IMPACT OF SUBPRIMAL ENHANCEMENT ON POSTMORTEM AGING AND RETAIL SHELF LIFE CHARACTERISTICS OF FRESH BEEF

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FORMAT OF THESIS

This Thesis is presented in Journal of Animal Science style format, as outlined by the Oklahoma State University Graduate College Style Manual. The use of this format allows for independent chapters to be prepared suitable for submission to scientific journals.

CHAPTER 1

Introduction

Meeting consumer expectations for product quality and consistency (particularly for tenderness) has been identified as a high priority by the U.S. beef industry (NCBA, 1998). This need for increased quality and consistency has resulted in the emergence of many branded beef programs. The objective of a clear majority of these programs is to gain customer loyalty by consistently providing a high-quality, palatable product. According to results of a recent consumer survey (Moeller and Courington, 1998), three primary factors that would motivate consumers to purchase more beef at retail markets are "lower retail beef prices," "improved product quality and consistency at the same price," and "improvements in the eating experience." Therefore, the importance of a superb eating experience is crucial to maintaining or even improving current beef buying trends. Enhancement of beef subprimals is quickly growing in popularity throughout many case-ready Branded Beef programs. Case-ready beef has been brought about by the huge demand for convenience that America has and is definitely the trend of the future. However, like many new technologies adopted by an aggressive beef industry, customer acceptance of "enhanced" beef cuts is average at best. Inconsistency in tenderness across different cuts, textural properties described as "rubbery" and off-flavor issues has led the Wal-Mart company to begin developing "Good Manufacturing Practices," (GMP) for their case-ready beef program. They determined, however, that there is a lack of scientific knowledge regarding the enhancement process and its impact on palatability and shelf-life traits of fresh beef products. Until these gaps in the knowledge base are addressed, it is nearly impossible to adequately develop the GMPs needed for case ready products. To that, we must refine the enhancement system to hopefully full proof the relationship between enhancement and case-ready packaging. Therefore, this project was designed to provide case-ready processors some guidelines to help develop GMP for value-added beef products.

CHAPTER 2

Literature Review

Today's Meat Industry

Decisions made by customers when buying food products are driven by the relation of how appetizing the food may be versus the price in which one pays for the product. Low overall consistency, inadequate tenderness and low overall palatability were the top three "quality" concerns noted by beef purveyors, restaurateurs, retailers and packers in the 1995 National Beef Quality Audit (NCA, 1996). The inconsistency of the eating experience of beefsteaks is a high concern in the marketing of beef. A pleasant eating experience is very important in maintaining customer satisfaction and confidence. Since beef is priced higher than other protein sources, consistent palatability is a must if consumer satisfaction is going to be achieved (Brooks et al., 2000).

Another important aspect in the perception of beef is visual appearance. Visual appearance is one of the major criteria used by consumers to assess the quality and palatability of a meat cut (Howe et al., 1982). Wholesomeness of appearance determines how consumers perceive quality and significantly influences purchasing decisions.

Palatability is defined as pleasant to the taste or mind, or the level of a pleasant eating experience. There are three major components in the palatability of beef: tenderness, juiciness, and flavor. The importance of tenderness, juiciness, and flavor to the consumer in deciding what to purchase at the marketplace was evaluated in the National Consumer Retail Beef Study (Savell et al., 1989). Of the three palatability drivers, the National Consumer Retail Beef Study (1983) determined that tenderness was the single most important factor in determining eating satisfaction of cooked beef. More recently, it was documented that consumers are willing to pay a premium for beef that is "guaranteed tender" (Boleman et al., 1997).

Tenderness

Tenderness potential is based largely by the genetic makeup of the animal, the physiological age of the animal upon harvest, and the post-harvest environment. Additionally, muscle type and location cause a wide spectrum for levels of tenderness.

Marbling is the deposition of fat between the muscle fiber bundles. Fat deposition in animals, particularly marbling, influences both the actual and perceived value of fresh meat. The idea that presence of fat in animal carcasses influences palatability, and thus value, supported the development of the U.S. Standards for Grades of Carcass Beef. Emerging in 1916, these standards were developed to provide uniform reporting of dressed beef markets according to various grades, and eventually became the Official United States Standards for the Grades of Carcass Beef, which served as the basis for carcass grading when the beef grading and stamping service began in May 1927 (USDA, 1997). These grades are intended to segment carcasses based upon their market value and more importantly, expected desirability or cooked palatability. Presently, the quality grades range from U.S. Prime to U.S. Canner and are determined by: physiological maturity of the carcass, marbling degree within the longissimus dorsi at the $12^{th}/13^{th}$ rib interface, and meat firmness (USDA, 1997). Since marbling does appear in older animals, something about the animal's age must be known in order to gain a true sense about the quality of the meat. Skeletal maturity is determined by the color of the lean in the longissimus dorsi at the $12^{th}/13^{th}$ rib interface, the shape, color and size of the ribs, as well as extent of ossification in the thoracic buttons, the lumbar vertebrae, and the sacral vertebrae. Once carcasses are segmented into maturity groups based on physiological indicators, marbling becomes the primary determinant when assigning the final USDA quality grade. According to the National Beef Quality Audit (NCA, 1996), 95% of cattle harvested in the U.S. qualify for the "A" maturity group. Thus, for the current meat supply in the food service and retail sectors, marbling rather than physiological maturity has a greater effect on the ultimate quality grade.

An extensive review by Jeremiah (1978) identifies considerable research, which indicates that marbling has a positive effect on beef palatability. McBee and Wiles (1967) found that shear force, sensory panel tenderness, juiciness and flavor improved as marbling increased. Dolezal et al. (1982a) concluded sensory panel ratings increased and shear force values decreased as marbling increased. Similarly, steaks with at least a "small" degree of marbling (Jones and Tatum, 1994) and steaks with at least a "modest" degree of marbling (Jennings,

1978) were reported to have lower shear force values than steaks with "slight" or lower marbling scores. Furthermore, it has been demonstrated with consumers that the effect of marbling on palatability has some regional implications; consumers in different regions of the country respond differently to steaks varying in their amounts of marbling (Savell et al., 1987; Neely et al., 1998). However, some researchers have shown marbling to be a poor indicator relative to cooked beef tenderness (Tuma, 1963; Romans et al., 1965; Parrish, 1973; Parrish, 1974; Dikeman and Crouse, 1975; Wheeler, et al., 1994).

Data from the National Beef Quality Audit (National Cattlemens Association [NCA], 1996) indicated that carcasses in the U.S. have become heavier, more muscular and have less marbling than those surveyed in 1994 (NCA, 1994), which has resulted in leaner, and potentially less palatable products. Excluding various changes in genetics and management practices, the new target for producing leaner beef had been partially attributed to the demands of a more health-conscious society. The beef industry fears that increasing leanness will contribute to decreases in palatability; eliminating "waste" while sacrificing "taste". Yet it has been reported that far more consumers of beef (nearly three fold) are concerned with the tenderness rather than the taste of cooked beef (McDonell, 1990).

As mentioned previously, tenderness for a muscle is dependent on the location and function of the particular muscle. Ramsbottom and Strandine (1948) recognized that tenderness varied between beef muscles and established tenderness ratings for 50 different muscles by collecting Warner-Bratzler shear values. Intuitively the most common explanation for tenderness differences among muscles is the amount and structure of connective tissue. Collagen is the most abundant protein in the animal body and significantly influences meat tenderness. Moreover, collagen is not equally distributed among muscles, but collagen amount is related to individual muscle activity; muscles that are more active have greater amounts of connective tissue (Hedrick et al., 1994). In a study conducted by Morgan et al. (1991), Warner-Bratzler shear values indicated a high percentage of chuck and round cuts would receive panel tenderness scores less than "slightly tender". Swatland (1984) reported that muscles used more frequently, such as muscles used for locomotion, have higher myoglobin concentrations due to increased oxygen demand as compared to support muscles. This, coupled with the findings of Quali (1990) which indicated that the degradation of myofibrillar structure was greater for muscles with increased contraction speed (white fibers) and lower for muscles with increased levels of heme iron (red fibers), may relate to possible differences in postmortem proteolysis.

Warner-Bratzler Shear

K. F. Warner invented an apparatus (Wheeler, 1996) to objectively measure and determine differences in meat tenderness, commonly known as Warner-Bratzler shear or shear force. Since then, numerous researchers have utilized this approach to objectively determine differences among various factors that may affect tenderness. Additionally, researchers have utilized individuals, either trained evaluators or lay consumers, to evaluate meat palatability differences. To obtain a 50 or 68% confidence level of having slightly tender top loin steaks (as determined by trained sensory panel), Shackelford (1991) concluded that Warner-Bratzler shear should not exceed 4.6 or 3.9 kg, respectively. Later, Shackelford et al. (1995b) compared the values of Warner-Bratzler shear against the values reported by a trained sensory panel across ten beef muscles. Those results indicated that Warner-Bratzler shear was not able to detect the same statistical differences among muscles as the sensory panel did for overall tenderness; therefore if muscles are to be ranked according to tenderness values, the ranking procedure is highly dependant upon the method employed to assess tenderness.

Methods to Enhance Tenderness

There are multiple post-harvest techniques to improve tenderness. One particular method to enhance tenderness is application of a marination/brine solution via injection at the subprimal level. In a recent study by Vote et al. (2000), strip loins from U.S. Choice and U.S. Select carcasses were injected with a solution containing sodium tripolyphosphate (STP), sodium lactate, and sodium chloride. Injection levels were 0%, 7.5%, 10%, 12.5%, and 15%. All injection solutions were formulated to contain .25% STP, .5% sodium chloride, and 2.5% sodium lactate. They found that all injected treatments were superior to the untreated controls in the areas of improved sensory panel tenderness and juiciness ratings, as well as lowered shear force values. Therefore enhancement significantly increased tenderness and eating quality.

Electrical Stimulation is another scheme in which to increase tenderness. Harsham and Deatherage (1951) first patented electrical stimulation as a means of improving meat tenderness. Carse (1973) demonstrated the ability of electrical stimulation to effectively prevent cold shortening due to its ability to increase postmortem glycolysis. One of the primary benefits of electrical stimulation is increased tenderness of cooked beef (Bouton et al., 1980, Cross et al., 1979; McKeith et al., 1980, 1981; Savell et al., 1978a, 1979). Theories associated with electrical stimulation's ability to increase muscle tenderness include prevention of cold shortening, physical disruption of muscle fibers, and increased proteolytic activity.

Postmortem aging is a process which improves the palatability attributes of beef, especially from the rib and loin. Improvement in tenderness is the primary reason for postmortem aging. However, postmortem aging also improves flavor. Postmortem aging or proteolysis is the conversion of muscle to meat, where enzymes found in muscles, break down specific proteins in muscle fibers. Natural enzymes or calpains within the muscle were believed historically to improve tenderness by degrading sarcomere boundaries or Z-lines, resulting in disruption in the myofibrillar structure. However, Taylor et al. (1995) concluded postmortem tenderization due to calpains involves at least three other interrelated events including: 1) weakening of the myofilament structure (actin/myosin interaction), 2) weakening of the thin filament/Z-disk connections and 3) degradation of intermyofibrillar linkages. Regardless of the actual process by which calpains enhance postmortem tenderization (Z-disk degradation or other mechanisms), the relationship between calpains and calpastatin is key. Calpains are regulated by the presence or absence of calcium ions, and is inhibited by calpastatin. Thus, increased levels of calcium enhance proteolysis. Numerous researchers have investigated the effectiveness of calcium chloride infusion as a postmortem tenderization technique for meat (Koohmaraie and Shackelford, 1991; Morgan et al., 1991; Diles et al., 1994; McFarlane and Unruh, 1996; Wulf et al., 1996; Clare et al., 1997).

Meat Color

When buying fresh beef, consumers have been conditioned to believe that bright cherry red equates to freshness; any deviation from this color is perceived as undesirable (Faustman and Cassens, 1990; Kropf, 1980). Even though color and discoloration of fresh meat does not necessarily reflect nutritional, flavor, or functional values (Zhu & Brewer, 1998), preservation of the bright cherry red color of beef in the retail case is imperative for selling beef. According to Carpenter et al. (2001), there is a close link between lean color preference and the decision to purchase, and consumers prefer to purchase bright red beef rather than purple or brown beef. Furthermore, consumers use color as an indicator of beef freshness, and will make a no-purchase decision when brown metmyoglobin reaches 30 to 40% of total pigments on the surface of fresh beef (Gee et al., 1981). Sherbeck et al. (1995) stated that lean color is very important to the appearance of beef products and influences consumer perception in the retail case. The consumer associates bright cherry red color with freshness and considers that product to be one of "quality" (Faustman and Cassens, 1990).

Meat color is contingent on the chemical state of myoglobin (Mb). In the reduced form, deoxymyoglobin is purplish; in the oxygenated form oxymyoglobin (Omb) is bright red; and in the oxidized form, metmyoglobin (MetMb) is brown after storage (Govindarajan, 1973). During postmortem storage, three forms of Mb can change through oxygenation, oxidation and reduction reaction. In general, low pH values favors oxidation of Mb (Brown and Mebine, 1969; Gidding, 1977) and decreased enzymatic reduction of metmyoglobin (Ledward, 1992). Therefore, the manifestation of MetMb is faster in meat with a low pH than in meat with a high pH and meat tends to discolor more readily in the low pH condition (Owen and Lawrie, 1975; Ledward, 1986). When myoglobin is observed in living tissue or immediately after exposure to air, it remains purple in color. When muscle tissue is in this stage, iron is in the ferrous form (Fe^{2+}). The time it takes deoxymyoglobin to be transformed into oxymyoglobin is known as "bloom time." The final color transformation occurs when oxymyoglobin is transformed into metmyoglobin. This process involves the loss of one electron from the iron molecule yielding the ferric state (Fe^{3+}) as well as the removal of O_2 from oxymyoglobin. Once O_2 is removed from oxymyoglobin, a hydrogen peroxide molecule binds in its place.

Several studies have examined the effects of light on discoloration of fresh meat, although they reported conflicting results. Zachariah and Satterlee (1973) and Solberg and Frank (1971) demonstrated that visible light (500 to 600 nm), at

540 to 2,150 lux, caused a small but significant increased in the accumulation of metMb at the surface of meat. Lentz (1971) reported that lean color of frozen beef remained attractive for 3 months when stored in the dark, but only 3 days when stored under illumination of 1,600 to 2,100 lux. Satterlee and Hansmeyer (1974) reported that low wavelength visible light intensified the oxidation of red Omb to brown MetMb.

Today's meat industry has utilized vacuum packaging in all boxed beef trade. American consumers have demonstrated a definite bias against purchase of vacuum packaged beef, which possesses the purple color of deoxymyoglobin (Meischen, Huffman, & Davis, 1987).

Case-Ready

Case-ready beef has been brought about by the huge demand for convenience that America has and is definitely the trend of the future. In the year 2000, retail stores sold 1.2 billion in case-ready products, which is more than double the number sold in 1997. The total retail meat industry is valued at $14 billion plus $4 billion for poultry (Brody, 2000). Case ready meats allow retailers to order the specific cuts to suit their unique consumer demand. For retailers, case ready products can reduce labor cost and increase profitability. Case ready meats also reduce the liability risks to retailers should a food safety problem occur. Additionally, case ready products would be at less risk of contamination due to fewer times the product is handled. Case ready products provide a consistent product for the consumer from purchase to purchase (Brody and Huston, 2002).

Case ready products are expected to expand over the next few years. Stores using case ready on average have experienced a 3.8% sales increase within their meat departments. Wal-Mart cemented the case ready way of conducting business with it's knife-less backroom stance, and Pinnacle Foods made believers out of the marketplace by producing case ready products to multi-retailer specifications (Pizzico, 2002). This phenomenon of case ready has been a reactionary process built on market demands, which has forced cost-cutting measures at specific segments of the supply and distribution channels. Case ready needs to become more efficient and more effective in its communications between packer and retail buyer, and between retail buyer and store meat manager, and computer-to-computer is what will be needed to take case ready to the next level and drive profitability (Pizzico, 2002). Enhancement of beef subprimals is quickly growing in popularity throughout many case-ready Branded Beef programs. However, like many new technologies adopted by an aggressive beef industry, customer acceptance of "enhanced" beef cuts is average at best. To that, more research is necessary to refine the enhancement system to hopefully full proof the relationship between enhancement and case-ready packaging.

Natural Antioxidants

An antioxidant is any substance that when found in food or the body at concentrations lower than those of oxidizable substrate delay or reduce the oxidation of that substrate. Many food manufacturers use antioxidants to increase the quality of their products as well as increase their nutritional value.

There are several major advantages of using natural antioxidants. Natural antioxidants tend to be more easily accepted by the American consumer (Rajalakshmi and Narasimhan, 1996). Another major benefit of natural antioxidants is that the government more easily regulates them. Rajalakshmi and Narasimhan (1996) stated that in many countries there is no testing required of antioxidants if the source is a food product that is considered safe. There is much concern about the fact that synthetic antioxidants have been shown to cause serious health problems while the opposite is true for natural substances (Rajalakshmi and Narasimhan, 1996).

Oleoresins are derived from spices by solvent extraction. The spices are treated with a solvent (acetone, isopropyl alcohol, petroleum ether, etc.) to remove the volatile and nonvolatile fractions. Once extracted, the solvent is removed, leaving the thick resinous material. These substances appeal to processors because they can be labeled as "natural flavorings." Recently, there has been an interest in using rosemary oleoresin in meat products because of its antioxidant properties. When combined with sodium tripolyphosphate, rosemary oleoresin decreased oxidative rancidity and increased the flavor preference of precooked roast beef slices that were stored frozen (Murphy et al., 1998).

Spices have been discovered to be one of the main sources of naturally occurring antioxidants. Chipault et al. (1956) discovered that allspice, rosemary, cloves, thyme, sage and oregano all exhibited antioxidant properties when combined with lard. The spices were combined with the lard by simply grinding them together. In later studies conducted by Chipault (1956), it was proven that of all of the spices previously mentioned, sage and rosemary showed the most promise for use in the meat industry.

Sodium Tripolyphosphate

The molecular structure of sodium tripolyphosphate (TPP) is $Na_5P_3O_{10}$. TPP helps to sequester multivalent metal ions, thereby inhibiting oxidative rancidity in food products. TPP also aids in the reduction of moisture loss during thawing and cooking. Furthermore, TPP promotes the emulsification of fat and protein, and improves solubility. The mode of action by which TPP increases moisture retention is not completely understood despite many studies. The action possibly involves the influence of pH changes, specific phosphate anion interactions with myofibrilar proteins and divalent cations, and effects of ionic strength. It is believed that calcium complexing and the resulting loosening of the tissue structure is a major function of polyphosphates. Binding of polyphosphate anions to proteins and the cleavage of cross-linkages between actin and myosin results in increased electrostatic repulsion between peptide chains and a swelling of the muscle system (Lindsay, 1985).

The addition of phosphates into meat has several desirable effects. Phosphates have been shown to stabilize ground meat color for extended periods of time (Savich and Jansen, 1954). It has also been reported that the addition of phosphates, either by dipping or by injection, increases the tenderness of the product (Carpenter, 1961; Hopkins and Zimont, 1957). Mahon et al. (1970) reported that when using alkaline phosphates such as sodium tripolyphosphate, moisture retention in the meat was at its highest. Ellenger (1972) showed that the effect on flavor by addition of phosphate was due to retention of proteins and the reduction of oxidative rancidity (Keeton, 1983). It has also been shown by Sheard et al. (1990) that sodium tripolyphosphate has a significant effect on cooking loss. In their research they found that the higher the levels of phosphate injected, cooking losses tended to be lower.

Sodium Chloride

Sodium chloride is one of the most common salts used in food processing to reduce cooking losses and effect inner-particle adhesion (Sheard et al. 1990). Salt was originally used to prevent the meat from spoiling. Meat that has been salted for preservation exhibits an unattractive gray color. In a study performed by Trout (1989), it was found that with the addition of sodium chloride in ground beef, percent myoglobin denaturation was increased as compared to ground beef with no added sodium chloride. This will decrease the amount of pinkness in the cooked meat product. Salt inhibits spoiling largely by reducing the amount of water available for microbial growth. Today, however, salt is not generally used at high enough levels (i.e. >2% by weight) to greatly effect preservation, although some preservative action will occur at low concentrations. Sodium chloride is also used in sausage emulsions to solubilize myofibrillar proteins into the aqueous state to become available for coating fat particles. One very important benefit of addition of sodium chloride is increased water holding capacity. Shackelford (1989) found that as salt levels increased protein content decreased. This was due to the increased water retaining ability and its dilution effect on the meat. Shackelford (1989) also found that higher salt levels (1.25%) caused a decrease in cooking losses and increased total yields when compared to the lower salt level (1%) treatment. These increased yields appeared to be mainly due to the decreased cooking losses caused by an increased water holding capacity that is associated with high salt containing products (Mandigo, 1982; Brewer et al., 1984; Cordray and Huffman, 1984; Chow et al., 1986; Lamkey et al., 1986).

CHAPTER 3

IMPACT OF SUBPRIMAL ENHANCMENT ON POSTMORTEM AGING AND RETAIL SHELF LIFE CHARACTERISTICS OF FRESH BEEF

ABSTRACT

A study was conducted to examine the tenderness and shelf life characteristic of beef subprimals with an industry utilized solution containing salt, phosphate, and rosemary oleoresin. USDA Choice and Select beef carcasses (n = 20 each) were identified at random and paired samples (n = 20 pairs) of USDA Choice and Select strip loins (IMPS #180), shoulder clods (IMPS #114), and top sirloin butts (IMPS #184) were individually identified prior to carcass disassembly. One-half of the subprimals were enhanced at 110% of their original weight with a solution and allowed to equilibrate for 1 h post-enhancement. Steaks (n = 7) were fabricated from subprimals and randomly allocated for 7 postmortem aging periods (1, 3, 6, 9, 12, 15, and 18d). Upon conclusion of each storage period, each steak was then frozen (-20°C) so the steaks could be simultaneously evaluated for tenderness utilizing WBS measurements. Additional USDA Choice and Select beef carcasses (n = 15) were identified at random. In a similar manner, paired samples of USDA Choice and Select strip loins, shoulder clods, and top sirloin butts were individually identified and randomly assigned to six treatments which included enhanced and non-enhanced subprimals, which were aged for 7, 14, or 21 d. At the conclusion of each storage period, subprimals were fabricated into steaks (2.54 cm), packaged in a modified atmosphere package (80% O_2/20%CO_2) and displayed in retail

cases to determine the effects of storage time and enhancement on shelf life. Enhanced strip loin steaks were more tender ($P < 0.05$) than non-enhanced steaks at all storage periods. Steaks from subprimals that were stored for longer periods had inferior ($P < 0.05$) retail-display characteristics and a shorter ($P < 0.05$) shelf life than steaks from shorter storage periods. Furthermore, as steaks were displayed for longer periods, retail-display characteristics declined ($P < 0.05$). Also, samples obtained from enhanced subprimals displayed significantly less lipid oxidation ($P < 0.05$) than did non-enhanced samples. These findings suggested that enhancing beef subprimals eliminated the need for postmortem aging in order to acquire acceptable tenderness and retail display characteristics.

Introduction

Decisions made by consumers when buying food products are driven by the relation of how appetizing the food may be versus the price in which one pays for the product. Low overall consistency, inadequate tenderness, and low overall palatability were the top three "quality" concerns noted by beef purveyors, restaurateurs, retailers and packers in the 1995 National Beef Quality Audit (NCA, 1996). The inconsistency of eating experience of beefsteaks is a high concern in the marketing of beef. A pleasant eating experience is very important in maintaining customer satisfaction and confidence. Since beef is priced higher than other protein sources, consistent palatability is a must if consumer satisfaction is going to be achieved (Brooks et al., 2000).

Another important aspect in the perception of beef is visual appearance. Visual appearance is one of the major criteria used by consumers to assess the quality and palatability of a meat cut (Howe et al., 1982). Wholesomeness of appearance determines how consumers perceive quality and significantly influences purchasing decisions.

Materials and Methods

Experimental Samples

Phase I. USDA Choice and Select, "A" maturity, beef carcasses (n = 20/ grade) from an unknown origin were selected at random from the National Beef Company in Liberal, KS. At approximately 48 h postmortem, paired samples (n = 20 pairs) of USDA Choice and Select strip loins (IMPS # 180), shoulder clods (IMPS #114), and top sirloin butts (IMPS #184) were individually identified and tagged prior to carcasses disassembly. The captivated subprimals were vacuum packaged and transported to Oklahoma State University for further analysis.

Postmortem Handling

Upon arrival to the Food and Agricultural Products Center located on the Oklahoma State University campus, paired subprimal samples were assigned randomly to one of two enhancement treatments. One-half of the subprimals were enhanced at 110% of their original weight with a industry utilized solution designed to provide 0.3% sodium chloride, 0.3% sodium tripolyphosphate, and 0.1% rosemary oleoresin solution in the final product. Following enhancement, subprimals were allowed to equilibrate for 12 h. Steaks (n = 7) were then fabricated from enhanced and non-enhanced subprimals. One steak from each subprimal was assigned randomly to a postmortem aging treatment of 1, 3, 6, 9, 12, 15, or 18 d. Samples were allowed to age for the respective storage period at refrigeration temperatures (4°C +/- 1°C) under vacuum, in the absence of light. At the conclusion of each storage period, each steak was then frozen at –20°C until Warner-Bratzler shear force analysis was conducted.

Warner-Bratzler Shear Force

Warner-Bratzler shear force value measurements were obtained for each sample as a measurement of tenderness. All steaks were randomly assigned to one of eight different cooking and testing dates. Steaks were tempered for 24 h at 4°C prior to cooking. Steaks were broiled in an impingement oven (Lincoln Impinger, Model 1132-00-A, Fort Wayne, IN) at 180°C to an internal temperature of 70°C (medium degree of doneness). Temperatures were monitored with a Digi Sense type T thermocouple (Model 91100-20, Cole-Parmer Instrument Company, Vernon Hills, IL). Steaks were then allowed to cool at room temperature 2 – 3 hours prior to the coring process. Upon cooling to 21°C, up to six cores were removed parallel to muscle fiber orientation and sheared using the Warner-Bratzler shear head attachment on an Universal Instron Testing Machine (Model 4502, Instron, Canton, MS) at a cross head speed of 200 mm per min. The peak load (kg) of each core was recorded by a Dell Opti-plex (MODEL GX 400) utilizing Instron Program software. Mean peak load of each sample was calculated and analyzed.

Statistical Analysis

The data were analyzed using ordinary least squares (PROC GLM, SAS Institute, Cary, NC). The data was blocked by subprimal. The model included treatment (enhancement), aging time, and USDA Quality grade as main effects. Mean separation was accomplished using Least Significant Difference.

Experimental Samples

Phase II. USDA Choice and Select, "A" maturity, beef carcasses (n = 15/grade) from an unknown origin were selected at random from the National Beef Company packer/processing facility in Liberal, KS. Paired samples (n = 15 pairs each) of USDA Choice and Select strip loins (IMPS # 180), shoulder clods (IMPS #114), and top sirloin butts (IMPS #184) were individually identified and tagged prior to carcasses disassembly. The captivated subprimals were vacuum packaged and transported to Oklahoma State University for further analysis.

Postmortem Handling

Upon arrival to the Food and Agricultural Products Center located on the Oklahoma State University campus, paired subprimal samples were assigned randomly to postmortem aging: enhancement treatment combinations (n = 5 reps/treatment): non-enhanced and enhanced beef subprimals, which were aged in vacuum-packaged bags for either 7, 14, or 21 d post-enhancement. Appropriate subprimals were enhanced at 110% of their original weight with a solution designed to provide 0.3% sodium chloride, 0.3% sodium tripolyphosphate, and 0.1% rosemary oleoresin solution in the final product. Once postmortem aging was completed, 2.54 cm-thick steaks (n = 1) were fabricated from the subprimals, and incorporated into a modified atmosphere packaged (MAP) system to determine the effect of storage time and enhancement on shelf life. Steaks were packaged in rigid, case-ready plastic trays (DuraFresh®, RockTenn Co.), flushed with 80% oxygen/20% carbon dioxide, and heat-sealed with a barrier film (LID 1050 film, Cryovac, Sealed Air, Duncan SC) using an in-house G. Mondini modified atmosphere packaging machine (Model CV/VG-5, G. Mondini S.P.A. Cologne, Italy). Ten percent of the samples were subjected to an oxygen headspace analyzer (Model HS-750, MOCON Modern Controls Inc., Minneapolis, MN) to ensure that the atmosphere contained 80% oxygen. Steaks were displayed in retail-style coffin cases under cool-white fluorescent light (1,600 to 1,900 lux) at 2 to 4°C for 7 d.

Retail Shelf Life

Retail display steaks were evaluated using objective and subjective measures. Trained personnel from Oklahoma State University subjectively evaluated steaks each day to assess differences in lean color (8=bright cherry red; 1=extremely dark brown), fat color (8=creamy white; 1=dark brown or green), percent discoloration (7=none; 1=complete), and overall acceptability (7=extremely desirable, 1=extremely undesirable). On d 1 and 8 of retail display Minolta color (L*, a*, and b*) was measured on the cut surface of the steak using a CR-300 Minolta Chromameter (Minolta Camera, Osaka, Japan) with settings of illuminant

D65 and 0° viewing angle. Steaks were allowed to bloom for a period of 20 min prior to objective color analysis.

Thiobarbituric Acid Assay

Estimates of lipid oxidation on the surface of samples are made using the thiobarbituric acid (TBA) analysis. Samples (n = 360) were distributed randomly across the four testing days to ensure all treatments were represented. Baseline and final TBAs were taken on d 1 and d 8 of retail display, respectively. The procedure was performed following protocol outlined by Buege and Aust (1978). The following modifications were made to the procedure: strip loin, top sirloin butt, and clod samples (10 g each) were homogenized with deionized water in a Waring Commercial Blender (Model 33BL79 (700), Waring Products Division Dynamics Corporation of America, New Hartford, Conn.) and centrifuged at 1,850 g for 10 min at 4°C (Beckman Induction Drive Centrifuge, Model J-6M, Beckman Instruments, Inc., Houston, TX). Two mL of homogenate, in duplicate, were subjected to TBA reagent and cooked in a boiling water bath. After cooling, absorbencies of the supernatant were measured at 531 nm using a spectrophotometer (Beckman, Model DU 7500). Results were recorded as thiobarbituric acid reactive substances (TBARS), which represent mg malonaldehyde (MDA) equivalents per kg of fresh beef.

Statistical Analysis

The data were analyzed using ordinary least squares (PROC GLM, SAS Institute, Cary, NC). The data was blocked by subprimal. The model included treatment (enhancement), aging time, retail display day, and USDA Quality grade as main effects. Mean separation was accomplished using Least Significant Difference.

Results and Discussion

Phase I

Effects of Enhancement on Warner-Bratzler Shear Values. Results summarizing the interactive effects of USDA Quality grade and enhancement on Warner-Bratzler shear force values of strip loins are overviewed in Figure 1. Least squares means are provided for each of the four groups corresponding to the treatment effect (superscripts denote statistical differences among groups). Mean differences between enhanced and non-enhanced strip loin steaks for both USDA Choice and Select grades indicated that enhancing with the industry standard injection solution significantly decreased Warner-Bratzler shear force values for each grade. USDA Choice steaks exhibited lower ($P < 0.001$) shear force values than did USDA Select steaks within respective enhancement groups (Figure 1). Most intriguingly, enhanced USDA Select steaks significantly out-performed -- were more tender -- non-enhanced USDA Choice steaks ($P < .001$). The significant interaction ($P = 0.0067$) between enhancement treatment and Quality grade shows that even though USDA Choice Strip loin steaks were more tender than their Select Quality counter parts, USDA Select Quality grade steaks responded to a greater extent (22.0 vs. 18.03% improvement) than USDA Choice steaks, to the enhancement process respectively.

Unlike strip loins steaks, no interaction ($P > 0.05$) between USDA Quality grade and enhancement treatment was evident involving top sirloin and shoulder clod steaks. However, for both groups of these subprimals, enhanced steaks outperformed ($P < 0.001$) non-enhanced steaks in terms of improved Warner-Bratzler shear force values (Figures 2 and 3, respectively). These findings are in agreement with researchers at Colorado State University (Vote et al., 2000) in that enhancing strip loin steaks with a solution containing sodium chloride, phosphate, and sodium lactate improved the Warner-Bratzler shear force, sensory tenderness, and juiciness ratings over non-enhanced controls and loins pumped only with distilled water. This research incorporated both USDA Choice and Select Quality grades, and they demonstrate that no significant effect due to Quality grade was observed among enhanced strip loins. In other words, enhancement appears to improve the tenderness ratings of top sirloin and clod steaks to an equal extent. An interesting question is "Do USDA Standard beef cuts, once enhanced, produce shear force values and palatability ratings equal to that of non-enhanced USDA Choice products?" If so, the potential for adding value to these cuts is tremendous.

Effects of Postmortem Aging on Warner-Bratzler Shear Values. As mentioned previously, seven different post-enhancement storage periods (1, 3, 6, 9, 12, 15, and 18 d) were investigated. Enhancement occurred on all subprimals following a 7 d postmortem storage period. For strip loins, postmortem aging influenced Warner-Bratzler shear force values in that, in general, as aging time increased, so did Warner-Bratzler shear force values of strip loin steaks (Figure 4). For both Quality grades, strip loin steaks that had been aged for 3 d possessed significantly lower shear values than did those that had been aged for only 1 d. Information if Figure 4 demonstrates that regardless of USDA Quality grade, day

1 Warner-Bratzler shear values were highest ($P < 0.05$) compared to other postmortem aging times. This was true for all cases with the unexplainable exception that occurred for US Select strip steaks in which Warner-Bratzler shear force spiked at 9 d of post-enhancement storage. With the exception of US Select steaks aged for 9 days, steaks aged for the remaining times had significantly lower shear values than strip loin steaks from the 1 and 3 d periods. One question being asked by the case-ready community is, "When can the enhancement procedure take place with regards to postmortem aging effects, both prior to and following enhancement?" Certainly, it is well documented that between 12 and 14 days of postmortem aging is recommended for fresh beef cuts to reach their respective tenderness maximization point (Davis et al., 1975; Savell et al., 1981; Calkins and Seideman, 1988; Diles et al., 1994; Eilers et al., 1996; O'Connor et al., 1997; Miller et al., 1997; Weatherly et al., 1998). Trying to fold the processes of postmortem aging and enhancement together has not been addressed, but is needed for the development of case-ready good manufacturing practices. In this investigation the impact of enhancement and postmortem aging on strip loin steaks is addressed in Figure 5. It appears that following 7 days, postmortem aging improved ($P < 0.05$) tenderness for enhanced strip loin steaks. In fact, enhanced strip steaks, regardless of postmortem aging time, were more tender than the non-enhanced strip loin samples which had received extended aging times (15 and 18 days post-enhancement). Even though a continual improvement was observed in enhanced strip loin steaks as a result of aging, this improvement was very negligible and all Warner-Bratzler shear values were

acceptable in tenderness. With clod steaks, a significant interaction (P = 0.013) existed between Quality grade and post-enhancement storage time on Warner-Bratzler shear force value (Figure 6). Weatherly et al. (1998) showed that shoulder clod steaks displayed a linear response in tenderness to aging, but that response was not statistically significant. Previous research findings have suggested the relationship between USDA Quality grade and "end-meat" tenderness was minimal. However, our findings suggest that clod steaks for US Select carcasses were initially tougher than US Choice clod steaks and this trend was evident until 19 days of aging (i.e., Aging = 7 days postmortem aging + 12 days of post-enhancement aging). These findings demonstrate that in order for US Select cuts to be utilized in case-ready programs, enhancement should be incorporated into the standard protocol of the production system. As demonstrated previously, enhancement enables tested USDA Quality grades (US Choice and US Select) to become non-factors with regard to postmortem aging effects.

Similar to clod steaks, top sirloin steaks also displayed an interaction (P = 0.027) between USDA Quality grade and post-enhancement aging time on Warner-Bratzler shear force values (Figure 7). Many would conclude that top sirloins will respond to postmortem aging for extended periods of time (i.e. $\geq$ 35 d postmortem). For example, Carpenter et al. (1976) stated that Warner-Bratzler shear force results declined in toughness from day 7 to day 35. In fact, Eilers et al. (1996) and Weatherly et al. (1998) concluded that top sirloin steaks display a slow, linear improvement in Warner-Bratzler shear force values up to 24 d of postmortem aging. The current results suggest that Select Quality top sirloin steaks followed these previous research findings in that a slow, gradual improvement in Warner-Bratzler shear force value was observed through post-enhancement storage days 9 to 18 (Figure 7). One interesting finding was that Choice top sirloin steaks did not respond to aging throughout the duration of the study. However, initial Choice top sirloin steaks (day 1) were as tender as 18 day post-enhancement aged Select steaks. Choice sirloin steaks did not show an improvement in Warner-Bratzler shear force until the last storage time (day 18) of the investigation.

Phase II

Overall Appearance

Panelist scores below 4.0 were representative of unacceptable product that would have been discriminated against due to its unfavorable appearance and not likely purchased by consumers at full retail value (Appendix C).

Strip loin steaks. The effect of enhancement application and USDA Quality grade on the overall appearance (OA) of strip loin steaks is shown in Figure 8. It should be mentioned that surprisingly non-enhanced US Choice strip loin steaks had significantly more desirable ($P < .05$) OA ratings than did their enhanced US Choice counterparts. A similar trend was found for non-enhanced US Select steaks having significantly higher ($P < .05$) OA scores when compared to enhanced Select steaks. Non-enhanced US Choice steaks performed identically to non-enhanced US Select steaks. However, the OA ratings as evaluated by panelists were least preferred for US Select steaks compared to other Quality grade: enhancement combination. The combined influence of storage period and retail display time on the OA of strip loin steaks is illustrated in Table 1. Steaks that were stored for 7 d had significantly higher ($P < 0.05$) OA scores for retail display days 3, 4, 5, and 7, when compared to steaks stored for 14 d. Still yet, steaks that were stored for all post-enhancement times were capable of obtaining at least 6 d of acceptable OA. Very strangely, steaks that were stored for 21 d showed an unacceptable OA rating on display day 5. This unexplainable blip in the data was stabilized in that OA rating on day 6 were scored as being acceptable.

Top sirloin steaks. Regardless of post-enhancement storage time, the maximum display time obtainable by top sirloin steaks was at the end of day 3 (Table 2). However, it should be mentioned that top sirloin steaks that were stored for 7 d following enhancement did complete 80% of day 4 in terms of overall acceptability. On the initial display day sirloin steaks from the 21 d storage period were considered less acceptable ($P < 0.05$) when compared to storage days 7 and 14 steaks. On display days 2 and 3, this similar trend was observed in that 7 and 14 day post-enhancement stored sirloin steaks are superior in terms of OA compared to the longer stored (21 d) top sirloin steaks. The role that enhancement application played in OA of top sirloin steaks differed between USDA Quality grades (Figure 9). This interaction illustrates that enhancing US Select top sirloin steaks significantly decreases ($P < .05$) the OA, whereas no impact on OA was observed in Choice top sirloin steaks

Shoulder Clod Steaks. The results in Table 3 overview retail display and post-enhancement storage period effects on OA of shoulder clod steaks. Steaks that were stored for 7 d showed the most days of acceptable OA, as they possessed desirable values for 5 d of retail display. Where as clod steaks stored for 14 d and 21 d post-enhancement, displayed OA which were rated as desirable for 4 and 3 d of retail display. It appeared that for every additional week of storage, OA decreased by one full day of retail display. For most retail display days 7 d storage period steaks had significantly higher OA scores than did those that received 14 d of storage ($P < 0.05$) and had significantly higher OA scores for all retail display days when compared to steaks that received 21 d of storage ($P < 0.05$). Furthermore, steaks that received 14 d of post-enhancement storage had significantly higher OA scores for most retail display days when compared to steaks that had received 21 d of storage ($P < 0.05$). An additional finding was the influence of enhancement on OA for shoulder clod steaks differed with different post-enhancement storage periods (Figure 10). For example, clods steaks receiving only 7 d of storage and enhanced demonstrated significantly higher OA scores when compared to their non-enhanced counterparts ($P < 0.05$). However, no enhancement influence on OA ($P > 0.05$) was noticed for clod steaks stored 14 d prior to retail display. However, at 21 d of storage, non-enhanced steaks had significantly higher OA scores than did enhanced clod steaks ($P < 0.05$). In summary, OA was negatively influenced by the enhancing procedure for clods that were stored for 21 d of storage.

Percent Discoloration

Consumers use color as an indicator of beef freshness, and will make a no-purchase decision when brown metmyoglobin (i.e. "surface browning") reaches 30 to 40% of total pigments on the surface of fresh beef (Greene, Hsin, & Zipser, 1971). Thus, panelist percent discoloration scores below 5.0 (Appendix C) were representative of unacceptable product that would have been discriminated against due to its unfavorable appearance and not likely purchased by consumers at full retail value.

Strip Loin Steaks Panelist scores indicated that the effect enhancement had on percent discoloration at different days of retail display was inconsistent between USDA Quality grades of strip loin steaks as illustrated in Table 4. Non-enhanced US Select strip loin steaks had a greater amount of discoloration on all days of retail display compared to Select non-enhanced strip steaks. In fact, on days 4 to 8, the magnitude of the difference between enhanced and non-enhanced Select strip loin steaks became greater ($P < 0.05$) in that non-enhanced steaks were more stable during retail display. It should also be mentioned that enhanced US Select steaks were the only group that displayed more than 10% of discoloration after 4 d of retail display. In terms of US Choice strip loin steaks, enhancement application had little influence on percent discoloration.

Top Sirloin Steaks. The role of enhancement application on top sirloin steaks, as shown in Figure 11, varied between USDA Quality grades in that enhanced US Choice steaks had significantly less lean surface discoloration as compared to non-enhanced US Choice steaks ($P < 0.05$). This action was the opposite for US

Select top sirloin steaks as enhanced US Select steaks had significantly more lean surface discoloration when compared to their non-enhanced Select counterparts ($P < 0.05$). USDA Quality grade influenced the rate at which top sirloin steaks discolored as shown in Table 5. Choice top sirloin steaks had significantly less lean discoloration on display day 6, and had 1 more day of acceptable percent discoloration scores when compared to US Select steaks. Much like strip loin steaks, top sirloin steaks stored for fewer days (storage d 7) discolored at a slower rate than d 14 and 21 storage treatments (Table 6). As shown, steaks stored for 7 d had 1 more day of acceptable surface discoloration scores when compared to steaks stored for 14 and 21 d. Steaks stored for 14 d had less ($P < 0.05$) discoloration on d 3 of retail display than did steaks stored for 21 d. However, both storage periods were still acceptable from a percent discoloration standpoint at 5 d of simulated retail display.

Shoulder Clod Steaks. As shown in Figure 12, enhancement effects on percent lean surface discoloration of shoulder clod steaks were different between USDA Quality grades. For US Choice steaks, no significant differences ($P > 0.05$) were observed for percent lean discoloration for enhanced and non-enhanced steaks. However, enhanced US Select steaks had significantly less surface discoloration than did non-enhanced US Select steaks ($P < 0.05$). The three-way interaction between post-enhancement storage period, enhancement application, and retail display time on percent discoloration scores for shoulder clod steaks is illustrated in Table 7. As expected, shoulder clod steaks that were stored for fewer days (7 d) discolored at a slower rate compared to extended storage times. Additionally, enhanced steaks that were stored for only 7 d had significantly less ($P < .05$) discoloration on d 6 and 7 of retail display and showed to have 1 more day of acceptable lean discoloration when compared to non-enhanced steaks that were stored for 7 d. Steaks stored for 14 d seemed to experience very similar effects. Enhanced steaks that were stored for 14 d had significantly less discoloration on d 5 and 6 of retail display than did non-enhanced steaks that were stored for 14 d, but for both enhanced and non-enhanced treatments, there were 6 d of acceptable time based on percent discoloration scores. Steaks stored for 21 d, displayed 5 d of acceptable appearance based on percent discoloration, regardless of enhancement.

Lean Color

Consumers use lean color as an indicator of beef freshness, and will make a no-purchase decision when surface browning (metmyoglobin) reaches 30 to 40% of total pigments on the surface of fresh beef (Greene, Hsin, & Zipser, 1971). Thus, panelist scores below 5.0 (Appendix C) were representative of unacceptable product that would have been discriminated against due to unfavorable appearance and not likely purchased by consumers at full retail value.

Strip Loin Steaks. The effect of enhancement and USDA Quality grade on strip loin steak lean color characteristics is shown in Figure 13. This interaction was very similar to the enhancement and USDA Quality grade effect on OA of strip loin steaks. Non-enhanced US Choice steaks were not different ($P > 0.05$) from non-enhanced US Select steaks. However, non-enhanced US Choice steaks had significantly more desirable ($P < 0.05$) lean color scores than did enhanced

US Choice steaks. Also, non-enhanced US Select steaks had significantly higher lean color scores when compared to enhanced US Select steaks. Furthermore, enhanced US Choice steaks had higher ($P < 0.05$) lean color scores than did enhanced US Select steaks, thus showing that enhancement inhibited US Select steaks more so than it did US Choice strip loin steaks as evaluated by trained panelists. The interaction between storage period and retail display day is shown in Table 8. As shown, steaks that were stored for only 7 d had 1 additional day of acceptable lean color than strip loin steaks stored for 21 d. Very uncharacteristically, steaks stored for 21 d had 1 more day of acceptable lean color scores than steaks stored for 14 d. However, due to the observation that at all days of display, with the exception of d 6, steaks stored for 14 d had numerically higher lean color scores than steaks stored for 21d, one must question the integrity of the value associated with 14 d of storage at 6 d of retail display.

Top Sirloin Steaks. There was no enhancement effect or interaction involving enhancement ($P > 0.05$) for lean color stability of top sirloin steaks. However, an interaction between storage period and retail display time on their influence of top sirloin lean color is shown in Table 9. Steaks stored for 7 d clearly showed an advantage to those stored for 14 and 21 d, as evidenced by their ability to maintain acceptable lean color scores for 5 d of retail display. Steaks stored for 14 and 21 d possessed acceptable lean color scores for only 3 d of retail display. This advantage is further shown as steaks stored for 7 d had significantly higher lean color scores on d 1, 3, 4, 5, 6, and 7 of retail display ($P < 0.05$) when compared to steaks stored for 14 and 21 d. Additionally, steaks stored for 14 d had significantly higher lean color scores on d 1, 3, 4, 5, 6, and 7 of retail display ($P < 0.05$) when compared to steaks stored for 21 d. The effect of USDA Quality grade and retail display time on lean color of top sirloin steaks is displayed in Table 10. As shown, US Choice steaks possessed significantly higher lean color scores on d 6, 7, and 8 of retail display than do US Select steaks ($P < .05$). However, there seems to be no practical significance of this interaction due to the observation that both USDA Choice and Select steaks have 3 d of acceptable lean color scores, and for those 3 d there was no significant difference in lean color scores ($P > 0.05$).

Shoulder Clod Steaks. The interaction of storage period and enhancement application on the lean color of shoulder clod steaks is illustrated in Figure 14. As shown, for both 7 and 14 d of storage, no significant difference ($P > 0.05$) in lean color was evident between enhanced and non-enhanced clod steaks. However, at 21 d of storage non-enhanced steaks had significantly brighter lean color scores than enhanced steaks stored for 21 d. It should also be mentioned that both enhanced and non-enhanced steaks stored for shorter periods (Day 7 and 14) had significantly higher lean color scores when compared to steaks that were stored for 21 d. Table 11 shows the effect of post-enhancement storage period and retail display time on the lean color stability of shoulder clod steaks. As shown, steaks stored for 7 d had 1 additional day of acceptable lean color scores when compared to steaks stored for 14 d and 21 days respectively.

Fat Color

Panelist scores below 5.0 (Appendix C) were representative of unacceptable product that would have been discriminated against due to its unfavorable appearance and not likely purchased by consumers at full retail value. *Strip Loin Steaks.* The influence of enhancement application on fat color varied among storage periods as shown in Figure 15. For steaks stored for 7 or 14 d, no differences ($P > 0.05$) were observed between enhanced and non-enhanced treatments within each storage period. However, non-enhanced steaks stored for 21 d had significantly whiter fat color scores when compared to enhanced steaks stored for the same length of time. It should also be mentioned that fat color scores significantly decreased from 7 d of storage to 14 d of storage for both enhanced and non-enhanced steaks ($P < 0.05$). There was also a significant decrease in fat color scores from enhanced steaks stored for 14 d to enhanced steaks stored for 21 d ($P < .05$). The interaction between post-enhancement storage period and retail display time on strip loin steak fat color is displayed in Table 12. As shown, steaks stored for 7 d had significantly whiter ($P < 0.05$) fat color scores on d 1, 3, 4, and 5 of retail display when compared to steaks stored for 14 d.

Top Sirloin Steaks. The effect that enhancement application on top sirloin steaks varied between USDA Quality grades as shown by Figure 16. As shown, enhanced US Choice top sirloin steaks had significantly whiter ($P < 0.05$) fat color scores than non-enhanced US Choice steaks. The effect of enhancement was not present in US Select steaks as there was no difference ($P > 0.05$)

between enhanced and non-enhanced steaks in terms of fat color stability. It should also be mentioned that enhanced US Choice steaks had significantly whiter ($P < 0.05$) fat color scores than enhanced and non-enhanced US Select steaks. The influence of post-enhancement storage period and retail display time on the fat color stability of top sirloin steaks is shown in Table 13. As expected, fat color scores from steaks stored for fewer days decreased at a slower rate than steaks stored for longer periods. Steaks stored for 7 d had acceptable fat color scores for 1 additional day than steaks stored for 14 d and had 2 additional days of acceptable fat color scores when compared to steaks stored for 21 d.

Shoulder Clod Steaks. Even though it was very small, a consistent influence of enhancement on shoulder clod steaks displayed whiter fat color than non-enhanced steaks (Figure 17).

Objective Color.

CIE color readings (L*, a*, b*) were taken as an objective measure of lean color and reported in tables 20-29. Values indicate that enhancement of strip loins produced steaks that were darker in color, less red, and less yellow when compared to non-enhanced strip loin steaks ($P < .05$). The same effect was shown in top sirloin steaks, as enhanced steaks were darker in color, less red, and less yellow than non-enhanced steaks ($P < .05$). However, shoulder clod steaks displayed no difference between enhancement treatments ($P > .05$). Steaks from all three subprimals became less red as steaks were displayed for an increased number of days ($P < .05$) and, top sirloin steaks became less yellow as they were displayed for an increased number of days ($P < .05$). Also, strip loin steaks were less red as they were stored for a greater number of days. However, top sirloin and shoulder clod steaks did not exhibit this same effect. US Choice top sirloin steaks were brighter and redder than US Select top sirloin steaks ($P < .05$). The increase in brightness could be partially due to a greater percentage of intramuscular fat.

Lipid oxidation.

Reducing lipid oxidation is a driving force behind extending fresh product retail shelf life. One indicator of the presence of lipid oxidation is the presence of thiobarbituric acid reactive substances (TBARS). Many research investigations have characterized meat samples having a TBARS level of 1.0 as having oxidative flavors that could be detected by trained consumer panelists. Most modified atmosphere packaging systems utilized purified oxygen that promotes oxidation of fresh meat samples. Many commercially available case-ready fresh beef systems utilize various antioxidants, which will retard the formation of oxidation in end products. In this study estimates of lipid oxidation on the surface of samples were made using the thiobarbituric acid (TBA) analysis and reported in Tables 14-19. It became very evident that as retail display time increased so did presence of TBARS. However, enhancement significantly reduced TBARS levels on day 8 of retail display for all storage periods and subprimals ($P < .05$). This can largely be attributed to the antioxidant properties of rosemary oleoresin. When combined with sodium tripolyphosphate, rosemary oleoresin decreased oxidative rancidity and increased the flavor preference of pre-cooked roast beef slices that were stored frozen (Murphy et al., 1998). Lai et al. (1991) showed that rosemary oleoresin and sodium tripolyphosphate decreased the amount of TBARS in chicken nuggets stored fresh and frozen. The effect of rosemary also was investigated using restructured beef as a model, showing that it was very effective at reducing TBARS during frozen storage; more so than sodium tripolyphosphate alone (Stoick et al., 1991).

Implications

Injecting beef strip loins, top sirloin butts, and shoulder clods with solutions containing sodium chloride, sodium tripolyphosphate, and rosemary oleoresin offers potential for enhancing tenderness. At the same time, enhancing with this solution generally inhibited color stability by one day. Application of this technology(Appendix D) may assist U.S. beef processors and purveyors in their efforts to develop good manufacturing practices for their case-ready beef program, thus enhancing beef demand. Our study was limited to USDA Select and Choice cuts which were injected at a common time postmortem. Additional studies involving lower grades of beef and multiple postmortem injection times should be conducted to fully grasp enhancement potential.

Table 1. Influence of post-enhancement storage period[1] and retail display time on the overall appearance[2] of strip loin steaks.

Storage Period, day	Retail display, day 1	2	3	4	5	6	7	8
7	7.00^{a}	6.55^{bc}	6.36^{c}	5.65^{d}	4.71^{f}	4.09^{hi}	3.65	3.41
14	6.94^{a}	6.45^{bc}	5.81^{d}	4.90^{f}	4.35^{g}	4.04^{hi}	3.43	3.21
21	6.66^{b}	6.39^{c}	5.31^{e}	4.23^{gh}	3.98^{i}	4.41^{g}	3.27	2.97

[1] Storage Period: days of storage following enhancement.

[2] Overall Appearance: 7 = extremely desirable, 4 = acceptable, 1 = extremely undesirable.

[a,b,c,d,e,f,g,h,i] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

General note: Shaded area corresponds to unacceptable appearance.

Table 2. Influence of storage period[1] and retail display time on the overall appearance[2] of top sirloin steaks.

Storage, day[2]	Retail display, day							
	1	2	3	4	5	6	7	8
7	6.99[a]	6.34[bc]	5.57[e]	3.99	3.36	2.89	2.24	1.73
14	6.96[a]	6.19[cd]	5.07[f]	3.57	3.07	2.55	2.23	1.46
21	6.46[b]	6.06[d]	4.50[g]	3.13	2.83	2.38	2.22	1.23

[1] Storage Period: days of storage following enhancement.

[2] Overall Appearance: 7 = extremely desirable, 4 = acceptable, 1 = extremely undesirable.

[a,b,c,d,e,f,g] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

General note: Shaded area corresponds to unacceptable overall appearance.

Table 3. Influence of post-enhancement storage period[1] and retail display time on the overall appearance[2] of shoulder clod steaks.

	Retail display, day							
Storage, day[2]	1	2	3	4	5	6	7	8
7	6.93^{a}	6.44^{c}	5.98^{e}	5.51^{f}	4.41^{h}	3.69	2.58	1.97
14	6.97^{a}	6.30^{cd}	5.39^{f}	4.24^{h}	3.73	3.43	2.29	1.80
21	6.67^{b}	6.21^{d}	4.74^{g}	3.35	3.04	3.14	2.26	1.61

[1] Storage Period: days of storage following enhancement.

[2] Overall Appearance: 7 = extremely desirable, 4 = acceptable, 1 = extremely undesirable.

[a,b,c,d,e,f,g,h] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

General note: Shaded area corresponds to unacceptable appearance.

Table 4. Influence of enhancement solution application, USDA Quality grade and retail display time on the percent discoloration[1] of strip loin steaks.

Retail display, day	US Choice		US Select	
	Enhanced	Non-enhanced	Enhanced	Non-enhanced
1	6.98^{ab}	7.00^{a}	6.98^{ab}	7.00^{a}
2	6.91^{ab}	6.99^{a}	6.90^{ab}	6.97^{ab}
3	6.66^{c}	6.83^{abc}	6.66^{c}	6.78^{bc}
4	$6.27d^{ef}$	6.43^{d}	6.10^{fgh}	6.36^{de}
5	6.06^{ghi}	6.16^{efg}	5.88^{hi}	6.23^{defg}
6	5.84^{i}	5.85^{i}	5.54^{j}	5.91^{hi}
7	5.31^{k}	5.28^{kl}	5.04^{lm}	5.43^{jk}
8	4.91^{m}	4.65^{n}	4.44^{n}	4.91^{m}

[1]Percent discoloration: 7 = none; 5 = 11-25%; 3 = 51-75%; 1 = complete.
[a,b,c,d,e,f,g,h,i,j,k,l,m,n] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was P = 0.0075.

Table 5. Influence of USDA Quality grade and retail display time on the percent discoloration[1] of top sirloin steaks.

	Retail display, day							
USDA Quality grade	1	2	3	4	5	6	7	8
Choice	7.00^{a}	6.86^{a}	6.57^{b}	5.72^{c}	5.39^{d}	5.03^{e}	4.07	3.18
Select	7.00^{a}	6.84^{a}	6.56^{b}	5.73^{c}	5.28^{d}	4.52	3.48	2.62

[1] Percent discoloration: 7 = none; 5 = 11-25%; 3 = 51-75%; 1 = complete.

[a,b,c,d,e] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

General note: Shaded area corresponds to unacceptable lean color.

Table 6. Influence of post-enhancement storage period[1] and retail display time on the percent discoloration[2] of top sirloin steaks.

	Retail display, day							
Storage, day[2]	1	2	3	4	5	6	7	8
7	7.00^{a}	7.00^{a}	6.92^{ab}	6.47^{cd}	5.78^{e}	5.18^{f}	4.18	3.16
14	7.00^{a}	6.84^{b}	6.54^{c}	5.71^{e}	5.19^{f}	4.75	3.72	2.92
21	7.00^{a}	6.71^{bc}	6.23^{d}	5.00^{fg}	5.05^{f}	4.41	3.44	2.62

[1] Storage period: days of storage following enhancement.

[2] Percent discoloration: 7 = none; 5 = 11-25%; 3 = 51-75%; 1 = complete.

[a,b,c,d,e,f,g] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

General note: Shaded area corresponds to unacceptable appearance.

Table 7. Influence of post-enhancement storage period[1], enhancement solution application, and retail display time on percent discoloration[2] in shoulder clod steaks.

Retail display, day	Storage period, d: Treatment					
	7		14		21	
	Enhanced	Non-enhanced	Enhanced	Non-enhanced	Enhanced	Non-enhanced
1	7.00^{a}	7.00^{a}	6.98^{a}	7.00^{a}	7.00^{a}	7.00^{a}
2	7.00^{a}	7.00^{a}	6.94^{a}	6.88^{ab}	6.80^{abc}	6.87^{ab}
3	7.00^{a}	7.00^{a}	6.69^{bcd}	6.79^{abc}	6.47^{d}	6.43^{de}
4	7.00^{a}	6.92^{ab}	5.79^{g}	5.70^{g}	5.43^{hij}	5.55^{ghi}
5	6.80^{abc}	6.59^{cd}	6.08^{f}	5.77^{g}	5.10^{kl}	5.25^{jk}
6	6.19^{ef}	5.77^{g}	5.67^{gh}	5.33^{ijk}	4.70^{m}	4.83^{lm}
7	5.54^{ghi}	4.70^{m}	4.70^{m}	4.27^{n}	3.69	3.83
8	3.77	3.30	3.45	3.05^{r}	2.94	2.96

[1] Storage period: days of storage following enhancement.

[2] Percent discoloration: 7 = none; 5 = 11-25%; 3 = 51-75%; 1 = complete.

a,b,c,d,e,f,g,h,I,j,k,l,m,n, Means lacking a common superscript differ ($P < .05$). The significance of this interaction was $P < .0001$.

General note: Shaded area corresponds to unacceptable appearance.

Table 8. Influence of post-enhancement storage period[1] and retail display time on the lean color[2] of strip loin steaks.

	Retail display, day							
Storage, day	1	2	3	4	5	6	7	8
7	7.09[a]	6.49[b]	6.10[c]	6.06[c]	5.79[de]	5.47[f]	5.00[hij]	4.43
14	7.02[a]	6.45[b]	6.06[c]	5.55[ef]	5.35[fg]	4.88	4.79	4.50
21	6.50[b]	6.42[b]	5.99[cd]	5.19[gh]	5.16[gh]	5.13[ghi]	4.62	4.37

[1] Storage period: days of storage following enhancement.

[2] Lean color: 8 = bright cherry-red; 4 = moderately dark-red or brown; 1 = extremely dark-brown.

[a,b,c,d,e,f,g,h,I,j] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

General note: Shaded area corresponds to unacceptable lean color.

Table 9. Influence of storage period[1] and retail display time on the lean color[2] of top sirloin steaks.

	Retail display, day							
Storage, day	1	2	3	4	5	6	7	8
7	6.98[a]	5.97[cd]	5.80[cd]	5.21[f]	5.00[f]	4.72	3.88	2.94
14	6.64[b]	5.86[cd]	5.54[e]	4.68	4.68	4.34	3.54	2.82
21	6.08[c]	6.02[cd]	5.24[f]	4.10	4.19	3.90	3.19	2.80

[1] Storage period: days of storage following enhancement.

[2] Lean color: 8 = bright cherry-red; 4 = moderately dark-red or brown; 1 = extremely dark-brown.

[a,b,c,d,e,f] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

General note: Shaded area corresponds to unacceptable lean color.

Table 10. Influence of USDA Quality grade and retail display time on the lean color[1] of top sirloin steaks.

USDA Quality grade	Retail display, day							
	1	2	3	4	5	6	7	8
Choice	6.58[a]	5.94[b]	5.55[c]	4.62	4.71	4.44	3.65	3.13
Select	6.56[a]	5.95[b]	5.50[c]	4.71	4.54	4.20	3.42	2.58

[1] Lean color: 8 = bright cherry-red; 4 = moderately dark-red or brown; 1 = extremely dark-brown.

[a,b,c] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P = 0.0008$.

General note: Shaded area corresponds to unacceptable lean color.

Table 11. Influence of post-enhancement storage period[1] and retail display time on the lean color[2] of shoulder clod steaks.

	Retail display, day							
Storage, day	1	2	3	4	5	6	7	8
7	6.64^{a}	6.17^{b}	5.83^{c}	5.82^{c}	5.41^{d}	5.16^{e}	4.49^{hi}	3.26
14	6.68^{a}	6.09^{b}	5.50^{d}	5.00^{ef}	5.08^{e}	4.83^{fg}	4.15^{j}	3.21
21	6.14^{b}	6.13^{b}	5.18^{e}	4.34^{ij}	4.69^{gh}	4.48^{hi}	3.72	3.24

[1] Storage period: days of storage following enhancement.

[2] Lean color: 8 = bright cherry-red; 4 = moderately dark-red or brown; 1 = extremely dark-brown.

[a,b,c,d,e,f,g,h,i,j]Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

General note: Shaded area corresponds to unacceptable lean color.

Table 12. Influence of post-enhancement storage period[1] and retail display time on the fat color[2] of strip loin steaks.

	Retail display, day							
Storage, day	1	2	3	4	5	6	7	8
7	7.58^{a}	6.98^{bc}	6.43^{e}	6.25^{ef}	5.64^{h}	5.31^{ij}	4.45^{l}	4.39^{lm}
14	7.13^{b}	6.85^{cd}	6.19^{f}	5.74^{gh}	5.42^{i}	5.17^{j}	4.53^{l}	4.23^{m}
21	6.88^{cd}	6.69^{d}	5.89^{g}	5.23^{ij}	5.28^{ij}	5.15^{j}	4.89^{k}	4.46^{l}

[1] Storage period: days of storage following enhancement.

[2] Fat color: 8 = creamy white; 5 = tan; 3 = moderately brown.

[a,b,c,d,e,f,g,h,i,j,k,l,m] Means that do not share a common superscript are significantly different ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

Table 13. Influence of post-enhancement storage period[1] and retail display time on the fat color[2] of top sirloin steaks.

	Retail display, day							
Storage, day	1	2	3	4	5	6	7	8
7	7.04[a]	6.73[b]	5.76[d]	5.45[e]	4.72	3.94	3.06	3.16
14	6.89[ab]	6.36[c]	5.20[e]	3.90	4.28	3.93	3.40	3.26
21	6.78[b]	5.88[d]	4.68	3.33	3.76	3.94	3.49	3.38

[1] Storage period: days of storage following enhancement.

[2] Fat color: 8 = creamy white; 5 = tan; 3 = moderately brown.

[a,b,c,d,e] Means that do not share a common superscript are significantly different ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

General note: Shaded area corresponds to unacceptable appearance.

Table 14. Effect of post-enhancement storage period[1], enhancement solution application, and retail display time on lipid oxidation[2] of strip loin steaks.

	Storage period/treatment					
	7		14		21	
Retail display, day	Enhanced	Non-enhanced	Enhanced	Non-enhanced	Enhanced	Non-enhanced
1	0.51^{cd}	1.23^{c}	0.05^{d}	0.55^{cd}	0.17^{d}	0.71^{cd}
8	0.73^{cd}	2.54^{b}	0.75^{cd}	2.00^{b}	0.65^{cd}	3.82^{a}

^{a,b,c,d}Means lacking a common superscript differ ($P < 0.05$).

[1]Storage period: days of storage following enhancement.

[2]Lipid oxidation: means recorded in mg of malonaldehyde/kg of tissue.

Table 15. Effect of post-enhancement storage period[1], enhancement solution application, and retail display time on lipid oxidation[2] of shoulder clod steaks.

	Storage period/treatment					
	7		14		21	
Retail display, day	Enhanced	Non-enhanced	Enhanced	Non-enhanced	Enhanced	Non-enhanced
1	0.42^{fg}	0.81^{ef}	0.17^{g}	0.46^{fg}	0.28^{fg}	0.55^{fg}
8	0.54^{fg}	3.58^{b}	1.36^{de}	4.76^{a}	1.45^{d}	2.92^{c}

[a,b,c,d,e,f,g]Means lacking a common superscript differ ($P < .05$).

[1]Storage period: days of storage following enhancement.

[2]Lipid oxidation: means recorded in mg of malonaldehyde/kg of tissue.

Table 16. Effect of post-enhancement storage period[1], USDA Quality grade, and retail display time on lipid oxidation[2] of shoulder clod steaks.

	Storage period/treatment					
	7		14		21	
Retail display, day	US Choice	US Select	US Choice	US Select	US Choice	US Select
1	0.95^{e}	0.92^{e}	0.30^{e}	0.41^{e}	0.90^{e}	1.02^{e}
8	2.34^{d}	3.28^{c}	2.98^{cd}	4.32^{a}	4.22^{ab}	3.36^{bc}

^{a,b,c,d,e}Means lacking a common superscript differ ($P < .05$).

[1]Storage period: days of storage following enhancement.

[2]Lipid oxidation: means recorded in mg of malonaldehyde/kg of tissue.

Table 17. Effect of enhancement solution application, USDA Quality grade, and retail display time on lipid oxidation[1] of top sirloin steaks.

Retail Display, day	USDA quality grade/treatment			
	US Choice		US Select	
	Enhanced	Non-enhanced	Enhanced	Non-enhanced
1	0.44^{e}	1.00^{de}	0.57^{e}	1.00^{de}
8	1.85^{c}	4.50^{b}	1.50^{cd}	5.81^{a}

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

[1]Lipid oxidation: means recorded in mg of malonaldehyde/kg of tissue.

Table 18. Effect of enhancement solution application, USDA Quality grade, and retail display time on lipid oxidation[1] of shoulder clod steaks.

Retail Display, day	USDA quality grade/treatment			
	US Choice		US Select	
	Enhanced	Non-enhanced	Enhanced	Non-enhanced
1	0.22^{e}	0.40^{de}	0.36^{de}	0.81^{cd}
8	1.23^{c}	3.07^{b}	1.00^{c}	4.44^{a}

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

[1]Lipid oxidation: means recorded in mg of malonaldehyde/kg of tissue.

Table 19. Effect of USDA quality grade, and storage period[1] on lipid oxidation[2] of top sirloin steaks.

	Storage Period		
USDA quality grade	7	14	21
US Choice	1.24^{ab}	0.66^{c}	1.70^{a}
US Select	1.26^{ab}	1.01^{bc}	0.98^{bc}

^{a,b,c}Means lacking a common superscript differ ($P < 0.05$).

[1]Storage, day: days of storage following enhancement.

[2]Lipid oxidation: means recorded in mg of malonaldehyde/kg of tissue.

Table 20. Effect of enhancement solution application on objective color values of strip loin steaks.

Treatment	L*	a*	b*
Enhanced	36.00^{a}	16.96^{a}	8.94^{a}
Non-enhanced	37.06^{b}	18.15^{b}	9.39^{b}

[a,b] Means in a column, lacking a common superscript differ ($P < .05$).

Table 21. Effect of post-enhancement storage period[1] and day of display on b* values of strip loin steaks.

Retail Display, day	Storage Period		
	7	14	21
1	9.60[ab]	8.89[c]	8.74[c]
8	9.12[bc]	9.67[a]	8.96[c]

[a,b,c] Means lacking a common superscript differ (P < .05).

[1]Storage period: days of storage following enhancement.

Table 22. Effect of post-enhancement storage period[1] and USDA Quality grade on L* values of strip loin steaks.

USDA Quality grade	Storage Period		
	7	14	21
US Choice	35.95[bc]	36.58[ab]	37.75[a]
US Select	35.29[c]	37.46[a]	36.18[b]

[a,b,c] Means lacking a common superscript differ ($P < .05$).

[1]Storage period: days of storage following enhancement.

Table 23. Effect of storage period[1] on a* values of strip loin steaks.

	Storage Period		
	7	14	21
a*	18.68^a	17.63^a	16.36^b

[a,b] Means lacking a common superscript differ ($P < .05$).

[1]Storage period: days of storage following enhancement.

Table 24. Effect of retail display time on L* and a* values of strip loin steaks.

Retail Display, day	L*	a*
1	36.12[a]	18.31[a]
8	36.94[b]	16.80[b]

[a,b] Means in a column, lacking a common superscript differ ($P < .05$).

Table 25. Effect of USDA Quality grade on L* and a* values of top sirloin steaks.

USDA Quality grade	L*	a*
US Choice	36.90^{a}	19.12^{a}
US Select	35.98^{b}	17.02^{b}

^{a,b} Means in a column, lacking a common superscript differ (P < .05).

Table 26. Effect of enhancement solution application on objective color values of top sirloin steaks.

Treatment	L*	a*	b*
Enhanced	35.74^{a}	17.75^{a}	10.74^{a}
Non-enhanced	37.15^{b}	18.39^{a}	11.75^{b}

^{a,b} Means in a column, lacking a common superscript differ ($P < .05$).

Table 27. Effect of post-enhancement storage period[1] and time of display on a* values of top sirloin steaks.

Retail Display, day	Storage Period		
	7	14	21
1	22.54[a]	23.16[a]	22.20[a]
8	15.46[b]	11.62[d]	13.45[c]

[a,b,c] Means lacking a common superscript differ ($P < .05$).

[1]Storage period: days of storage following enhancement.

Table 28. The effect of post-enhancement storage period[1], USDA Quality grade, and retail display time on b* values of top sirloin steaks.

	USDA Quality grade/retail display, d			
	US Choice		US Select	
Storage Period, d	1	8	1	8
7	12.58[a]	10.70[bc]	12.45[a]	10.42[cd]
14	12.70[a]	11.23[b]	10.31[cd]	11.07[bc]
21	12.98[a]	9.98[d]	10.63[bcd]	9.90[d]

[a,b,c,d]Means lacking a common superscript differ ($P < .05$).

[1]Storage period: days of storage following enhancement.

Table 29. Effect of post-enhancement storage period[1] and retail display time on a* and b* values of shoulder clod steaks.

	Storage period/retail display, d					
	7		14		21	
	1	8	1	8	1	8
a*	20.26^{b}	17.08^{c}	23.20^{a}	11.62^{d}	21.20^{ab}	13.32^{d}
b*	9.18^{c}	10.08^{a}	10.92^{ab}	9.44^{bc}	9.78^{ab}	8.92^{c}

[a,b,c,d]Means in a row, lacking a common superscript letter differ ($P < .05$).

[1]Storage period: days of storage following enhancement.

Table 30. Influence of storage period[1] and retail display time on the percent discoloration[2] of strip loin steaks.

	Retail display, day							
Storage, day[2]	1	2	3	4	5	6	7	8
7	7.00[a]	7.00[a]	7.00[a]	6.96[ab]	6.81[bc]	6.33[e]	5.83[f]	4.96
14	6.98[ab]	6.95[ab]	6.69[cd]	6.28[e]	5.98[f]	5.43[h]	5.18	4.84
21	6.99[a]	6.88[ab]	6.52[d]	5.65[g]	5.45[h]	5.60[gh]	4.81	4.38

[1] Storage period: days of storage following enhancement.

[2] Percent discoloration: 7 = none; 5 = 11-25%; 3 = 51-75%; 1 = complete.

[a,b,c,d,e,f,g,h] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

General note: Shaded area corresponds to unacceptable appearance.

Table 31. Influence of post-enhancement storage period[1] and retail display time on the fat color[2] of shoulder clod steaks.

	Retail display, day							
Storage, day	1	2	3	4	5	6	7	8
7	7.11[a]	6.83[bc]	5.89[e]	5.46[f]	4.85[g]	4.39[hi]	3.45	3.34
14	6.92[ab]	6.46[d]	5.54[f]	4.83[g]	5.48[f]	4.43[hi]	3.57	3.34
21	6.66[cd]	6.12[e]	4.99[g]	4.13[j]	4.20[ij]	4.50[h]	3.56	3.59

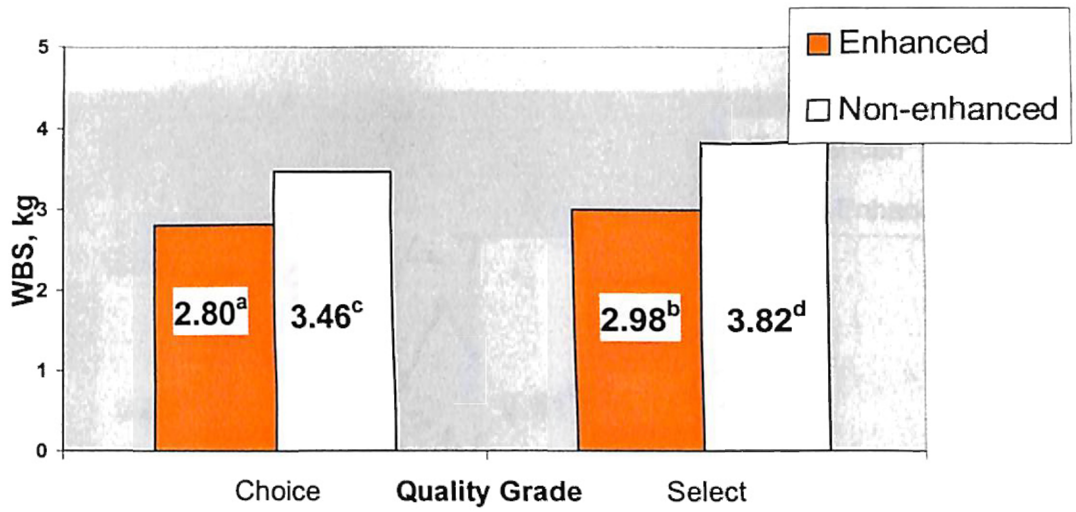
[1] Storage period: days of storage following enhancement.

[2] Fat color: 8 = creamy white; 5 = tan; 3 = moderately brown.

[a,b,c,d,e,f,g,h,i] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

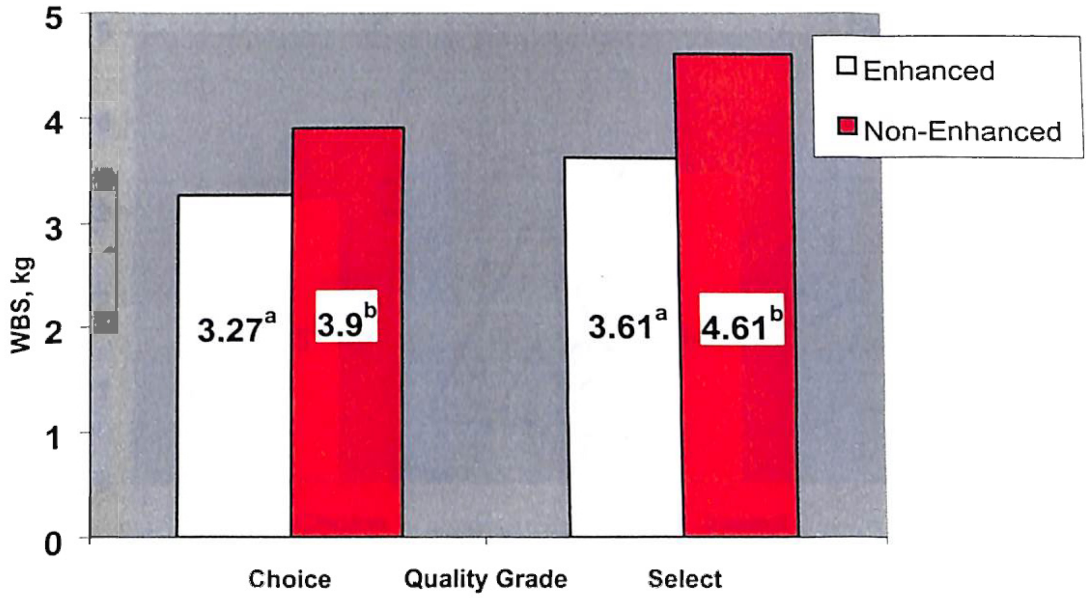
General note: Shaded area corresponds to unacceptable appearance.

Figure 1. Impact of quality grade and enhancement solution application on Warner-Bratzler shear force values of strip loin steaks.



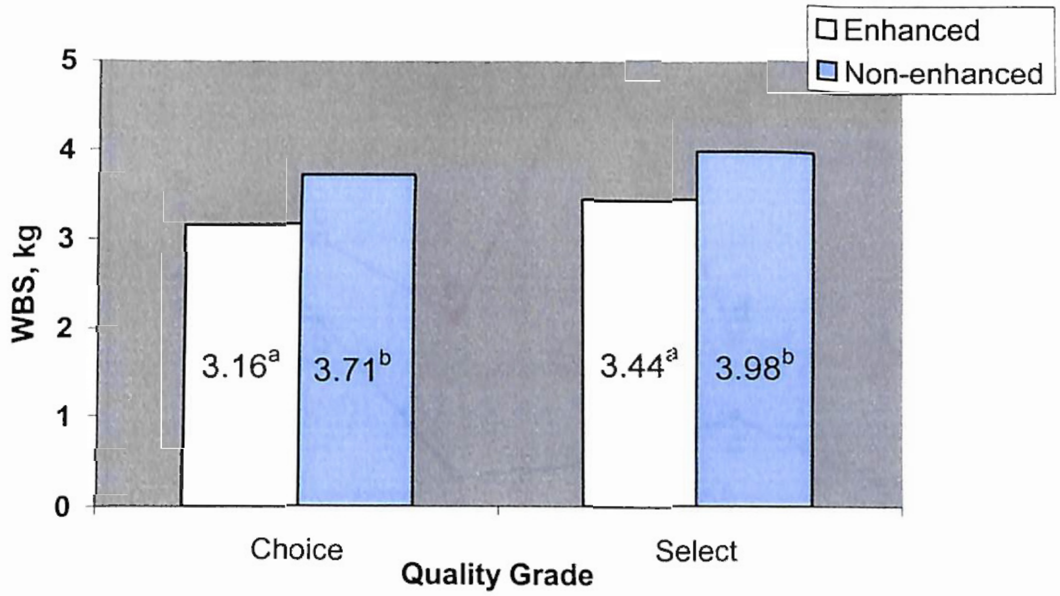
a,b,c,d Means lacking a common superscript letter differ ($P < 0.05$).

Figure 2. Influence of enhancement solution application on Warner-Bratzler shear force values for top sirloin steaks stratified by quality grade.



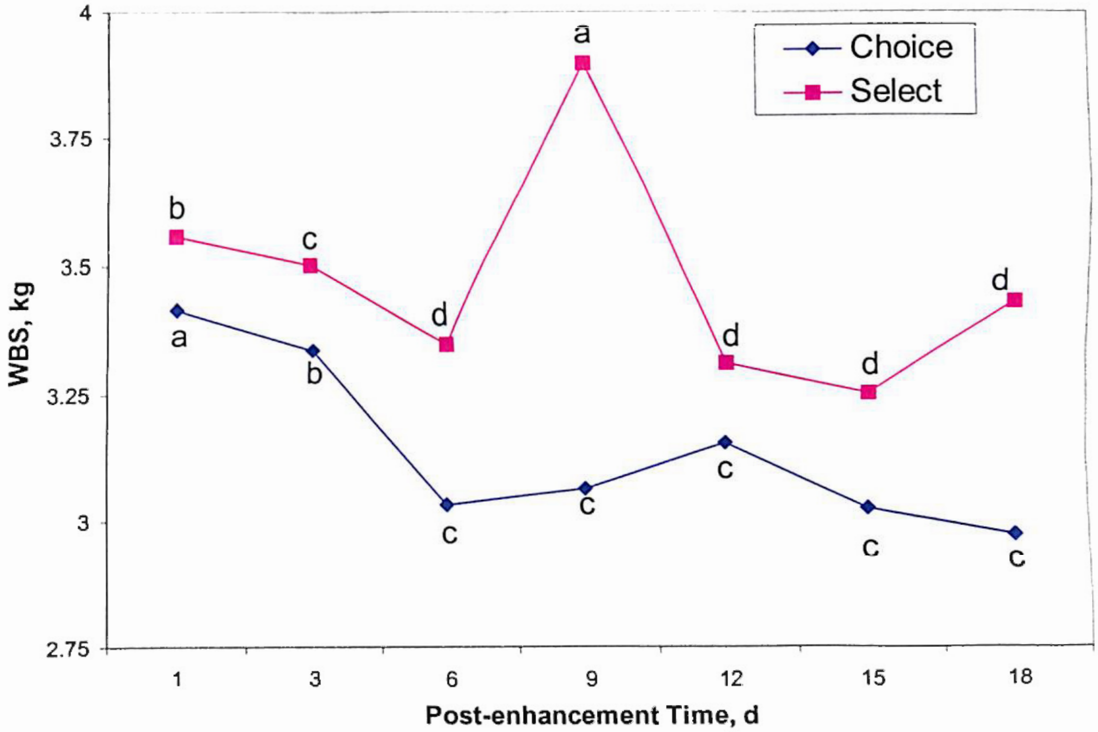
[a,b] Means within a Quality grade lacking a common superscript letter differ ($P < 0.001$).

Figure 3. Influence of enhancement solution application on Warner-Bratzler shear force values for clod steaks stratified by quality grade.



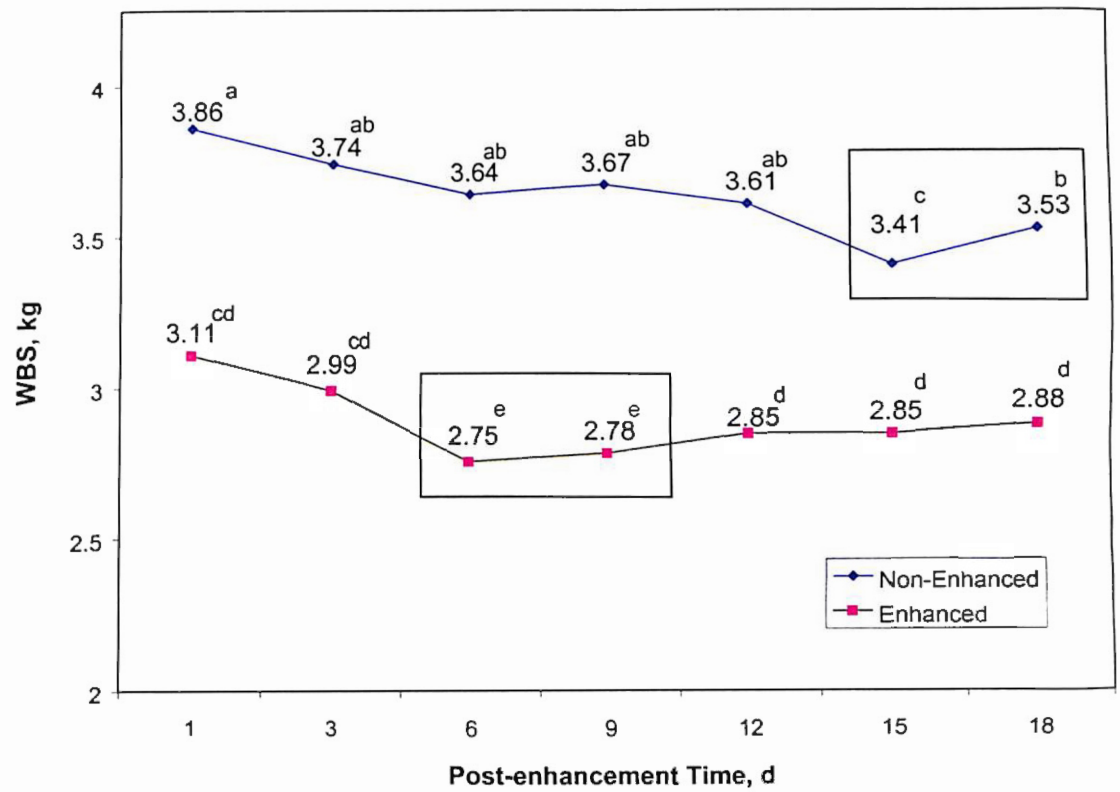
a,b Means within a Quality grade lacking a common superscript letter differ ($P < 0.001$).

Figure 4. Influence of post-enhancement time on Warner-Bratzler shear (WBS) force values for strip loin steaks stratified by USDA Quality grade.



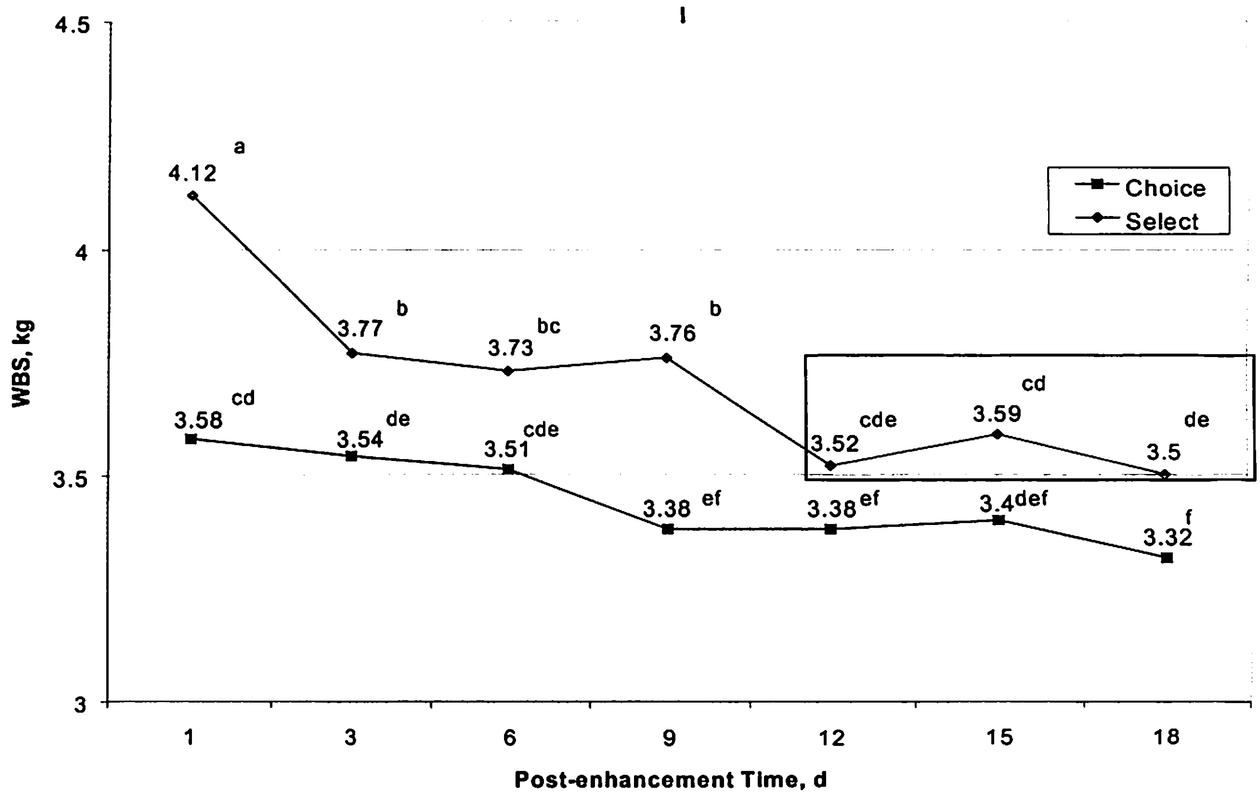
a,b,c,d Means within a quality grade lacking a common superscript letter differ (P < .05).

Figure 5. Effect of post-enhancement time and enhancement solution application on Warner-Bratzler shear (WBS) force values of strip loin steaks.



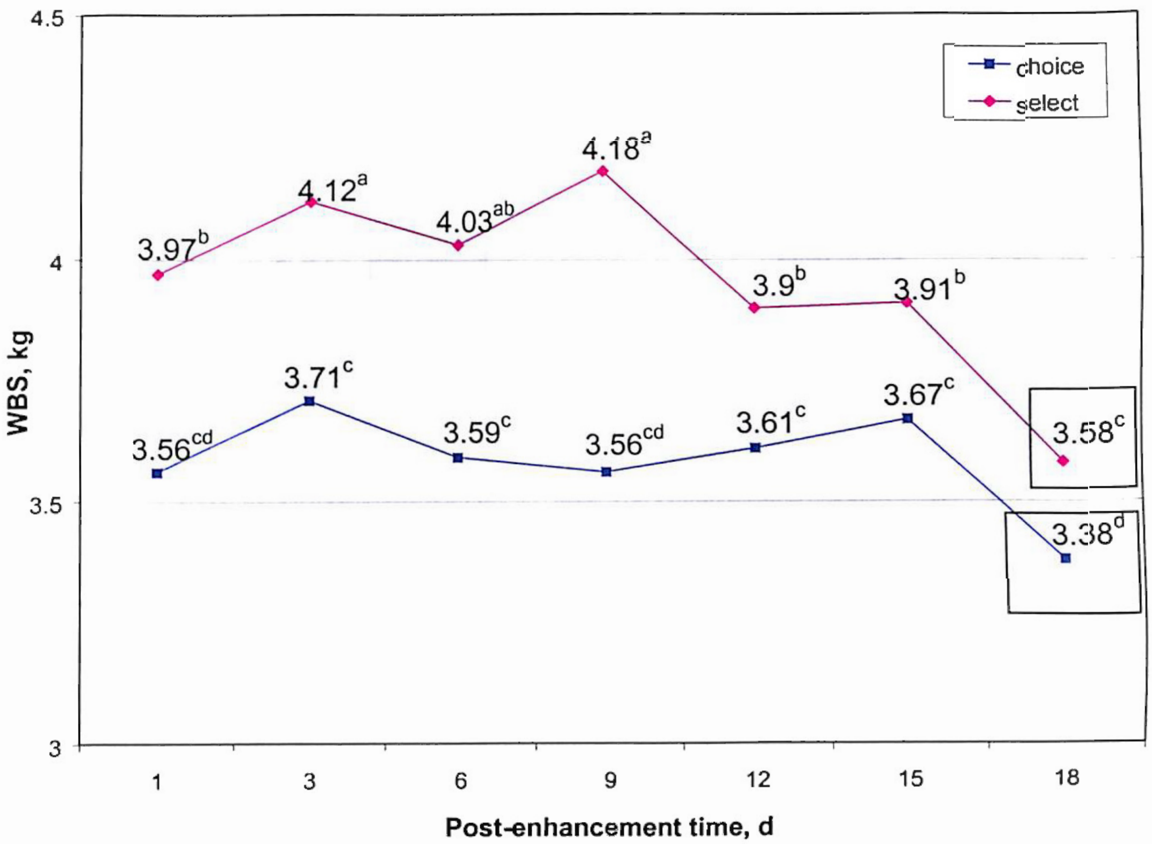
[a,b,c,d,e] Means lacking a common superscript letter differ ($P < 0.05$).

Figure 6. Effect of USDA quality grade and post-enhancement time on Warner-Bratzler shear (WBS) force values of shoulder clod steaks.



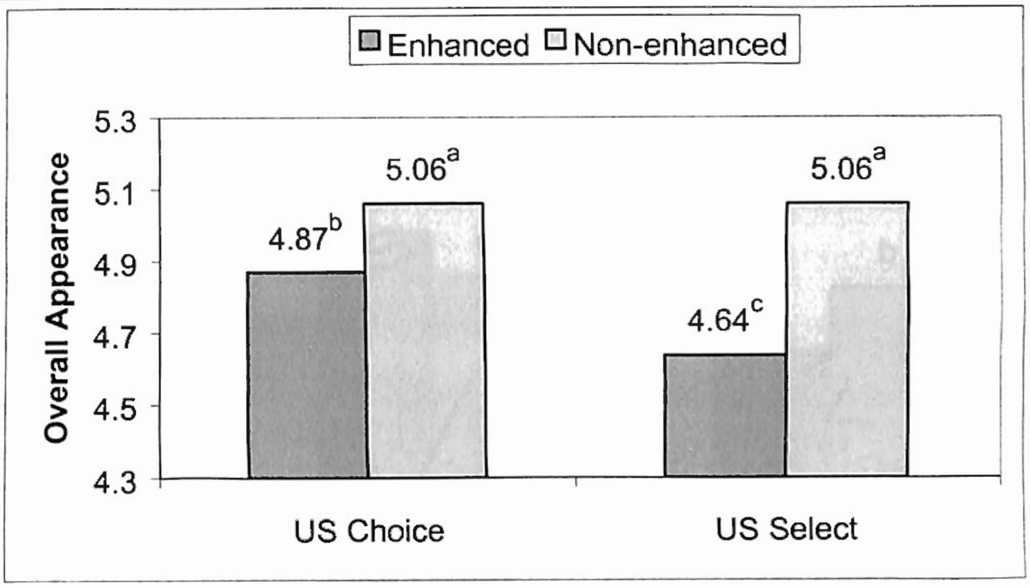
a,b,c,d,e Means lacking a common superscript letter differ ($P < 0.05$).

Figure 7. Effect of USDA quality grade and post-enhancement time on Warner-Bratzler shear (WBS) force values of top sirloin steaks.



a,b,c,d Means lacking a common superscript letter differ ($P < 0.05$).

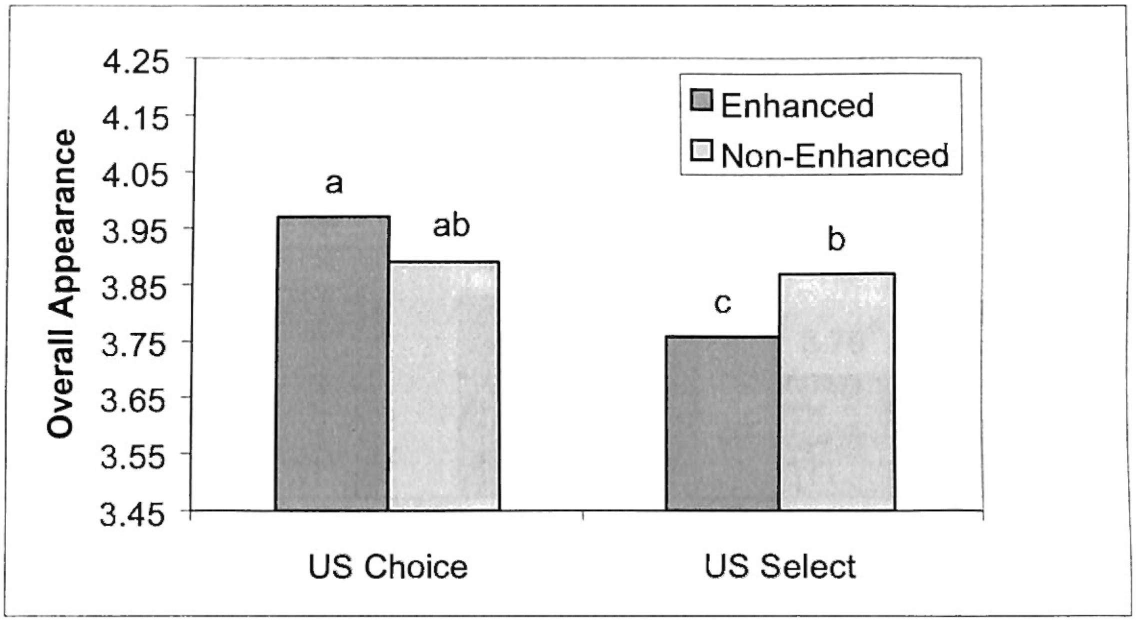
Figure 8. Influence of USDA Quality grade and enhancement solution application on the overall apperance[1] of strip loin steaks.



[1]Overall Appearance: 7 = extremely desirable; 4 = acceptable; 1 = extremely undesirable.

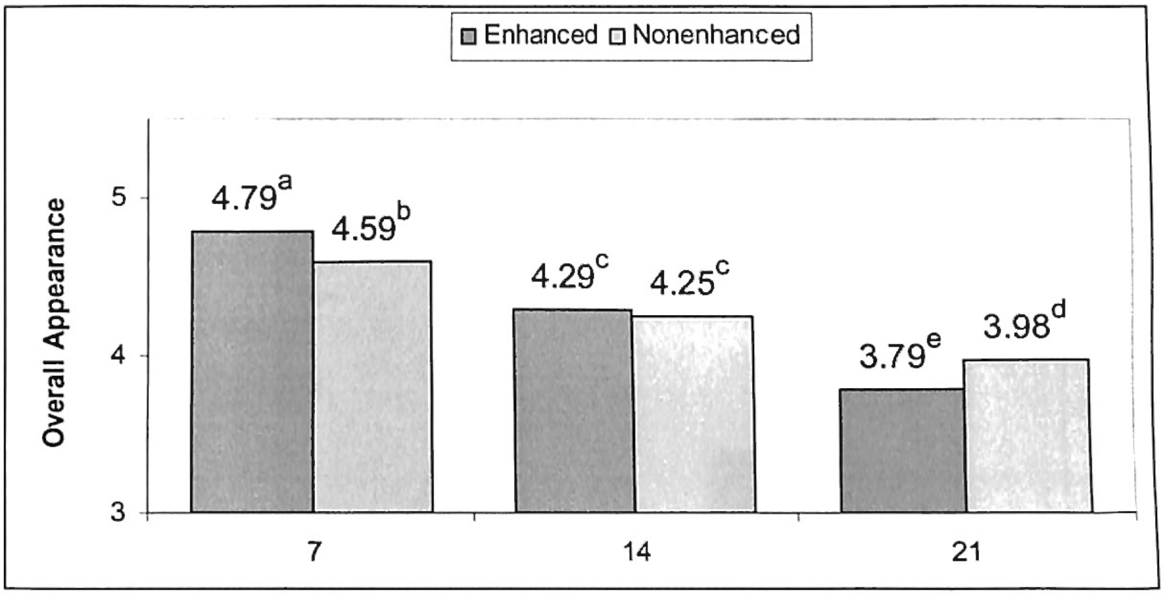
[a,b,c] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

Figure 9. Influence of USDA Quality grade and enhancement solution application on the overall appearance[1] of top sirloin steaks.



[1] Overall Appearance: 7 = extremely desirable; 4 = acceptable; 1 = extremely undesirable.
[a,b,c] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P = 0.0029$.

Figure 10. Influence of post-enhancement storage period[1] and enhancement solution application on the overall appearance[2] of shoulder clod steaks.

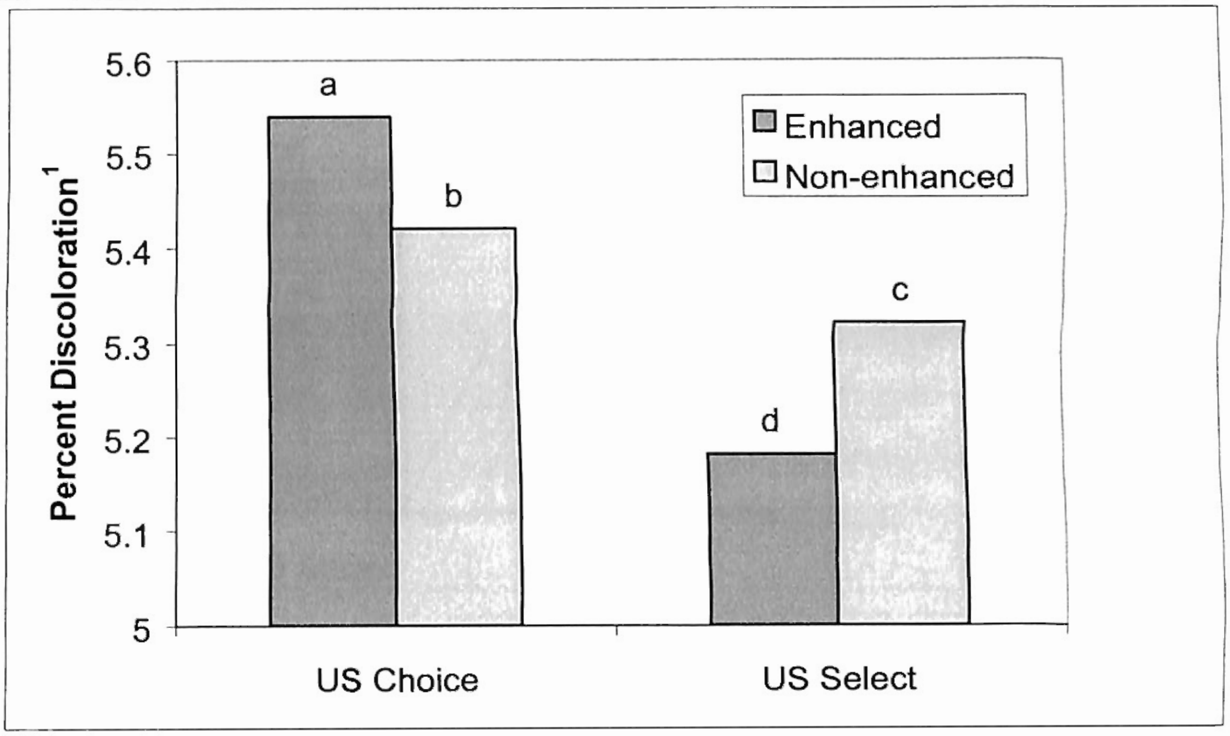


[1] Storage period: days of storage following enhancement.

[2]Overall Appearance: 7 = extremely Desirable; 4 = acceptable; 1 = extremely undesirable.

[a,b,c,d,e] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

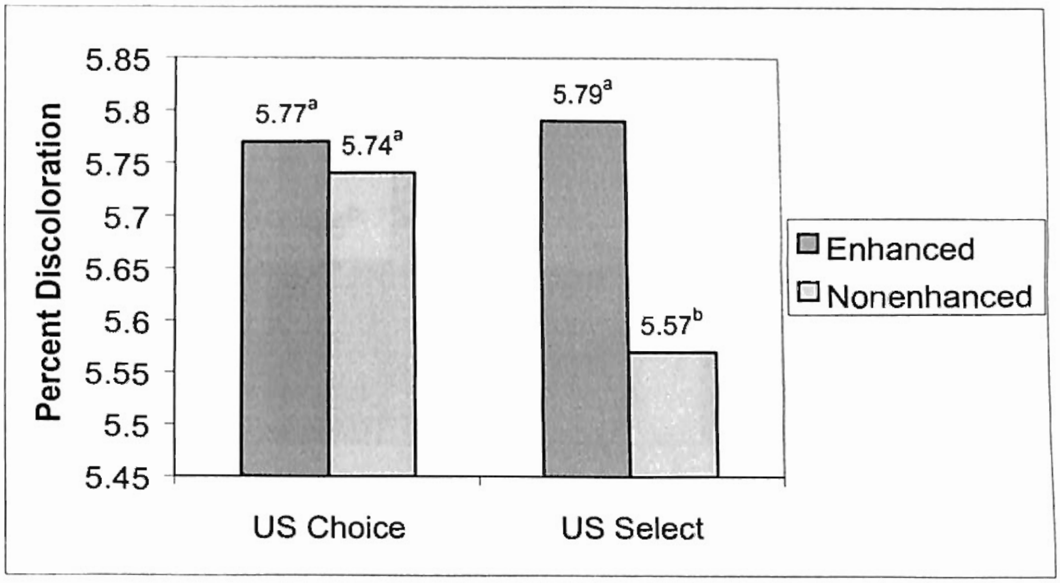
Figure 11. Influence of USDA Quality grade and enhancement solution application on the percent discoloration[1] of top sirloin steaks.



[1]Percent discoloration: 7 = none; 5 = 11-25%; 3 = 51-75%; 1 = complete.

[a,b,c,d] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P = 0.0002$.

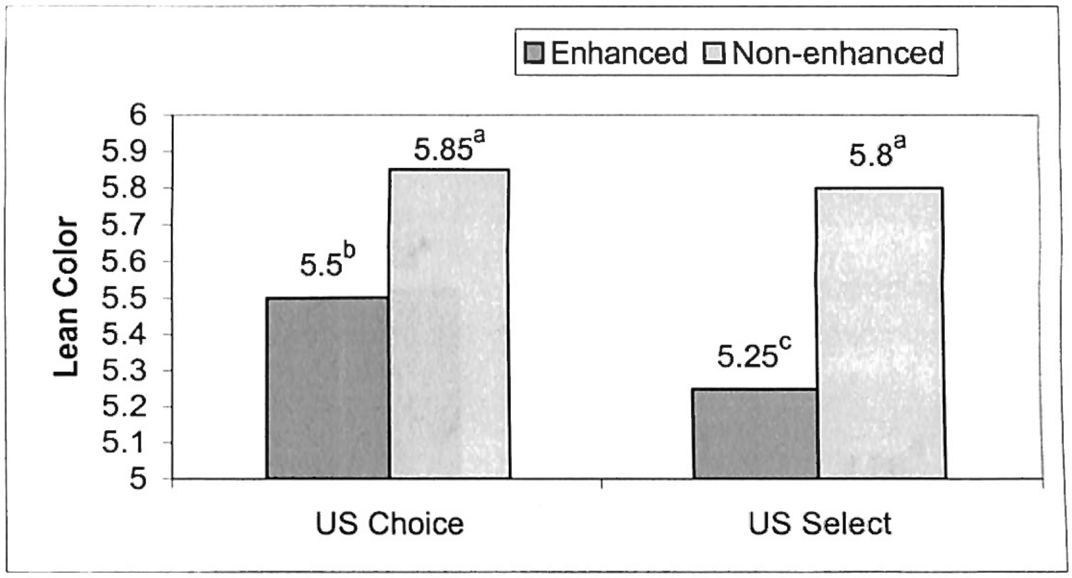
Figure 12. Influence of USDA Quality grade and enhancement solution application on the percent discoloration[1] of shoulder clod steaks.



[1]Percent discoloration: 7 = none; 5 = 11-25%; 3 = 51-75%; 1 = complete.

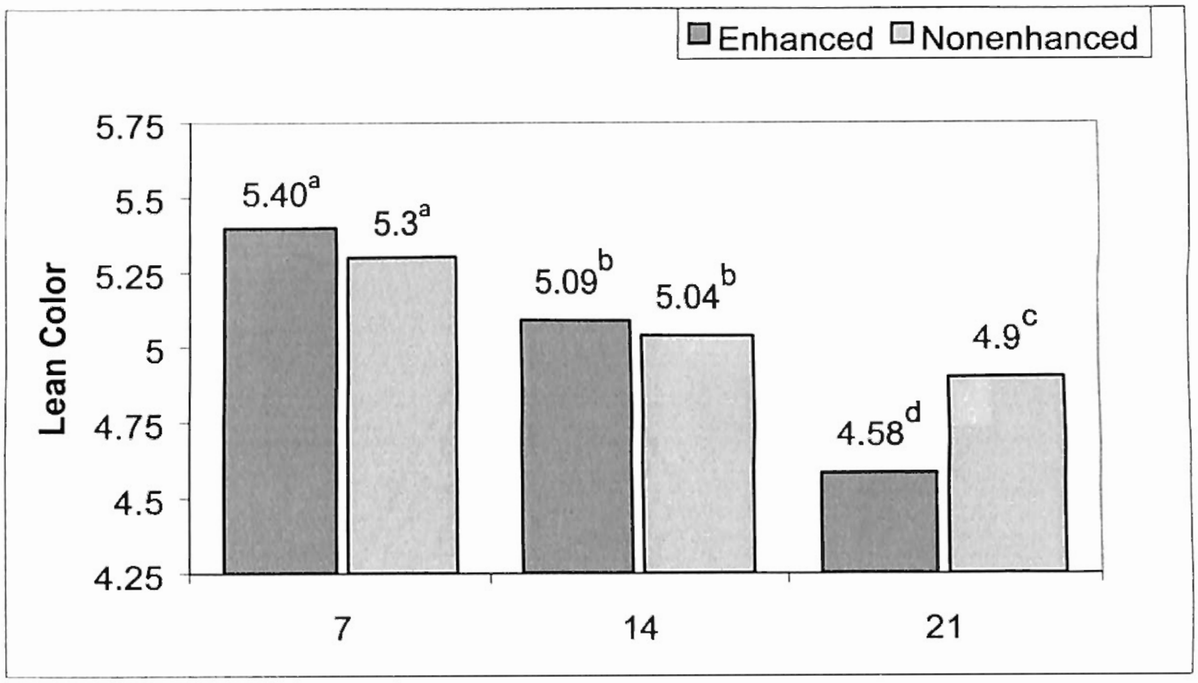
[a,b] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P = 0.0037$.

Figure 13. Influence of USDA Quality grade and enhancement solution application on the lean color[1] of strip loin steaks.



[1] Lean color: 8 = bright cherry-red; 4 = moderately dark-red or brown; 1 = extremely dark-brown.
[a,b,c] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

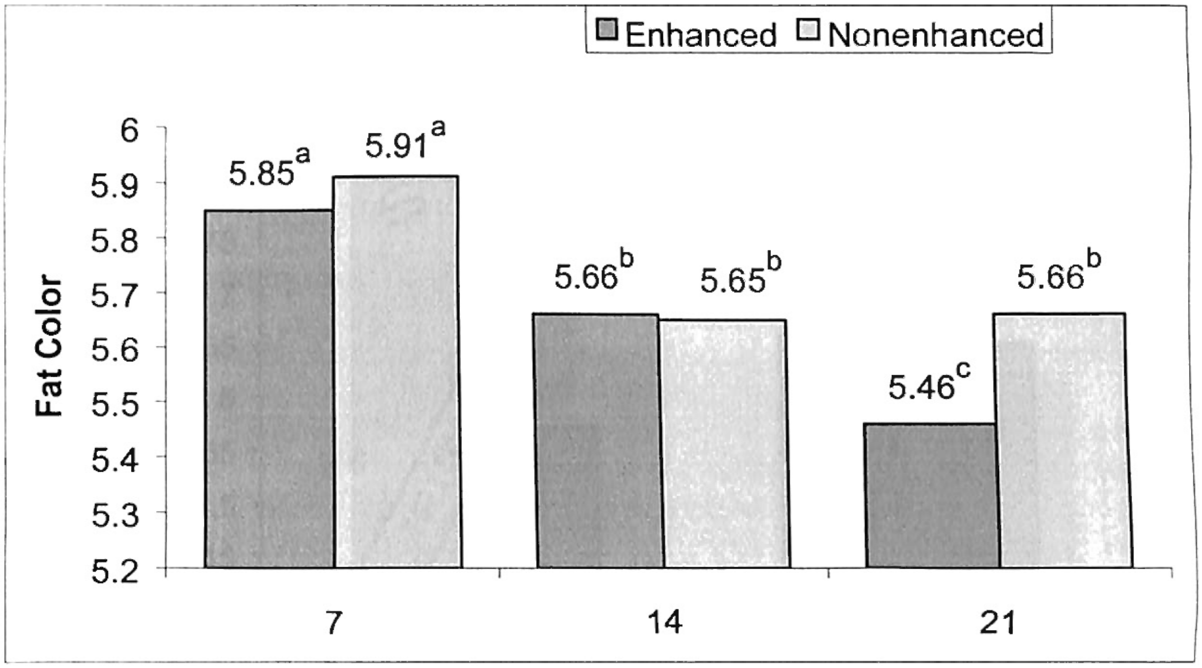
Figure 14. Influence of post-enhancement storage period and enhancement solution application on the lean color[1] of shoulder clod steaks



[1] Lean color: 8 = bright cherry-red; 4 = moderately dark-red or brown; 1 = extremely dark-brown

[a,b,c,d] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P < 0.0001$.

Figure 15. Influence of post-enhancement storage period[1] and enhancement solution application on the fat color[2] of strip loin steaks

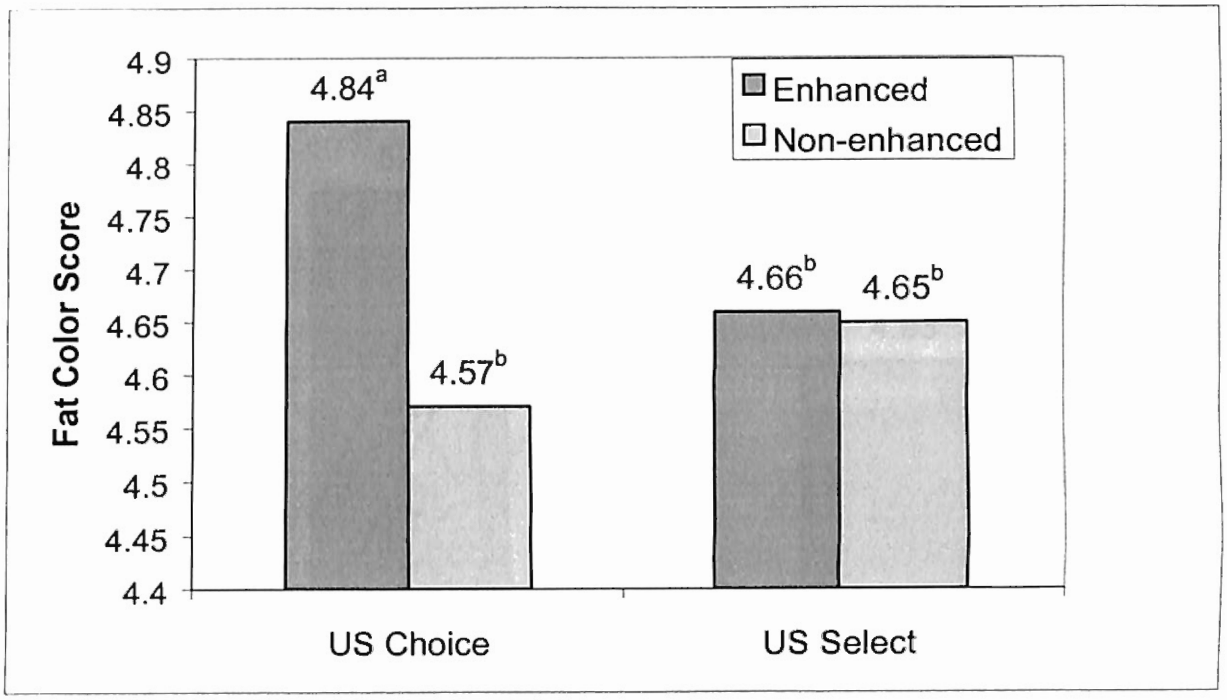


[1] Storage period: days of storage following enhancement.

[2] Fat color: 8 = creamy white; 5 = tan; 3 = moderately brown.

[a,b,c] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P = 0.0307$.

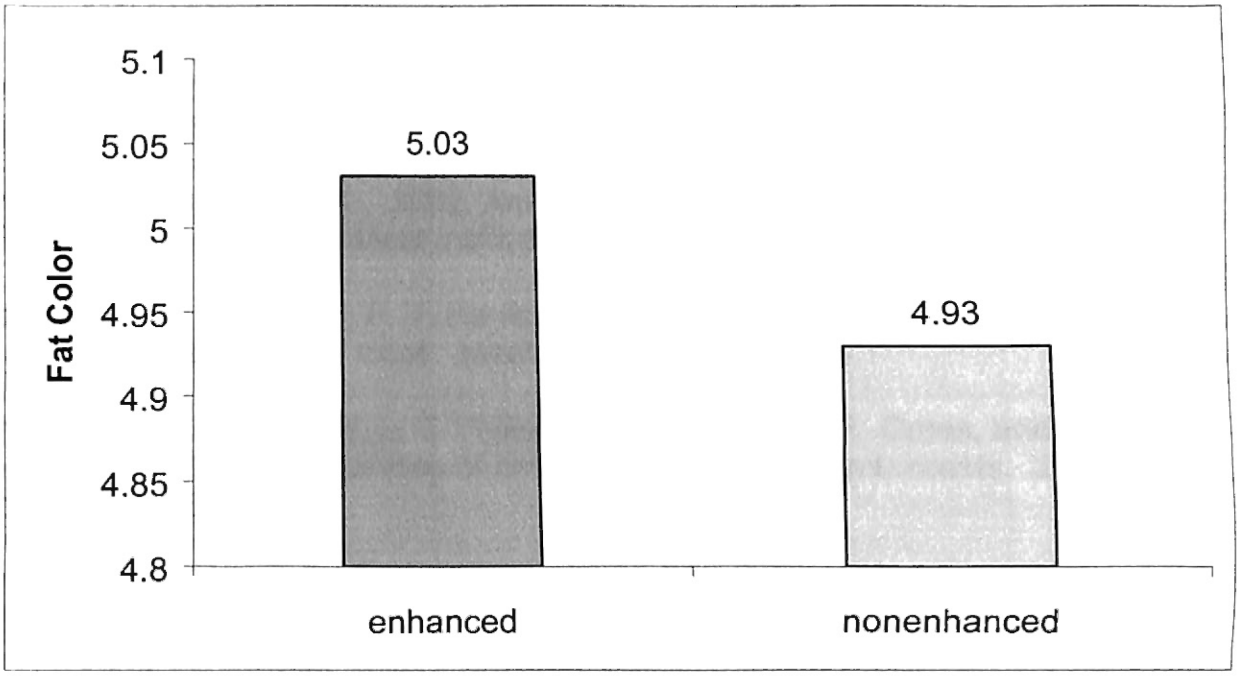
Figure 16. Influence of USDA Quality grade and enhancement solution application on the fat color[1] of top sirloin steaks



[1] Fat color: 8 = creamy white; 5 = tan; 3 = moderately brown.

[a, b] Means lacking a common superscript differ ($P < 0.05$). The significance of this interaction was $P = 0.0007$.

Figure 17. Influence of enhancement solution application on fat color scores[1] of shoulder clod steaks.



[1] Fat color: 8 = creamy white; 5 = tan; 3 = moderately brown.
Least squares means for two treatments differ (P = 0.0112).

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Appendix

Appendix A

Project design representing sample size per treatment (Phase I).

USDA Quality grade	Carcass #	Treatment	Subprimal	Aging groups, d (# steaks)						
				1	3	6	9	12	15	18
US Choice	20	Enhanced	Strip loin	20	20	20	20	20	20	20
			Top Butt	20	20	20	20	20	20	20
			Shoulder Clod	20	20	20	20	20	20	20
		Non-enhanced	Strip loin	20	20	20	20	20	20	20
			Top Butt	20	20	20	20	20	20	20
			Shoulder Clod	20	20	20	20	20	20	20
US Select	20	Enhanced	Strip loin	20	20	20	20	20	20	20
			Top Butt	20	20	20	20	20	20	20
			Shoulder Clod	20	20	20	20	20	20	20
		Non-enhanced	Strip loin	20	20	20	20	20	20	20
			Top Butt	20	20	20	20	20	20	20
			Shoulder Clod	20	20	20	20	20	20	20

Appendix B

Project design representing sample size per treatment (Phase II).

USDA Quality grade	Carcass #	Treatment	Subprimal	Storage period		
				7	**14**	**21**
US Choice	15	Enhanced	Strip loin	5	5	5
			Top Butt	5	5	5
			Shoulder Clod	5	5	5
		Non-enhanced	Strip loin	5	5	5
			Top Butt	5	5	5
			Shoulder Clod	5	5	5
US Select	15	Enhanced	Strip loin	5	5	5
			Top Butt	5	5	5
			Shoulder Clod	5	5	5
		Non-enhanced	Strip loin	5	5	5
			Top Butt	5	5	5
			Shoulder Clod	5	5	5

Appendix C

Visual Appraisal Forms Guidelines

Lean Color

8 Bright Cherry-Red
7 Moderately Bright Cherry-Red
6 Cherry-Red
5 Slight Dark-Red
4 Moderately Dark-Red or Brown
3 Dark-Red or Brown
2 Very Dark-Brown
1 Extremely Dark-Brown

Fat Color

8 Creamy White
7 Mostly Creamy White
6 Slightly Tan
5 Tan
4 Slightly Brown
3 Moderately Brown
2 Brown or Slightly Green
1 Dark Brown or Green

Percent Discoloration

7 None
6 1 – 10
5 11 – 25
4 26 – 50
3 51 – 75
2 76 – 99
1 Complete

Overall Appearance

7 Extremely Desirable
6 Desirable
5 Slightly Desirable
4 Acceptable
3 Slightly Undesirable
2 Undesirable
1 Extremely Undesirable

Appendix D

Postmortem aging recommendations to best maximize tenderness: shelf-life relationship

Subprimal	Enhance	Recommendations
Strip loin (IMPS # 180)	Yes	♦ No aging requirement. ♦ Fewer days stored, the greater the shelf life.
	No	♦ To maximize tenderness, should age ≥ 15 d. ♦ Product should display 6 d of acceptable appearance when stored 14 d postmortem.
Top Sirloin Butt (IMPS # 184)	Yes	♦ No aging requirement. ♦ Fewer days stored, the greater the shelf life.
	No	♦ To maximize tenderness, should age ≥ 24 d. ♦ Very poor shelf life regardless of storage period. However, should expect 3 d of acceptable appearance for 14, 21 or 28 d of storage.
Shoulder Clod (IMPS # 114)	Yes	♦ No aging requirement ♦ Fewer days stored, the greater the shelf life.
	No	♦ To maximize tenderness, should age ≥ 19 d. ♦ Product should display 5 d of acceptable appearance when stored for 14 d, and 1 less day for each additional week of storage.

VITA

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