duplicate samples, still in the circular form, display surface up, into an impermeable 15.2 × 30.5 cm vacuum bag (Ultra Vac Solutions LLC; Kansas City, MO) sealed down the center with a seal bar.



7. Then vacuum package seal the bag. (Note: vacuum may slightly flatten or round the samples).

8. Immediately after vacuum packaging, take three color measurements per duplicate sample using a HunterLab MiniScan™ EZ for reflectance from 400 to 700 nm.

9. Place samples in an incubator set at 30ºC and rescanned every 60 min for 2 h.

10. Color standards were made following the AMSA Color Guidelines (2012) and used to calculate percent metmyoglobin, decrease in percent metmyoglobin over 60 and 120 min, rate of reduction of metmyoglobin per minute.

Calculations:

%MMb = [K/S572 − K/S525 (for100%DMb)] − [K/S572 − K/S525 (sample)] ÷

[K/S572 − K/S525(for100%DMb)] − [K/S572 − K/S525 (for100%MMb)] [× 100]

MRA (% of MMb reduced) = [(Initial %MMb − Final %MMb) ÷ Initial %MMb] ×100 or

Use the initial MMb formed as an indicator of MRA (see note below)

Note: Since some authors (McKenna et al., 2005 and Mancini et al., 2008) indicate that the initial amount of MMb formed is as good or better indicator of sample MRA. It is best to collect and statistically analyze both the initial amount of MMb form as well as the percentage of MMb reduced over the incubation time.

References:

McKenna, D.R., P.D. Mies, B.E. Baird, K.D. Pfeiffer, J.W. Ellebracht and J.W. Savell. 2005. Biochemical and physical factors affecting discoloration characteristics of 19 bovine muscles. *Meat Science, 70,* 665-682.

Mancini, R.A., M. Seyfert, and M.C. Hunt. 2008. Effects of data expression, sample location, and oxygen partial pressure on initial nitric oxide metmyoglobin formation and metmyoglobin-reducing-activity measurement in beef muscle. *Meat Science,* 779

Sammel, L.M, M.C. Hunt, D.H. Kropf, K.A. Hachmeister and D.E.Johnson. 2002b. Comparison of assays for metmyoglobin reducing ability in beef inside and outside semimembranosus muscle. *J. Food Science. 67,* 978-984.

Watts, B.M., J. Kendrick, M.W. Zipser, B. Hutchins and B. Saleh. 1966. Enzymatic reducing pathways in meat. *J Food Sci, 31,* 855-861.

A-6. Color Standards

Solutions:

1. 1.0% potassium ferricyanide

   - Immediately before submerging the meat product mix solution in a volumetric flask using distilled-deionized H_2O.

Procedures:

1. Color standards for deoxymyoglobin, oxymyoglobin and metmyoglobin for each subprimal were created 48 h after grinding for use in the formulas for oxygen consumption and the metmyoglobin reducing ability.

Deoxymyoglobin

A. First, ground beef was left in the vacuum package for 48 h then scanned with a Hunter Lab mini scan (Note: If the deoxymyoglobin form was not forming the patties were placed in an incubator set at 30ºC for approximately 30 min to help complete the O_2 consumption process).

Oxymyoglobin

A. Ground beef samples were left in the high oxygen packaging (99.8% O_2) for 24-48 h at refrigeration temperature then scanned with a Hunter Lab mini scan.

   1. Place sample in a large vacuum package bag and sealed along the open edge with a seal bar.

   2. Then cut a small triangle in each of the top two corner.

   3. Flush vacuum bag with O_2 for several minutes.

   4. Allowing the bag to fill up then push air out and repeat.

5. When you are confident the bag has been well flushed seal one corner of the bag then allow the bag to fill as much as possible with O_2 then seal other side quickly as you remove gas nozzle from bag.

(Note: As product ages the maximum blooming time is sooner and the muscle discolors faster.)

Metmyoglobin

A. Formed by using the oxymyoglobin ground beef samples after they were opened and scanned.
   1. Samples were submerged in 1.0% potassium ferricyanide for 1 min and then drained.
   2. Next, the surface was blotted with a paper towel and covered in oxygen-permeable film to oxidize at 2-4ºC for 48 h and then scanned using a Hunter Lab mini scan.

Before scanning patties the Hunter Lab mini scan was standardized using the vacuum packaging material used for the OCR and MRA.

References:

American Meat Science Association. 2011. Guidelines for meat color evaluation. *Recip. Meat Conf. Proc., 44*, 1-17.

Color Standards

Chuck roll Premium Choice

	100% OMb	100% DMb	100% MMb
470	9.09	17.37	13.65
480	10.81	18.56	13.55
520	11.49	12.98	12.82
530	7.94	11.96	13.27
570	7.16	9.74	17.83
580	5.44	10.95	16.74
610	38.13	23.48	22.44
474	9.78	17.85	13.61
525	9.72	12.47	13.05
572	6.82	9.98	17.61
610	38.13	23.48	22.44
474 K/S	4.16	1.89	2.74
525 K/S	4.20	3.07	2.90
572 K/S	6.37	4.06	1.93
610 K/S	0.50	1.25	1.34

Chuck roll Select

	100% OMb	100% DMb	100% MMb
470	7.85	15.2	12.19
480	9.32	16.28	11.98
520	9.63	10.96	11.14
530	6.69	10.08	11.71
570	5.96	8.34	16.47
580	4.56	9.37	15.65
610	32.23	20.84	19.82
474	8.44	15.63	12.11
525	8.16	10.52	11.43
572	5.68	8.55	16.31
610	32.23	20.84	19.82
474 K/S	4.97	2.28	3.19
525 K/S	5.17	3.81	3.43
572 K/S	7.83	4.89	2.15
610 K/S	0.71	1.50	1.62

Knuckle Premium Choice

	100% OMb	100% DMb	100% MMb
470	7.14	13.56	10.79
480	8.43	14.39	10.56
520	8.59	10.1	9.76
530	6.07	9.64	10.49
570	5.47	8.21	15.63
580	4.19	9.06	15.19
610	27.8	18.4	17.32
474	7.66	13.89	10.70
525	7.33	9.87	10.13
572	5.21	8.38	15.54
610	27.80	18.40	17.32
474 K/S	5.57	2.67	3.73
525 K/S	5.86	4.12	3.99
572 K/S	8.62	5.01	2.29
610 K/S	0.94	1.81	1.97

Knuckle Select

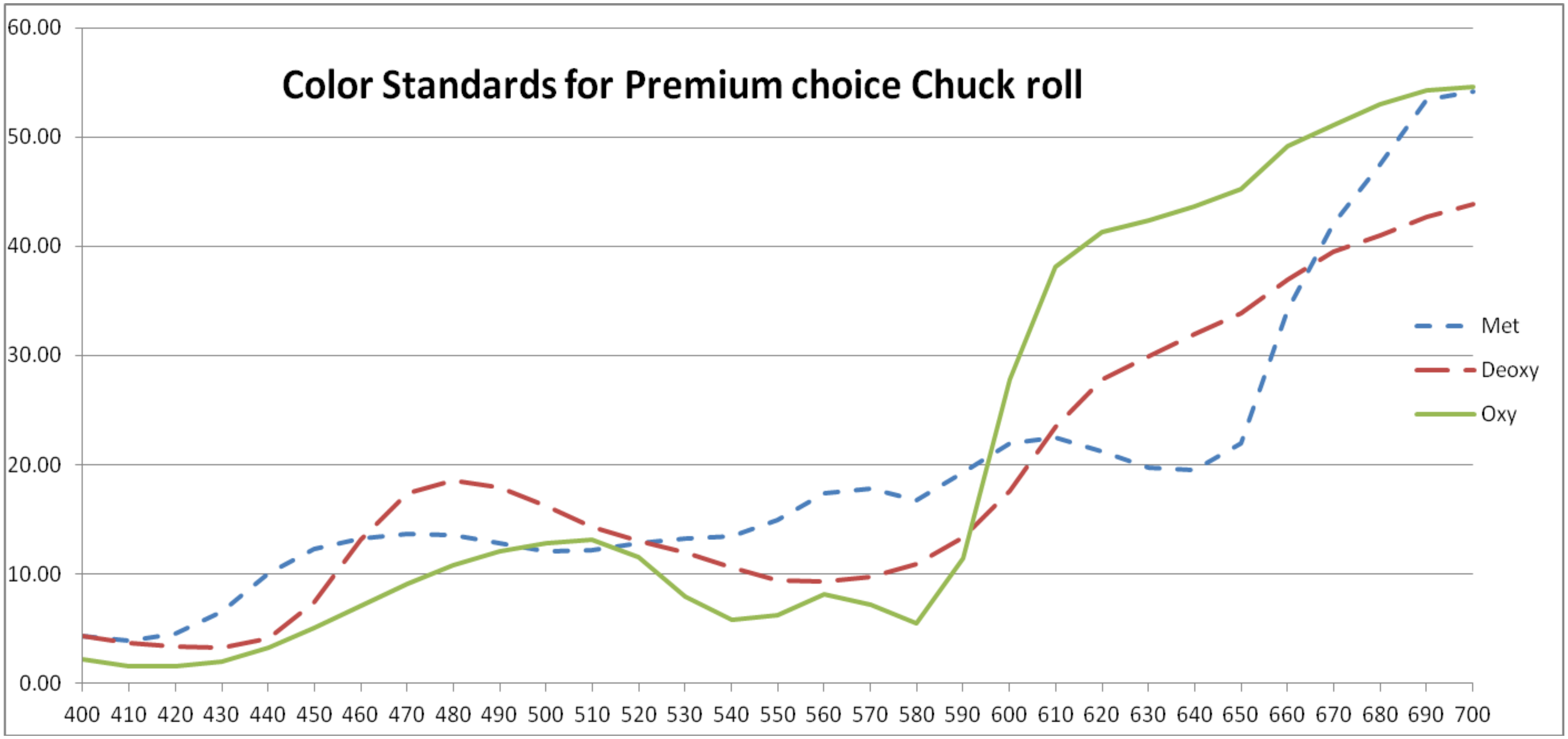
	100% OMb	100% DMb	100% MMb
470	7.71	12.22	10.83
480	8.96	12.59	10.57
520	8.96	9.54	9.7
530	6.47	9.34	10.45
570	5.92	9.09	15.65
580	4.53	9.87	15.38
610	26.3	17.52	16.88
474	8.21	12.37	10.73
525	7.72	9.44	10.08
572	5.64	9.25	15.60
610	26.30	17.52	16.88
474 K/S	5.13	3.10	3.72
525 K/S	5.52	4.34	4.01
572 K/S	7.89	4.45	2.28
610 K/S	1.03	1.94	2.05

Color Standards for Premium Choice chuck roll

	400	410	420	430	440	450	460	470	480	490	500	510	520	530
MMb	4.36	3.89	4.56	6.58	10.07	12.29	13.29	13.65	13.55	12.82	12.12	12.16	12.82	13.27
DMb	4.36	3.63	3.39	3.27	4.07	7.37	13.14	17.37	18.56	17.92	16.24	14.31	12.98	11.96
OMb	2.23	1.57	1.52	1.96	3.22	5.05	7.05	9.09	10.81	12.04	12.84	13.16	11.49	7.94

	540	550	560	570	580	590	600	610	620	630	640	650	660	670
MMb	13.47	14.93	17.43	17.83	16.74	19.31	21.99	22.44	21.19	19.70	19.56	21.96	34.23	42.00
DMb	10.63	9.44	9.26	9.74	10.95	13.38	17.61	23.48	27.80	29.92	31.93	33.88	36.89	39.46
OMb	5.77	6.27	8.18	7.16	5.44	11.48	27.85	38.13	41.32	42.4	43.67	45.21	49.2	51.12

	680	690	700
MMb	47.41	53.42	54.18
DMb	40.94	42.66	43.83
OMb	52.98	54.31	54.59


Color Standards for Premium choice Chuck roll
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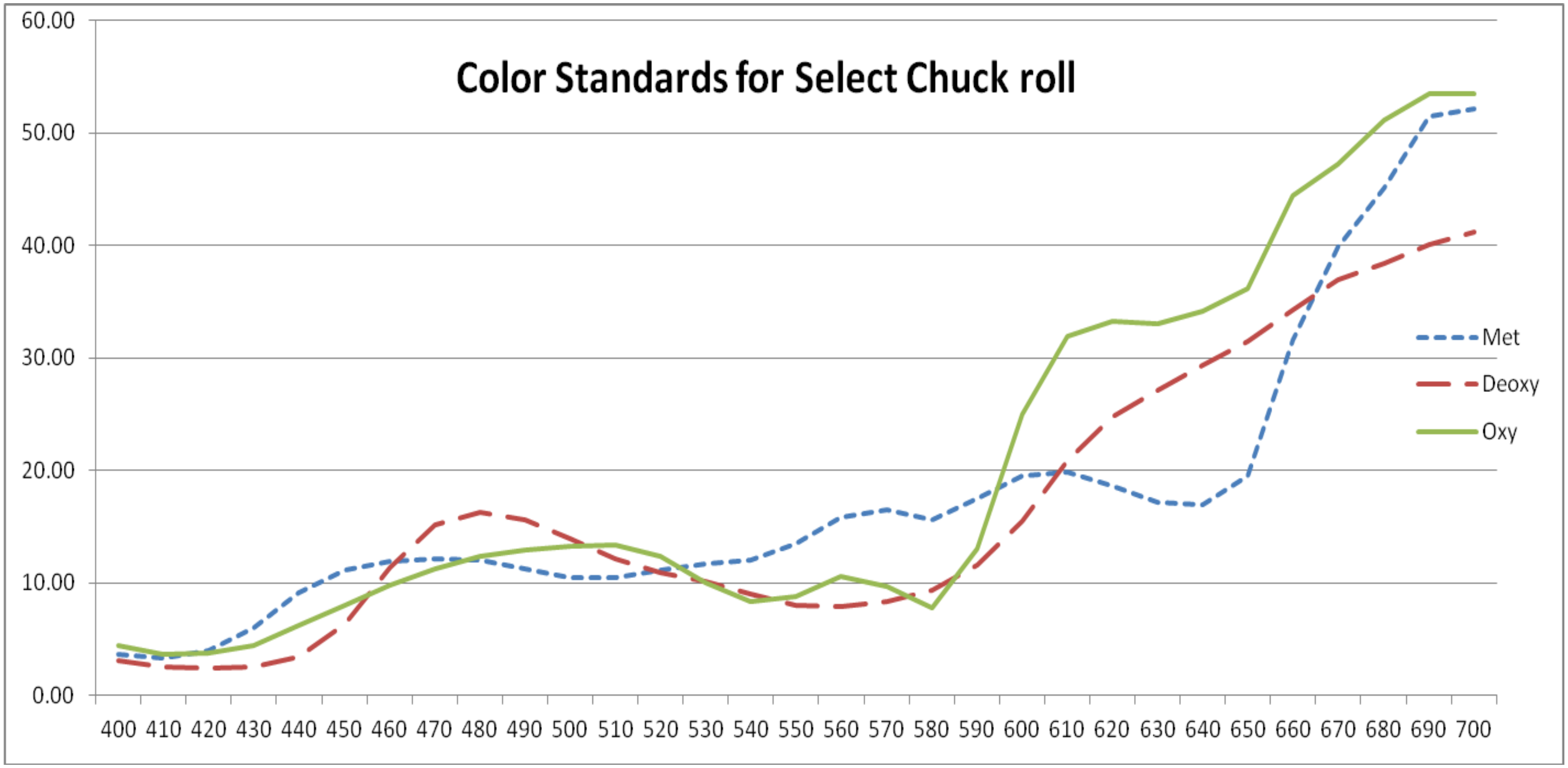
670
680
690
700
Met
Deoxy
Oxy

Color Standards for Select chuck roll

	400	410	420	430	440	450	460	470	480	490	500	510	520	530
MMb	3.70	3.29	3.96	5.94	9.10	11.13	11.96	12.19	11.98	11.22	10.49	10.48	11.14	11.71
DMb	3.06	2.48	2.44	2.53	3.39	6.35	11.33	15.20	16.28	15.60	13.94	12.13	10.96	10.08
OMb	2.29	1.75	1.63	2.00	3.09	4.55	6.23	7.85	9.32	10.46	11.13	11.24	9.63	6.69

	540	550	560	570	580	590	600	610	620	630	640	650	660	670
MMb	12.08	13.50	15.86	16.47	15.65	17.51	19.49	19.82	18.58	17.13	16.96	19.47	31.56	39.85
DMb	8.98	8.03	7.92	8.34	9.37	11.55	15.45	20.84	24.73	27.12	29.32	31.42	34.32	36.91
OMb	4.95	5.27	6.64	5.96	4.56	9.47	23.95	32.23	38.82	40.75	42.42	44.03	47.64	49.46

	680	690	700
MMb	45.12	51.44	52.16
DMb	38.35	40.06	41.21
OMb	51.16	52.37	52.72


Color Standards for Select Chuck roll
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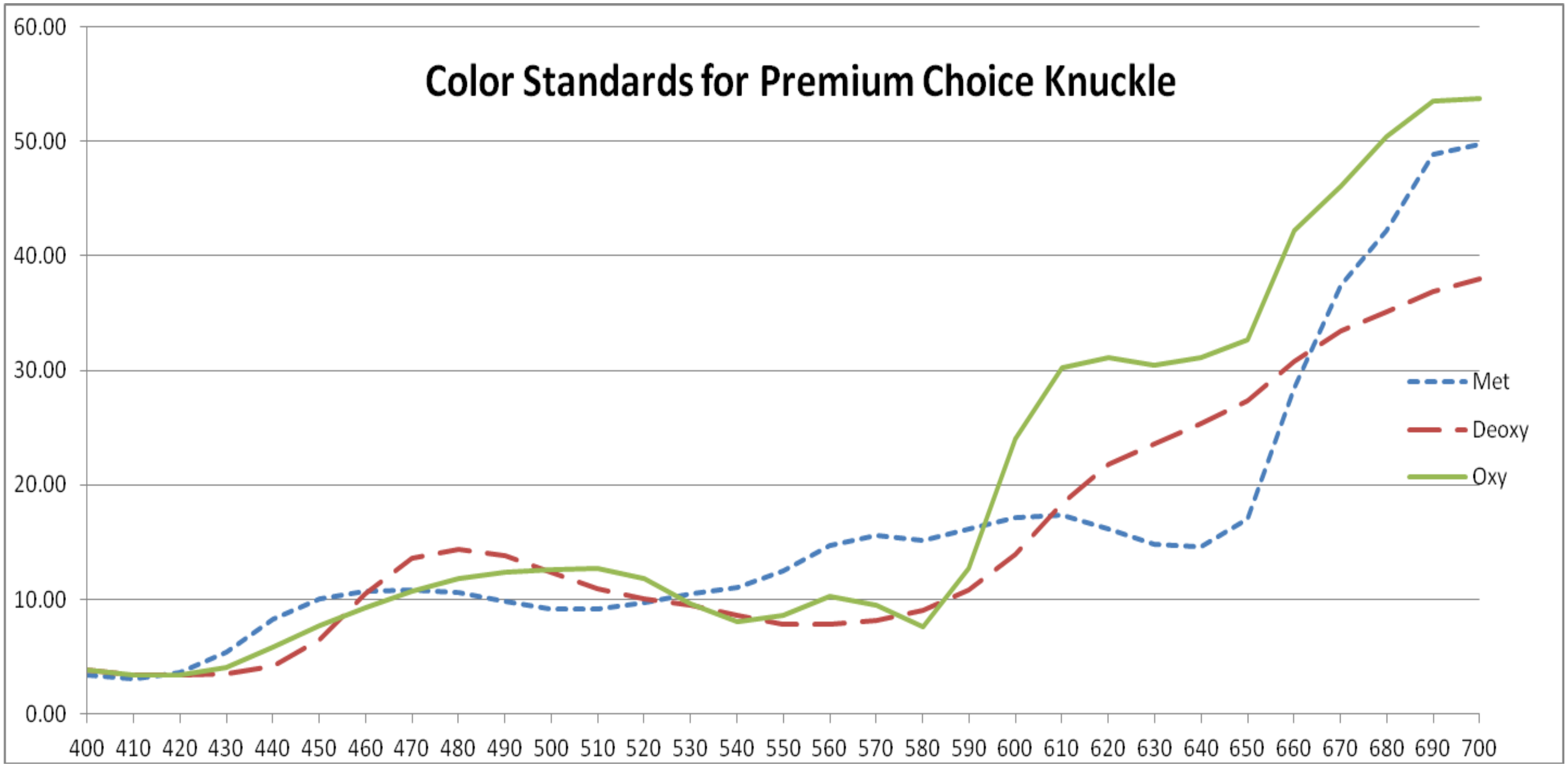
660
670
680
690
700
Met
Deoxy
Oxy

Color Standards for Premium Choice knuckle

	400	410	420	430	440	450	460	470	480	490	500	510	520	530
MMb	3.42	3.01	3.63	5.34	8.23	10.05	10.68	10.79	10.56	9.82	9.17	9.14	9.76	10.49
DMb	3.89	3.42	3.42	3.48	4.13	6.49	10.49	13.56	14.39	13.77	12.39	10.97	10.10	9.46
OMb	1.77	1.28	1.27	1.67	2.67	4.11	5.66	7.14	8.43	9.26	9.71	9.79	8.59	6.07

	540	550	560	570	580	590	600	610	620	630	640	650	660	670
MMb	11.07	12.45	14.65	15.63	15.19	16.09	17.19	17.32	16.17	14.81	14.62	17.03	28.51	37.42
DMb	8.63	7.88	7.83	8.21	9.06	10.81	13.90	18.40	21.84	23.62	25.38	27.37	30.82	33.41
OMb	4.48	4.79	6.08	5.47	4.19	8.37	19.66	27.80	28.45	28.73	29.44	30.68	36.17	38.5

	680	690	700
MMb	42.26	48.89	49.74
DMb	35.09	36.91	37.96
OMb	41.12	43.00	43.41



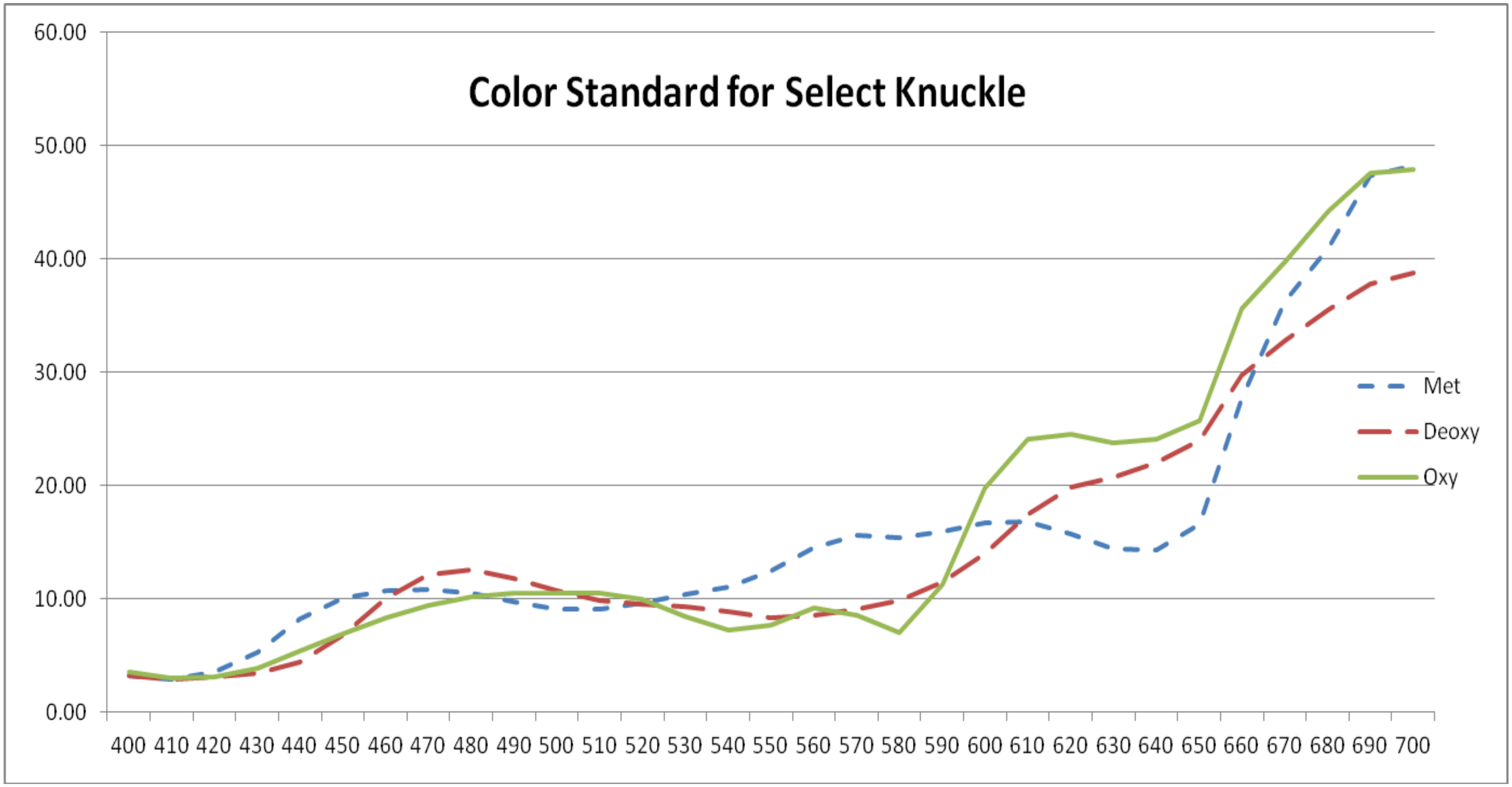
Color Standards for Premium Choice Knuckle
60.00
50.00
40.00
30.00
20.00
10.00
0.00
400 410 420 430 440 450 460 470 480 490 500 510 520 530 540 550 560 570 580 590 600 610 620 630 640 650 660 670 680 690 700
Met
Deoxy
Oxy

Color Standards for Select knuckle

	400	410	420	430	440	450	460	470	480	490	500	510	520	530
MMb	3.26	2.92	3.54	5.36	8.24	10.10	10.74	10.83	10.57	9.82	9.13	9.07	9.70	10.45
DMb	3.26	2.89	3.12	3.50	4.43	6.87	10.15	12.22	12.59	11.87	10.74	9.87	9.54	9.34
OMb	2.04	1.47	1.47	1.88	2.96	4.48	6.13	7.71	8.96	9.75	10.11	10.15	8.96	6.47

	540	550	560	570	580	590	600	610	620	630	640	650	660	670
MMb	11.10	12.45	14.60	15.65	15.38	16.00	16.77	16.88	15.80	14.47	14.30	16.62	27.75	36.27
DMb	8.86	8.38	8.61	9.09	9.87	11.47	14.03	17.52	19.89	20.80	22.08	24.06	29.81	32.77
OMb	4.86	5.20	6.60	5.92	4.53	9.01	19.93	26.30	27.45	27.34	27.91	29.26	35.92	38.75

	680	690	700
MMb	40.98	47.37	48.25
DMb	35.57	37.83	38.77
OMb	41.80	44.04	44.51


Color Standard for Select Knuckle
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50.00
40.00
30.00
20.00
10.00
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400 410 420 430 440 450 460 470 480 490 500 510 520 530 540 550 560 570 580 590 600 610 620 630 640 650 660 670 680 690 700
Met
Deoxy
Oxy

Calculations:

$K/S = (1 - R)^2 \div (2R)$ where, R = % reflectance, which should be expressed as a decimal

$$\textbf{\% Oxymyoglobin} = \frac{\{(K/S\ 610) / (K/S\ 525) \text{ for } 100\%\ MMb\} - \{(K/S\ 610) / (K/S\ 525) \text{ for sample}\}}{\{(K/S\ 610) / (K/S\ 525) \text{ for } 100\%\ MMb\} - \{(K/S\ 610) / (K/S\ 525) \text{ for } 100\%\ OMb\}}$$

$$\textbf{\% Metmyoglobin} = \frac{\{(K/S\ 572) / (K/S\ 525) \text{ for } 100\%\ OMb\} - \{(K/S\ 572) / (K/S\ 525) \text{ for sample}\}}{\{(K/S\ 572) / (K/S\ 525) \text{ for } 100\%\ OMb\} - \{(K/S\ 572) / (K/S\ 525) \text{ for } 100\%\ MMb\}}$$

$$\textbf{\% Deoxymyoglobin} = \frac{\{(K/S\ 474) / (K/S\ 525) \text{ for } 100\%\ MMb\} - \{(K/S\ 474) / (K/S\ 525) \text{ for sample}\}}{\{(K/S\ 474) / (K/S\ 525) \text{ for } 100\%\ MMb\} - \{(K/S\ 474) / (K/S\ 525) \text{ for } 100\%\ DMb\}}$$

Finding Standard values:

1. Average all color measurements then remove any outliers (greater than 2 standard deviations)

2. Then plot MMb, OMb, and DMb lines.

3. If lines to not cross at 525, return to original values and remove any other readings that seem out of place. (Note: The lines need to a-line at 474, 525, 572 and 610 nm. Once you have the curves you can edit the data to help the curves a-line correctly. For example if an individual OMb, DMb, or MMb curve looks good but are too high or too low, a constant can be used to shift the entire curve up or down to achieve the correct values).

4. Only a single color reading needs to be used to create your curve if that one fits the best but averaging is always better. For examples, several OMb readings of samples were better than

the created standards so these readings were substituted in or added into the average to create a better curve.

CP – Oxy – Rep 1 – Day 1 Sample 29

CS – Oxy – Rep 1 - Day 3 Sample 169

KP – Oxy – Rep 1 - Day 1   Sample 98

KS – Oxy – Average (Rep 1 - Day 1 Sample 59 & 60 & Rep 2 – Day 3 Sample 144)

(Note: Obtaining good DMb readings is very difficult. Because it was only necessary to find %OMb and %MMb, I did not use my DMb curves because the data did not work in both equations and so I only used OMb and MMb data for the equations.

4. Once good lines were charted, then K/S values were found and the above equations were completed.

A-7. Visual Color Panel – Visual color

Ground Beef Patties

Fluorescent Display Case

NAME: ______________________________ DATE: ________ Time: _______

Color Scale: To characterize retail color shelf-life

1 = Extremely bright cherry-red
2 = Bright cherry-red
3 = Moderately bright cherry-red
4 = Slightly bright cherry-red
5 = Slightly dark cherry-red
6 = Moderately dark red
7 = Dark red
8 = Extremely dark red

*****Score to half-point increments*****

Fluorescent Display Case				
Package ID	**Color Score**		**Package ID**	**Color Score**
_02			**_42**	
_07			**_43**	
_15			**_54**	
_25			**_63**	
_27			**_88**	
_40			**_98**	

A-8 Visual Color Panel - Discoloration

Ground Beef Patties
Fluorescent Display Case

NAME: ___________________________________ DATE: ________ Time: _______

Color Scale: To characterize retail color shelf-life

1 = Very bright red

2 = Bright red

3 = Dull red

4 = Slightly dark red

5 = Moderately dark red

6 = Dark red to tannish red

7 = Dark reddish tan

8 = Tan to brown

*****Score to half-point increments*****

Fluorescent Display Case				
Package ID	**Color Score**		**Package ID**	**Color Score**
_02			**_42**	
_07			**_43**	
_15			**_54**	
_25			**_63**	
_27			**_88**	
_40			**_98**	

A-9. Visual Color Panel - Initial Color

Ground Beef Patties
Fluorescent Display Case

NAME: ____________________________________ DATE: _________ Time: ________

Color Scale: To characterize retail color shelf-life

1 = Very light red

2 = Moderately light red

3 = Light red

4 = Slightly bright red

5 = Bright red

6 = Slightly dark red

7 = Moderately dark red

8 = Dark red

*****Score to half-point increments*****

Fluorescent Display Case				
Package ID	**Color Score**		**Package ID**	**Color Score**
_02			**_42**	
_07			**_43**	
_15			**_54**	
_25			**_63**	
_27			**_88**	
_40			**_98**	

A-10. Determination of fatty acid composition

Reagents: (use deionized water)

1. Methanolic –HCl; Acetyl chloride, 20ml; Methanol, anhydrous HPLC grade, 100ml
   - Use a magnetic stir plate and prepare by SLOWLY adding acetyl chloride to the methanol. Make fresh daily.
2. Benzene, reagent grade
3. Methyl tridecanoic acid (C13:0),

   -Dissolve 2 mg/ml(2000ug/ml) in benzene (0.50g/250ml), store in sealed container in freezer.
4. Potassium carbonate, 6%

   - Dissolve 60 g K_2CO_3 in water, bring volume to 1 liter.
5. Sodium sulfate (anhydrous)
6. Activated charcoal, powder
7. Supelco 37 FAME mix (Supelco # 47885-U)

Procedure:

1. Weigh 50-500 mg of air-dry samples, containing 10-50 mg fatty acid (maximum 30 mg fatty acid in the case of soaps), into screw cap tubes with Teflon lined caps.
2. Add 2 ml internal standard in benzene and 3 ml freshly made methanolic-HCl to all tubes.
3. Gas with N_2 and cap tightly. Vortex gently, avoid splashing sample on sides of tube.
4. Heat tubes for 2 hr 15 min in a 80°C water bath (90°C is recommended for calcium soaps). Vortex on “HIGH” at 45 min and 90 min.
5. Remove tubes from water bath and cool to room temperature.

6. Add 5 ml 6% K_2CO_3 and 2ml benzene to all tubes and vortex well.
7. Centrifuge tubes at 500 x g for 5 min.
8. Transfer upper organic solvent layer to a GC vial.

GC Analysis:

Column: Supelco SP-2560 capillary (100m X 0.25 mm X 0.20*u* film)

Injection Temp: 260°C

Detector Temp: 260°C

Initial oven temp: 140°C – hold 5 minutes.

Heating rate: 4°C/min

Final oven temp: 240° C – hold 15 minutes

Column flow rate: 1.1 ml/min

Split ratio: 48:1

Standard: Supelco 37 FAME mix (Supelco # 47885-U)

Sample volume: 1.0 *u*l

Reference:

Sukhija, P.S. and D.L. Palmquist. 1988. Rapid method for determination of total fatty acid content and composition of feedstuffs and feces. J. Agric. And Food Chem. 36:1202-1206.

A-12. Sensory Evaluation

Patty cookery:

1. Thaw patties at 2ºC for 24 h.
2. Record raw weight.
3. Cook patties on a griddle set at 163ºC (325ºF).
4. Heat each patty for 1-2 min then flipped every 2 min until an internal end point temp of 71ºC (160ºF) is reached.
5. Remove patties from heat, blot, and record cooked weight and thickness.
6. Monitor internal temperature by intermittently inserting an Omega hypodermic temperature probe attached to a Doric Trendicator.

Sensory Panel:

1. Cut patties into eights (quarter patties and then half each quarter) and evaluate with a trained sensory panel using a scale of 1 – 8.
2. Trained sensory panelists were given an unscored “warm-up” sample and discussed prior to evaluation of six samples representing the quality grade × aging time treatments within subprimal types.

Firmness scale:
8. Extremely firm
7.Very firm
6. Moderately firm
5. Slightly firm
4. Slightly soft
3. Moderately soft
2. Very soft
1. Extremely soft.

Cohesiveness scale:
8. Extremely cohesive
7. Very cohesive
6. Moderately cohesive
5. Slightly cohesive
4. Slightly uncohesive
3. Moderately uncohesive
2.Very uncohesive
1. Not cohesive at all

Juiciness scale:
8. Extremely juicy
7. Very juicy
6. Moderately juicy
5. Slightly juicy
4. Slightly dry
3. Moderately dry
2. Very dry
1. Extremely dry

Beef flavor intensity scale:
8. Extremely intense
7. Very intense
6. Moderately intense
5. Slightly intense
4. Slightly bland
3. Moderately bland
2. Very
1. Extremely bland

Mouth coat scale:
8. None
7. Practically none
6. Traces
5. Slight
4. Moderate
3. Slightly abundant
2. Moderately abundant
1. Abundant

Off-flavor intensity scale:
8. None
7. Practically none
6. Traces
5. Slight
4. Moderate
3. Slightly abundant
2. Moderately abundant
1. Abundant

Desirability scale:
8. Extremely Liked
7. Very Liked
6. Moderately Liked
5. Slightly Liked
4. Slightly Disliked
3. Moderately Disliked
2. Very Disliked
1. Extremely Dislike

Kansas State University - Sensory Panel Evaluation - Ground Beef

Study:___________Carrie Highfill Ground Beef________________

Name: **Date:** **Time:**

SAMPLE	FIRMNESS	COHESIVENESS	JUICINESS	BEEF FLAVOR INTENSITY	MOUTH COAT	OFF FLAVOR INTENSITY	OFF FLAVOR DESCRIPTOR	DESIRABILITY
WU								
A								
B								
C								
D								
E								
F								
	8. Extremely firm	8. Extremely cohesive	8. Extremely juicy	8. Extremely intense	8. None	8. None		8. Extremely Liked
	7.Very firm	7. Very cohesive	7. Very juicy	7. Very intense	7. Practically none	7. Practically none		7. Very Liked
	6. Moderately firm	6. Moderately cohesive	6. Moderately juicy	6. Moderately intense	6. Traces	6. Traces		6. Moderately Liked
	5. Slightly firm	5. Slightly cohesive	5. Slightly juicy	5. Slightly intense	5. Slight	5. Slight		5. Slightly Liked
	4. Slightly soft	4. Slightly uncohesive	4. Slightly dry	4. Slightly bland	4. Moderate	4. Moderate		4. Slightly Disliked
	3. Moderately soft	3. Moderately uncohesive	3. Moderately dry	3. Moderately bland	3. Slightly abundant	3. Slightly abundant		3. Moderately Disliked
	2. Very soft	2.Very uncohesive	2. Very dry	2. Very bland	2. Moderately abundant	2. Moderately abundant		2. Very Disliked
	1. Extremely soft	1. Not cohesive at all	1. Extremely dry	1. Extremely bland	1. Abundant	1. Abundant		1. Extremely Dislike

Sensory Panel Off-flavors reported

Measured Off-Flavors	
Premium Choice chuck roll	liver, slightly rancid, serumy, sour, chemical
Select chuck roll	oxidized, warmed over, liver, rancid, bitter
Premium Choice knuckle	chemical, rancid, metallic, livery, oxidized, organ, serumy, grassy
Select knuckle	serumy, livery, oxidized, organ
7 d	oxidized, warmed over, rancid, serumy, chemical, livery, organ, grassy
21 d	slightly rancid, metallic, sour
42 d	oxidized, serumy, rancid, stale

A-11. Determination of cooking data, Warner-Bratzler, Lee-Kramer, Texture Profile Analysis

Patty cookery:

1. Thaw patties at 2ºC for 24 h.
2. Record raw weight.
3. Cook patties on a griddle set at 163ºC (325ºF).
4. Heat each patty for 1-2 min then flipped every 2 min until an internal end point temp of 71ºC (160ºF) is reached.
5. Remove patties from heat, blot, and record cooked weight and thickness.
6. Monitor internal temperature by intermittently inserting an Omega hypodermic temperature probe attached to a Doric Trendicator.

Warner-Bratzler Slice Shear Force:

1. Cool patties to room temperature (approximately 30 min).
2. Cut two, 3-cm × patty depth strips were removed from the center of each patty and shear each strip twice.
3. Two patties per sample replication were utilized resulting in 8 measurements that were averaged for analysis.
4. The blade was attached to the crosshead of an Instron Model 5569 (Instron Caibration Lab Norwood, MA model 5569) with a 50 kg load cell and crosshead speed of 250mm/min.

Lee-Kramer Shear:

1. Cool patties to room temperature (approximately 30 min).
2. Cut a 6.0 × 6.0 cm × patty depth sample piece from each of two patties from all sample replications.
3. Weigh each square and shear in the Lee-Kramer cell attached to the Instron with a 500 kg load cell and a crosshead speed of 350 mm/min.
4. Peak force (kg) and total energy (kg x mm) were determined and divided by the weight to obtain force or energy/ g. The average of the two patty measurements was used for analysis.

Texture Profile Analysis:

1. Cool patties to room temperature (approximately 30 min).
2. Remove three 2.54 cm cores from each patty.
3. Compressed each core 30% of its original height for two cycles.
4. The Instron was programmed for 40% load range of a 50 kg load cell and a cross head speed of 200 mm/min.

Hardness: Peak force of 1st compression, kg

Cohesiveness: Total energy of 2nd compression ÷ total energy of the 1st compression

Springiness: Height that the food recovers during the time elapsed between the end of the 1st compression and the start of the 2nd compression

Gumminess: Hardness x Cohesiveness

Chewiness: Gumminess x Springiness

Appendix B - Additional Result Tables

Table B.1. Subprimal type × aging time × display time interaction means for visual color scores[1] of ground beef patties (SE = 0.13)

	Display time				P-values		
	0 h	**24 h**	**48 h**	**72 h**	**Linear**	**Quadratic**	**Cubic**
Chuck roll							
7 d	2.9^{aw}	3.9^{by}	4.2^{bv}	4.9^{cx}	<0.01	0.23	0.04
21 d	3.1^{ax}	4.0^{by}	4.6^{cw}	5.2^{dx}	<0.01	0.44	0.81
42 d	3.5^{ax}	4.3^{by}	5.4^{cx}	6.3^{dy}	<0.01	0.70	0.31
Knuckle							
7 d	4.6^{ay}	6.0^{bz}	6.2^{by}	6.6^{cy}	<0.01	<0.01	0.07
21 d	4.8^{ay}	6.0^{bz}	6.3^{by}	7.1^{cz}	<0.01	0.26	0.16
42 d	5.5^{az}	6.1^{bz}	6.8^{cz}	7.2^{dz}	<0.01	0.88	0.57

$^{a-d}$Means within a row with a different letter differ (P<0.05)
$^{v-z}$ Means within a column with a different letter differ (P<0.05)
[1] Visual color: 1 = Extremely bright cherry-red; 4 = Slightly Bright cherry-red; 8 = Extremely dark red

Table B.2. Subprimal type × aging time × display time interaction means for visual color discoloration[1] of ground beef patties (SE = 0.18)

	Display time				P-values		
	0 h	**24 h**	**48 h**	**72 h**	**Linear**	**Quadratic**	**Cubic**
Chuck roll							
7 d	2.1^{aw}	3.3^{bx}	3.4^{bv}	4.4^{cv}	<0.01	0.84	<0.01
21 d	2.7^{ax}	3.5^{bxy}	4.0^{cw}	4.9^{dw}	<0.01	0.91	0.50
42 d	3.0^{axy}	3.8^{by}	5.0^{cx}	5.9^{dx}	<0.01	0.53	0.28
Knuckle							
7 d	3.4^{ay}	5.3^{bz}	6.0^{cy}	6.7^{dy}	<0.01	<0.01	0.18
21 d	4.2^{az}	5.5^{bz}	6.3^{cyz}	7.1^{dz}	<0.01	0.08	0.30
42 d	4.5^{az}	5.5^{bz}	6.6^{cz}	7.1^{dz}	<0.01	0.19	0.37

$^{a-d}$ Means within a row with a different letter differ (P<0.05)
$^{v-z}$ Means within a column with a different letter differ (P<0.05)
[1] Discoloration: 1 = Very bright red; 4 = Slightly dark red; 8 = Tan to brown

Table B.3. Subprimal type × aging time × display time interaction means for a* and chroma instrumental color values for ground beef patties

	Display time											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
a*												
Chuck roll												
7 d^{123}	33.2^{jy}	30.0^{iz}	27.8^{hz}	26.3^{gz}	25.4^{fz}	24.3^{ez}	23.4^{dz}	23.0^{cdz}	22.5^{bcz}	20.3^{az}	21.7^{bz}	0.4354
21 d^{123}	35.2^{gz}	30.0^{fz}	27.5^{eyz}	25.9^{dz}	24.7^{dz}	23.4^{cz}	22.7^{cz}	21.6^{by}	20.4^{ay}	20.0^{az}	19.5^{ay}	
42 d^{123}	31.9^{ix}	29.1^{hz}	26.3^{gy}	24.7^{fy}	22.9^{ey}	21.1^{dy}	20.2^{cdy}	19.7^{cx}	18.1^{bx}	17.0^{ay}	16.3^{ax}	
Knuckle												
7 d^{123}	28.3^{gw}	24.9^{fy}	22.2^{ex}	21.8^{ex}	20.0^{dx}	18.9^{cdx}	17.9^{bx}	17.7^{abw}	17.2^{abwx}	18.0^{bcy}	16.5^{ax}	
21 d^{123}	28.9^{hw}	24.9^{gy}	22.2^{fx}	21.4^{fx}	19.4^{ex}	18.5^{dx}	18.0^{cdx}	17.0^{bcw}	16.5^{abw}	15.7^{ax}	15.9^{ax}	
42 d^{123}	28.0^{hw}	25.0^{gy}	22.1^{fx}	20.7^{fx}	19.4^{ex}	18.1^{dx}	17.2^{cdx}	16.8^{cw}	15.0^{bv}	13.9^{aw}	13.2^{aw}	
Chroma^{4}												
Chuck roll												
7 d^{123}	42.0^{iy}	38.3^{hz}	35.8^{gz}	33.9^{fz}	32.9^{efz}	31.7^{dez}	30.8^{cdz}	30.4^{cdz}	30.1^{bcz}	27.5^{az}	29.1^{bz}	0.5041
21 d^{123}	44.1^{iz}	38.3^{hz}	35.4^{gyz}	33.6^{fz}	32.1^{ez}	30.8^{dz}	30.1^{cdz}	28.8^{bcy}	27.8^{aby}	27.5^{az}	27.1^{ay}	
42 d^{123}	40.8^{hy}	37.5^{gz}	34.4^{fy}	32.5^{ez}	30.4^{dy}	28.6^{cy}	27.6^{cy}	27.4^{cx}	25.8^{bx}	24.5^{ay}	24.2^{ax}	
Knuckle												
7 d^{123}	35.5^{gx}	31.5^{fy}	28.6^{ex}	28.5^{ey}	26.3^{dx}	25.4^{cdx}	24.1^{abx}	24.1^{abw}	23.9^{abw}	24.7^{bcy}	23.3^{aw}	
21 d^{123}	35.9^{gx}	31.6^{fy}	28.7^{ex}	28.2^{ey}	25.6^{dx}	25.0^{dx}	24.6^{cdx}	23.4^{bcw}	23.1^{abvw}	22.3^{ax}	22.8^{abw}	
42 d^{123}	35.6^{ix}	32.0^{hy}	28.9^{gx}	27.4^{fy}	25.9^{ex}	24.9^{dex}	23.9^{cdx}	23.9^{cw}	22.4^{bv}	21.3^{ax}	20.7^{av}	

$^{a-j}$ Means within a row with a different letter differ ($P<0.05$)

$^{v-z}$ Means within a column and traits with a different letter differ ($P<0.05$)

[1] Linear ($P<0.05$)

[2] Quadratic ($P<0.05$)

[3] Cubic ($P<0.05$)

[4] Chroma = $(a^2 + b^2)^{1/2}$

Table B.4. Subprimal type × display time interaction means for L*, b*, a/b ratio, and hue angle instrumental color values for ground beef patties

	Display time											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
L*												
Chuck roll[123]	50.7^{dz}	49.2^{cz}	47.9^{bz}	47.3^{az}	48.0^{bz}	47.7^{abz}	47.5^{abz}	47.8^{abz}	47.5^{abz}	47.4^{az}	47.6^{abz}	0.741
Knuckle[123]	47.1^{ey}	46.0^{dy}	44.7^{by}	44.1^{ay}	45.3^{cy}	44.9^{bcy}	45.0^{bcy}	45.0^{bcy}	44.8^{by}	45.1^{bcy}	44.9^{bcy}	
b*												
Chuck roll[123]	26.0^{iz}	23.8^{hz}	22.3^{gz}	21.4^{fz}	20.5^{ez}	19.9^{dz}	19.5^{cz}	19.3^{cz}	19.1^{bcz}	18.3^{az}	18.7^{abz}	0.1858
Knuckle[123]	21.5^{fy}	19.6^{ey}	18.3^{dy}	18.2^{dy}	17.0^{cy}	16.9^{bcy}	16.6^{aby}	16.5^{ay}	16.4^{ay}	16.2^{ay}	16.3^{ay}	
a/b ratio												
Chuck roll[1]	1.29^{jz}	1.25^{iz}	1.22^{hz}	1.19^{gz}	1.19^{gz}	1.15^{fz}	1.13^{ez}	1.11^{dz}	1.06^{cz}	1.04^{bz}	1.02^{az}	0.009
Knuckle[12]	1.32^{iy}	1.28^{hz}	1.21^{gz}	1.17^{fz}	1.15^{ey}	1.10^{dy}	1.07^{dy}	1.04^{cy}	0.99^{by}	0.98^{by}	0.93^{ay}	
Hue angle[4]												
Chuck roll[1]	37.8^{az}	38.6^{bz}	39.3^{cz}	40.0^{dz}	40.1^{dy}	41.1^{ey}	41.5^{ey}	42.1^{fy}	43.4^{gy}	44.0^{hy}	44.6^{iy}	0.244
Knuckle[1]	37.1^{ay}	38.1^{bz}	39.6^{cz}	40.5^{cdz}	41.0^{dz}	42.4^{ez}	43.0^{fz}	43.9^{gz}	45.5^{hz}	45.9^{hz}	47.2^{iz}	

$^{a-j}$ Means within a row with a different letter differ ($P<0.05$)
$^{y-z}$ Means within a column and trait with a different letter differ ($P<0.05$)
[1] Linear ($P<0.05$)
[2] Quadratic ($P<0.05$)
[3] Cubic ($P<0.05$)
[4] Hue angle = $\tan^{-1} b/a$

Table B.5. Quality grade × display time interaction means for b*, a/b ratio, and hue angle instrumental color values for ground beef patties

	Display time											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
b*												
Premium Choice[1,2,3]	24.9^{gz}	22.6^{fz}	21.1^{ez}	20.4^{dz}	19.5^{cz}	19.2^{cz}	18.6^{bz}	18.6^{bz}	18.4^{bz}	17.8^{az}	18.3^{bz}	0.186
Select[1,2,3]	22.6^{hy}	20.8^{gy}	19.5^{fy}	19.2^{fy}	18.0^{ey}	17.7^{dey}	17.5^{cdy}	17.2^{bcy}	17.2^{bcy}	16.8^{aby}	16.7^{ay}	
a/b ratio												
Premium Choice[1]	1.29^{iy}	1.25^{hy}	1.20^{gy}	1.17^{fz}	1.16^{ey}	1.12^{dz}	1.10^{dz}	1.08^{cz}	1.03^{bz}	1.02^{bz}	0.99^{az}	0.009
Select[1]	1.32^{jz}	1.28^{iz}	1.23^{hz}	1.19^{gz}	1.18^{gz}	1.13^{fz}	1.10^{ez}	1.08^{dz}	1.02^{cz}	0.99^{by}	0.96^{ay}	
Hue angle[4]												
Premium Choice[1]	37.8^{az}	38.7^{bz}	39.8^{cz}	40.4^{dz}	40.8^{dz}	41.9^{ez}	42.3^{ez}	43.0^{fz}	44.2^{gz}	44.4^{gy}	45.5^{hy}	0.244
Select[1]	37.1^{ay}	38.0^{by}	39.1^{cz}	40.1^{dz}	40.3^{dz}	41.6^{ez}	42.3^{fz}	43.0^{gz}	44.6^{hz}	45.5^{iz}	46.4^{jz}	

$^{a-j}$ Means within a row with a different letter differ ($P<0.05$)
$^{y-z}$ Means within a column and trait with a different letter differ ($P<0.05$)
[1] Linear ($P<0.05$)
[2] Quadratic ($P<0.05$)
[3] Cubic ($P<0.05$)
[4] Hue angle = $\tan^{-1} b/a$

Table B.6. Aging time × display time interaction means for b*, a/b ratio, and hue angle instrumental color values for ground beef patties

	Display time											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
L*												
7 d^{123}	48.0^{fy}	47.1^{ey}	45.8^{cdy}	44.7^{ay}	45.7^{bcdy}	45.4^{bcx}	46.0^{dy}	45.5^{bcdy}	45.1^{aby}	45.5^{bcdy}	45.4^{bcdy}	0.768
21 d^{123}	50.8^{ez}	48.1^{dz}	46.8^{bcz}	45.9^{az}	47.1^{cz}	46.3^{aby}	45.8^{ay}	46.9^{bcz}	46.4^{abcz}	46.4^{abcyz}	45.9^{ay}	
42 d^{2}	47.9^{dy}	47.6^{cdyz}	46.3^{ayz}	46.4^{abz}	47.2^{bcdz}	47.2^{bcdz}	47.0^{abcz}	46.7^{abz}	46.9^{abcz}	46.8^{abcz}	47.4^{cdz}	
b*												
7 d^{12}	23.6^{ez}	21.5^{dz}	20.3^{cz}	20.1^{cz}	19.0^{bz}	18.7^{bz}	18.1^{az}	18.1^{az}	18.3^{abz}	17.7^{az}	17.9^{az}	0.228
21 d^{12}	23.9^{ez}	21.7^{dz}	20.3^{cz}	19.9^{cz}	18.7^{bz}	18.4^{bz}	18.4^{bz}	17.6^{az}	17.5^{ay}	17.3^{ayz}	17.6^{az}	
42 d^{123}	23.7^{hz}	21.8^{gz}	20.4^{fz}	19.5^{ez}	18.6^{dz}	18.2^{cdz}	17.7^{by}	18.0^{bcz}	17.5^{by}	16.9^{ay}	16.9^{ay}	
a/b ratio												
7 d^{12}	1.31^{gy}	1.28^{gz}	1.23^{fz}	1.20^{ez}	1.19^{ez}	1.16^{dz}	1.14^{dz}	1.12^{cz}	1.08^{bz}	1.09^{bz}	1.06^{az}	0.011
21 d^{123}	1.35^{hz}	1.28^{hz}	1.23^{gz}	1.19^{fz}	1.18^{fz}	1.13^{ez}	1.11^{dy}	1.09^{dz}	1.05^{cy}	1.03^{by}	1.00^{ay}	
42 d^{1}	1.27^{jx}	1.24^{iy}	1.19^{hy}	1.16^{gy}	1.14^{gy}	1.08^{fy}	1.05^{ex}	1.01^{dy}	0.94^{cx}	0.91^{bx}	0.87^{ax}	
Hue angle^{4}												
7 d^{1}	37.5^{ay}	38.1^{bz}	39.0^{cy}	39.9^{dy}	40.0^{dy}	40.9^{efx}	41.3^{fgy}	41.8^{gy}	42.8^{hix}	42.7^{hx}	43.5^{ix}	0.299
21 d^{13}	36.7^{ay}	38.1^{bz}	39.2^{cy}	40.1^{dz}	40.3^{dy}	41.4^{ey}	42.0^{efy}	42.5^{fy}	43.7^{gy}	44.3^{gy}	45.1^{hy}	
42 d^{12}	38.3^{az}	38.9^{az}	40.1^{bz}	40.8^{bz}	41.4^{cz}	42.9^{dz}	43.5^{dz}	44.7^{ez}	46.8^{fz}	47.8^{gz}	49.2^{hz}	

$^{a-j}$ Means within a row with a different letter differ ($P<0.05$)

$^{x-z}$ Means within a column and traits with a different letter differ ($P<0.05$)

[1] Linear ($P<0.05$)

[2] Quadratic ($P<0.05$)

[3] Cubic ($P<0.05$)

[4] Hue angle = $\tan^{-1} b/a$

Table B.7. Effect of subprimal type

	Subprimal type		
	Chuck roll	**Knuckle**	**SE**
OMb 40 min[1]	17.8^{a}	19.5^{b}	0.365

[1] Percent of oxymyoglobin after 40 min vacuum packaged

Table B.8. Effect of quality grade

	Quality grade		
	Premium Choice	**Select**	**SE**
Visual Color[1]	5.0^{a}	5.5^{b}	0.06
Discoloration[2]	4.4^{a}	5.1^{b}	0.12
L*	47.2^{b}	46.1^{a}	0.722
a*	22.7^{b}	21.2^{a}	0.195
Chroma[3]	30.2^{b}	28.1^{a}	0.213

[a-b] Means within a row with a different letter differ ($P<0.05$)

[1] Visual color: 1 = Extremely bright cherry-red; 4 = Slightly Bright cherry-red; 8 = Extremely dark red

[2] Discoloration: 1 = Very bright red; 4 = Slightly dark red; 5 = Moderately dark red; 8 = Tan to brown

[3] Chroma = $(a2 + b2)^{1/2}$

Table B.9. Effect of aging time

	Aging time			
	7 d	21 d	42 d	SE
OCR (0-20)[2]	50.5^{a}	48.5^{a}	57.8^{b}	3.018
MMb 0 h[1]	77.0^{a}	75.9^{b}	75.4^{c}	0.216

[1] Oxygen consumption rate from 0 to 40 min after vacuum packaging (((Initial – Final) / Initial) x 100))

[2] Percent of metmyoglobin after 0 h vacuum packaged

Table B.10. Effect of display time

	Display time		
	0 h	24 h	SE
MMb 0 h[1]	75.7^{a}	76.6^{b}	0.172

[1] Percent of metmyoglobin after 0 h vacuum packaged

Table B.11. Subprimal type × aging time interaction means

	Chuck roll			Knuckle			
	7 d	21 d	42 d	7 d	21 d	42 d	SE
a/b ratio	1.19^{c}	1.17^{c}	1.09^{a}	1.15^{b}	1.13^{b}	1.06^{a}	0.0112

[a-b] Means within a row with a different letter differ ($P<0.05$)

Table B.12. Quality grade × aging time interaction means

	Premium Choice			Select			
	7 d	21 d	42 d	7 d	21 d	42 d	SE
OMb 40 min[1]	20.2^{c}	19.2^{bc}	14.1^{a}	22.0^{d}	19.1^{bc}	17.5^{b}	0.631

[a-d] Means within a row with a different letter differ ($P<0.05$)

[1] Percent of oxymyoglobin after 40 min vacuum packaged

Table B.13. Subprimal type × display time interaction means

	Chuck roll		Knuckle		
	0 h	24 h	0 h	24 h	SE
OMb 20 min[1]	43.3^{b}	39.5^{b}	43.5^{b}	31.3^{a}	2.867
OCR (0-20)[2]	55.7^{b}	42.6^{a}	55.5^{b}	55.3^{b}	3.055

[a-b] Means within a row and trait with a different letter differ ($P<0.05$)

[1] Percent of oxymyoglobin after 20 min vacuum packaged

[2] Oxygen consumption rate from 0 to 20 min after vacuum packaging [(Initial %MMb − Final %MMb) ÷ Initial %MMb] ×100

Table B.14. Quality grade × display time interaction means

	Premium Choice		Select		
	0 h	24 h	0 h	24 h	SE
OMb 20 min[1]	42.4^{bc}	38.5^{b}	44.3^{c}	32.3^{a}	2.867
OCR (0-20)[2]	56.0^{b}	43.1^{a}	55.2^{b}	54.8^{b}	3.055

[a-c] Means within a row and trait with a different letter differ ($P<0.05$)

[1] Percent of oxymyoglobin after 20 min vacuum packaged

[2] Oxygen consumption rate from 0 to 20 min after vacuum packaging [(Initial %MMb − Final %MMb) ÷ Initial %MMb] ×100

Table B.15. Aging time × display time interaction means

	7 d		21 d		42 d		
	0 h	**24 h**	**0 h**	**24 h**	**0 h**	**24 h**	**SE**
OMb 20 min[1]	41.7^{b}	40.7^{b}	50.9^{c}	36.7^{b}	37.6^{b}	28.7^{a}	3.160
OMb 40 min[2]	26.3^{e}	15.9^{c}	25.6^{e}	12.7^{b}	23.9^{d}	7.7^{a}	0.577
MRA (0-1)[3]	33.4^{d}	28.1^{c}	33.1^{d}	16.9^{b}	15.7^{b}	9.3^{a}	2.915
MRA (0-2)[4]	78.5^{e}	73.3^{d}	75.6^{de}	60.3^{c}	50.0^{b}	40.0^{a}	4.902

[a-e] Means within a row with a different letter differ ($P<0.05$)

[1] Percent of oxymyoglobin after 20 min vacuum packaged

[2] Percent of oxymyoglobin after 40 min vacuum packaged

[3] Metmyoglobin reducing ability from 0 to 1 h after vacuum packaging (((Initial – Final) / Initial) x 100))

[4] Metmyoglobin reducing ability from 0 to 2 h after vacuum packaging (((Initial – Final) / Initial) x 100))

Table B.16. Subprimal type × quality grade interaction means

	Chuck roll		Knuckle		
	Premium Choice	**Select**	**Premium Choice**	**Select**	**SE**
OMb 20 min[1]	40.0^{b}	42.7^{b}	40.9^{b}	33.9^{a}	3.026
OCR (0-20)[2]	49.1^{a}	49.1^{a}	49.9^{a}	60.9^{b}	3.232
MMb 0 h[3]	82.7^{a}	78.7^{b}	72.5^{c}	70.4^{d}	0.239
Raw Weight (g)	114.82^{a}	115.87^{b}	116.71^{c}	116.76^{c}	0.1850
Chewiness (kg)[4]	7.25^{a}	8.34^{b}	8.17^{b}	8.03^{b}	1.021

[a-c] Means within a row with a different letter differ ($P<0.05$)

[1] Percent of oxymyoglobin after 20 min vacuum packaged

[2] Oxygen consumption rate from 0 to 20 min after vacuum packaging [(Initial %MMb − Final %MMb) ÷ Initial %MMb] ×100

[3] Percent of metmyoglobin after 20 min vacuum packaged

[4] Chewiness: Gumminess x Springiness

Table B.17. Subprimal type × quality grade × aging time interaction means

		Chuck roll		Knuckle		
		Premium Choice	**Select**	**Premium Choice**	**Select**	**SE**
OCR (0-40)[1]	7 d	76.3^{ay}	74.8^{ax}	75.8^{ay}	74.0^{ay}	1.080
	21 d	78.2^{ay}	79.3^{ay}	77.2^{ay}	77.7^{az}	
	42 d	83.3^{bz}	83.4^{bz}	83.4^{bz}	76.1^{ayz}	
MMb 0 h[2]	7 d	83.7	79.2	73.74	71.5	0.3740
	21 d	82.9	78.8	71.9	70.0	
	42 d	81.6	78.3	71.9	69.8	
MMb 1 h[3]	7 d	57.1^{bx}	52.1^{ay}	53.2^{aby}	50.8^{ay}	2.500
	21 d	62.5^{by}	54.7^{ay}	55.5^{ay}	54.8^{ayz}	
	42 d	70.9^{cz}	70.3^{cz}	64.5^{bz}	58.5^{az}	
MMb 2 h[4]	7 d	22.1^{bx}	18.6^{aby}	19.6^{aby}	14.3^{ax}	4.110
	21 d	30.0^{by}	23.6^{aby}	22.7^{ay}	21.7^{ay}	
	42 d	46.5^{bcz}	49.0^{cz}	41.0^{bz}	30.4^{az}	
MRA (0-1)[5]	7 d	31.9^{abz}	34.2^{bz}	27.8^{az}	29.0^{abz}	3.354
	21 d	24.6^{ay}	30.7^{bz}	23.0^{az}	21.8^{ay}	
	42 d	13.1^{abx}	10.3^{ay}	10.4^{ay}	16.2^{by}	
MRA (0-2)[6]	7 d	73.6^{az}	76.6^{az}	73.5^{az}	80.0^{az}	5.529
	21 d	63.9^{ay}	70.1^{az}	68.6^{az}	69.2^{ay}	
	42 d	43.0^{ax}	37.5^{ay}	43.2^{ay}	56.4^{bx}	

[a-d] Means within a row with a different letter differ ($P<0.05$)

[x-z] Means within a column and trait with a different letter differ ($P<0.05$)

[1] Oxygen consumption rate from 0 to 40 min after vacuum packaging (((Initial – Final) / Initial) x 100))

[2] Percent of metmyoglobin after 0 h vacuum packaged

[3] Percent of metmyoglobin after 1 h vacuum packaged

[4] Percent of metmyoglobin after 2 h vacuum packaged

[5] Metmyoglobin reducing ability from 0 to 1 h after vacuum packaging (((Initial – Final) / Initial) x 100))

[6] Metmyoglobin reducing ability from 0 to 2 h after vacuum packaging (((Initial – Final) / Initial) x 100))

Table B.18. Subprimal type × quality grade × aging time × display time means

			7 d		21 d		42 d		
			0 h	**24 h**	**0 h**	**24 h**	**0 h**	**24 h**	**SE**
OMb 0 min[1]	**Chuck roll**	**Premium Choice**	93.4^{cz}	68.8^{bx}	98.7^{dz}	67.6^{by}	93.5^{cy}	61.5^{ayz}	1.438
	Chuck roll	**Select**	94.3^{cz}	77.6^{bz}	97.7^{dz}	67.7^{ay}	98.5^{dz}	65.1^{az}	
	Knuckle	**Premium Choice**	94.6^{dz}	74.2^{cyz}	96.9^{dz}	69.1^{byz}	96.0^{dyz}	60.6^{ay}	
	Knuckle	**Select**	95.0^{cz}	71.9^{by}	99.6^{dz}	73.0^{bz}	96.7^{cdyz}	64.7^{az}	
OMb 20 min[2]	**Chuck roll**	**Premium Choice**	35.6	42.9	50.2	43.7	33.4	34.5	5.085
	Chuck roll	**Select**	42.8	47.5	51.4	35.0	46.5	33.3	
	Knuckle	**Premium Choice**	49.1	45.8	48.8	35.2	37.6	28.8	
	Knuckle	**Select**	39.2	26.8	53.1	33.0	33.1	18.2	
OMb 40 min[3]	**Chuck roll**	**Premium Choice**	25.4	14.0	24.4	12.9	21.2	6.7	1.134
	Chuck roll	**Select**	26.0	17.8	24.4	11.5	23.4	6.3	
	Knuckle	**Premium Choice**	25.5	15.9	26.8	12.6	22.3	6.1	
	Knuckle	**Select**	28.3	15.9	26.9	13.7	28.6	11.9	
OMb 60 min[4]	**Chuck roll**	**Premium Choice**	26.3^{dy}	13.1^{by}	24.2^{cdy}	13.7^{bz}	20.9^{cy}	6.6^{ay}	1.262
	Chuck roll	**Select**	26.7^{dy}	19.3^{cz}	24.6^{dy}	14.4^{bz}	23.7^{dy}	7.5^{ay}	
	Knuckle	**Premium Choice**	27.9^{dy}	19.1^{bz}	28.6^{dz}	15.6^{bz}	23.1^{cy}	6.7^{ay}	
	Knuckle	**Select**	33.2^{dz}	21.5^{bz}	29.2^{cz}	16.0^{az}	29.0^{cz}	14.5^{az}	
OCR (0-60)[5]	**Chuck roll**	**Premium Choice**	71.8^{az}	80.9^{cz}	75.7^{abz}	79.8^{cz}	77.7^{bcz}	89.4^{dz}	1.591
	Chuck roll	**Select**	71.7^{az}	75.2^{by}	75.3^{bz}	78.7^{bz}	76.1^{bz}	88.5^{cz}	
	Knuckle	**Premium Choice**	70.5^{az}	74.3^{abxy}	70.6^{ay}	77.4^{bz}	75.9^{bz}	88.9^{cz}	
	Knuckle	**Select**	65.0^{ay}	70.0^{bx}	71.8^{byz}	78.2^{cz}	70.1^{by}	77.8^{cy}	

$^{a\text{-}d}$ Means within a row with a different letter differ ($P<0.05$)

$^{x\text{-}z}$ Means within a column and trait with a different letter differ ($P<0.05$)

[1] Percent of oxymyoglobin after 0 min vacuum packaged

[2] Percent of oxymyoglobin after 20 min vacuum packaged

[3] Percent of oxymyoglobin after 40 min vacuum packaged

[4] Percent of oxymyoglobin after 60 min vacuum packaged

[5] Oxygen consumption rate from 0 to 60 min after vacuum packaging
[(Initial %MMb − Final %MMb) ÷ Initial %MMb] ×100

Table B.19. Interaction contrast p-values for instrumental color of ground beef patties

			P Values		
			Linear	**Quadratic**	**Cubic**
L*	**Subprimal type × display time**	**Chuck roll**	<0.0001	<0.0001	<0.0001
		Knuckle	0.0002	<0.0001	0.0003
	Aging time × display time	**7 d**	<0.0001	0.0007	0.0131
		21 d	<0.0001	<0.0001	<0.0001
		42 d	0.3937	0.0462	0.3385
a*	**Subprimal type × aging time × display time**	**Chuck roll 7 d**	<0.0001	<0.0001	0.0048
		Chuck roll 21 d	<0.0001	<0.0001	0.0002
		Chuck roll 42 d	<0.0001	<0.0001	0.0176
		Knuckle 7d	<0.0001	<0.0001	0.0093
		Knuckle 21 d	<0.0001	<0.0001	0.0016
		Knuckle 42 d	<0.0001	<0.0001	0.0009
b*	**Subprimal type × display time**	**Chuck roll**	<0.0001	<0.0001	0.0007
		Knuckle	<0.0001	<0.0001	0.0004
	Quality grade × display time	**Premium Choice**	<0.0001	<0.0001	0.0172
		Select	<0.0001	<0.0001	0.0282
	Aging time × display time	**7 d**	<0.0001	<0.0001	0.1408
		21 d	<0.0001	<0.0001	0.1593
		42 d	<0.0001	<0.0001	0.0100

Table B.20. Interaction contrast p-values for instrumental color of ground beef patties (Table B-19 continued)

			P Values		
			Linear	**Quadratic**	**Cubic**
a/b ratio	**Subprimal type × display time**	**Chuck roll**	<0.0001	0.8034	0.3800
		Knuckle	<0.0001	0.0167	0.1958
	Quality grade × display time	**Premium Choice**	<0.0001	0.0891	0.1776
		Select	<0.0001	0.5250	0.4164
	Aging time × display time	**7 d**	<0.0001	0.0132	0.5523
		21 d	<0.0001	0.0002	0.0017
		42 d	<0.0001	0.0669	0.8965
Hue angle	**Subprimal type × display time**	**Chuck roll**	<0.0001	0.1568	0.4540
		Knuckle	<0.0001	0.7869	0.3471
	Quality grade × display time	**Premium Choice**	<0.0001	0.7886	0.2957
		Select	<0.0001	0.3262	0.5274
	Aging time × display time	**7 d**	<0.0001	0.1109	0.6851
		21 d	<0.0001	0.0819	0.0119
		42 d	<0.0001	0.0009	0.8146
Chroma	**Subprimal type × aging time × display time**	**Chuck roll 7 d**	<0.0001	<0.0001	0.0053
		Chuck roll 21 d	<0.0001	<0.0001	0.0014
		Chuck roll 42 d	<0.0001	<0.0001	0.0174
		Knuckle 7d	<0.0001	<0.0001	0.0160
		Knuckle 21 d	<0.0001	<0.0001	0.0282
		Knuckle 42 d	<0.0001	<0.0001	0.0001

Table B.21. Subprimal type × quality grade × aging time means

	Chuck roll						Knuckle						
	Premium Choice			Select			Premium Choice			Select			
	7 d	21 d	42 d	7 d	21 d	42 d	7 d	21 d	42 d	7 d	21 d	42 d	SE
pH	5.78	5.80	5.97	5.73	5.76	5.93	5.74	5.78	5.95	5.71	5.76	5.97	0.051
Initial Color[1]	3.62	3.06	4.42	4.20	3.82	4.55	5.30	5.13	5.83	6.30	5.94	6.42	0.201
Moisture, %	62.55	62.77	61.32	66.06	67.19	66.15	70.99	70.67	70.52	72.60	72.89	72.46	0.5400
Protein, %	17.55	17.47	17.51	18.50	18.83	18.25	19.00	19.71	19.30	20.03	20.39	19.69	0.2800
Fat, %	19.23	19.06	20.97	14.92	13.22	14.64	8.09	8.50	8.89	5.79	5.20	6.45	0.7191

[1] Initial Meat Color: 1 = Very light red; 3 = Light red; 5 = Bright red; 8 = Dark red.

Table B.22. Subprimal type × quality grade means

	Chuck roll		Knuckle		
	Premium Choice	Select	Premium Choice	Select	SE
Total Myoglobin[1]	5.88	5.54	6.23	6.37	0.1335
Myoglobin Concentration[2]	6.27	5.81	6.53	6.63	0.1810

[1] Total Myoglobin = mg/mL meat

[2] Myoglobin Concentration = mg/g meat

Table B.23. Subprimal type × quality grade × aging time × display time means

	Chuck roll												
	Premium Choice						Select						
	7 d		21 d		42 d		7 d		21 d		42 d		
	0 h	24 h	0 h	24 h	0 h	24 h	0 h	24 h	0 h	24 h	0 h	24 h	SE
APC[1]	2.82	2.92	3.42	4.41	6.30	7.20	2.78	2.80	3.68	4.57	6.26	7.18	0.216
LAB[2]	2.77	2.86	3.38	4.40	6.32	7.23	2.71	2.70	3.51	4.57	6.31	7.14	0.204
TBARS[3]	0.237	0.493	0.529	0.810	0.569	0.767	0.223	0.589	0.581	0.946	0.628	0.990	0.0667
OMb 0 min[4]	93.43	68.82	98.65	67.64	93.54	61.48	94.26	77.64	97.70	67.65	98.50	65.12	1.4383
OMb 20 min[5]	35.60	42.87	50.17	43.69	33.38	34.50	42.79	47.53	51.37	35.00	46.48	33.29	5.0853
OMb 40 min[6]	25.35	13.98	24.36	12.95	21.17	6.67	26.03	17.81	24.42	11.52	23.39	6.30	1.1537
OMb 60 min[7]	26.31	13.13	24.24	13.73	20.88	6.64	26.65	19.29	24.64	14.45	23.71	7.47	1.2618
OCR (0-20)[8]	61.97	38.81	50.16	35.49	64.48	43.78	54.98	39.10	49.25	48.63	53.22	49.53	5.5138
OCR (0-40)[9]	72.83	79.86	75.59	80.85	77.36	89.28	72.39	77.16	75.50	83.02	76.39	90.35	1.3620
OCR (0-60)[10]	71.83	80.94	75.68	79.76	77.65	89.36	71.70	75.18	75.29	78.69	76.10	88.52	1.5912
MMb 0 h[11]	83.36	84.10	82.62	83.09	80.85	82.31	78.66	79.69	78.19	79.31	77.81	78.80	0.4244
MMb 1 h[12]	54.66	59.44	55.60	69.46	67.47	74.36	50.32	53.85	47.81	61.61	66.14	74.45	2.6370
MMb 2 h[13]	20.41	23.84	24.19	35.76	43.07	50.01	17.23	19.88	18.54	28.71	43.16	54.81	4.228
MRA (0-1)[14]	34.41	29.34	32.73	16.41	16.55	9.657	36.02	32.44	38.95	22.37	14.99	5.53	3.5370
MRA (0-2)[15]	75.49	71.67	70.76	56.96	46.72	39.26	78.08	75.06	76.37	63.86	44.52	30.45	5.6891

[1] Aerobic plate count (log CFU/g or log CFU/cm2)

[2] Lactic acid plate count (log CFU/g or log CFU/cm2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

[4] Percentage of oxymyoglobin after 0 min vacuum packaged

[5] Percentage of oxymyoglobin after 20 min vacuum packaged

[6] Percentage of oxymyoglobin after 40 min vacuum packaged

[7] Percentage of oxymyoglobin after 60 min vacuum packaged

[8] Oxygen consumption rate from 0 to 20 min vacuum packaged

[9] Oxygen consumption rate from 0 to 40 min vacuum packaged

[10] Oxygen consumption rate from 0 to 60 min vacuum packaged

[11] Percentage of metmyoglobin after 0 h vacuum packaged

[12] Percentage of metmyoglobin after 1 h vacuum packaged

[13] Percentage of metmyoglobin after 2 h vacuum packaged

[14] Metmyoglobin reducing ability from 0 to 1 h vacuum packaged

[15] Metmyoglobin reducing ability from 0 to 2 h vacuum packaged

Table B.24. Subprimal type × quality grade × aging time × display time means

	Knuckle												
	Premium Choice						Select						
	7 d		21 d		42 d		7 d		21 d		42 d		
	0 h	24 h	0 h	24 h	0 h	24 h	0 h	24 h	0 h	24 h	0 h	24 h	SE
APC[1]	3.07	3.11	3.94	4.72	6.47	7.11	2.99	3.02	4.63	5.09	6.71	7.41	0.216
LAPC[2]	3.00	2.98	3.88	4.74	6.57	7.04	2.95	2.89	4.45	5.06	6.81	7.34	0.204
TBARS[3]	0.260	0.635	0.584	0.912	0.721	1.036	0.348	1.045	0.630	1.108	0.673	1.034	0.0672
OMb 0 min[4]	94.60	74.24	96.87	69.10	96.01	60.63	95.02	71.90	99.61	73.01	96.72	64.66	1.4383
OMb 20 min[5]	49.05	45.80	48.81	35.24	37.62	28.78	39.17	26.75	53.10	33.02	33.07	18.16	5.0853
OMb 40 min[6]	25.54	15.91	26.80	12.58	22.30	6.12	28.30	15.92	26.93	13.67	28.60	11.85	1.1537
OMb 60 min[7]	27.91	19.08	28.63	15.57	23.10	6.77	33.16	21.47	29.21	16.00	28.97	14.46	1.2618
OCR (0-20)[8]	48.12	38.37	50.35	49.44	60.84	52.56	58.92	63.79	49.15	55.57	65.82	71.95	5.5138
OCR (0-40)[9]	72.97	78.56	72.55	81.83	76.78	89.97	70.15	77.84	74.00	81.39	70.40	81.73	1.3620
OCR (0-60)[10]	70.47	74.33	70.62	77.44	75.93	88.88	65.05	69.97	71.78	78.18	70.08	77.77	1.5912
MMb 0 h[11]	73.66	73.83	71.24	72.63	71.32	72.51	71.27	71.82	69.69	70.38	69.22	70.30	0.424
MMb 1 h[12]	50.52	55.93	49.26	61.69	62.20	66.86	48.49	53.01	48.90	60.79	56.46	60.50	2.637
MMb 2 h[13]	16.71	22.44	16.44	28.91	36.61	45.29	11.86	16.66	15.28	28.07	27.70	33.17	4.228
MRA (0-1)[14]	31.33	24.26	30.88	15.07	12.81	7.99	31.79	26.21	29.91	13.70	18.46	13.93	3.5370
MRA (0-2)[15]	77.28	69.63	76.97	60.25	48.74	37.61	83.25	76.82	78.19	60.21	60.05	52.80	5.6891

[1] Aerobic plate count (log CFU/g or log CFU/cm2)

[2] Lactic acid plate count (log CFU/g or log CFU/cm2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

[4] Percentage of oxymyoglobin after 0 min vacuum packaged

[5] Percentage of oxymyoglobin after 20 min vacuum packaged

[6] Percentage of oxymyoglobin after 40 min vacuum packaged

[7] Percentage of oxymyoglobin after 60 min vacuum packaged

[8] Oxygen consumption rate from 0 to 20 min vacuum packaged

[9] Oxygen consumption rate from 0 to 40 min vacuum packaged

[10] Oxygen consumption rate from 0 to 60 min vacuum packaged

[11] Percentage of metmyoglobin after 0 h vacuum packaged

[12] Percentage of metmyoglobin after 1 h vacuum packaged

[13] Percentage of metmyoglobin after 2 h vacuum packaged

[14] Metmyoglobin reducing ability from 0 to 1 h vacuum packaged

[15] Metmyoglobin reducing ability from 0 to 2 h vacuum packaged

Table B.25. Subprimal type × quality grade × aging time × display time means for visual color and discoloration of ground beef patties

Visual color[1] **(SE = 0.1857)**

	7 d				**21 d**				**42 d**			
	0 h	**24 h**	**48 h**	**72 h**	**0 h**	**24 h**	**48 h**	**72 h**	**0 h**	**24 h**	**48 h**	**72 h**
Chuck roll - Premium Choice	2.65	3.78	4.02	4.68	2.66	3.77	4.13	4.63	3.42	4.18	5.23	6.08
Chuck roll - Select	3.18	4.05	4.33	5.07	3.54	4.20	5.11	5.81	3.58	4.45	5.62	6.57
Knuckle - Premium Choice	4.15	5.77	5.88	6.30	4.41	5.66	6.38	6.78	5.28	5.78	6.35	6.95
Knuckle - Select	5.12	6.20	6.56	6.87	5.19	6.25	6.28	7.37	5.77	6.33	7.15	7.53

Discoloration[2] **(SE = 0.2285)**

	7 d				**21 d**				**42 d**			
	0 h	**24 h**	**48 h**	**72 h**	**0 h**	**24 h**	**48 h**	**72 h**	**0 h**	**24 h**	**48 h**	**72 h**
Chuck roll - Premium Choice	1.90	3.22	3.23	4.27	2.30	3.21	3.62	4.16	3.02	3.68	4.72	5.63
Chuck roll - Select	2.35	3.33	3.48	4.62	3.01	3.81	4.46	5.55	3.07	3.97	5.27	6.23
Knuckle - Premium Choice	2.98	4.93	5.43	6.22	3.76	5.25	5.94	6.79	4.23	5.12	6.13	6.70
Knuckle - Select	3.87	5.62	6.50	7.15	4.55	5.79	6.61	7.42	4.80	5.87	7.05	7.50

[1] Visual color: 1 = Extremely bright cherry-red; 4 = Slightly Bright cherry-red; 5 = Slightly dark cherry-red; 8 = Extremely dark red
[2] Discoloration: 1 = Very bright red; 4 = Slightly dark red; 5 = Moderately dark red; 8 = Tan to brown

Table B.26. Subprimal type × quality grade × aging time × display time means for L*, a*, b*, a/b ratio, hue angle, and chroma of ground beef patties from Premium Choice chuck roll subprimals

	Chuck roll Premium Choice											
	7 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
L	50.56	48.90	47.82	47.32	47.61	47.73	47.72	47.55	47.40	47.40	47.80	0.9785
a*	33.97	30.65	28.09	26.54	25.53	24.32	23.57	23.28	22.96	20.48	22.23	0.6157
b*	26.72	24.75	23.19	22.32	21.59	20.86	20.43	20.43	20.67	18.76	20.44	0.4551
a/b ratio	1.27	1.24	1.21	1.19	1.18	1.17	1.16	1.14	1.11	1.09	1.09	0.02137
Hue angle[1]	38.17	38.92	39.55	40.07	40.24	40.63	40.92	41.25	42.02	42.57	42.62	0.5987
Chroma[2]	43.22	39.40	36.43	34.68	33.44	32.04	31.20	30.98	30.89	27.78	30.21	0.7130
	21 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	
L	53.44	50.65	49.35	48.48	48.91	48.73	48.40	49.42	49.08	48.39	49.09	
a*	36.80	30.79	28.34	26.90	25.82	24.06	23.26	22.44	21.64	21.57	20.93	
b*	28.35	24.80	23.31	22.60	21.81	20.79	20.30	19.93	19.75	19.86	19.81	
a/b ratio	1.30	1.24	1.22	1.19	1.18	1.16	1.15	1.13	1.10	1.09	1.06	
Hue angle[1]	37.57	38.83	39.43	40.03	40.19	40.83	41.11	41.60	42.38	42.64	43.43	
Chroma[2]	46.46	39.54	36.69	35.13	33.80	31.81	30.88	30.02	29.30	29.32	28.82	
	42 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	
L	50.28	49.82	48.54	48.21	48.55	48.86	48.37	48.83	48.57	47.42	48.12	
a*	32.39	29.91	27.14	25.26	24.09	22.01	21.263	20.30	18.82	17.94	17.35	
b*	22.60	24.53	22.88	21.57	21.14	20.11	19.56	19.62	19.07	18.32	18.69	
a/b ratio	1.25	1.22	1.19	1.17	1.14	1.09	1.09	1.04	0.10	0.98	0.93	
Hue angle[1]	38.75	39.35	40.13	40.51	41.30	42.49	42.68	44.08	45.43	45.66	47.20	
Chroma[2]	41.55	38.68	35.50	33.22	32.05	29.83	28.90	28.24	26.80	25.64	25.51	

[1] Hue angle = $\tan^{-1}$ b/a

[2] Chroma = $(a^2 + b^2)^{1/2}$

Table B.27. Subprimal type × quality grade × aging time × display time means for L*, a*, b*, a/b ratio, hue angle, and chroma of ground beef patties from Select chuck roll subprimals

	Chuck roll Select											
	7 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
L	48.95	48.87	47.26	45.30	46.50	46.09	46.91	46.73	45.70	46.89	46.38	0.9785
a*	32.35	29.38	27.56	25.97	25.18	24.26	23.30	22.79	22.13	20.19	21.10	0.6157
b*	24.77	22.73	21.82	21.19	20.17	19.93	19.46	19.17	19.27	18.18	18.48	0.4551
a/b ratio	1.31	1.30	1.26	1.23	1.25	1.22	1.20	1.19	1.15	1.11	1.14	0.02137
Hue angle[1]	37.42	37.69	38.37	39.24	38.70	39.41	39.88	40.09	41.16	42.10	41.31	0.5987
Chroma[2]	40.75	37.15	35.16	33.03	32.27	31.41	30.36	29.79	29.36	27.20	28.06	0.7130
	21 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	
L	52.05	48.69	47.80	47.04	47.86	46.52	45.94	46.88	47.04	46.74	46.39	
a*	33.52	29.28	26.67	24.81	23.51	22.68	22.08	20.70	19.20	18.51	18.09	
b*	24.93	23.35	21.36	20.34	19.41	19.46	19.29	18.34	18.04	17.81	17.86	
a/b ratio	1.35	1.29	1.25	1.22	1.21	1.17	1.15	1.13	1.07	1.04	1.01	
Hue angle[1]	36.56	37.92	38.69	39.33	39.53	40.64	41.13	41.56	43.32	44.13	44.78	
Chroma[2]	41.78	37.14	34.17	32.08	30.49	29.89	29.33	27.66	26.36	25.71	25.44	
	42 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	
L	48.96	48.21	46.85	47.28	48.57	48.44	47.77	47.18	47.36	47.67	47.99	
a*	31.37	28.33	25.49	24.16	21.75	20.21	19.22	19.03	17.30	16.00	15.27	
b*	24.95	22.81	21.19	20.68	18.81	18.46	18.01	18.43	17.88	17.12	17.15	
a/b ratio	1.26	1.25	1.20	1.17	1.16	1.10	1.07	1.03	0.97	0.93	0.89	
Hue angle[1]	38.47	38.82	39.90	40.59	40.85	42.44	43.22	44.14	45.99	47.01	48.41	
Chroma[2]	40.09	36.38	33.23	31.80	28.76	27.37	26.34	26.51	24.88	23.44	22.97	

[1] Hue angle = $\tan^{-1} b/a$

[2] Chroma = $(a^2 + b^2)^{1/2}$

Table B.28. Subprimal type × quality grade × aging time × display time means for L*, a*, b*, a/b ratio, hue angle, and chroma of ground beef patties from Premium Choice knuckle subprimals

	Knuckle Premium Choice										
	7 d										
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
L	44.67	45.95	44.50	44.38	45.01	44.11	45.19	44.18	44.65	45.23	44.17	0.9785
a*	29.47	25.75	22.78	21.52	20.86	20.00	18.76	18.58	17.74	18.51	17.29	0.6157
b*	22.48	20.12	18.59	18.06	17.68	17.74	16.71	17.02	16.79	16.92	16.97	0.4551
a/b ratio	1.32	1.28	1.23	1.20	1.18	1.13	1.12	1.09	1.06	1.10	1.02	0.02137
Hue angle[1]	37.28	37.97	39.13	39.94	40.24	41.55	41.67	42.45	43.41	42.43	44.44	0.5987
Chroma[2]	37.07	32.69	29.41	28.10	27.35	26.74	25.12	25.21	24.44	25.08	24.24	0.7130
	21 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
L	48.60	46.34	44.593	43.57	45.64	44.86	44.82	45.30	44.50	45.14	44.26	
a*	30.51	25.84	23.09	22.50	19.91	19.39	18.75	18.01	17.42	16.53	16.66	
b*	22.90	20.50	19.28	19.47	17.41	17.63	17.53	16.91	17.09	16.69	17.32	
a/b ratio	1.33	1.26	1.20	1.16	1.15	1.10	1.07	1.07	1.02	0.99	0.96	
Hue angle[1]	36.85	38.36	39.85	40.85	41.14	42.24	43.05	43.14	44.44	45.29	46.14	
Chroma[2]	38.15	32.99	30.08	29.76	26.45	26.21	25.68	24.71	24.41	23.50	24.04	
	42 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
L	47.09	46.81	46.09	45.91	47.25	46.72	47.08	45.99	46.55	46.68	47.11	
a*	28.60	25.68	22.50	21.34	19.73	18.81	17.58	17.57	15.54	14.68	14.29	
b*	22.67	20.78	19.16	18.66	17.66	17.82	17.00	17.75	16.88	16.20	16.49	
a/b ratio	1.27	1.24	1.17	1.14	1.12	1.06	1.03	0.99	0.92	0.91	0.87	
Hue angle[1]	38.37	38.99	40.47	41.21	41.92	43.58	44.14	45.42	47.49	47.94	49.19	
Chroma[2]	36.50	33.03	29.56	28.35	26.50	25.93	24.49	24.99	22.97	21.88	21.85	

[1] Hue angle = $\tan^{-1} b/a$

[2] Chroma = $(a^2 + b^2)^{1/2}$

Table B.29. Subprimal type × quality grade × aging time × display time means for L*, a*, b*, a/b ratio, hue angle, and chroma of ground beef patties from Select knuckle subprimals

	Knuckle Select											
	7 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
L	45.95	44.78	43.59	41.87	43.66	43.53	44.09	43.72	42.69	42.64	43.42	0.9785
a*	27.12	23.96	21.55	22.03	19.17	17.86	17.04	16.74	16.60	17.49	15.65	0.6157
b*	20.43	18.54	17.48	18.69	16.55	16.13	15.64	15.76	16.34	16.76	15.86	0.4551
a/b ratio	1.33	1.30	1.23	1.18	1.16	1.11	1.09	1.06	1.02	1.04	0.99	0.02137
Hue angle[1]	36.97	37.69	39.04	40.37	40.82	42.19	42.59	43.37	44.68	43.87	45.55	0.5987
Chroma[2]	33.96	30.30	27.75	28.89	25.33	24.09	23.14	23.01	23.31	24.24	22.31	0.7130
	21 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
L	48.97	46.67	45.55	44.64	45.89	45.24	44.10	46.12	45.08	45.35	44.05	
a*	27.24	24.01	21.26	20.34	18.93	17.70	17.24	16.03	15.53	14.94	15.04	
b*	19.59	18.31	17.16	17.16	16.08	15.90	16.37	15.21	15.28	15.02	15.58	
a/b ratio	1.40	1.31	1.24	1.19	1.18	1.12	1.09	1.06	1.02	1.00	0.97	
Hue angle[1]	35.65	37.32	38.87	40.13	40.34	41.94	42.62	43.53	44.50	45.13	45.99	
Chroma[2]	33.56	30.20	27.32	26.61	24.84	23.77	23.44	22.10	21.79	21.19	21.66	
	42 d											
	0 h	**8 h**	**16 h**	**24 h**	**32 h**	**40 h**	**48 h**	**56 h**	**64 h**	**72 h**	**80 h**	**SE**
L	45.35	45.48	43.63	44.34	44.52	44.87	44.60	44.80	45.06	45.27	46.45	
a*	27.43	24.30	21.72	20.04	19.02	17.41	16.77	16.04	14.50	13.17	12.09	
b*	21.19	19.24	18.19	17.24	16.79	16.30	16.23	16.14	16.16	15.84	15.36	
a/b ratio	1.30	1.27	1.20	1.16	1.13	1.07	1.03	0.99	0.90	0.83	0.79	
Hue angle[1]	37.63	38.33	39.96	40.73	41.50	43.18	44.14	45.32	48.25	50.52	52.17	
Chroma[2]	34.66	31.00	28.33	26.44	25.38	23.87	23.36	22.78	21.74	20.66	19.61	

[1] Hue angle = $\tan^{-1} b/a$

[2] Chroma = $(a^2 + b^2)^{1/2}$

Table B.30. Subprimal type × quality grade × aging time means

	Chuck Roll						Knuckle						
	Premium Choice			**Select**			**Premium Choice**			**Select**			
	7 d	**21 d**	**42 d**	**7 d**	**21 d**	**42 d**	**7 d**	**21 d**	**42 d**	**7 d**	**21 d**	**42 d**	**SE**
Total SFA (g/100g)[1]	8.82	9.02	9.08	6.71	6.09	6.95	3.58	3.47	4.02	2.72	2.47	2.76	0.3265
C16:0 (g/100g)	4.75	4.79	4.75	3.42	3.18	3.51	1.99	1.95	2.23	1.43	1.30	1.50	0.1852
C18:0 (g/100g)	2.75	2.90	2.98	2.23	2.11	2.50	1.06	1.03	1.25	0.89	0.82	0.89	0.1156
Total MUFA (g/100g)[2]	9.79	9.55	10.37	6.79	6.38	6.90	4.03	3.95	4.51	2.90	2.69	3.04	0.3758
C18:1 (g/100g)	8.33	8.15	8.97	5.71	5.44	5.93	3.36	3.31	3.80	2.42	2.23	2.54	0.3297
Total PUFA (g/100g)[3]	0.63	0.68	0.77	0.35	0.57	0.72	0.25	0.41	0.47	0.20	0.39	0.38	0.0639
Total FA (g/100g)	19.24	19.24	20.22	13.85	13.05	14.57	7.86	7.82	9.00	5.83	5.54	6.18	0.6683
Total SFA (%)[1]	45.87	46.85	44.91	48.43	47.24	47.55	45.50	44.34	44.58	46.62	44.45	44.61	0.7791
C16:0 (%)	24.68	24.92	23.47	24.65	24.52	23.95	25.30	24.90	24.73	24.48	23.33	24.22	0.4625
C18:0 (%)	14.32	15.03	14.75	16.08	16.52	17.20	13.53	13.18	13.85	15.27	14.80	14.42	0.5302
Total MUFA (%)[2]	50.87	49.63	51.29	48.85	48.46	47.49	51.25	50.63	50.12	49.79	48.53	49.15	0.8742
C18:1 (%)	43.30	42.32	44.38	41.10	41.12	40.87	42.80	42.47	42.22	41.57	40.35	41.07	0.8377
Total PUFA (%)[3]	3.27	3.53	3.81	2.72	4.31	4.96	3.25	5.03	5.30	3.59	7.02	6.23	0.663
MUFA[2] : SFA[1]	1.11	1.06	1.15	1.01	1.04	1.00	1.13	1.14	1.13	1.07	1.10	1.10	0.034
PUFA[3] : SFA[1]	0.07	0.08	0.09	0.06	0.09	0.11	0.07	0.12	0.12	0.08	0.16	0.14	0.015
Raw Weight (g)	114.90	114.92	114.65	115.88	116.35	115.37	117.38	116.90	115.83	117.10	117.05	116.13	0.3069
Cooked Weight (g)	81.68	81.08	82.65	84.07	83.57	83.33	86.42	86.95	86.13	85.23	87.88	87.77	0.8191
Cooking Loss[4]	28.92	29.43	27.93	27.47	28.17	27.75	26.38	25.63	25.63	27.22	24.93	24.43	0.6911
Cooking Time (sec)	392.2	403.5	417.5	420.0	387.0	403.0	398.3	396.0	434.5	414.7	402.7	430.5	16.521
Thickness (mm)	1.38	1.40	1.45	1.38	1.40	1.40	1.43	1.43	1.50	1.43	1.45	1.53	0.0269

[1] Saturated Fatty Acids: C10:0, C11:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0, 21:0, C22:0, C24:0

[2] Monounsaturated Fatty Acids: C14:1, C15:1, C16:1, C17:1, C18:1n9t, C18:1n9c, C18:1n7, C18:1n11, C20:1, C24:1

[3] Polyunsaturated Fatty Acids: C18:2n6t, C18:2n6c, C18:3n3, C18:3n6, C20:2, C20:5n3, C20:3n6, C20:4n6, C22:5n3, C22:6n3, Conjugated linoleic acid (C18:2) isomers

[4] (Raw weight – Cooked Weight) / Raw weight

Table B.31. Quality grade × aging time means for sensory traits for ground beef patties

	Premium Choice			Select			
	7 d	**21 d**	**42 d**	**7 d**	**21 d**	**42 d**	**SE**
Chuck roll							
Firmness[1]	4.77	4.48	4.78	4.92	4.83	4.88	0.110
Cohesiveness[2]	4.92	4.75	4.85	4.97	4.77	4.92	0.100
Juiciness[3]	5.43	5.60	5.52	5.27	5.15	5.43	0.168
Beef Flavor[4]	5.08	5.38	5.45	5.20	5.33	5.27	0.130
Moat Coat[5]	6.67	6.75	6.73	6.90	6.87	6.77	0.089
Off Flavor[6]	7.27	7.75	7.87	7.42	7.80	7.72	0.156
Desirability[7]	5.18	5.67	5.43	5.23	5.40	5.42	0.164
Knuckle							
Firmness[1]	5.08	4.93	4.83	5.07	4.93	5.18	0.115
Cohesiveness[2]	5.02	4.92	4.90	4.98	4.90	5.20	0.099
Juiciness[3]	4.75	5.10	5.43	4.78	5.08	5.58	0.144
Beef Flavor[4]	5.10	5.32	5.33	5.10	5.15	5.32	0.096
Moat Coat[5]	7.18	7.00	6.83	7.22	7.05	6.95	0.067
Off Flavor[6]	7.60	7.82	7.55	7.48	7.72	7.48	0.114
Desirability[7]	4.87	5.33	5.30	4.77	5.02	5.20	0.150

[1] Firmness scale: 8. Extremely firm, 1. Extremely soft.

[2] Cohesiveness scale: 8. Extremely cohesive, 1. Not cohesive at all

[3] Juiciness scale: 8. Extremely juicy, 1. Extremely dry

[4] Beef flavor intensity scale: 8. Extremely intense, 1. Extremely bland

[5] Mouth coat scale: 8. None, 5. Slight, 4. Moderate, 1. Abundant

[6] Off-flavor intensity scale: 8. None, 5. Slight, 1. Abundant

[7] Desirability scale: 8. Extremely Liked, 1. Extremely Dislike

Table B.32. Subprimal type × quality grade × aging time means

	Chuck roll						Knuckle						
	Premium Choice			**Select**			**Premium Choice**			**Select**			
	7 d	**21 d**	**42 d**	**7 d**	**21 d**	**42 d**	**7 d**	**21 d**	**42 d**	**7 d**	**21 d**	**42 d**	**SE**
Slice shear force													
Peak force (kg)	3.089	2.517	2.432	3.18	2.524	2.500	3.450	2.768	2.856	3.582	3.13	3.535	0.1734
Total energy (kg × mm)	21.803	17.602	18.609	23.387	18.177	18.254	24.038	19.337	20.691	24.048	21.199	25.651	1.4481
Lee-Kramer shear force													
Peak force (kg)	2.518	2.365	2.405	2.997	2.658	2.562	3.170	2.932	2.770	3.635	3.283	3.000	0.1018
Total energy (kg × mm)	15.020	14.413	14.669	16.996	14.296	14.445	17.582	17.633	15.921	19.130	17.811	17.601	0.9061
Texture Profile Analysis													
Peak force 1 (kg)[2]	3.258	3.433	3.472	3.648	3.504	3.958	3.953	3.898	3.966	3.886	4.122	4.459	0.4876
Total energy 1 (kg × mm)[3]	4.817	5.525	6.148	5.383	5.270	6.913	6.460	6.607	7.253	6.375	7.367	8.358	0.8656
Peak force 2 (kg)	2.933	3.077	3.101	3.306	3.180	3.556	3.627	3.571	3.602	3.577	3.778	4.079	0.4315
Total energy 2 (kg × mm)[4]	2.720	2.975	3.060	3.088	3.003	3.542	3.712	3.655	3.655	3.627	4.052	4.250	0.4513
Cohesiveness[5]	0.551	0.512	0.551	0.559	0.576	0.545	0.568	0.542	0.508	0.571	0.568	0.530	0.0176
Gumminess (kg)[6]	1.784	1.834	1.905	2.006	1.808	1.887	1.988	1.937	2.010	2.003	2.117	2.150	0.1667
Springiness[7]	4.303	4.093	3.575	4.396	4.092	3.735	4.054	3.847	3.377	4.048	3.600	3.141	0.1157
Chewiness (kg)[8]	7.925	7.590	6.235	9.189	8.147	7.698	9.168	8.487	6.868	9.052	7.900	7.133	1.0809

[1] Hardness: Peak force of first compression, kg
[2] Total energy 1st comp (kg x mm)
[3] Total energy 2nd comp (kg x mm)
[4] Cohesiveness: Total energy of 2nd compression ÷ total energy of the 1st compression
[5] Gumminess: Hardness x cohesiveness
[6] Springiness: Height that the food recovers during the time elapsed between the end of the first compression and the start of the second compression
[7] Chewiness: Gumminess x Springiness

Appendix C - Correlation Tables

Table C.1. Correlation coefficients for ground beef patties from chuck roll subprimals at 0 h of display

	pH	**APC[1]**	**LAB[2]**	**TBARS[3]**	**MMb 0[4]**	**MRA 0-2[5]**	**OMb 0[6]**	**OCR 0-20[7]**	**Initial C[8]**	**Visual C[9]**	**Discolor[10]**
pH	1.00	0.73***	0.75***	0.43**	-0.03	-0.72***	0.15	-0.13	0.44**	0.31	0.40*
APC[1]		1.00	0.99***	0.60***	-0.34*	-0.82***	0.04	0.16	0.53**	0.47**	0.62***
LAB[2]			1.00	0.59***	-0.33	-0.82***	0.05	0.14	0.53***	0.46**	0.61***
TBARS[3]				1.00	-0.22	-0.62***	0.36*	-0.20	0.17	0.37	0.59
MMb 0[4]					1.00	0.16	-0.06	0.02	-0.43**	-0.66***	-0.60***
MRA 0-2[5]						1.00	-0.05	-0.07	-0.44**	-0.32	-0.43**
OMb 0[6]							1.00	-0.72***	-0.11	-0.00	0.14
OCR 0-20[7]								1.00	0.02	0.03	-0.07
Initial C[8]									1.00	0.67***	0.45**
Visual C[9]										1.00	0.84***
Discolor[10]											1.00
L*											
a*											
b*											
a/b ratio											
Hue angle[11]											
Chroma[12]											

* = <0.05; ** = <0.01; *** = <0.001

[1] Aerobic Plate Count (log CFU/g or log CFU/cm^2)

[2] Lactic Acid Plate Count (log CFU/g or log CFU/cm^2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

[4] Percent of metmyoglobin at 0 h after vacuum packaging

[5] Metmyoglobin reducing ability from 0 to 2 h in vacuum package

[6] Percent of oxymyoglobin at 0 min after vacuum packaging

[7] Oxygen consumption rate from 0 to 20 min in vacuum package

[8] Initial color: 1 = Very light red; 8 = Dark red.

[9] Visual color: 1 = Extremely bright cherry-red; 8 = Extremely dark red

[10] Discoloration: 1 = Very bright red; 8 = Tan to brown

[11] Hue angle = tan^{-1} b/a

[12] Chroma = $(a^2 + b^2)^{1/2}$

Table C.2. Correlation coefficients for ground beef patties from chuck roll subprimals at 0 h of display (Table C-1 continued)

	L	a	b	a/b ratio	Hue angle[11]	Chroma[12]
pH	-0.23	-0.09	0.21	-0.67***	0.68***	0.03
APC[1]	-0.23	-0.45**	-0.21	-0.47**	0.49**	-0.36*
LAB[2]	-0.23	-0.43**	-0.19	-0.49**	0.51**	-0.35*
TBARS[3]	0.17	-0.09	-0.08	0.03	-0.00	-0.09
MMb 0[4]	0.28	0.54***	0.61***	-0.29	0.27	0.58***
MRA 0-2[5]	0.15	0.36*	0.14	0.45**	-0.46**	0.28
OMb 0[6]	0.04	0.42*	0.37*	0.04	-0.02	0.41*
OCR 0-20[7]	0.18	-0.38*	-0.33	-0.05	0.04	-0.36*
Initial C[8]	-0.74***	-0.60***	-0.41*	-0.33*	0.33	-0.53***
Visual C[9]	-0.44**	-0.51**	-0.49**	0.07	-0.05	-0.51**
Discolor[10]	-0.19	-0.37*	-0.35*	0.06	-0.04	-0.37*
L*	1.00	0.40*	0.21	0.40*	-0.38*	0.33*
a*		1.00	0.90***	0.03	-0.03	0.98***
b*			1.00	-0.40*	0.40*	0.96***
a/b ratio				1.00	-0.99***	-0.14
Hue angle[11]					1.00	0.14
Chroma[12]						1.00

* = <0.05; ** = <0.01; *** = <0.001

[1] Aerobic Plate Count (log CFU/g or log CFU/cm^2)

[2] Lactic Acid Plate Count (log CFU/g or log CFU/cm^2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

[4] Percent of metmyoglobin at 0 h after vacuum packaging

[5] Metmyoglobin reducing ability from 0 to 2 h in vacuum package

[6] Percent of oxymyoglobin at 0 min after vacuum packaging

[7] Oxygen consumption rate from 0 to 20 min in vacuum package

[8] Initial color: 1 = Very light red; 8 = Dark red.

[9] Visual color: 1 = Extremely bright cherry-red; 8 = Extremely dark red

[10] Discoloration: 1 = Very bright red; 8 = Tan to brown

[11] Hue angle = $\tan^{-1} b/a$

[12] Chroma = $(a^2 + b^2)^{1/2}$

Table C.3. Correlation coefficients for ground beef patties from chuck roll subprimals at 24 h of display

	pH	APC[1]	LAB[2]	TBARS[3]	MMb 0[4]	MRA 0-2[5]	OMb 0[6]	OCR 0-20[7]	Visual C[8]	Discolor[9]
pH	1.00	0.74***	0.73***	0.19	-0.00	-0.74***	-0.56***	0.15	0.21	0.22
APC[1]		1.00	0.99***	0.49**	-0.27	-0.84***	-0.67**	0.19	0.38*	0.49**
LAB[2]			1.00	0.50**	-0.26	-0.85***	-0.67***	0.18	0.38*	0.50**
TBARS[3]				1.00	-0.44**	-0.60***	-0.29	0.27	0.31	0.39*
MMb 0[4]					1.00	0.17	-0.13	-0.35*	-0.46**	-0.47**
MRA 0-2[5]						1.00	0.56***	-0.06	-0.37*	-0.42*
OMb 0[6]							1.00	-0.40*	-0.40*	-0.51**
OCR 0-20[7]								1.00	0.32	0.27
Visual C[8]									1.00	0.84***
Discolor[9]										1.00
L*										
a*										
b*										
a/b ratio										
Hue angle[10]										
Chroma[11]										

* = <0.05; ** = <0.01; *** = <0.001

[1] Aerobic Plate Count (log CFU/g or log CFU/cm^2)

[2] Lactic Acid Plate Count (log CFU/g or log CFU/cm^2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

[4] Percent of metmyoglobin at 0 h after vacuum packaging

[5] Metmyoglobin reducing ability from 0 to 2 h in vacuum package

[6] Percent of oxymyoglobin at 0 min after vacuum packaging

[7] Oxygen consumption rate from 0 to 20 min in vacuum package

[8] Initial color: 1 = Very light red; 8 = Dark red.

[9] Visual color: 1 = Extremely bright cherry-red; 8 = Extremely dark red

[10] Discoloration: 1 = Very bright red; 8 = Tan to brown

[11] Hue angle = $\tan^{-1}$ b/a

[12] Chroma = $(a^2 + b^2)^{1/2}$

Table C.4. Correlation coefficients for ground beef patties from chuck roll subprimals at 24 h of display (Table C-3 continued)

	L	a	b	a/b ratio	Hue angle[10]	Chroma[11]
pH	0.06	-0.25	-0.18	-0.40*	0.39*	-0.21
APC[1]	-0.04	-0.62***	-0.57***	-0.56***	0.55***	-0.59***
LAB[2]	-0.10	-0.33	-0.12	-0.40*	0.43**	-0.25
TBARS[3]	0.28	-0.24	-0.64***	-0.35*	0.35*	-0.62***
MMb 0[4]	0.40*	0.37*	0.50**	-0.07	0.06	0.44**
MRA 0-2[5]	0.00	0.56***	0.48**	0.61***	-0.60***	0.52**
OMb 0[6]	0.05	0.53**	0.47**	0.52**	-0.51**	0.48**
OCR 0-20[7]	-0.04	-0.24	-0.29	-0.06	0.05	-0.26
Visual C[8]	-0.54***	-0.40*	-0.47**	-0.11	0.12	-0.42*
Discolor[9]	-0.54***	-0.48**	-0.56***	-0.13	0.13	-0.49**
L*	1.00	0.24	0.33	-0.07	0.06	0.31
a*		1.00	0.97***	0.74***	-0.75***	0.99***
b*			1.00	0.55***	-0.56***	0.98***
a/b ratio				1.00	-0.99***	0.66***
Hue angle[10]					1.00	-0.66***
Chroma[11]						1.00

* = <0.05; ** = <0.01; *** = <0.001

[1] Aerobic Plate Count (log CFU/g or log CFU/cm^2)

[2] Lactic Acid Plate Count (log CFU/g or log CFU/cm^2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

[4] Percent of metmyoglobin at 0 h after vacuum packaging

[5] Metmyoglobin reducing ability from 0 to 2 h in vacuum package

[6] Percent of oxymyoglobin at 0 min after vacuum packaging

[7] Oxygen consumption rate from 0 to 20 min in vacuum package

[8] Initial color: 1 = Very light red; 8 = Dark red.

[9] Visual color: 1 = Extremely bright cherry-red; 8 = Extremely dark red

[10] Discoloration: 1 = Very bright red; 8 = Tan to brown

[11] Hue angle = tan^{-1} b/a

[12] Chroma = $(a^2 + b^2)^{1/2}$

Table C.5. Correlation coefficients for ground beef patties from knuckle subprimals at 0 h of display

	pH	APC[1]	LAB[2]	TBARS[3]	MMb 0[4]	MRA 0-2[5]	OMb 0[6]	OCR 0-20[7]	Initial C[8]	Visual C[9]	Discolor[10]
pH	1.00	0.82***	0.83***	0.54***	-0.24	-0.39*	-0.03	0.24	0.25	0.41*	0.31
APC[1]		1.00	0.99***	0.69***	-0.50**	-0.59***	-0.14	0.36	0.33*	0.61***	0.62***
LAB[2]			1.00	0.70***	-0.47**	-0.63***	0.13	0.40*	0.33	0.59***	0.60***
TBARS[3]				1.00	-0.49**	-0.50**	0.22	0.29	0.10	0.28	0.43**
MMb 0[4]					1.00	0.09	-0.29	-0.32	-0.32	-0.48**	-0.80***
MRA 0-2[5]						1.00	-0.01	-0.36*	-0.17	-0.17	-0.27
OMb 0[6]							1.00	-0.30	0.03	0.04	0.31
OCR 0-20[7]								1.00	0.30	0.33*	0.30
Initial C[8]									1.00	0.81***	0.62***
Visual C[9]										1.00	0.77***
Discolor[10]											1.00
L*											
a*											
b*											
a/b ratio											
Hue angle[11]											
Chroma[12]											

* = <0.05; ** = <0.01; *** = <0.001

[1] Aerobic Plate Count (log CFU/g or log CFU/cm^2)

[2] Lactic Acid Plate Count (log CFU/g or log CFU/cm^2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

[4] Percent of metmyoglobin at 0 h after vacuum packaging

[5] Metmyoglobin reducing ability from 0 to 2 h in vacuum package

[6] Percent of oxymyoglobin at 0 min after vacuum packaging

[7] Oxygen consumption rate from 0 to 20 min in vacuum package

[8] Initial color: 1 = Very light red; 8 = Dark red.

[9] Visual color: 1 = Extremely bright cherry-red; 8 = Extremely dark red

[10] Discoloration: 1 = Very bright red; 8 = Tan to brown

[11] Hue angle = tan^{-1} b/a

[12] Chroma = $(a^2 + b^2)^{1/2}$

Table C.6. Correlation coefficients for ground beef patties from knuckle subprimals at 0 h of display (Table C-5 continued)

	L	a	b	a/b ratio	Hue angle[11]	Chroma[12]
pH	-0.40*	0.10	0.34*	-0.62***	0.62***	0.21
APC[1]	-0.19	-0.10	0.10	-0.40*	0.41*	-0.01
LAB[2]	-0.19	-0.10	0.12	-0.42*	0.43**	-0.00
TBARS[3]	0.04	-0.06	0.04	-0.20	0.20	-0.02
MMb 0[4]	-0.04	0.35*	0.36*	-0.24	0.23	0.36*
MRA 0-2[5]	-0.09	0.11	-0.06	0.30	0.31	0.04
OMb 0[6]	0.36	0.16	0.03	0.22	-0.22	0.11
OCR 0-20[7]	-0.13	-0.31	-0.15	-0.21	0.22	-0.25
Initial C[8]	-0.43**	-0.61***	-0.43**	-0.05	0.06	-0.54**
Visual C[9]	-0.41*	-0.46**	-0.26	-0.17	0.19	-0.38*
Discolor[10]	-0.02	-0.44**	-0.38*	0.15	-0.13	-0.42*
L*	1.00	-0.05	-0.29	0.59***	-0.59***	-0.16
a*		1.00	0.92***	-0.43**	0.41*	0.99***
b*			1.00	-0.74***	0.73***	0.97***
a/b ratio				1.00	-0.99***	-0.58***
Hue angle[11]					1.00	0.56***
Chroma[12]						1.00

* = <0.05; ** = <0.01; *** = <0.001

[1] Aerobic Plate Count (log CFU/g or log CFU/cm^2)

[2] Lactic Acid Plate Count (log CFU/g or log CFU/cm^2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

[4] Percent of metmyoglobin at 0 h after vacuum packaging

[5] Metmyoglobin reducing ability from 0 to 2 h in vacuum package

[6] Percent of oxymyoglobin at 0 min after vacuum packaging

[7] Oxygen consumption rate from 0 to 20 min in vacuum package

[8] Initial color: 1 = Very light red; 8 = Dark red.

[9] Visual color: 1 = Extremely bright cherry-red; 8 = Extremely dark red

[10] Discoloration: 1 = Very bright red; 8 = Tan to brown

[11] Hue angle = $\tan^{-1} b/a$

[12] Chroma = $(a^2 + b^2)^{1/2}$

Table C.7. Correlation coefficients for ground beef patties from knuckle subprimals at 24 h of display

	pH	**APC[1]**	**LAB[2]**	**TBARS[3]**	**MMb 0[4]**	**MRA 0-2[5]**	**OMb 0[6]**	**OCR 0-20[7]**	**Visual C[8]**	**Discolor[9]**
pH	1.00	0.84***	0.82***	0.14	-0.20	-0.38*	-0.75***	0.40	-0.10	0.04
APC[1]		1.00	0.99***	0.31	-0.38*	-0.64***	-0.70***	0.38*	0.08	0.21
LAB[2]			1.00	0.32	-0.39*	-0.65***	-0.71***	0.37*	0.09	0.23
TBARS[3]				1.00	-0.24	-0.32	-0.38*	0.49**	0.28	0.52**
MMb 0[4]					1.00	-0.01	0.10	-0.43**	-0.57***	-0.57***
MRA 0-2[5]						1.00	0.50**	0.08	0.04	0.06
OMb 0[6]							1.00	-0.48**	0.09	-0.12
OCR 0-20[7]								1.00	0.31	0.49**
Visual C[8]									1.00	0.77***
Discolor[9]										1.00
L*										
a*										
b*										
a/b ratio										
Hue angle[10]										
Chroma[11]										

* = <0.05; ** = <0.01; *** = <0.001

[1] Aerobic Plate Count (log CFU/g or log CFU/cm^2)

[2] Lactic Acid Plate Count (log CFU/g or log CFU/cm^2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

[4] Percent of metmyoglobin at 0 h after vacuum packaging

[5] Metmyoglobin reducing ability from 0 to 2 h in vacuum package

[6] Percent of oxymyoglobin at 0 min after vacuum packaging

[7] Oxygen consumption rate from 0 to 20 min in vacuum package

[8] Initial color: 1 = Very light red; 8 = Dark red.

[9] Visual color: 1 = Extremely bright cherry-red; 8 = Extremely dark red

[10] Discoloration: 1 = Very bright red; 8 = Tan to brown

[11] Hue angle = $\tan^{-1} b/a$

[12] Chroma = $(a^2 + b^2)^{1/2}$

Table C.8. Correlation coefficients for ground beef patties from knuckle subprimals at 24 h of display (Table C-7 continued)

	L	a	b	a/b ratio	Hue angle[10]	Chroma[11]
pH	0.37*	-0.23	-0.24	-0.17	0.16	-0.24
APC[1]	0.35*	-0.58***	-0.52**	-0.50**	0.50**	-0.57***
LAB[2]	0.34*	-0.60***	-0.54***	-0.53***	0.52**	-0.59***
TBARS[3]	0.08	-0.28	-0.20	-0.37*	0.37*	-0.25
MMb 0[4]	0.10	0.55***	0.61***	0.22	-0.21	0.58***
MRA 0-2[5]	-0.39*	0.50**	0.33*	0.69***	-0.68***	0.45**
OMb 0[6]	-0.36*	0.26	0.22	0.28	-0.28	0.25
OCR 0-20[7]	0.08	-0.17	-0.26	0.06	-0.06	-0.20
Visual C[8]	-0.37*	-0.37*	-0.44**	-0.11	0.10	-0.40*
Discolor[9]	-0.38*	-0.48**	-0.51*	-0.26	0.26	-0.49**
L*	1.00	-0.03	-0.09	0.09	-0.07	-0.05
a*		1.00	0.95***	0.73***	-0.72***	0.99***
b*			1.00	0.48**	-0.47**	0.98***
a/b ratio				1.00	-0.99***	0.65***
Hue angle[10]					1.00	-0.64***
Chroma[11]						1.00

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* = <0.05; ** = <0.01; *** = <0.001

[1] Aerobic Plate Count (log CFU/g or log CFU/cm^2)

[2] Lactic Acid Plate Count (log CFU/g or log CFU/cm^2)

[3] Thiobarbituric acid reactive substances (mg malonaldehyde/ kg)

[4] Percent of metmyoglobin at 0 h after vacuum packaging

[5] Metmyoglobin reducing ability from 0 to 2 h in vacuum package

[6] Percent of oxymyoglobin at 0 min after vacuum packaging

[7] Oxygen consumption rate from 0 to 20 min in vacuum package

[8] Initial color: 1 = Very light red; 8 = Dark red.

[9] Visual color: 1 = Extremely bright cherry-red; 8 = Extremely dark red

[10] Discoloration: 1 = Very bright red; 8 = Tan to brown

[11] Hue angle = $\tan^{-1}$ b/a

[12] Chroma = $(a^2 + b^2)^{1/2}$

Table C.9. Correlation coefficients for sensory traits of ground beef patties from chuck roll subprimals

	Total Fat[1]	SSF Peak F[2]	SSF Total E[3]	LK Peak F[4]	LK Total E[5]	TPA F C 1[6]	TPA TE 1[7]	TPA F C 2[8]	TPA TE 2[9]
Total Fat[1]	1.00	-0.12	-0.11	-0.55***	-0.15	-0.20	-0.06	-0.22	-0.20
SF P Force[2]		1.00	0.81***	0.53**	0.53***	-0.06	-0.22	-0.05	-0.09
SF T Energy[3]			1.00	0.39*	0.32	0.26	0.10	0.26	0.20
LK P Force[4]				1.00	0.71***	-0.07	-0.25	-0.05	-0.08
LK T Energy[5]					1.00	-0.28	-0.32	-0.27	-0.23
TPA FC1[6]						1.00	0.93***	0.99***	0.98***
TPA TE 1[7]							1.00	0.92***	0.95***
TPA FC 2[8]								1.00	0.98***
TPA TE 2[9]									1.00
TPA Cohes[10]									
TPA Gum[11]									
TPA Spring[12]									
TPA Chew[13]									
Firmness[14]									
Cohesive[15]									
Juiciness[16]									
Beef Flavor[17]									
Mouth Coat[18]									
Off Flavor[19]									
Desirability[20]									

* = <0.05; ** = <0.01; *** = <0.001

[1] Total Percent Fat (%)

[2] Slice Shear Force Peak Force (kg)

[3] Slice Shear Force Total Energy (kg x mm)

[4] Lee-Kramer Peak force (kg/g)

[5] Lee-Kramer Total Energy (kg x mm/g)

[6] Texture Profile Analysis 1st Force Compression (kg) or Hardness

[7] Texture Profile Analysis 1st Force Compression Total Energy (kg x mm)

[8] Texture Profile Analysis 2nd Force Compression (kg)

[9] Texture Profile Analysis 2nd Force Compression Total Energy (kg x mm)

[10] Cohesiveness: Total energy 2nd compression ÷ total energy 1st compression

[11] Gumminess: Hardness x cohesiveness (kg)

[12] Springiness: Height that the food recovers during the time elapsed between the end of the 1st compression and the start of the 2nd compression

[13] Chewiness: Gumminess x Springiness (kg)

[14] Firmness scale: 8. Extremely firm, 1. Extremely soft.

[15] Cohesiveness scale: 8. Extremely cohesive, 1. Not cohesive at all

[16] Juiciness scale: 8. Extremely juicy, 1. Extremely dry

[17] Beef flavor intensity scale: 8. Extremely intense, 1. Extremely bland

[18] Mouth coat scale: 8. None, 1. Abundant

[19] Off-flavor intensity scale: 8. None, 1. Abundant

[20] Desirability scale: 8. Extremely Liked, 1. Extremely Dislike

Table C.10. Correlation coefficients for sensory traits of ground beef patties from chuck roll subprimals (Table C-9 continued)

	TPA Cohesiv[10]	TPA Gum[11]	TPA Spring[12]	TPA Chew[13]	Firm[14]	Cohesiv[15]	Juiciness[16]	Beef Flavor[17]	Mouth Coat[18]	Off Flavor[19]	Desir[20]
Total Fat[1]	-0.09	-0.06	-0.10	-0.31	-0.38*	-0.18	0.29	0.02	-0.32	-0.01	0.10
SF P Force[2]	0.06	-0.01	0.41*	0.24	0.23	0.10	-0.22	-0.35*	0.27	-0.33*	-0.25
SF T Energy[3]	-0.06	0.28	0.29	0.42*	0.26	0.23	-0.03	-0.26	0.06	-0.42*	-0.29
LK P Force[4]	0.17	-0.18	0.45**	0.30	0.37*	0.15	-0.39*	-0.14	0.35*	-0.06	-0.17
LK T Energy[5]	0.27	-0.32	0.22	-0.06	0.43**	0.22	-0.28	-0.10	0.41*	0.12	-0.09
TPA FC1[6]	-0.41*	0.81***	-0.19	0.74***	0.00	-0.10	0.13	-0.14	-0.33	-0.22	-0.18
TPA TE 1[7]	-0.44**	0.72***	-0.48**	0.47**	-0.04	-0.08	0.27	-0.03	-0.32	-0.05	-0.06
TPA FC 2[8]	-0.41*	0.81***	-0.17	0.76***	0.01	-0.10	0.11	-0.15	-0.31	-0.22	-0.18
TPA TE 2[9]	-0.43**	0.75***	-0.28	0.66***	0.08	-0.02	0.15	-0.08	-0.30	-0.13	-0.09
TPA Cohes[10]	1.00	-0.24	0.12	-0.24	0.20	-0.11	-0.12	-0.17	0.14	-0.00	-0.30
TPA Gum[11]		1.00	-0.07	0.67***	0.03	-0.08	-0.00	-0.18	-0.29	-0.32	-0.25
TPA Spring[12]			1.00	0.50**	-0.05	-0.03	-0.37*	-0.33	0.02	-0.43**	-0.31
TPA Chew[13]				1.00	0.03	-0.12	-0.18	-0.33*	-0.22	-0.46**	-0.37*
Firmness[14]					1.00	0.72***	-0.21	0.22	0.22	0.13	0.08
Cohesive[15]						1.00	0.00	0.37*	0.11	0.06	0.30
Juiciness[16]							1.00	0.38*	-0.42*	-0.03	0.26
Beef Flavor[17]								1.00	0.3	0.54***	0.74***
Mouth Coat[18]									1.00	0.40*	0.05
Off Flavor[19]										1.00	0.68***
Desirability[20]											1.00

* = <0.05; ** = <0.01; *** = <0.001

[1] Total Percent Fat (%)

[2] Slice Shear Force Peak Force (kg)

[3] Slice Shear Force Total Energy (kg x mm)

[4] Lee-Kramer Peak force (kg/g)

[5] Lee-Kramer Total Energy (kg x mm/g)

[6] Texture Profile Analysis 1st Force Compression (kg) or Hardness

[7] Texture Profile Analysis 1st Force Compression Total Energy (kg x mm)

[8] Texture Profile Analysis 2nd Force Compression (kg)

[9] Texture Profile Analysis 2nd Force Compression Total Energy (kg x mm)

[10] Cohesiveness: Total energy 2nd compression ÷ total energy 1st compression

[11] Gumminess: Hardness x cohesiveness (kg)

[12] Springiness: Height that the food recovers during the time elapsed between the end of the first compression and the start of the second comp.

[13] Chewiness: Gumminess x Springiness (kg)

[14] Firmness scale: 8. Extremely firm, 1. Extremely soft.

[15] Cohesiveness scale: 8. Extremely cohesive, 1. Not cohesive at all

[16] Juiciness scale: 8. Extremely juicy, 1. Extremely dry

[17] Beef flavor intensity scale: 8. Extremely intense, 1. Extremely bland

[18] Mouth coat scale: 8. None, 1. Abundant

[19] Off-flavor intensity scale: 8. None, 1. Abundant

[20] Desirability scale: 8. Extremely Liked, 1. Extremely Dislike

Table C.11. Correlation coefficients for sensory traits of ground beef patties from knuckle subprimals

	Total Fat[1]	**SSF Peak F[2]**	**SSF Total E[3]**	**LK Peak F[4]**	**LK Total E[5]**	**TPA F C 1[6]**	**TPA TE 1[7]**	**TPA F C 2[8]**	**TPA TE 2[9]**
Total Fat[1]	1.00	-0.30	-0.21	-0.51**	-0.33	-0.24	-0.17	-0.27	-0.28
SF P Force[2]		1.00	0.90***	0.43**	0.31	-0.04	-0.06	-0.02	-0.06
SF T Energy[3]			1.00	0.29	0.12	0.19	0.17	0.20	0.13
LK P Force[4]				1.00	0.72***	--0.12	-0.29	-0.09	-0.07
LK T Energy[5]					1.00	-0.17	-0.19	-0.15	-0.14
TPA FC1[6]						1.00	0.89***	0.99***	0.96***
TPA TE 1[7]							1.00	0.88***	0.90***
TPA FC 2[8]								1.00	0.96***
TPA TE 2[9]									1.00
TPA Cohes[10]									
TPA Gum[11]									
TPA Spring[12]									
TPA Chew[13]									
Firmness[14]									
Cohesive[15]									
Juiciness[16]									
Beef Flavor[17]									
Mouth Coat[18]									
Off Flavor[19]									
Desirability[20]									

* = <0.05; ** = <0.01; *** = <0.001

[1] Total Percent Fat (%)

[2] Slice Shear Force Peak Force (kg)

[3] Slice Shear Force Total Energy (kg x mm)

[4] Lee-Kramer Peak force (kg/g)

[5] Lee-Kramer Total Energy (kg x mm/g)

[6] Texture Profile Analysis 1st Force Compression (kg) or Hardness

[7] Texture Profile Analysis 1st Force Compression Total Energy (kg x mm)

[8] Texture Profile Analysis 2nd Force Compression (kg)

[9] Texture Profile Analysis 2nd Force Compression Total Energy (kg x mm)

[10] Cohesiveness: Total energy 2nd compression ÷ total energy 1st compression

[11] Gumminess: Hardness x cohesiveness (kg)

[12] Springiness: Height that the food recovers during the time elapsed between the end of the first compression and the start of the second compression

[13] Chewiness: Gumminess x Springiness (kg)

[14] Firmness scale: 8. Extremely firm, 1. Extremely soft.

[15] Cohesiveness scale: 8. Extremely cohesive, 1. Not cohesive at all

[16] Juiciness scale: 8. Extremely juicy, 1. Extremely dry

[17] Beef flavor intensity scale: 8. Extremely intense, 1. Extremely bland

[18] Mouth coat scale: 8. None, 1. Abundant

[19] Off-flavor intensity scale: 8. None, 1. Abundant

[20] Desirability scale: 8. Extremely Liked, 1. Extremely Dislike

Table C.12. Correlation coefficients for sensory traits of ground beef patties from knuckle subprimals (Table C-11 continued)

	TPA Cohesiv[10]	TPA Gum[11]	TPA Spring[12]	TPA Chew[13]	Firm[14]	Cohesiv[15]	Juiciness[16]	Beef Flavor[17]	Mouth Coat[18]	Off Flavor[19]	Desir[20]
Total Fat[1]	-0.44**	-0.25	-0.08	-0.21	-0.21	-0.14	0.27	0.31	-0.36*	0.09	0.33*
SF P Force[2]	0.18	-0.05	0.02	-0.00	0.29	0.36*	-0.26	-0.28	0.24	-0.07	-0.49**
SF T Energy[3]	-0.01	-0.07	-0.14	-0.01	0.25	0.31	-0.18	-0.16	0.04	-0.08	-0.34
LK P Force[4]	0.43**	-0.03	0.38*	0.30	0.24	0.16	-0.36*	-0.29	0.43**	-0.10	-0.45**
LK T Energy[5]	0.26	0.02	0.14	0.02	0.40*	0.36*	-0.09	0.07	0.37*	0.00	-0.24
TPA FC1[6]	-0.02	0.44**	-0.28	0.39*	0.23	0.05	0.17	0.08	-0.20	-0.13	0.25
TPA TE 1[7]	-0.29	0.35*	-0.60***	-0.02	0.13	0.02	0.33*	0.20	-0.30	-0.04	0.28
TPA FC 2[8]	0.01	0.46**	-0.25	0.42*	0.13	0.02	0.33*	0.20	-0.30	-0.04	0.28
TPA TE 2[9]	-0.04	0.42*	-0.32	0.32	0.23	0.04	0.12	0.07	-0.14	-0.12	0.17
TPA Cohes[10]	1.00	0.37*	0.64***	0.58***	0.09	-0.10	-0.38*	-0.30	0.47**	-0.17	-0.30
TPA Gum[11]		1.00	0.06	0.31	0.14	-0.00	0.08	0.08	0.08	-0.48**	-0.07
TPA Spring[12]			1.00	0.76***	-0.00	-0.11	-0.57***	-0.28	0.46**	0.04	-0.27
TPA Chew[13]				1.00	0.17	-0.04	-0.44**	-0.26	0.34*	-0.11	-0.11
Firmness[14]					1.00	0.82***	-0.09	0.21	-0.05	-0.14	-0.05
Cohesive[15]						1.00	0.10	0.28	-0.05	-0.07	-0.01
Juiciness[16]							1.00	0.48**	-0.50**	0.02	0.66***
Beef Flavor[17]								1.00	-0.49**	0.13	0.51**
Mouth Coat[18]									1.00	-0.30	-0.67***
Off Flavor[19]										1.00	0.43**
Desirability[20]											1.00

* = <0.05; ** = <0.01; *** = <0.001

[1] Total Percent Fat (%)

[2] Slice Shear Force Peak Force (kg)

[3] Slice Shear Force Total Energy (kg x mm)

[4] Lee-Kramer Peak force (kg/g)

[5] Lee-Kramer Total Energy (kg x mm/g)

[6] Texture Profile Analysis 1st Force Compression (kg) or Hardness

[7] Texture Profile Analysis 1st Force Compression Total Energy (kg x mm)

[8] Texture Profile Analysis 2nd Force Compression (kg)

[9] Texture Profile Analysis 2nd Force Compression Total Energy (kg x mm)

[10] Cohesiveness: Total energy 2nd compression ÷ total energy 1st compression

[11] Gumminess: Hardness x cohesiveness (kg)

[12] Springiness: Height that the food recovers during the time elapsed between the end of the first compression and the start of the second compression

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[20] Desirability scale: 8. Extremely Liked, 1. Extremely Dislike