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# Color and tenderness in chilled or frozen pork loin chops after antioxident dipping and modified atmosphere packaging

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# COLOR AND TENDERNESS IN CHILLED OR FROZEN PORK LOIN CHOPS AFTER ANTIOXIDANT DIPPING AND MODIFIED ATMOSPHERE PACKAGING

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## ABSTRACT

The objective of this research was to evaluate color and tenderness in chilled or frozen pork loin chops after antioxidant dipping and modified atmosphere packaging. Loin chops were dipped in 0.3 M calcium chloride, 2.0 % sodium ascorbate, 0.2 M calcium ascorbate, or 0.3 M calcium ascorbate. Non-dipped chops served as controls. Chops were packaged in high oxygen (80% $O_2$ / 20% $CO_2$) or no oxygen (80% $N_2$ / 20% $CO_2$) and stored chilled (4° C) for 7 days or frozen (-18° C) for 21 days. After storage, chops were displayed under continuous fluorescent lighting for 3 or 6 days. Instrumental color evaluations indicated that *Longissimus dorsi* (LD) L* values (lightness) were not significantly different between treatment combinations. However, chops dipped in 0.2 M or 0.3 M calcium ascorbate, stored frozen, packaged in high oxygen, and displayed for 3 days had higher final LD a* (redness) and b* (yellowness) values than other treatment combinations. Sodium or calcium ascorbate increased a* and b* values in vertebrae bone. Chops frozen for 21 days, dipped in 0.2 M or 0.3 calcium ascorbate, packaged in high oxygen, and displayed for 3 days had higher vertebrae a* and b* values than other treatment combinations. This combination of factors indicates that high oxygen atmospheres along with ascorbate and freezing will help keep the hemoglobin iron in a reduced state. In addition, chops dipped in 0.2 M calcium ascorbate, packaged in high oxygen, frozen for 21 days, and displayed for 3 days had lower percent drip loss, percent cook loss, and shear force values than other treatment combinations. Based on the results of our experiment, dipping pork loin chops in 0.2 M calcium ascorbate, packaging in high oxygen, freezing for 21 days, and displaying for 3 days will enhance color and tenderness.

# CHAPTER 1. INTRODUCTION

Over the last twenty years, the per capita red meat consumption of boneless retail meat products by Americans has fallen from 132.6 lbs. to 118.3 lbs. (USDA, 2004). However, per capita consumption of pork by Americans has been steady at approximately 51 lbs. over this time with 19 lbs. being fresh pork products and 32 lbs. being processed pork products (Davis & Lin, 2005). American meat consumers are still purchasing pork products, because they have been marketed to be healthy and palatable (NPPC, 2005).

Meat products are selected by the consumer on the basis of color and there is an inverse relationship between the degree of discoloration and the rate of sale (Ordonez & Ledward, 1977). Consumers perceive meat that is discolored to be no longer fresh and (or) wholesome (Harris, Huff-Lonergan, Lonergan, Jones, & Rankins, 2001). Desirable meat color (Wheeler, Koohmaraie, & Shackelford, 1996) and tenderness (Savell, *et al*., 1989; Whipple, Koohmaraie, Dikeman, Crouse, Hunt, & Klemm, 1990) have been identified as the most important factors in the perception of meat quality by consumers.

In addition to muscle color degradation, bone discoloration has been noted by the industry as a problem affecting product display life (Mancini, Hunt, Hachmeister, Kropf, & Johnson, 2004). Meat that contains bone may turn green or brown because of the loss of reducing compounds. The pigment hemoglobin denatures and loses its ability to give bone marrow a bright red color. A method to maintain color in both muscle and bone is to add ingredients that will act as reducing agents (Yancey, Dikeman, Addis, Katsanidis, & Pullen, 2002; Mancini *et al*., 2004).

Although color is a primary determinant at the time of purchase, tenderness is the most important quality and sensory characteristic of meat (Koohmaraie, Babiker, Schroeder, Merkel,

& Dutson, 1988*b*). For many years, it has been known that postmortem aging improves meat tenderness, with most researchers in agreement that calpain enzyme proteolysis is responsible for this improvement (Wheeler, Koohmaraie, Shackelford, & Hruska, 1994). Postmortem tenderization can also be through mechanical tenderization, for example, blade tenderization or needle injection, or addition of ingredients.

In addition to ingredients, storage and packaging conditions can influence meat color and tenderness. Meat products can be found at supermarkets either fresh or frozen. These products can be packaged in numerous ways. A few packaging styles are freezer paper wrapping, vacuum packaging, styrofoam trays over-wrapped with a polyvinylidene chloride film, or plastic trays sealed with a nylon/polyethylene film.

Modified atmosphere packaging (MAP) is a method employed by the industry to improve meat color (Livingston, Brewer, Killifer, Bidner, & McKeith, 2004). Elemental gas or gas mixtures are injected into packages prior to sealing. These gases, accompanied by cold storage and display temperature, can improve meat color and reduce microbial growth (Okayama, 1987).

The general objective of this study was to compare calcium ascorbate with calcium chloride for tenderization and sodium ascorbate for color stability of raw meat under different storage conditions and at simulated display periods in case-ready packaging.

# CHAPTER 2. LITERATURE REVIEW

## General

The three major aspects of meat acceptance are color, flavor, and texture (Nielsen, 1998). Color is the critically important, visual characteristic of meat, which gives the all-important first impression when a sample is viewed (Cassens *et al*., 1995). The appearance of meat is important because it is practically the only criterion the consumer can use to judge the acceptability of meat at purchase (Warriss, 2000). Variations in initial color, color uniformity, and color stability within meat can be related to early postmortem conditions (Sammel, Hunt, Kropf, Hachmeister, Kastner, and Johnson, 2002) that can affect the meat pigments. Color of fresh or frozen meat is largely determined by the relative amounts of myoglobin (Mb), oxymyoglobin ($MbO_2$), and metmyoglobin present (MetMb) (Bertelsen & Skibsted, 1987).

Meat packaging materials may also enhance the quality trait of color and influence consumer purchases. The principle preservative function of meat packaging is to provide protection against damage, physical and chemical changes, and microbial contamination (Fennema, 1996). Packaging materials must not impart odors, but should retain natural odors and flavors inherent to products. Modified atmosphere packaging has become a means to increase shelf-life of a meat product (Gill & Jones, 1994; Livingston *et al*., 2004).

Another sought-after quality of meat by consumers is tenderness (Rowe, 1977). The state of contraction of the myofibrils (actomyosin toughness) and the amount and degree of molecular stability of intramuscular collagen (background toughness) are the most important factors in evaluating meat tenderness (Chizzolini, Ledward, & Lawrie, 1977).

Flavor is a characteristic closely associated with the perception of quality. There are two components of flavor: taste and aroma (Warriss, 2000). Flavor is mainly determined by the

breakdown of water-soluble constituents and fat components within meat after heating (Warriss, 2000). During the cooking of meat, specific characteristic flavors develop that are unique to the species from which the meat is obtained (Warriss, 2000).

## Color

### Meat Color and Pigments

Meat color is the total impression seen by the eye and is influenced by the viewing conditions (Aberle, Forrest, Gerrard, & Mills, 2001). Any specific color of meat has three attributes known as hue, chroma, and value. Hue describes the wavelength of light radiation. Chroma describes the intensity of a fundamental color with respect to the amount of white light that is mixed with it. The value of a color is an indication of the overall amount of light reflectance of the color (Nielsen, 1998). A common numerical system that is used to measure meat color is the CIELAB color space (Minolta, 1993). This system gives numerical values for color measurements from light to dark (L*), red to green (a*), and blue to yellow (b*) (Minolta, 1993). The values obtained from these measurements give an accurate description of the state of meat pigments (Kropf, Olson, & West, 1984).

The most important contributors to meat color are the pigments that absorb certain wavelengths of light and reflect others (Aberle *et al*., 2001). Meat pigments consist largely of two proteins: hemoglobin (Hb), the pigment in blood for oxygen transport, and myoglobin (Mb), the pigment for oxygen storage in tissues (Nielsen, 1998). Myoglobin constitutes 80-90% of the total meat pigment (Aberle *et al*., 2001). Myoglobin and hemoglobin are similar in structure, except that the myoglobin molecule is a monomer one fourth as large as the hemoglobin molecule, a tetramer (Nelson & Cox, 2005). Both molecules contain a non-protein portion with an iron atom surrounded by a porphyrin ring. Myoglobin has only one iron atom and porphyrin ring whereas hemoglobin has four separate porphyrin rings, each containing an iron atom.

The color of meat is dependent on the oxidation state of this iron atom. The pigment myoglobin has several chemical and physical forms (Nelson, *et al*., 2005). In reduced form, myoglobin is purplish. In a reduced state, the iron atom of meat is able to acquire an oxygen atom, which will give meat a bright red color. In an oxidized form, the iron atom of meat is unable to bind oxygen and the porphyrin conformation causes meat to appear brown (Nelson *et al*., 2005). In order to keep myoglobin in a reduced form postmortem, substrates in enzymatic systems donate electrons, which allow the iron molecule to maintain a ferrous state. Once these enzymatic systems have been disrupted and are no longer able to keep myoglobin in a reduced form, metmyoglobin becomes the majority of pigment observed by the consumer (Renerre & Labas, 1987). This change in pigment to a brown color is not acceptable to the consumer (Renerre *et al*., 1987).

Myoglobin quantities vary with species, age, sex, and muscle (Aberle *et al*., 2001). Muscles with greater amounts of myoglobin may appear redder and darker in color (Warriss, 2000). Ruminants such as beef and sheep have much more quantities of myoglobin in their muscles in comparison with non-ruminants such as pigs and chickens (Aberle *et al*., 2001). Beef and sheep exhibit a darker, redder color whereas pork and chicken meat appear to be paler. In addition to species, age and sex of the animal can affect the color of meat. Older animals will have greater amounts of myoglobin in the muscle (Warriss, 2000). Furthermore, intact males have more myoglobin in muscle when compared with females or castrates (Warriss, 2000). There is also a muscle to muscle variation that occurs with myoglobin. In chicken, light breast muscles contrast strongly with the dark muscles of the leg and thigh (Warriss, 2000).

The myoglobin pigment of living muscle undergoes constant chemical changes (Nelson *et al*., 2005). As the iron atom becomes oxidized, the heme portion loses its oxygen atom and

myoglobin becomes metmyoglobin (Nelson *et al*., 2005). Metmyoglobin is constantly generated in muscle, and is reduced to a ferro-derivative form by enzymatic systems that work in anaerobic (Stewart, Zipser, & Watts, 1965*a*) or in aerobic conditions (Ledward, 1972). Enzymes and substrates present in muscle are capable of reducing metmyoglobin to reduced myoglobin, which can then bind oxygen to form oxymyoglobin.

**Postmortem Factors and Meat Pigment Changes**

There are several factors that contribute to the change in form of myoglobin and hemoglobin pigments that result in discoloration. Light, pH, temperature, lipid oxidation, and oxygen pressure ($pO_2$) are known to influence the oxidation of hemoglobin and myoglobin (Renerre *et al*., 1987).

Postmortem muscle pH can directly affect the appearance of meat (Aberle *et al*., 2001). In postmortem muscle, lactic acid accumulates and pH begins to decline. Build up of lactic acid in meat causes acidification and lowers the ultimate pH, which adversely affects water holding capacity (WHC) of meat. Aberle *et al*. (2001) reported that as muscle pH approaches the isoelectric point of actin and myosin, WHC decreases. This loss of WHC indirectly affects color of the meat by alteration of the myofibrillar spacing, decreasing the absorption of light; i. e., an increase in light reflectance causing meat to appear lighter in color. However, the amount of light reflected is directly related to the amount of water on the surface of the meat and the light intensity of a display case or cooler (Aberle *et al*., 2001).

Because reflected light determines the color of meat, the appearance of meat can change depending on the amount of light, the light source, the observer's angle of view, and background differences (Giese, 2003). Visible light that is reflected back to the consumer has a wavelength region of approximately 380 to 780 nm (Minolta, 1993).

Upon cutting, grinding, or exposure to air, pigments in meat undergo color changes due to their reaction with oxygen (Aberle *et al*., 2001). Enzymes and substrates aid in the binding of oxygen molecules in meat, which changes metmyoglobin to oxymyoglobin (Nelson *et al*., 2005). As postmortem meat ages, the substrate for these enzymes becomes depleted due to usage and lack of production of new substrate (Ranken, 2000). When metmyoglobin can no longer be reduced, the brown metmyoglobin layer becomes wider until it finally becomes visible through a narrowing oxymyoglobin layer and meat appears brown on the surface (Madhavi & Carpenter, 1993). The Metmyoglobin Reducing Activity (MRA) of meat indirectly measures the ferricyanide reductase that reduces metmyoglobin to myoglobin (Renerre *et al*., 1987; Hagler, Coppes, & Herman, 1974; Ledward, 1985). MRA loss in postrigor meat is due to factors such as decrease in tissue pH, depletion of substrates and cofactors such as coenzymes (NADH), oxidative deteriorative changes, and decreased oxygen consumption rate (OCR) (Renerre *et al*., 1987).

Oxygen consumption rate (OCR) influences color stability by altering the depth at which the layer forms; the closer to the initial layer of the surface, the more rapid the deterioration (Madhavi *et al*., 1993). When OCR is high, oxygen does not penetrate far into the meat, the metMb layer forms near the surface, and color deteriorates rapidly (Madhavi *et al*., 1993). The OCR decreases with aging of meat postmortem due to depletion of substrates and coenzymes and degradation of enzymes involved in mitochondrial respiration (O'Keeffe & Hood, 1982). In order for MRA and OCR to be maintained, researchers have suggested that addition of ingredients, such as ascorbates or erythrobates, which can donate reducing compounds to myoglobin and hemoglobin, will continue the process of oxidation-reduction reactions (Madhavi *et al*., 1993).

**Effect of Ascorbic Acid and Vitamin E on Color**

Ascorbic acid and erythorbic acid are two common reducing agents that are added to food products to enhance color stability (Fennema, 1996). Erythorbic acid and erythorbates are optical isomers of ascorbic acid and ascorbates, except that erythorbic acid and the erythorbates have no vitamin C activity (Fennema, 1996). Generally, ascorbic acid (sodium ascorbate) is added to meat products for its effects upon color formation and antioxidant activity (Houben & Krol, 1986). In accordance with the Food Safety and Inspection Service and the Code of Federal Regulations, ascorbic acid added to meat must not exceed a maximum level of ¾ oz. to 100 lb. of meat (FSIS, 2005). Numerous researchers have used ascorbic acid to combat surface discoloration of meat products by delaying myoglobin oxidation (Harbers, Harrison, & Kropf, 1981; Lee, Hendricks, & Cornforth, 1999; Mitsumoto, Cassens, Schaefer, & Scheller, 1991*b*; Shivas, Kropf, Hunt, Kastner, Kendall, & Dayton, 1984). Ascorbic acid in concentrations between 0.5% and 2.5% can act as an antioxidant when added to meat and in concentrations below 0.5% or above 3.5% can act as a pro-oxidant for lipid autooxidation (Sato and Hegarty, 1971).

It has been reported that sodium ascorbate (vitamin C) has been used in various ways to enhance the lean color stability of meat during display (Hood, 1975; Okayama, Imai, & Yamanoue, 1987; Mitsutmoto, Cassens, Schaefer, Arnold, & Scheller, 1991*a*; Mitsumoto *et al*., 1991*b*). Sodium ascorbate is a reducing agent that has been known to convert metmyoglobin to reduced myoglobin and methemoglobin to reduced hemoglobin. Hood (1975) showed that intravenous injection of sodium ascorbate into heifers prior to slaughter improved color stability. Harbers *et al*. (1981) studied the effect of dip treatment with an ascorbic acid solution on the

color of intact beef cuts and indicated that the ascorbic acid solution retarded pigment oxidation in the presence of radiant energy.

Okayama *et al*., (1987) observed that beef loin steaks dipped in a 3% ascorbic acid solution maintained acceptable meat color through 13 days of fresh storage (3˚C) and color measurements were significantly different when compared with the control group. Also, at 13 days of storage, TBA numbers for lipid oxidation were significantly lower for the ascorbic acid-treated steaks than the control group steaks.

Mistsumoto *et al*. (1991*a*) dipped beef *longissimus dorsi* (LD) samples into a 1% sodium ascorbate solution and displayed them under continuous fluorescent light for 1, 4, 7, 10, 13, and 16 days. The dip treatment with sodium ascorbate was effective in retarding oxidation of beef color in comparison with undipped control samples. Samples in the sodium ascorbate dip treatment had lower percentages of metmyoglobin and higher percentages of oxymyoglobin than the control samples through 7 to 10 days of display. Mitsumoto *et al*. (1991*b*) observed the effects of adding sodium ascorbate to ground beef. LD muscles were ground and mixed with 500 mg/kg tissue of sodium ascorbate/chlortetracycline solution. They concluded that sodium ascorbate addition improved pigment and lipid stability in ground beef through 7 days of display when compared with control samples.

Zhao and Sebranek (1996) evaluated color stability and sensory panel traits of fresh pork chops that were irradiated and dipped in 550 ppm of sodium ascorbate. They found that chops dipped in sodium ascorbate decreased drip loss and improved color and lipid stability of irradiated chops and resulted in better tenderness and juiciness scores than undipped irradiated samples.

Mancini *et al*. (2004) studied the effects of ascorbic acid on beef lumbar vertebrae discoloration. Ascorbic acid was pipetted and spread over each steak surface. Steaks were packaged in high oxygen modified atmosphere packaging and displayed under continuous light (1614 lux) for 18 hours at 1ºC. They concluded that minimal bone discoloration was achieved using a 2.5% ascorbic acid solution through a five-day display period at 1ºC.

Another approved compound that can donate reducing compounds for color stability is α-tocopherol or vitamin E. Asghar *et al*., (1991*a*) concluded that incorporation of α-tocopherol via the diet is effective in extending shelf life of pork chops. Monahan, Ashgar, Gray, and Buckley (1994) reported that supplementing vitamin E in swine diets improved the oxidative stability of both raw and cooked muscle after storage at 4ºC for up to 8 days. Supplementation of vitamin E in the diet has been shown to protect lipid membranes and prevent myoglobin oxidation in beef carcasses (Liu, Lanari, & Schaefer, 1995). Buckley, Morrissey, and Gray (1995) reported that dietary vitamin E improved pork quality through its antioxidant properties by protecting cell membranes from damage and subsequent fluid loss and by stabilizing color pigments in meat.

In contrast to adding vitamin E to the diet, Mitsumoto, Faustman, Cassens, Arnold, Schaefer, and Scheller (1991*c*) found that blending 6 mg of vitamin E/kg of tissue in ground beef reduced lipid and pigment oxidation after 7 days of display compared with control samples. Mitsumoto, Arnold, Schaefer, and Cassens (1993) found endogenous vitamin E supplementation improved color stability greater than exogenous vitamin E addition to beef postmortem, however, postmortem addition was slightly more effective in maintaining color stability when compared with control samples. Yancey *et al*. (2002) concluded that infusing vitamins E and C into beef *Semimembranosus* steaks significantly improved color stability when compared with control samples.

**Storage, Packaging, and Retail Display**

Preservative storage of raw meat must delay the deterioration of product appearance and retard the onset of bacterial spoilage (Gill, 1991). Following the slaughter process, meat can be stored at chilled temperatures, approximately 1 to 4ºC, or stored frozen, -18ºC and below (Aberle *et al*., 2001). Research has shown that freezing pork chops for 30 months lowered muscle a* values when compared to a* values from chops that were chilled for 2 days and then measured (Hansen, Juncher, Henckel, Karlsson, Bertelsen, & Skibsted, 2004).

Meat can also be stored under chilled or frozen conditions in different types of packaging: case-ready MAP, over-wrap, vacuum packaging. Legaretta, Usborne, and Ashton (1988) reported that high oxygen packaging had negative effects on hue, pH, and WHC of pork sausages that were chill stored for 16 days. Sausage a* and b* values were higher for samples stored in high oxygen and frozen for 16 days when compared with sausage stored in high oxygen and chill stored for 16 days.

Shelf-life and quality of meat can be extended by using case-ready MAP coupled with refrigerated storage (Zhao, Wells, & McMillin, 1994). Case-ready packaging or centralized packaging may be defined as the fabrication and packaging of consumer-sized retail meat items in a central location and display in retail stores with minimal or no package manipulation after removal from the shipping carton (McMillin, 1994). Case-ready packaging systems may be categorized by the type of environmental gas for display, (air, vacuum, high $O_2$, or gas mixtures) and by whether the conditions in the case-ready package remain static or are changed during transport and display operations (McMillin, Huang, Ho, & Smith, 1999).

An important means of stabilizing meat color is to store it under appropriate atmospheric conditions (Nielsen, 1998). Modified atmosphere packaging uses a combination of specific gases

($O_2$, CO, $CO_2$, $N_2$, Ar), which can enhance color and shelf life of retail meat products (Jeremiah, 2001). Modified gas atmosphere packaging has been reported to extend the shelf life of fresh meats (Okayama, 1987) by minimizing discoloration caused by myoglobin and hemoglobin oxidation ($Fe^{+2} \rightarrow Fe^{+3}$).

Atmospheres containing both oxygen and carbon dioxide are used commercially to approximately double the storage life of chilled meat compared with the normal storage life in air (Gill & Harrison, 1989). Storage in an oxygen-enriched atmosphere slows metmyoglobin formation and maintains a desirable red surface color in the meat (Gill *et al*., 1994). The high oxygen concentration allows for formation of oxymyoglobin creating the more desirable pink/red color of fresh meat (Gill, 1991).

Another gas that is being used is a combination of 80% nitrogen and 20% carbon dioxide. Packaging retail cuts of fresh meat in oxygen-free nitrogen and/or carbon dioxide allows for extended storage because oxidative color changes are prevented and bacterial growth is reduced (O'Keeffe & Hood, 1980). Krause, Sebranek, Rust, and Honeyman (2003) packaged injected (brine containing 9.3% potassium lactate, 3.7% sodium phosphate, and 2.8% sodium chloride) and non-injected pork chops under MAP conditions using carbon monoxide (CO) and found that CO significantly improved color stability and sensory panel scores for both injected and non-injected pork chops when compared with chops that were packaged in air. Livingston *et al*. (2004) reported that a combination of MAP with oxygen gas and an enhancement solution of sodium acetate effectively enhanced shelf-life color and reduced microbial growth in pork loin chops compared with chops that were not enhanced with sodium acetate and packaged in high oxygen.

Managing the microbial load in meat products has become as important as color stability to the retailer (Livingston *et al*., 2004). Most aerobic bacteria are inhibited by carbon dioxide concentrations of 10% or higher, while obligate anaerobic bacteria are inhibited by the presence of even small amounts of oxygen (Ray, 2001). It is well known that a carbon dioxide enriched atmosphere inhibits microbial growth, especially that of gram-negative bacteria (Huffman, Davis, Marple, & McGuire, 1975; Gee & Brown, 1981; Spahl, Reineccius, & Tatini, 1981). In aerobic systems, such as are used for display packs, atmospheres containing 20 to 30% carbon dioxide are used, as increasing the carbon dioxide concentration beyond that level had little additional inhibitory effect on *Pseudomonas*-dominated spoilage floras (Gill, 1988).

Modified atmosphere packaging can aid color stability during retail display. Display is defined as the offering of food product under lighting in the retail case, usually under refrigeration (Kropf, 1998). The role of lighting is to show the true quality of the meat product, without detracting from appearance or deceiving the customer about product quality (Kropf, 1998). Lighting can speed up product discoloration, but is essential for marketing and presentation of meat, both for over-wrap packaging and for case-ready packaging sales (Kropf, 1998).

Several investigations have confirmed that light is the important factor in discoloration of fresh and frozen meat in the retail trade (Bertelsen *et al*., 1987). An increase in light energy can cause the surface temperature of meat to increase, which will speed up the rate of degradative enzymatic processes. Lighting in retail display cases produces energy that is released in the forms of ultraviolet wavelengths. Ultraviolet wavelengths come in contact with the surface of meat products, which can result in increased surface temperature. This increased surface temperature will cause denaturation of meat pigments (Kropf, 1998).

In addition to retail display case temperature, the increase in surface temperature is dependent on the type of lighting used for display. Incandescent and fluorescent lighting are two styles of lighting that have been used in retail display cases. Kropf (1998) reported that temperatures were raised 1ºF for every 10 foot-candles of incandescent lighting in retail display cases with a 70 cubic foot per minute air velocity. However, under the same scenario, fluorescent lighting radiated about one-fifth as much heat as the incandescent lamps (Kropf, 1998). Most meat display case lights are of the fluorescent rather than incandescent type (Warriss, 2000). Fluorescent lighting is brighter and has a greater effect of reflecting meat color back to the consumer (Nielsen, 1998). The specific type of fluorescent lighting is important because of differences in color balance, i. e., the degree to which spectral energy of the light coincides with spectral reflectance of meat. Sources that provide good color balance have about 20-35% of their emission in the red light range (Warriss, 2000). Consequently, light intensity is an important consideration for display lighting and a range of 800 to 1100 lux is optimum for retail display cases (Nielsen, 1998). Current retail display lighting for meat display cases are not standardized between stores. However, Kropf (1980) reported that light intensities in retail meat cases ranged from 1129 to 2797 lux.

As stated above, it is important the correct type of fluorescent lighting is used in meat display cases. Using a fluorescent light with a higher intensity may increase surface temperature and speed up formation of pro-oxidant molecules (superoxide anions, hydrogen peroxide, and hydroxyl radicals) (Liu *et al*., 1995). These oxidizing species could interact directly with ferrous iron or cause the formation of lipid radicals or peroxides, which could oxidize ferrous iron (Liu *et al*., 1995). A high concentration of free radicals coupled with optimum reaction temperatures could result in a faster rate of metmyoglobin formation (Mitsumoto *et al*., 1991*b*).

In addition to increased surface temperature, fluorescent lighting may cause undesirable photochemical effects in meat. Photochemical effects are caused by certain wavelength energies that excite one or more molecules and initiate or catalyze such reactions as oxidation, which lead to a change in meat pigments (Kropf, 1998). Wavelengths that are absorbed cause photochemical effects, resulting in greater "destruction" of heme pigments, but wavelengths that are primarily reflected produce less of a photochemical effect (Kropf, 1998). Fluorescent lighting is characterized by spikes of energy emission at certain wavelengths. Meat pigments are characterized by certain wavelengths (Soret bands) where light is strongly absorbed. If the wavelengths from fluorescent lighting in display cases are the same as the Soret bands for myoglobin, undesirable effects in meat color can occur (Kropf, 1998). For many years, ultraviolet wavelengths were stated to result in photo-oxidation (Kropf, 1998). Photo-oxidation by ultraviolet light can lead to production of hydroxy-free radicals that can change the iron molecule of the heme compound from ferrous to ferric, thus resulting in metmyoglobin formation (Christen and Smith, 2000). Ramsbottom, Goeser, and Schultz (1951) reported that ultraviolet wavelengths from a 60-foot candle light exposure caused discoloration that was not caused by other components of fluorescent light.

## Tenderness

Tenderness is the predominant quality determinant and probably the most important organoleptic characteristic of meat (Weir, 1960; Lawrie, 1966; Moeller, Fields, Dutson, Landmann, & Carpenter, 1977). The tenderness of meat is due to two major fibrous components of meat, i.e. (1) the muscle fibers and (2) the collagen fibers of the connective tissue (Rowe, 1977). Specific meat products, such as muscles from the chuck or shoulder, may have high levels of actomyosin and collagen fibers, which may influence the level of tenderness and the

consumer's perception of the meat product (Warriss, 2000). The number and degree of contraction of actomyosin crossbridges are influenced by postmortem aging and enzymatic processes (Whipple *et al*., 1990).

Postmortem biochemical processes influence the tenderization process. Shortening, prerigor glycolytic activity, and proteolysis are events that occur in postmortem muscle and are activated by calcium ions (Mickelson, 1983), which ultimately affect tenderness. Studies have shown that calcium chloride ($CaCl_2$) linked with postmortem storage and pH can enhance tenderness (Koohmaraie, Schollmeyer, & Dutson, 1986; Dutson, 1983*a*).

**Effect of Postmortem Storage and pH on Tenderness**

Conditioning is the term applied to the process of tenderization when meat is stored or aged postrigor (Warriss, 2000). The conditioning process takes place in two phases (Nishimura, Liu, Hattori, & Takahashi, 1998). There is a rapid first phase caused by changes in the myofibrillar component and a slower second phase caused by structural weakening of the intramuscular connective tissue (Nishimura *et al*., 1998). However, proteolysis of the myofibrillar structures is much more evident than connective tissue breakdown (Whipple & Koohmaraie, 1992). There is evidence that detachment of the thin filament from the z-disk occurs (Boyer-Berri & Greaser, 1998), but the actomyosin crossbridges continue to be locked together.

These changes that occur postmortem are influenced by storage temperature (Honikel, Roncales, & Hamm, 1983). The temperature at which carcasses are conditioned has a major influence on rate of tenderization (Yu & Lee, 1986). Many conventional chilling systems chill carcasses near 1ºC for 24 hours (Huff-Lonergan & Page, 2001). During the chilling process, heat can be removed from the carcass by transferring heat to the atmosphere through convection or

conduction. Convection heat transfer is carried out when heat is transferred from the surface of the product into a cooling medium that passes over the product. Conduction heat transfer transfers heat from a solid via vibrating molecule, i.e. placing a product on ice. Conventionally, livestock carcasses are chilled by convection heat transfer while hanging from rails in coolers.

The rate of carcass chilling has implications on the decline of pH postmortem. Carcass temperature coupled with the production of lactic acid affect the rate of pH decline of a carcass (Warriss, 2000). Koohmaraie *et al*. (1986) reported that under normal conditions, pH will decline from 7.0 to 7.5 to 5.5 to 5.8 by 24 hours postmortem in beef carcasses. However, the rate at which pH declines is highly variable (Judge, Aberle, Forrest, Hendrick, & Merkel, 1989). One of the main limiting factors of pH decline is temperature (Aberle *et al*., 2001). Carcasses held at temperatures closer to 10°C will have a pH decline that appears more linear with time (Warriss, 2000). Higher temperatures will promote a more rapid pH decline and the ultimate tenderness of a carcass will be negatively affected (Dutson, 1983).

It is important that carcass temperature reach at least 35ºC or lower within 2.5 hours after slaughter and should reach at least 7ºC or lower by 22 hours after slaughter (Huff-Lonergan *et al*., 2001). A rapid pH decline while the carcass is above 35°C leads to the denaturation of the myofibrillar proteins that bind water resulting in soft and exudative lean. If muscle pH continues to decline, it will reach a point where the net charge associated with the major contractile proteins is equal to zero. At this point, the muscle proteins reach their isoelectric point and possess a very low affinity for water (Kauffman *et al*., 1993).

Another factor that can affect the decline of pH is the amount of glycogen stored in postmortem muscle (Monin & Sellier, 1985). Glycogen potential (GP) is a measure of all compounds present in the muscle that can be converted into lactic acid. It is an index of the

muscle's capacity for postmortem glycolysis, and therefore, of the muscle's potential for pH decline after slaughter (Monin *et al*., 1985). GP can be measured by the amounts of pro- and macro-glycogen stored in the carcass (van Laack, 2001). Proglycogen has a molecular weight of 400 kDa, contains 10% protein and is acid insoluble. Macroglycogen has a much larger molecular weight, contains less than 1% protein, and is acid soluble (Lomako, Lomako, & Whelan, 1991). Studies have suggested that muscle contains both forms of glycogen (Bloom, Lewis, Schumpert, & Shen, 1950) and may be related to ultimate pH.

Glycolysis and the conversion of ATP to ADP and inorganic phosphate in muscle take place until the onset of rigor mortis when glycogen or ADP becomes depleted (Greaser, 1986). If ADP is depleted first, glycolysis will cease even if there is remaining glycogen (van Laack, 2001). The rate at which ADP and glycogen is depleted affects the ultimate pH of meat (Bendall, 1973). If the depletion rate is fast, postmortem pH will drop faster and ultimate pH will be reached sooner. Some researchers have suggested that higher ATP-ase activity results in lower ultimate pH and vice versa (van Laack, 2001). If increased postmortem metabolism leads to a high level of lactate and a low pH while the carcass temperature is still high, inferior meat quality such as low WHC and poor color stability will result (Bendall, 1973; Briskey, 1964; Greaser, 1986).

**Postmortem Changes in Muscle**

The most obvious physical change postmortem is the delay, onset, completion, and resolution of rigor mortis. Rigor mortis is the stiffness of muscle that occurs after death. This stiffness is due to the formation of crossbridges in muscle between the contractile proteins actin and myosin (Marsh & Leet, 1966) along with the depletion of ATP. In living muscle, ATP provides the energy to allow muscles to move from a contracted form to a relaxed form and vice

versa by forming and breaking the bonds of actomyosin. A muscle in a relaxed form will allow actin and myosin to slide passively over one another without forming crossbridges. However, when these crossbridges form and swivel, a contractile force is generated, resulting in muscle contraction (Aberle *et al*., 2001).

Living muscle cells obtain their biochemical energy from aerobic glycolysis in respiring mitochondria. This aerobic respiration slowly ceases when the blood circulation stops after exsanguination and oxygen is no longer available. Under these circumstances, stores of creatine phosphate (CP) are used for the re-phosphorylation of ADP to ATP. As stores of CP are depleted, phosphorylation of ADP becomes insufficient to maintain the tissue in a relaxed state (Aberle *et al*., 2001). Without ATP, muscle cannot return to a relaxed state during rigor mortis. Actomyosin crossbridges form and the muscles lose all extensibility until rigor mortis has completed. Following the completion of rigor, muscle begins to soften while stored in chilled conditions, however, most actomyosin crossbridges are not broken. During this postmortem storage, tension is decreased, but the muscle never returns to prerigor levels of unformed actomyosin crossbridges. Degradation of myofibrillar structures is a proposed possibility for the loss of tension in post-rigor muscle (Warriss, 2000).

**Degradation of Myofibrillar Structures**

Proteolysis of myofibrillar proteins has been considered one of the mechanisms by which postmortem tenderization of meat occurs (Slinde & Kryvi, 1986). The first process of proteolysis is the weakening and degradation of the Z-line. Z-line degradation results in myofibrils fragmenting into smaller segments, termed myofibril fragmentation (Takahashi, Fukagawa, & Yasui, 1967; Davey & Gilbert, 1969). This proteolytic degradation is in association with the degradation of the myofibrillar proteins desmin, titin, and nebulin (Slinde *et al*., 1986). Due to its

role in muscle structure to bind muscle bundles together, alterations in desmin would be expected to disrupt muscle cell integrity (Robson & Huiatt, 1983). Others indicate that the degradation of titin may be responsible for the degradation of the Z-line (Goll, Otsuka, Nagainis, Shannon, Sathe, & Muguruma, 1983). Titin is the myofibrillar structure that secures the actin filament to the Z-line (Aberle *et al*., 2001).

Cytoskeletal proteins are not the only proteins that undergo postmortem degradation. A major regulatory protein that has been found to disappear during postmortem storage is troponin-T. Troponin-T, in conjunction with troponin-I and troponin-C, make up the troponin protein, located periodically along the F-actin filament (Aberle *et al*., 2001). As the troponin-T component disappears, the appearance of a 30,000-dalton component is observed (Etherington, 1984). This 30,000-dalton component is thought to be a product of troponin-T proteolytic degradation (Etherington, 1984).

Although these myofibrillar proteins are degraded during postmortem storage, the contractile proteins of actin and myosin are left unaffected even after 56 days aging (Aberle *et al*., 2001). However, Boyer-Berri and Greaser (1998) reported that the attachments of the actin filaments to the Z-disks show some breakdown and may be related to tenderness. In addition, Yates (1977) found that myosin heavy chain was split at several different points in postmortem beef muscle stored at 37ºC. It has been proposed that weakening of the bonds between actin and myosin may contribute to the increase in tenderness (Hopkins and Thompson, 2001). Therefore, degradation of specific cytoskeletal and regulatory proteins coupled with activity by endogenous muscle proteases may enhance postmortem tenderness.

**Proteolytic Enzymatic Processes of Muscle**

Several enzyme systems present in skeletal muscle have been implicated in the postmortem proteolytic degradation of myofibrillar proteins. Specific muscle proteins are degraded during postmortem aging of muscle under chilled conditions and there is evidence that cysteine proteases, in particular the calpains, are largely responsible for this degradation (Hopkins *et al*., 2001). The calpain system consists of two calcium dependent enzymes, and a specific inhibitor, calpastatin. These calcium-dependent proteases (CDP's) degrade the Z-disk, titin, nebulin, desmin, and troponin.

The calpains are found in two forms, CDP-I and CDP-II, (Dayton, Schollmeyer, Lepley & Cortés, 1981) inside striated muscle cells at the level of the Z-disk (Ishiura, Sugita, Nonaka, & Imahori, 1980). The two enzymes of this system differ in their calcium requirement for activation. One calpain requires millimolar calcium (m-calpain or CDP-II) and the other, micromolar calcium (μ-calpain or CDP-I) concentrations for activation. Dayton *et al*. (1981) reported that CDP-I can be converted to CDP-II through phosphorylation, which strengthened experimental evidence for a role of CDP-I in postmortem tenderization of meat (Ilian, Bekhit, & Bickerstaffe, 2003).

The proteolysis of specific myofibrillar linkage proteins (MLP) by CDP-I occurs at low pH and temperature and is similar to the degradation pattern of these MLP in postmortem bovine muscle (Huff-Lonergan *et al*., 1996). CDP-I translocates from the z-line (Warriss, 2000) to the myofibril during postmortem aging (Beohm, Kendall, Thompson, & Goll, 1998) and carries out the degradation of myofibrillar structures. In addition, it is widely believed that unless meat is treated with mM levels of calcium, CDP-II is not active during postmortem storage and may not

be involved in postmortem tenderization of meat (Geesink, Ilian, Morton, & Bickerstaffe, 2000; Veiseth, Shackelford, Wheeler, & Koohmaraie, 2001).

The third component of the calpain system is a specific inhibitor, known as calpastatin, which inhibits CDP-I and CDP-II in postmortem muscle. Normally, calpastatin is bound to the calpains in living muscle. Once rigor mortis occurs in postmortem muscle, the membrane systems of the SR and mitochondria no longer sequester calcium ions. Calcium ions are released into the sarcoplasm and bathe the myofibrils (Jeacocke, 1993). The calcium ions remove the inhibitive properties of calpastatin and allow proteolysis by the calpains to occur (Warriss, 2000). Calpastatin itself is eventually broken down by the calpains (Warriss, 2000). Calpastatin varies between species and between specific breeds (Huff-Lonergan *et al*., 1996; Aberle *et al*., 2001; Warriss, 2000). Animals with higher calpastatin activity will have greater tendencies to bind calpastatin to CDP-I and CDP-II, which will reduce tenderness (Aberle *et al*., 2001). High postmortem calpastatin levels inhibit the calpain enzyme system and the degree of tenderness is less in postmortem aging (Huff-Lonergan, Mitsuhashi, Beekman, Parrish, Olson, & Robson, 1996; Warriss, 2000).

An understanding of the calpain enzyme system must also include how the decline in postmortem pH affects CDP-I and CDP-II activity. The pH immediately after death ranges from 7.0 to 7.5 and ultimate pH is generally 5.5 to 5.8 (Koohmaraie, *et al*., 1986). CDP-I is maximally active at pH 7.5 and 24-28% of its maximum activity is retained at pH 5.5 to 5.8 at 5ºC (Koohmaraie, *et al*., 1986). CDP-II is maximally active at pH 7.0 to 8.0, but is inactive unless calcium reaches mM levels (Dayton, Reville, Goll, & Stromer, 1976). Intracellular free calcium concentrations are 1 to 10 μM after exsanguination (Goll *et al*., 1983). Therefore, if CDPs are

involved in postmortem proteolysis, it is likely that CDP-I is responsible, due to its low calcium requirement and broader range of pH activity (Dayton *et al*., 1981).

Ultimately, the enzymatic processes of the calpain system aid in the proteolysis of myofibrillar structures, which increase muscle tenderness (Koohmaraie *et al*., 1991). CDPs have been found to degrade the cytoskeletal proteins desmin (Young, Graathuis, & Davey, 1981) and titin (Robson & Huiatt, 1983) that are associated with the z-disk (Olson, Parrish, Dayton, & Goll, 1977; Dayton, *et al*., 1981; Koohmaraie, Kennick, Elgasim, & Anglemier, 1984) and the regulatory protein troponin-T (Samejima & Wolfe, 1976; Olson *et al*., 1977; Whipple & Koohmaraie, 1992). Furthermore, CDPs do not affect the contractile proteins actin and myosin (Henderson, Goll, & Stromer, 1970; Olson *et al*., 1977; Goll, Thompson, Taylor, & Christiansen, 1992).

**Effect of $CaCl_2$ on Tenderness**

The processes that have been previously discussed appear to influence tenderness to varying degrees. These processes are regulated by the concentration of calcium in the cytoplasm (Chinet, Decrouy and Even, 1992; Mickelson and Louis, 1993). The sarcoplasmic reticulum (SR) is the major regulator of $Ca^{+2}$ concentration in skeletal muscle cells (Bendall, 1973; Briskey, 1964; Greaser, 1986). During postmortem storage, the SR loses its ability to sequester calcium, which in turn, allows binding of calcium ions with troponin-C and the concentration of free calcium to decrease (Warriss, 2000).

However, several studies have shown that adding dietary calcium to feed or adding calcium chloride postmortem by injection or marination can raise levels of free calcium in postmortem muscle (Koohmaraie, Whipple, & Crouse, 1990; Koohmaraie *et al*., 1991; Morgan, Miller, Mendez, Hale & Savell, 1991*a*; Wheeler, Koohmaraie, & Crouse, 1991; Wheeler, Crouse

& Koohmaraie, 1992; Whipple & Koohmaraie, 1992). Over the last 22 years, research has shown that calcium chloride is an ingredient that improves meat tenderness when injected into carcasses (Breidenstein & Carpenter, 1983; Koohmaraie, Babiker, Merkel, & Duston., 1988*a*, Koohmaraie *et al*., 1990; Koohmaraie *et al*., 1991) or to specific cuts of meat (Koohmaraie *et al*., 1990; Morgan *et al*., 1991*a*; Wheeler *et al*., 1992).

Koohmaraie *et al*. (1988*b*) reported that infusion of calcium chloride through the carotid artery prior to evisceration lowered longissimus muscle shear force values by 24 hours as opposed to 3-7 days required for the same tenderization to occur in the control group. Koohmaraie *et al*. (1989) infused lamb carcasses with 0.3 M calcium chloride immediately following exsanguination and used low frequency electrical stimulation (ES). Infusion with calcium chloride accelerated postmortem tenderization such that postmortem storage beyond 24 hours was not necessary as opposed to 7 days required for the same tenderization to occur in the control group. Shear force values were lower for calcium infused, non-ES carcasses when compared with control carcasses.

Koohmaraie *et al*. (1991) observed that feeding a ß-adrenergic agonist (BAA) to sheep and cattle resulted in decreased meat tenderness. They concluded that calcium chloride infusion (3.3% at 10% by weight) of carcasses from BAA-fed sheep significantly improved tenderness of longissimus muscle samples, but not to the level of tenderness in meat from carcasses from non-BAA-fed sheep.

Koohmaraie *et al*. (1990) observed the effects of directly injecting calcium chloride (3.3% at 10% by weight) at 45-min postmortem into longissimus muscles of Brahman carcasses. Shear force values were less for injected samples measured at 1 and 14 days postmortem when compared with samples that were non-injected. Wheeler *et al*. (1991) injected calcium chloride

into hot-boned bottom round muscles from *Bos indicus* bulls and observed that shear force values were significantly reduced compared with non-injected muscles at 1, 7, and 14 days postmortem.

A study conducted by Boleman, Boleman, Bidner, McMillin, & Monlezun (1995) determined the effects of injection of calcium chloride at 1, 12, and 24 hours postmortem in beef *Semimembranosus* muscles. They concluded that calcium chloride injection of beef *Semimembranosus* muscles at 1-hour postmortem was more effective in reducing shear force values than injection at 12 or 24 hours. Although shear force values at 12 and 24 hours were higher than 1-hour shear force values, all injected samples had lower shear forces compared with the control samples. McFarlane and Unruh (1996) determined the effects of blast chilling pork carcasses for 1 hour and injecting a 0.3 M calcium chloride solution into longissimus muscles 23 hours later. No differences ($p>0.05$) in purge or cooking loss were observed, but rapid chilling reduced ($p<0.05$) the combination of purge and cooking loss without influencing shear force values. The injection of calcium chloride at 24 hours postmortem lowered ($p<0.05$) shear force values of pork longissimus muscles.

Other studies suggested that injection of calcium chloride coupled with blade tenderization can be used to enhance tenderness (Benito-Delgado, Marriott, Claus, Wang, & Graham, 1994). Prerigor and postrigor beef *Longissimus dorsi* and *Infraspinatus* muscles were blade tenderized and injected with 0.3 M calcium chloride. Postrigor muscles had improved palatability and shear force values. However, prerigor muscles showed no signs of improved palatability and minimal effects on shear force values with calcium chloride injection.

While most studies were on the effects of injecting or infusing calcium chloride into muscle, Gonzales, Salitto, Carduza, Pazos, and Lasta (2000) marinated bovine *Cutaneus trunci*

muscles in 0.25 M calcium chloride for 2 hours and aged them for 7 days. They reported that muscle fragmentation index (MFI) values for calcium chloride marinated samples were significantly different from the control samples and calcium chloride could be used in *Cutaneus trunci* muscle to reduce the aging time required to increase tenderness. Koohmaraie *et al*. (1986) determined the effects of marination on beef *Longissimus dorsi* steaks in calcium chloride after freezing. Those authors reported that steaks marinated in calcium chloride and stored frozen had lower shear force values than steaks untreated and stored frozen. Those authors suggested that calcium released from the sarcoplasmic reticulum during postmortem storage aids in calpain proteolysis, which may still have some degradative activity under frozen conditions.

In 2002, Rees, Trout, and Warner reported that calcium chloride infusion produced low initial shear force values for accelerated boned pork *m. longissimus thoracis et lumborum* muscles. They concluded that *longissimus* muscles infused with calcium chloride at 6 days postmortem had shear force values that were significantly lower when compared with the control group. Furthermore, calcium chloride infusion was shown to be an effective method of reducing toughness associated with accelerated processing of pork.

Wheeler *et al*. (1992) determined the effects of marinating beef *longissimus dorsi* steaks in 600 ml of 150 mM calcium chloride at 4ºC. Freezing steaks after marination improved tenderness by enhancing the ability of the calcium ions to increase the activity of the calpain system. Those authors reported that higher levels of calcium activate CDP-I and CDP-II proteolytic systems in postmortem muscle, thus causing a breakdown of the myofibril and a decrease in shear force values. In addition, freezing lowered the activity of calpastatin and enhanced the ability of the calpain proteolytic system.

Calcium chloride improves tenderness by increasing the activation of the CDPs (Koohmaraie *et al*., 1988*a*; Koohmaraie *et al*., 1989), by causing extreme contraction of the muscle fibers resulting in disruption of the myofibrillar network (Morgan *et al*., 1991*a*), or by altering the protein to protein interactions due to the elevated ionic strength (Wu & Smith, 1987). In non-injected postmortem meat, free calcium levels must be high enough to carry out the activation of proteolysis by CDP-I. If calcium levels are high enough, CDP-II can be hydrolyzed to form CDP-I and the degree of tenderness can be enhanced (Dayton *et al*., 1981).

**Effect of Calcium Ascorbate on Tenderness**

Incorporating ingredients into marination technology would economically improve important traits such as tenderization, lengthening color life, or inhibiting microbial growth (Lawrence, Dikeman, Hunt, Kastner, & Johnson, 2003). Studies have shown that combining calcium chloride with sodium ascorbate enhances meat color and tenderness (Wheeler *et al*., 1996). A 1% sodium ascorbate and 200 mM calcium chloride solution injected into beef bottom rounds increased a* values through 7 days of display and lowered shear force averages. In 2001, Yancey, Hunt, Dikeman, Addis, & Katsanidis reported that the L*, a*, and b* values of ground beef were higher with sodium ascorbate and sodium chloride when compared with the control group. Katsanidis *et al*. (2003) showed that infusion of a calcium chloride and sodium ascorbate solution via the carotid artery in beef carcasses lowered TBARS values and improved color stability.

Calcium ascorbate is a chemical compound prepared from ascorbic acid and calcium carbonate. It is soluble in water and alcohol, but practically insoluble in methanol and ethanol. Its primary purpose is to serve as a preservative and antioxidant for color and lipid stability (Gimeno, Astiasarán, & Bello, 2001). The USDA and FSIS have recognized calcium ascorbate

as an ingredient that is Generally Recognized As Safe (GRAS). The final report to the FDA of the Select Committee on GRAS substances stated in 1980 that calcium ascorbate should maintain its GRAS status with no limitations other than a good manufacturing process (Gimeno, *et al*., 2001).

Calcium ascorbate has been employed in cooked, cured, or pulverized meat products and in pickles in which pork and beef products are cured and packed (Gimeno *et al*., 2001). Gimeno *et al*. (2001) reported that using calcium ascorbate in the place of salt for cured fermented sausage caused higher acidification related with the higher lactic acid bacteria development. In addition, the instrumental measurement of color gave rise to some significant differences for L*, a*, and b* values. Higher a* and b* values and lower L* values were reported in calcium ascorbate samples when compared with the control group color values.

Lawrence *et al*. (2002) injected beef longissimus muscles with different concentrations of calcium ascorbate. They concluded that a 0.1 M calcium ascorbate solution inhibited lipid oxidation and increased longissimus a* and b* values. However, using a 0.3 M calcium ascorbate solution lowered purge, cook loss percentages, and shear force values when compared with the 0.1 M calcium ascorbate group.

Differing methods have been used in applying ingredients to meat products, i. e. dipping, marinating, injecting, etc. However, dipping and marinating are two methods that are non-invasive to a product (Aberle *et al*., 2001). Injection, a form of mechanical tenderization, requires the use of a needle which may increase tenderness by disrupting muscle cell integrity (Aberle *et al*., 2001). Vacuum tumbling is another method of ingredient application that works in conjunction with injection or marination (Ranken, 2000). The pressure produced by the vacuum in the tumbler forces hydrophilic areas of macerated meat proteins to become exposed, which

allows for ingredient binding (Ranken, 2000). Marination requires no mechanical usage, but the product must be stored in an ingredient solution for an extended period of time (Aberle *et al*., 2001). Dipping also requires no mechanical usage and the product passes through an ingredient solution for a short period of time (Aberle *et al*., 2001).

# CHAPTER 3. THE EFFECTIVENESS OF ADDED INGREDIENTS ON TENDERIZATION AND COLOR ENHANCEMENT OF FRESH PORK CHOPS

## Materials and Methodology

White-line crossbred gilts (n=12) were harvested at a local slaughter and processing facility (Roucher's Meat Market, Plaquemine, Louisiana). After chilling of carcasses for 24 hours at 4˚C, wholesale loin sections (n=12, IMPS 410, NAMP (1997)) were removed from the left sides of the carcasses and were randomly assigned a loin tag number ranging from 1-12. All twelve loins were randomly assigned to fresh or frozen conditions. Immediately after tagging, loins were stored chilled (approximately 8°C) in a plastic bin until transportation. Loins were placed on a layer of bagged ice at the bottom of the bin and then covered with a layer of freezer paper. The cover to the plastic bin was placed on top of the bin once all twelve loins were in the bin. Carcass breaking and loin collection was approximately 2 hours in total. Transportation time from the plant to the Louisiana State University Agricultural Center Meat Laboratory was approximately 1-hour. At the laboratory, loins were transferred from the plastic bin to the processing room (6°C) and then separated into the fresh or frozen groups. After removal of external skin and trimming fat to 0.5 in., loins were cut into 2.0 cm thick chops on a band saw. Twenty chops from each loin were randomly selected, scraped of bone dust, and given a chop identification tag that represented a specific treatment combination of storage condition, dipping treatment, packaging condition, and day of display. Chops from each loin were placed into an individual white lug and covered with freezer paper. A total of twelve lugs of chops were loaded into a van and transported to the Louisiana State University Agricultural Center Food Processing and Technology Pilot Plant. Transportation time was approximately five minutes.

There were a total of 240 chops for this experiment; 48 chops for each of the five dipping treatments to repeat each treatment four times within each loin. Each storage group (fresh or frozen) contained 120 chops. Each of the 20 chops from each loin were randomly assigned to a respective dipping treatment: (1) no dip (control); (2) 0.3 M calcium chloride ($CaCl_2$) (Mallinckrodt Baker, Inc., Paris, KY); (3) 2% sodium ascorbate (NaAsc) (TCI America, Portland, OR); (4) 0.2 M calcium ascorbate (0.2 M CaAsc) (The Wright Group™, Crowley, LA); (5) 0.3 M calcium ascorbate (0.3 M CaAsc) (The Wright Group™, Crowley, LA), packaging condition: high oxygen or no oxygen, and display period: 3 days or 6 days.

Lugs were unloaded from the van and transported to the Louisiana State University Agricultural Center Food Processing and Technology Pilot Plant processing room (4°C). Lugs were placed onto tables and arranged in numerical order, 1-12. Chops were moved to the first station where surface pH (initial pH) of each chop was taken on the *Longissimus dorsi* muscle (LD). Initial pH was measured using a Sentron ConFET combination electrode attached to a Sentron Argus pH meter (Sentron Europe B.V., Roden, The Netherlands). After initial pH was recorded, chops were individually weighed on a gram scale (initial weight). Before dipping chops, the instrumental color (CIE L*, a*, b*) on the fresh cut surface of the LD (initial LD color) and marrow of the lumbar vertebrae (initial bone color) were measured (Minolta Spectrophotometer Model CM-508d, Illuminant A, 11 mm aperture, 10º standard observer, Specular Component Excluded, Minolta Co., Ltd., Osaka, Japan). Color measurements were recorded, in triplicate, by rotating the spectrophotometer 90° to the right between each measurement. Chroma and hue angle values were calculated from these formulas:

$$\text{Chroma} = \sqrt{((a^*)^2 + (b^*)^2)}$$

$$\text{Hue Angle} = \tan^{-1}(b^*/a^*)$$

Treatment dips were formulated (Table 1) 20 minutes before scheduled usage. A bucket was placed on a tared gram scale and filled with warm water (20ºC). The bucket was filled until the scale reached 7000 g. Each chemical compound was slowly sprinkled into its respective water bath and stirred until all crystals had been dissolved. Each treatment dip was poured into the Bettcher Automatic Batter-Breader System (Model HBB, Bettcher Industries Inc., Vermilion, OH). The bucket was cleaned with warm water and soap and rinsed with cold water between mixing of each treatment dip.

Table 1. Formulation of treatment dips

| Dip | Ingredients | Weight, g | Concentration in Brine, % | pH |
|---|---|---|---|---|
| 0.3 M $CaCl_2$ | | | | |
| | Water | 7000 | 96.777880 | |
| | $CaCl_2$ | 233.058 | 3.222123 | |
| | Total | 7233.058 | 100 | 6.75 |
| 2.0% NaAsc | | | | |
| | Water | 7000 | 98.039220 | |
| | NaAsc | 140.00 | 1.960784 | |
| | Total | 7140.00 | 100 | 6.42 |
| 0.2 M CaAsc | | | | |
| | Water | 7000 | 92.142970 | |
| | CaAsc | 596.89 | 7.857031 | |
| | Total | 7596.89 | 100 | 6.49 |
| 0.3 M CaAsc | | | | |
| | Water | 7000 | 88.659950 | |
| | CaAsc | 895.335 | 11.340050 | |
| | Total | 7895.335 | 100 | 6.51 |

Chops were individually placed on the batter-breading system belt and run once through their respective solution at a rate of 34.5 ft./min. (0.57 ft./sec.). Residence time in the dip for a single chop was 4 seconds. Chops were dipped in a specific order (Figure 1) to ensure that calcium chloride and sodium ascorbate dips would not be mixed with calcium ascorbate. The batter-breader system was cleaned with warm water and soap and rinsed with cold water between each dip treatment.

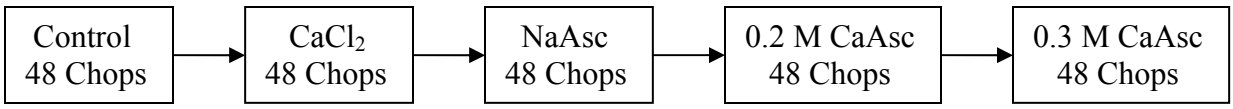



Figure 1. Flow diagram of dipping treatments.

Upon emerging from the batter-breader, chops were allowed to drip for 4 seconds on the chain link belt of the batter-breader dry breader section. Chops were removed from the breader belt, weighed on a gram scale (dipped weight), and individually placed into preformed barrier trays (#3 CR-Freshlock™ (polyethylene, Associated Packaging Technologies™ Jupiter, FL)) containing an absorbent pad (Dri-Loc® AC-25, Cryovac®, Duncan, SC) and then packaged (Ross Model 580, Midland, VA) using a barrier film (1830-G, 0.1 cc/100 $in.^2$ at 73ºF $O_2$ permeation, $H_2O$ vapor transmission rate = 1 g/100 $in.^2$ at 100ºF, Curwood® Inc., Oshkosh, WI). Pickup percentage was determined by dividing dipped weight by initial weight, then multiplying by 100. One hundred twenty chops were designated and packaged under modified atmosphere packaging conditions using no oxygen (80% $N_2$: 20% $CO_2$, Air Liquide, Baton Rouge, LA) and another one hundred twenty chops were designated and packaged in high oxygen (80% $O_2$: 20% $CO_2$, Air Liquide, Baton Rouge, LA). Oxygen and carbon dioxide levels were measured in five randomly selected packages of each dipping treatment using an oxygen and carbon dioxide analyzer (Mocon® PAC Check analyzer, Minneapolis, MN) at room temperature (25°C) within three to five minutes after packaging to allow for gas equilibration within the package.

After packaging thirty-six chops in the Ross packager, the packager malfunctioned and could not be immediately repaired. Twenty-four chops were from the fresh or frozen, control, no oxygen, 3 or 6 day treatment combinations. Twelve chops were from the fresh, calcium chloride, no oxygen, 3 or 6 day treatment combinations. It was decided that the 36 packages of chops should be placed into a cardboard box. The remaining 204 chops were dipped in their respective baths, placed into trays, and set on metal shelves of a multi-shelf tray cart. The cart was covered

in a plastic, zippered bag and loaded into the bed of a pick-up truck and transported back to the meat laboratory within five minutes. The cart was unloaded and transferred into the meat lab processing room. The remaining unsealed trays were placed into 3 mil standard nylon/polyethylene barrier vacuum pouches (10 x 20 $cm^2$, 3.5 cc/100 $in.^2$ at 25°C $O_2$ permeation, 0.6 cc/100 $in.^2$ at 0°C; $H_2O$ vapor transmission rate = 0.6 g/100 $in.^2$ at 40°C; Koch Supplies, Inc., Kansas City, MO). Packages were placed into a vacuum packager (Turbovac Model SB600, The Netherlands), flushed with their respective gases, and sealed (vacuum setting 4 for 22 seconds; flush setting 6 for 17.5 seconds; seal setting 4, for 9 seconds; atmospheric pressure = 15 psi). Although only 36 of the 48 control chops were packaged in the Ross packager with no oxygen, no statistics were used to compare the different packaging methods.

After packaging, both fresh group and frozen group chops were placed in cardboard boxes (28 in. x 25 in. x 16 in.). Box lids were closed shut and sealed with packaging tape to ensure that no light would enter the box during the storage time. Fresh group chops were stored for 7 days at 4°C and frozen group chops were stored for 21 days at -18°C.

| Harvest → | 24 h* → | 1d 16 h* → | 9 d 1 h* → | 23 d 1 h* → | 24 d 1 h* |
|---|---|---|---|---|---|
| | Collect data | Store chops -fresh at 4˚C -frozen at -18˚C | Fresh chops displayed for 3 or 6 days | Thaw frozen chops at 4˚C | Thawed frozen chops displayed for 3 or 6 days |

*-time postmortem
Figure 2. Time line of data collection and storage.

After 7 days of chilled storage, fresh group chops were removed from the boxes and displayed under continuous fluorescent light (1200 ± 200 lux) for 3 or 6 days at 4°C (Figure 2). After 21 days of frozen storage, frozen group boxes were removed from the freezer and placed in the cooler (4˚C) to allow chops to thaw. After 24 hours at 4˚C, frozen group chops were removed

from the boxes and displayed under continuous fluorescent light (1200 ± 200 lux) for 3 or 6 days at 4°C.

At end of each display time, packages were placed into cardboard boxes, closed shut and sealed with packaging tape, and transported in a van to The Food Processing and Technology Pilot Plant within five minutes. Boxes were unloaded and transferred to the processing room (4ºC) where they were opened and packages were placed onto a table. Packages were brought three at a time into a separate room (25°C) where final oxygen and carbon dioxide levels were measured (Mocon® PAC Check analyzer, Minneapolis, MN). Once measured, packages were brought back to the processing room and placed onto a different table. After gas had been measured in all packages, they were placed back into boxes, closed shut and sealed with packaging tape, loaded into the van, and transported back to the meat laboratory. Boxes were unloaded from the van and transferred to the cooking and sensory laboratory. Packages were removed from boxes and placed onto a table. Packages were weighed individually on a gram scale to determine a wet sample weight. The gram scale was tared with the weight of an unused package (tray + film + Dri-loc® pad). Packages were weighed (chop + film + tray + Dri-loc® pad) to determine a wet weight. Once a chop had been weighed, it was placed into a refrigerator (5°C).

After all chops had been weighed, chops were removed from the refrigerator, three at a time, for measurement of color, pH, and blotted weight measurements and prepared for cooking. Each chop was removed from its respective package and blotted dry with paper towels to remove excess surface moisture. Chops were placed onto a foam tray (2S footprint, 21 x 4.5 cm, Koch Supplies, Inc., Kansas City, MO) and color was allowed to equilibrate for 30 seconds before the instrumental color (CIE L* a* b*) of the LD (final muscle color) and marrow of the lumbar

vertebrae (final bone color) were measured (Minolta Spectrophotometer Model CM-508d, Illuminant A, 11 mm aperture, 10º standard observer, Minolta Co., Ltd., Osaka, Japan). Color measurements were recorded in triplicate per sample. The spectrophotometer was rotated 90° to the right between each color measurement. After color measurements, chops were weighed to obtain a blotted weight on a gram scale tared with an unused, clean foam tray. The blotted sample weight was subtracted from the wet sample weight to give the drip loss weight. Drip loss percentage was estimated by dividing drip loss weight by wet sample weight, then multiplying by 100. Final pH of each chop was measured on the surface of the LD (ConFET combination electrode attached to an Argus pH meter, Sentron Europe BV, Roden, The Netherlands).

Once pH, color, and weight measurements were taken, chops were cooked to an internal temperature of 70°C (Farberware® Millenium® Open Hearth® Smokeless Indoor Grill/Rotisserie Model FSR200, Salton/MAXIM Housewares, Inc., Mt. Prospect, IL) after turning once at 35°C. Internal temperature of each chop was monitored using a copper-constantan thermocouple (Omega® Engineering, Inc., Stamford, CT) attached to a recorder (Honeywell Multitrend Plus V5, York, PA). Once a chop reached an internal temperature of 70°C, it was placed on a foam tray, cooled to room temperature (25°C), and blotted dry with paper towels. The chop was weighed again to obtain a final cooked weight on a gram scale tared with an unused, clean foam tray. Cook loss percentage was determined by dividing the difference in blotted uncooked and cooked weights by the blotted uncooked weight, then multiplying by 100. Chops were individually tagged with an identification tag, placed into a single 3 mil standard nylon/polyethylene barrier vacuum pouch, (18 x 18 $cm^2$, 3.5 cc/100 $in.^2$ at 70°F $O_2$ permeation, 0.6 cc/100 $in.^2$ at 32°F; $H_2O$ vapor transmission rate = 0.6 g/100 $in.^2$ at 100°F; Koch Supplies, Inc., Kansas City, MO), sealed shut with packaging tape, and stored for 24 hours at 4°C.

After 24 hours of storage at 4°C, chops were removed from the refrigerator. Five half-inch cores were removed parallel to the fiber length from the LD of each chop and placed in a numbered plastic container. Four cores were randomly selected and sheared with a crosshead speed of 200 mm/min perpendicular to the muscle fiber orientation using a Warner-Bratzler shear force attachment (Model TA-HDi®; 250 kg load cell; Texture Technologies Corp., Scarsdale, NY). The fifth core was left in its numbered plastic container and frozen (-18°C) for 3 weeks for a mineral analysis.

A total of ten cores from the frozen storage, 3d display group were randomly selected for an analysis of calcium and sodium with two cores for each dipping treatment. Five of the ten cores were from the high oxygen group and the other five cores were from the no oxygen group. Cores were individually placed into plastic containers and labeled with type of storage, dipping treatment, packaging type, and display time. Plastic containers were placed into a box, covered, and transported to the Louisiana State University Agricultural Center Agricultural Chemistry Laboratory and stored at -18ºC for 24 hours.

Frozen core samples were individually taken out of their plastic container, weighed, and cut to approximately 0.5 grams. Each sample was placed into Teflon digestion vessels and mixed with 10 mL of nitric acid. The vessels were sealed and placed into a microwave (CEM MDS-2000, Matthews, NC) for pressure digestion. Pressure was increased to 20 psi (6 min.) and held for five minutes, increased to 40 psi (6 min.) and held for five minutes, and increased to 85 psi (10 min.) and held for five minutes. Samples were removed from the microwave and placed under a hood where they were allowed to cool and pressure was vented. The vessels were placed back into the microwave and heated once again. Pressure was increased to 85 psi (10 min.) and

held for five minutes before samples were removed from the microwave and cooled under the hood before pressure venting (EPA, 1996).

After cooling and venting, dried samples were transferred to a 100 ml volumetric flask where they were rinsed three times with deionized water. The flask was brought to volume with deionized water and shaken. Sample solutions were individually poured into sample tubes for Inductively Coupled Plasma (ICP) analysis (Oracle Model, Trion Technology, Inc., Tempe, AZ). Individual weights and volumes were recorded and entered into the ICP computer. Concentrations of minerals were determined by the ICP computer software program (Martin, Brockhoeft, & Creed, 1991).

## Statistical Analysis

The experimental design was predetermined before the experiment as a split plot experiment, with loins as whole plots and chops within loins as split plots. Twelve loins were randomly divided into two groups of six loins each. The two groups were then randomly assigned to the two levels (fresh or frozen) of storage condition. The twenty chops from each loin were randomly assigned to the twenty combinations of display time, package condition, and dipping treatment. The split plot model used to analyze the data was:

$$Y_{ijklm} = \bar{u}_{ijkl} + \rho_{im} + \varepsilon_{ijklm}$$

for storage condition i, display time j, package condition k, dipping treatment l, and loin m within storage condition i,

where $\mu_{ijkl}$ is the population average value for the dependent variable Y,

$\rho_{im}$ is the random effect of loin within storage,

$\varepsilon_{ijklm}$ is the experimental error,

$\rho_{im}$ is $N(0, \sigma_\rho^2)$,

$\varepsilon_{ijklm}$ is $N(0, \sigma_\varepsilon^2)$, and

all $\rho_{im}$'s and $\varepsilon_{ijklm}$'s are independent.

The model accounts for forty population average values for the dependent variable through $\mu_{ijkl}$. Forty values are required since there are forty different combinations of storage condition, display time, package condition, and dipping treatment. The model term $\rho_{im}$ accounts for the (positive) correlation between values of the dependent variable for different chops that were cut from the same loin.

Table 2. Main effects and two factor interactions.

| Single Factor Averages | Factors | Null Hypotheses* |
|---|---|---|
| $\bar{u}_{i\cdot\cdot\cdot}$ | Storage | $\bar{u}_{1\cdot\cdot\cdot} = \bar{u}_{2\cdot\cdot\cdot}$ |
| $\bar{u}_{\cdot j\cdot\cdot}$ | Display | $\bar{u}_{\cdot 1\cdot\cdot} = \bar{u}_{\cdot 2\cdot\cdot}$ |
| $\bar{u}_{\cdot\cdot k\cdot}$ | Package | $\bar{u}_{\cdot\cdot 1\cdot} = \bar{u}_{\cdot\cdot 2\cdot}$ |
| $\bar{u}_{\cdot\cdot\cdot l}$ | Dip | $\bar{u}_{\cdot\cdot\cdot 1} = \bar{u}_{\cdot\cdot\cdot 2} = \bar{u}_{\cdot\cdot\cdot 3} = \bar{u}_{\cdot\cdot\cdot 4} = \bar{u}_{\cdot\cdot\cdot 5}$ |
| **Two Factor Averages** | **Factors** | **Null Hypotheses*** |
| $\bar{u}_{ij\cdot\cdot}$ | Storage * Display | $\bar{u}_{11\cdot\cdot} - \bar{u}_{12\cdot\cdot} = \bar{u}_{21\cdot\cdot} - \bar{u}_{22\cdot\cdot}$ |
| $\bar{u}_{i\cdot k\cdot}$ | Storage * Package | $\bar{u}_{1\cdot 1\cdot} - \bar{u}_{1\cdot 2\cdot} = \bar{u}_{2\cdot 1\cdot} - \bar{u}_{2\cdot 2\cdot}$ |
| $\bar{u}_{i\cdot\cdot l}$ | Storage * Dip | $\bar{u}_{1\cdot\cdot 1} - \bar{u}_{2\cdot\cdot 1} = \bar{u}_{1\cdot\cdot 2} - \bar{u}_{2\cdot\cdot 2} = \bar{u}_{1\cdot\cdot 3} - \bar{u}_{2\cdot\cdot 3} = \bar{u}_{1\cdot\cdot 4} - \bar{u}_{2\cdot\cdot 4} = \bar{u}_{1\cdot\cdot 5} - \bar{u}_{2\cdot\cdot 5}$ |
| $\bar{u}_{\cdot jk\cdot}$ | Display * Package | $\bar{u}_{\cdot 11\cdot} - \bar{u}_{\cdot 12\cdot} = \bar{u}_{\cdot 21\cdot} - \bar{u}_{\cdot 22\cdot}$ |
| $\bar{u}_{\cdot j\cdot l}$ | Display * Dip | $\bar{u}_{\cdot 1\cdot 1} - \bar{u}_{\cdot 2\cdot 1} = \bar{u}_{\cdot 1\cdot 2} - \bar{u}_{\cdot 2\cdot 2} = \bar{u}_{\cdot 1\cdot 3} - \bar{u}_{\cdot 2\cdot 3} = \bar{u}_{\cdot 1\cdot 4} - \bar{u}_{\cdot 2\cdot 4} = \bar{u}_{\cdot 1\cdot 5} - \bar{u}_{\cdot 2\cdot 5}$ |
| $\bar{u}_{\cdot\cdot kl}$ | Package * Dip | $\bar{u}_{\cdot\cdot 11} - \bar{u}_{\cdot\cdot 21} = \bar{u}_{\cdot\cdot 12} - \bar{u}_{\cdot\cdot 22} = \bar{u}_{\cdot\cdot 13} - \bar{u}_{\cdot\cdot 23} = \bar{u}_{\cdot\cdot 14} - \bar{u}_{\cdot\cdot 24} = \bar{u}_{\cdot\cdot 15} - \bar{u}_{\cdot\cdot 25}$ |

*-Alternate hypotheses state that the corresponding nulls are false.

Main effects were compared for each of the four factors of storage condition, display time, package condition, and dipping treatment. The six two factor interactions were also examined. The main effect and interaction hypotheses appear in Table 2 and were rejected in favor of the corresponding alternate hypotheses whenever the associated probability values were

less than or equal to 0.05. The appropriate t and F test statistics were calculated using the General Linear Model (GLM) procedure in SAS (SAS, 2001).

## Results and Discussion

The four factors of this experiment were storage condition: fresh (7 days at 4˚C) or frozen (21 days at -18˚C); dipping treatment: control, calcium chloride, sodium ascorbate, 0.2 M calcium ascorbate, 0.3 M calcium ascorbate; package condition: 80% $O_2$ / 20% $CO_2$ (high oxygen) or 80% $N_2$ / 20% $CO_2$ (no oxygen); and display time: 3 or 6 days. Dependent variables were initial pH, final pH, initial LD L*, a*, b* color values, initial LD chroma, initial LD hue angle, final LD L*, a*, b* color values, final LD chroma, final LD hue angle, initial vertebrae L*, a*, b* color values, initial vertebrae chroma, initial vertebrae hue angle, final vertebrae L*, a*, b* color values, initial weight, dipped weight, percent pickup, final vertebrae chroma, final vertebrae hue angle, wet weight, blotted weight, percent drip loss, cooked weight, percent cook loss, and shear force average. In addition, a mineral analysis was conducted on randomly selected samples.

The dipping treatment main effects were significantly different for the dependent variables initial pH, final pH, initial LD L*, initial LD b*, initial LD chroma, initial LD hue, final LD L*, final LD a*, final LD b*, final LD chroma, initial vertebrae L*, initial vertebrae a*, final vertebrae L*, final vertebrae a*, final vertebrae b*, final vertebrae chroma, final vertebrae hue angle, percent pickup, blotted weight, percent drip loss, cooked weight, and shear force. Dependent variables that did not have significantly different dipping treatment main effects were initial LD a*, final LD hue angle, initial vertebrae b*, initial vertebrae chroma, initial vertebrae hue angle, and percent cook loss.

The storage main effect was significantly different for most of the dependent variables examined. The frozen treatments were significantly different from the fresh treatments for the dependent variables final pH, final LD L*, final LD a*, final vertebrae L*, final vertebrae a*, final vertebrae b*, final vertebrae chroma, percent drip loss, and percent cook loss. Dependent variables that did not have significantly different storage main effect were initial pH, initial LD L*, a*, b*, chroma and hue angle, initial weight, dipped weight, final LD b*, final LD chroma and hue angle, initial vertebrae L*, a*, b*, chroma and hue angle, final vertebrae hue angle, blotted weight, cooked weight, and shear force.

The packaging condition main effect was significantly different for the dependent variables final pH, final LD L*, final LD a*, initial vertebrae L*, final vertebrae L*, final vertebrae a*, final vertebrae b*, final vertebrae chroma, and final vertebrae hue angle, and shear force. Dependent variables that did not have significantly different packaging condition main effect were initial pH, initial LD L*, a*, b*, chroma, hue angle, initial weight, dipped weight, final LD b*, chroma, hue angle, initial vertebrae a*, b*, chroma, hue angle, blotted weight, percent drip loss, cooked weight, and percent cook loss.

The display time main effect was significantly different for the dependent variables blotted weight, cooked weight, and shear force. Dependent variables that did not have significantly different display time main effect were initial and final pH, initial and final LD L*, a*, b*, chroma, and hue angle, initial and final vertebrae L*, a*, b*, chroma, and hue angle, initial weight, dipped weight, percent drip loss and percent cook loss.

Gas compositions were measured in each package at each time of sampling (Table 3). The only differences in gas compositions were between the high oxygen and no oxygen

packages. There were no differences in oxygen concentration among high oxygen packages and no differences in oxygen concentration among no oxygen packages.

Table 3. Gas compositions of packages.

| Treatment | | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| HiOx | | | | | |
| | Oxygen | 81.3% | 0.952 | 73.9% | 82.7% |
| | Carbon Dioxide | 18.9% | 0.502 | 17.7% | 20.4% |
| NoOx | | | | | |
| | Oxygen | 2.8% | 2.318 | 0.3% | 9.2% |
| | Carbon Dioxide | 19.4% | 0.582 | 18.0% | 21.7% |

Differences in pH for dipping solutions were minimal as all solutions were in the pH range of 6.42-6.75. Solutions containing ascorbate had lower pH values than the calcium chloride solution. This may be due to calcium chloride contributing negative ions to the solution, which may have raised the pH when compared to the ascorbate solutions.

Differences ($p \leq 0.05$) in initial pH were noted between the control and calcium chloride and 0.2 M calcium ascorbate treatments (Table 4). However, the control treatment and the sodium ascorbate and 0.3 M calcium ascorbate treatments were not significantly different for initial pH. The variation in initial pH among treatments may be due to a high ultimate pH in one or more of the loins that was chosen for sampling. Chops dipped in sodium ascorbate or 0.3 M calcium ascorbate had higher ($p \leq 0.05$) pH values compared with control and calcium chloride chops. These results are not in agreement with work conducted by Lawrence *et al*. (2003). Those authors reported that initial and final pH values were not different after injection with calcium chloride, calcium lactate, or calcium ascorbate and storage for 14 days at 1˚C. The differences we observed between initial and final pH for each dip treatment may be due to packaging conditions. Lawrence *et al*. (2003) placed their steaks on foam trays and wrapped them in heat shrinkable PVC film. Our chops were packaged in high oxygen and no oxygen atmospheres,

which may have led to optimal environments for oxidation reactions to change the surface pH of the chops.

Table 4. Initial and final pH LS Means with different dipping treatments.

| Treatment | Initial pH | Final pH |
|---|---|---|
| Control | 5.70[a] | 6.02[b] |
| $CaCl_2$ | 5.64[bc] | 6.01[b] |
| NaAsc | 5.67[ab] | 6.10[a] |
| 0.2 CaAsc | 5.63[c] | 6.06[ab] |
| 0.3 CaAsc | 5.68[ab] | 6.11[a] |
| SE | 0.015 | 0.008 |

[abc] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 5. Initial CIELAB LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different dipping treatments.

| Treatment | LD L* | LD a* | LD b* | V L* | V a* | V b* |
|---|---|---|---|---|---|---|
| Control | 60.01[a] | 4.32[a] | 15.56[a] | 54.09[a] | 13.27[a] | 15.19[a] |
| $CaCl_2$ | 61.35[a] | 4.40[a] | 15.80[a] | 54.21[a] | 12.77[a] | 15.20[a] |
| NaAsc | 61.68[a] | 4.85[a] | 15.82[a] | 54.09[a] | 13.17[a] | 15.53[a] |
| 0.2 CaAsc | 60.03[a] | 4.85[a] | 15.97[a] | 51.80[ab] | 14.35[a] | 15.02[a] |
| 0.3 CaAsc | 60.02[a] | 5.02[a] | 15.51[a] | 51.22[b] | 15.15[a] | 15.75[a] |
| SE | 0.825 | 0.328 | 0.336 | 0.964 | 0.866 | 0.536 |

[abc] LS Means in the same column with the same letters are not different ($p<0.05$).

There were no significant differences between dipping treatments for initial LD L*, a*, and b* values (Table 5). Initial vertebrae L* values for chops from the 0.3 M calcium ascorbate group were significantly lower than the control, calcium chloride, and sodium ascorbate groups. This difference in initial vertebrae L* for chops dipped in 0.3 M calcium ascorbate may be due to amount of hemoglobin present at the bone surface or the amount of oxidation that had already occurred in the bone. There were no significant differences among dipping treatments for initial vertebrae a* or b* values.

Table 6. Initial chroma and hue angle LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different dipping treatments.

| Treatment | LD Chroma | LD Hue Angle | V Chroma | V Hue Angle |
|---|---|---|---|---|
| Control | 16.21[a] | 1.30[a] | 20.27[a] | 0.87[a] |
| $CaCl_2$ | 16.71[a] | 1.31[a] | 20.00[a] | 0.83[a] |
| NaAsc | 16.60[a] | 1.28[a] | 20.47[a] | 0.88[a] |
| 0.2 CaAsc | 16.38[a] | 1.26[a] | 20.93[a] | 0.83[a] |
| 0.3 CaAsc | 16.40[a] | 1.24[a] | 21.99[a] | 0.83[a] |
| SE | 0.386 | 0.013 | 0.925 | 0.039 |

[ab] LS Means in the same column with the same letters are not different ($p<0.05$).

There were no significant differences among treatments for initial LD chroma and hue angle and initial vertebrae chroma and hue angle. Chroma is a calculated measurement that represents the degree of saturation of a color (Minolta, 1993). Hue angle is a calculated measurement of hue and assesses classifications to colors, which are seen by the human eye (Minolta, 1993). Chroma and hue angle values express colors numerically and aid in communicating colors more accurately (Minolta, 1993).

The design of the experiment was set up for loins to be cut into chops 2.0 cm thick. There were significant differences noted in initial weights of chops among the dipping treatment groups. Chops in the 0.3 M calcium ascorbate group had significantly higher initial weights than the other dipping treatment groups. Initial weights for chops in the control group were significantly higher than the sodium ascorbate or 0.2 M calcium ascorbate groups, but not significantly different from the calcium chloride group. These differences in initial weight suggest that chop thickness may have varied or the loin-eye area was different among loins. Dipped weights for chops in the 0.3 M calcium ascorbate group were significantly higher than the other three groups of chops that were dipped. However, there was no significant difference for dipped weights among the calcium chloride, sodium ascorbate, and 0.2 M calcium ascorbate groups.

There were no significant differences for percent pickup among the calcium chloride, sodium ascorbate, or 0.2 M or 0.3 M calcium ascorbate groups, which indicated that variation in initial weights were balanced by corresponding dipped weights for each dip treatment. Dipped chops picked up between 1.5 and 2.5 percent solution, which is in accordance with a preliminary project conducted by our group. In that preliminary study, pork loin chops were dipped in 0.2 M and 0.3 M calcium chloride solutions using the same batter-breader machine at the same chain speed. Those chops picked up between 1.4 and 2.5 percent solution, regardless of the dip treatment. Thus, the present results are consistent with the findings in the project.

Table 7. Initial weight, dipped weight, and percent pickup LS Means with different dipping treatments.

| Treatment | Initial weight, g | Dipped weight, g | Pickup, % |
|---|---|---|---|
| Control | 250.06$^{b}$ | 0.00$^{c}$ | 0.00$^{b}$ |
| $CaCl_2$ | 245.90$^{bc}$ | 250.80$^{b}$ | 102.02$^{a}$ |
| NaAsc | 234.05$^{c}$ | 238.47$^{b}$ | 101.93$^{a}$ |
| 0.2 CaAsc | 235.26$^{c}$ | 238.91$^{b}$ | 102.13$^{a}$ |
| 0.3 CaAsc | 262.95$^{a}$ | 269.46$^{a}$ | 102.47$^{a}$ |
| SE | 2.792 | 2.764 | 0.16 |

$^{abc}$ LS Means in the same column with the same letters are not different ($p<0.05$).

Significant differences were observed between dipping treatments for final color measurements of the LD and the lumbar vertebrae. Final LD L* values were significantly lower for chops dipped in calcium ascorbate than chops dipped in calcium chloride (Table 8), but were not significantly different from chops in the control or sodium ascorbate groups. Lawrence *et al*. (2003) also observed lower LD L* for steaks injected and marinated with 0.2 M calcium ascorbate compared with steaks injected and marinated with calcium chloride or 0.1 or 0.3 calcium ascorbate. Those authors suggest that injecting and marinating beef steaks with calcium ascorbate caused the muscle to appear redder and darker in color.

Final LD a* values were significantly higher for chops in the control group than chops dipped in sodium ascorbate, but those chops had a* values similar to chops in other treatments.

Our results contradicted research on beef dipped or injected with sodium ascorbate (Lawrence *et al*. 2003; Mistsumoto *et al*., 1991*b*). Those authors found that ascorbic acid, or its salt form sodium ascorbate, produced significantly higher LD a* values in beef steaks compared with untreated steaks. Our results are unexpected as the antioxidant properties of sodium ascorbate should have had raised LD a* values higher than in chops from the control group. Lower LD a* values may be due to smaller amounts of ascorbate being retained in the product after dipping in the sodium ascorbate group compared with the calcium ascorbate groups (Table 11). Also, pork has less myoglobin than beef (Aberle *et al*., 2001), which may cause differing results among species with added ascorbate. Therefore, the amount of sodium ascorbate retained needs to be increased above 0.5%, thus causing sodium ascorbate to have greater antioxidant activity. Chops dipped in sodium ascorbate were not significantly different from chops dipped in calcium chloride or 0.2 M or 0.3 M calcium ascorbate for final LD a* and had the lowest numerical value for a*. Again, our results contradict research by Wheeler *et al*. (1996) as they found higher LD a* values in beef steaks injected with sodium ascorbate compared with beef steaks injected with calcium chloride.

Table 8. Final CIELAB LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different dipping treatments.

| Treatment | LD L* | LD a* | LD b* | V L* | V a* | V b* |
|---|---|---|---|---|---|---|
| Control | $62.95^{ab}$ | $2.86^{a}$ | $14.72^{a}$ | $53.89^{b}$ | $10.93^{cd}$ | $15.11^{b}$ |
| $CaCl_2$ | $63.59^{a}$ | $2.56^{ab}$ | $14.77^{a}$ | $55.37^{ab}$ | $10.29^{d}$ | $15.11^{b}$ |
| NaAsc | $63.07^{ab}$ | $2.00^{b}$ | $13.77^{b}$ | $56.23^{a}$ | $12.26^{bc}$ | $15.63^{b}$ |
| 0.2 CaAsc | $61.49^{b}$ | $2.26^{ab}$ | $13.92^{ab}$ | $54.76^{ab}$ | $14.38^{a}$ | $16.73^{a}$ |
| 0.3 CaAsc | $61.72^{b}$ | $2.58^{ab}$ | $14.67^{a}$ | $55.13^{ab}$ | $13.32^{ab}$ | $16.57^{a}$ |
| SE | 0.727 | 0.275 | 0.909 | 2.095 | 1.616 | 0.902 |

$^{abcd}$ LS Means in the same column with the same letters are not different ($p<0.05$).

Final LD b* values were lower ($p\leq0.05$) for chops dipped in sodium ascorbate compared with chops in the control, calcium chloride, and 0.3 M calcium ascorbate groups. Chops dipped in sodium ascorbate were not significantly different from chops dipped in 0.2 M calcium

ascorbate for final LD b*. However, chops dipped in 0.2 M calcium ascorbate were not significantly different from chops in the control, calcium chloride, or 0.3 M calcium ascorbate groups for final LD b*. Our results of lower LD b* values with the use of 0.2 M calcium ascorbate and sodium ascorbate supports results in previous research (Lawrence *et al*., 2003; Mitsumoto, Faustman, Cassens, Arnold, Schaefer, & Scheller, 1991*a*). Lawrence *et al*. (2003) reported significantly lower LD b* in beef steaks treated with 0.2 M calcium ascorbate compared with the control and calcium chloride treatment groups. Mistumoto *et al*. (1991*b*) observed significantly lower LD b* values in beef steaks that were treated with 1.5 and 2.0% sodium ascorbate compared with the control steaks. Chops dipped in 0.3 M calcium ascorbate should have had significantly higher LD b* values than the control or calcium chloride chops. This suggestion is in agreement with Lawrence *et al*. (2003). Those authors stated that use of calcium ascorbate resulted in darker steaks that were less red, less yellow, and more brown than calcium chloride marinated beef steaks. The antioxidant properties of ascorbate should have aided in the reduction of iron in myoglobin.

Control chops had lower final vertebrae L* values than dipped chops; however, final vertebrae L* were not significantly different among the control and calcium groups. Chops in the control group had significantly lower vertebrae L* values than chops dipped in sodium ascorbate. Our results are in agreement with research conducted by Mitsumoto *et al*. (1991*b*). Those authors reported higher L* values in beef steaks treated with a 2.0% sodium ascorbate solution compared with the untreated steaks. However, Mancini et al. (2004) reported no differences in vertebrae L* values between beef steaks treated with 1.5% ascorbic acid and untreated steaks.

Final vertebrae a* values were significantly higher with the use of 0.2 M or 0.3 M calcium ascorbate than control or calcium chloride groups. This was expected, as Mancini *et al*. (2004) found significantly higher vertebrae a* values for chops covered in an ascorbic acid solution compared with control samples. Those authors suggest that applying between 1.5%-2.5% ascorbic acid to the fresh cut surface of lumbar vertebrae will maintain a redder color. These higher final vertebrae a* values may be due to the ascorbate compound in 0.2 M and 0.3 M calcium ascorbate, which aids in the reduction of the iron atom in hemoglobin. There were no significant differences for final vertebrae a* values between chops in the 0.3 M calcium ascorbate and sodium ascorbate groups. However, chops dipped in 0.3 M calcium ascorbate had numerically higher vertebrae a* values than chops dipped in sodium ascorbate. This may be due to higher concentrations of ascorbate in chops dipped in 0.3 M calcium ascorbate compared with chops dipped in sodium ascorbate (Table 11).

Final vertebrae b* values were significantly higher for chops dipped in 0.2 M or 0.3 M calcium ascorbate than control, calcium chloride, or sodium ascorbate chops. Chops in the control, calcium chloride, and sodium ascorbate groups were not significantly different from one another. Our results contradict research conducted by Mancini *et al*. (2004) and Lawrence *et al*. (2003). Mancini *et al*. (2004) authors found no significant differences in vertebrae b* values between beef steaks treated with ascorbic acid and steaks left untreated. Lawrence *et al*. (2003) reported that steaks injected with calcium ascorbate were less yellow (lower b* values) than steaks in the control or calcium chloride treatment groups. Our results of higher vertebrae b* values with the use of calcium ascorbate may be due to the effect of other experimental variables.

Final LD chroma values were higher for chops in the control and calcium chloride groups than chops dipped in sodium ascorbate (Table 9). Lawrence *et al*. (2003) also reported higher LD chroma values in the control and calcium chloride treated beef steaks compared with steaks treated with 0.2 M and 0.3 M calcium ascorbate. Significantly higher LD chroma values indicated that samples in the control, calcium chloride, and 0.3 M calcium ascorbate groups had a more vivid, brighter grayish pink color of the lean than samples in the sodium ascorbate group. Final LD chroma values were not significantly different for chops dipped in sodium ascorbate compared with chops dipped in 0.2 M calcium ascorbate.

There were no significant differences among dipping treatments for final LD hue angle. Although there were significant differences among treatments for final LD a*, hue angle uses a* and b* values in the calculation of the inverse tangent of b* divided by a*. Therefore, since no significant differences were observed, the LD hue of pork chops were similar.

Samples dipped in calcium ascorbate solutions had increased vertebrae bone chroma values. Final vertebrae chroma values were higher ($p \leq 0.05$) with the addition of 0.2 M or 0.3 M calcium ascorbate compared with control or calcium chloride chops. In addition, final vertebrae chroma values were significantly higher for chops dipped in sodium ascorbate compared with chops dipped in calcium chloride. Mancini *et al*. (2004) and Mitsumoto *et al*. (1991*b*) also reported significantly higher vertebrae chroma values for beef steaks treated with 1.5 and 2.0% sodium ascorbate compared with the untreated steaks. Again, the use of an ascorbate compound reduced the iron atoms, which increased final vertebrae a* values. Final vertebrae hue angle values were decreased ($p \leq 0.05$) for chops dipped in 0.2 M or 0.3 M calcium ascorbate compared with chops in the calcium chloride group. Chops in the control and calcium chloride groups were not significantly different from one another for final vertebrae hue angle.

Table 9. Final chroma and hue angle LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different dipping treatments.

| Treatment | LD Chroma | LD Hue Angle | V Chroma | V Hue Angle |
|---|---|---|---|---|
| Control | 15.03[a] | 1.38[a] | 18.80[cd] | 0.96[ab] |
| $CaCl_2$ | 15.06[a] | 1.28[a] | 18.44[d] | 0.99[a] |
| NaAsc | 13.96[b] | 1.23[a] | 20.01[bc] | 0.93[bc] |
| 0.2 CaAsc | 14.14[ab] | 1.42[a] | 22.22[a] | 0.89[c] |
| 0.3 CaAsc | 15.04[a] | 1.21[a] | 21.42[ab] | 0.92[bc] |
| SE | 0.348 | 0.104 | 0.544 | 0.019 |

[abcd] LS Means in the same column with the same letters are not different ($p<0.05$).

Our results of lower LD b* values and higher vertebrae a* values may be attributes that are considered acceptable by consumer panelists. Thus, our work would support results reported by Norman, Berg, Heymann, and Lorenzen (2003). Those authors reported that consumer panelists chose pork loin chops with higher a* values and lower b* values 52.8% of the time compared with pork loin chops that had lower a* values and higher b* values (47.2% of the time). Consumer panelists could not recognize differences in overall liking across color categories, yet when give the opportunity for repeat selection, chose pork chops with lower L* values compared with paler pork chops (Norman *et al*., 2003). In addition, Brewer and McKeith (1999) indicated the largest differences among pork loin chops appeared in L* values. However, our results indicated that differences were minimal for LD and vertebrae L* values after dipping, packaging, storage, and display.

Dipping treatment main effects were significantly different for the dependent variables percent drip loss and shear force. Sodium ascorbate and calcium chloride dipped chops produced the highest percentage of drip loss with drip loss of sodium ascorbate chops being significantly higher than in control, calcium chloride, and calcium ascorbate chops (Table 10). High drip loss from chops dipped in sodium ascorbate is in agreement with studies conducted by Hood *et al*. (1975) and Katsanidis *et al*. (2003). These authors found that postmortem injection of either 1% or 1.5% sodium ascorbate solution into beef steaks significantly increased percent drip loss

compared with non-injected samples. The addition of a salt (calcium chloride) to a solution would increase ionic strength, thereby increasing the number of hydrophilic protein interactions, which would cause an increase in the binding of free water (Lawrence *et al*., 2003).

Table 10. Percent drip loss, percent cook loss, and shear force LS Means with different dipping treatments.

| Treatment | Drip Loss, % | Cook Loss, % | Shear Force, g |
|---|---|---|---|
| Control | $3.80^{c}$ | $2.15^{a}$ | $3073.38^{ab}$ |
| $CaCl_2$ | $4.61^{b}$ | $2.18^{a}$ | $2846.13^{b}$ |
| NaAsc | $5.40^{a}$ | $2.06^{a}$ | $3186.02^{a}$ |
| 0.2 CaAsc | $4.25^{bc}$ | $2.13^{a}$ | $2963.61^{ab}$ |
| 0.3 CaAsc | $4.43^{bc}$ | $1.97^{a}$ | $3115.93^{ab}$ |
| SE | 0.331 | 0.812 | 103.110 |

$^{abc}$ LS Means in the same column with the same letters are not different ($p<0.05$).

Table 11. Percent ingredient in product with different dipping treatments.

| Treatment | Ingredient in Product, % | Ingredient in Product After Drip Loss, % |
|---|---|---|
| Control | 0.000 | 0.000 |
| $CaCl_2$ | 0.065 | 0.068 |
| NaAsc | 0.038 | 0.040 |
| 0.2 CaAsc | 0.167 | 0.174 |
| 0.3 CaAsc | 0.280 | 0.293 |

Percent drip loss was only slightly higher for chops in the calcium ascorbate groups than the control. This is important because a lower percent drip loss would indicate that more of the calcium ascorbate solution was retained in the meat matrix, thus having a higher probability to carry out tenderizing and antioxidant processes. Furthermore, percent drip loss was not significantly different between chops dipped in calcium chloride and 0.2 M or 0.3 M calcium ascorbate. Our results coincide with research conducted by Lawrence *et al*. (2003). These authors also reported no difference in percent purge loss between beef steaks treated with 0.2 M and 0.3 M calcium ascorbate and 0.3 M calcium chloride.

There were no significant differences between dipping treatments for percent cook loss. This may be due to chops having sufficient time during their storage and display times to lose

most of the unbound water, thus having smaller amounts intracellular free water to lose during the cooking process.

Shear force was lowest in chops dipped in calcium chloride, but was not significantly different from chops in the control or 0.2 M or 0.3 M calcium ascorbate groups. Chops dipped in sodium ascorbate had higher shear force values than chops dipped in calcium chloride. Therefore, our data supports research conducted by Yancey *et al*. (2002). Those authors reported that calcium chloride injected steaks had lower shear force values than steaks injected with sodium ascorbate. In addition, those authors reported that shear force values for steaks injected with a calcium chloride plus sodium ascorbate solution were not significantly different from steaks injected with only calcium chloride. Contrary to our results, numerous previous studies have reported a significant reduction in shear force values of beef steaks following injection, infusion, marination, or dipping in a 0.3 M calcium chloride solution (Koohmaraie *et al*., 1989; Koohmaraie *et al*., 1990; Whipple *et al*., 1992; Gonzales *et al*., 2000). Lawrence *et al*. (2003) reported no difference in shear force between beef steaks treated with 0.2 M or 0.3 M calcium ascorbate and 0.3 M calcium chloride. However, these authors found that treating beef steaks with calcium ascorbate or calcium chloride produced lower shear force values than the untreated steaks. Our results did show that shear force values were significantly lower for chops dipped in calcium chloride than for chops dipped in sodium ascorbate. We may have seen lower shear force values in chops treated with calcium chloride or calcium ascorbate if the treatments were applied within six hours postmortem. Calkins and Seideman (1988) reported that most tenderization occurs by 24 hours postmortem and increasing calcium levels closer to the time of harvest will increase CDP-II activity, causing a decrease in shear force values in beef steaks.

For the factor of storage, there were no significant differences between storage conditions for initial pH (Table 12). However, final pH values were higher ($p \leq 0.05$) for chops in the frozen group than chops in the fresh group. Other research has shown that initial measurements of frozen meat pH do not differ from final measurements of frozen meat pH (Mortensen, Anderson, Engelsen & Bertram, 2006; Sante & Fernandez, 2000). Also, initial LD and vertebrae CIE L*, a*, b*, (Table 13) chroma, and hue angle values (Table 14) and initial and dipped weights (Table 15) were not significantly different between storage conditions. No difference between storage groups for initial LD and vertebrae color values was expected since chops were randomly selected and had not been subjected to either storage treatment. The average pickup of 2.4% agreed with results in the preliminary study.

Table 12. Initial and final pH LS Means with different storage conditions.

| Treatment | Initial pH | Final pH |
|---|---|---|
| Fresh | 5.67[a] | 5.67[b] |
| Frozen | 5.66[a] | 6.45[a] |
| SE | 0.015 | 0.030 |

[ab] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 13. Initial CIELAB LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different storage conditions.

| Treatment | LD L* | LD a* | LD b* | V L* | V a* | V b* |
|---|---|---|---|---|---|---|
| Fresh | 60.25[a] | 4.81[a] | 15.45[a] | 52.91[a] | 13.83[a] | 15.28[a] |
| Frozen | 59.78[a] | 4.57[a] | 15.33[a] | 53.26[a] | 13.65[a] | 15.40[a] |
| SE | 0.727 | 0.275 | 0.909 | 2.095 | 1.616 | 0.902 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 14. Initial chroma and hue angle LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different storage conditions.

| Treatment | LD Chroma | LD Hue Angle | V Chroma | V Hue Angle |
|---|---|---|---|---|
| Fresh | 16.23[a] | 1.27[a] | 20.72[a] | 0.86[a] |
| Frozen | 16.05[a] | 1.29[a] | 20.74[a] | 0.84[a] |
| SE | 0.348 | 0.104 | 0.544 | 0.019 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 15. Initial weight and dipped weight LS Means with different storage conditions.

| Treatment | Initial weight, g | Dipped weight, g | Pickup, % |
|---|---|---|---|
| Fresh | 243.72[a] | 197.62[a] | 102.44[a] |
| Frozen | 247.56[a] | 201.44[a] | 102.38[a] |
| SE | 2.792 | 2.764 | 2.736 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Final LD L*, a*, and b* values were different between storage conditions (Table 16). Chops in the frozen group had lower ($p\leq0.05$) LD L* values and higher ($p\leq0.05$) a* and b* values than chops in the fresh group. Our data supports data by Ledward *et al*. (1972). These authors observed lower LD L* values in beef steaks that were stored frozen compared with steaks stored fresh. These authors suggest that the brighter color observed in beef steaks may be related to increased oxygenation in temperatures optimal for reducing reactions to occur. Our results of higher LD a* values in pork chops stored frozen compared with chops stored fresh contradicts work by Hansen *et al*. (2004). Those authors found higher LD a* values in pork chops stored fresh (4°C for 6 days) than chops stored frozen (-20°C for 30 months). Our higher LD a* values for frozen chops may be a result of three of the five dip treatments with added antioxidants, whereas Hansen *et al*. (2004) did not use antioxidant treatments. However, our results are in agreement with Hansen *et al*. (2004) for LD b* values. Those authors also found higher LD b* values in pork chops stored frozen compared with chops stored fresh. The results reported by Hansen *et al*. (2004) suggests that storing chops frozen causes LD color to appear darker over a 30 month time span. High LD a* values after short term freezing were also found by other researchers (Hoving-Bolink, Eikelenboom, van Diepen, Jongbloed, & Houben, 1997). These authors reported higher LD a* values in pork chops that were untreated and stored frozen for 6 days compared with the untreated chops considered fresh. Also, LD a* values were higher in chops treated with vitamin E and stored frozen compared with chops treated with vitamin E and considered fresh.

Chops in the frozen group had lower ($p \leq 0.05$) vertebrae L* values and higher ($p \leq 0.05$) a* and b* values than chops in the fresh group. The higher vertebrae L* values in the fresh group may be due to oxygen reacting with hemoglobin causing a brighter appearance. These results may be due to a reduction in oxidation reaction rates during frozen storage. During fresh storage, oxidation would occur at a faster rate because temperatures are approaching optimum for oxidation reactions to occur (Christen *et al*. 2000). Our results support research conducted by Okayama *et al*. (1987). These authors reported higher a* and b* values in beef steaks after frozen storage and display compared with steaks displayed fresh. These high vertebrae a* and b* values may be due to less pigment degradation as a result of the preservative effects of frozen storage. Research by Huff-Lonergan *et al*. (2001) showed that beef steaks stored frozen had shorter shelf-lives and higher discoloration scores for bone color than steaks that were stored fresh and displayed. Those authors suggested that high discoloration in frozen steaks was due to faster oxidation after thawing, which was a result of breakdown of metmyoglobin reductase during the freezing process.

Final LD and vertebrae chroma values were higher ($p \leq 0.05$) for chops in the frozen group than the fresh group (Table 17). Our results suggest that freezing promotes higher degrees of saturation in LD and vertebrae. This may be due to less inhibition of oxidation reactions during the freezing process, which would lower the amount of pigment oxidation, causing the LD and vertebrae to have high chroma values. There were no differences between storage conditions for final LD or vertebrae hue angle values.

Chops in the fresh group had lower ($p \leq 0.05$) percent drip loss, percent cook loss, and shear force values than chops in the frozen group (Table 18). If water molecules in the LD were not frozen quick enough, large ice crystals may have formed which would puncture muscle

fibers, releasing even more moisture when thawed. During thawing and cooking, these chops experienced high drip and cook losses. Previous research suggests that frozen storage can aid in the tenderization of meat (Ngpao, Babare, Reynolds, & Mawson, 1999), which is contradictory to results in the current study. Kahn and Lentz (1976) reported frozen beef steaks had shear force values equal to or higher to that of fresh beef steaks when steaks were frozen at -30°C, but steaks that were frozen at -18°C had lower shear force values than fresh steaks. Furthermore, we observed more drip and cook loss in chops stored frozen compared with fresh. The increased moisture loss for chops stored frozen may indicate a decrease in protein-bound water in the chops, which would increase the force to shear samples from those chops.

Table 16. Final CIELAB LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different storage conditions.

| Treatment | LD L* | LD a* | LD b* | V L* | V a* | V b* |
|---|---|---|---|---|---|---|
| Fresh | 65.34[a] | 1.98[b] | 13.96[b] | 58.12[a] | 10.90[b] | 14.30[b] |
| Frozen | 59.79[b] | 2.91[a] | 14.78[a] | 52.03[b] | 13.58[a] | 17.36[a] |
| SE | 0.727 | 0.275 | 0.909 | 2.095 | 1.616 | 0.902 |

[ab] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 17. Final chroma and hue angle LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different storage conditions.

| Treatment | LD Chroma | LD Hue Angle | V Chroma | V Hue Angle |
|---|---|---|---|---|
| Fresh | 14.17[b] | 1.25[a] | 18.13[b] | 0.95[a] |
| Frozen | 15.12[a] | 1.36[a] | 22.22[a] | 0.93[a] |
| SE | 0.348 | 0.104 | 0.544 | 0.019 |

[ab] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 18. Percent drip loss, percent cook loss, and shear force LS Means with different storage conditions.

| Treatment | Drip Loss, % | Cook Loss, % | Shear Force, g |
|---|---|---|---|
| Fresh | 3.92[b] | 2.02[b] | 2955.66[b] |
| Frozen | 5.11[a] | 2.18[a] | 3118.37[a] |
| SE | 0.331 | 0.812 | 103.110 |

[ab] LS Means in the same column with the same letters are not different ($p<0.05$).

There were no significant differences between packaging conditions for initial pH (Table 19). Chops packaged in high oxygen had higher ($p\leq0.05$) final pH values than chops packaged in

no oxygen. Huang, Ho, and McMillin (2005) reported that from day 0 to day 7, pH values decreased for pork packaged in 80% $N_2$ & 20% $CO_2$. After 7 days of storage, Huang *et al*. (2005) repackaged the pork chops in 80% $O_2$ & 20% $CO_2$. From day 7 to day 14, pH increased in the untreated chops, however pH change was minimal in packages containing pork dipped in ascorbic or citric acid. The significant difference observed between packaging types for final pH may be due to the specific gases added to MAP. Gill and Penney (1985) found that high muscle pH in lamb cuts packaged in oxygen permeable packages was contributed by spoilage bacteria. However, microbiological analyses were not performed in the current study.

Initial LD and vertebrae CIE L*, a*, and b* values (Table 20) and chroma and hue angle values (Table 21) and initial and dipped weights (Table 22) were not significantly different between packaging conditions.

Table 19. Initial and final pH LS Means with different packaging conditions.

| Treatment | Initial pH | Final pH |
|---|---|---|
| HiOx | 5.67[a] | 6.09[a] |
| NoOx | 5.66[a] | 6.03[b] |
| SE | 0.015 | 0.030 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 20. Initial CIELAB LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different packaging conditions.

| Treatment | LD L* | LD a* | LD b* | V L* | V a* | V b* |
|---|---|---|---|---|---|---|
| HiOx | 59.74[a] | 4.71[a] | 15.33[a] | 53.72[a] | 13.50[a] | 15.22[a] |
| NoOx | 60.29[a] | 4.68[a] | 15.45[a] | 52.44[a] | 13.99[a] | 15.46[a] |
| SE | 0.727 | 0.275 | 0.909 | 2.095 | 1.616 | 0.902 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 21. Initial chroma and hue angle LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different packaging conditions.

| Treatment | LD Chroma | LD Hue Angle | V Chroma | V Hue Angle |
|---|---|---|---|---|
| HiOx | 16.10[a] | 1.28[a] | 20.50[a] | 0.84[a] |
| NoOx | 16.19[a] | 1.28[a] | 20.96[a] | 0.85[a] |
| SE | 0.348 | 0.104 | 0.544 | 0.019 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 22. Initial weight and dipped weight LS Means with different package conditions.

| Treatment | Initial weight, g | Dipped weight, g | Pickup, % |
|---|---|---|---|
| HiOx | 198.48[a] | 245.01[a] | 102.15[a] |
| NoOx | 200.58[a] | 246.27[a] | 102.38[a] |
| SE | 2.792 | 2.764 | 2.736 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Final LD L*, a*, and b* values were different ($p\leq0.05$) between packaging conditions (Table 23). Chops packaged in high oxygen had lower ($p\leq0.05$) LD L* values and higher ($p\leq0.05$) a* values than chops packaged in no oxygen. Our results support work conducted by Huang *et al*. (2005). Those authors reported higher L* values for pork chops packaged in no oxygen compared with chops packaged in high oxygen. When those authors exchanged anoxic gas for high oxygen gas, they saw a rapid decrease in L* values after two days. Brewer, Zhu, Bidner, Meisinger, and McKeith (2001) indicated that L* values in pork are unrelated to oxymyoglobin pigment concentrations, so the reason for higher L* values in the current study with higher oxygen is not apparent. There were no significant differences between packaging conditions for final LD b* values. This was unexpected as Huang *et al*. (2001) reported lower LD b* values in pork chops packaged in high oxygen compared with chops packaged in no oxygen.

Chops packaged in high oxygen had higher ($p\leq0.05$) final vertebrae a* values than chops packaged in no oxygen. This was expected as the high oxygen packages provided oxygen molecules for formation of oxyhemoglobin, causing a redder appearance. There were no significant differences between packaging conditions for final LD chroma or hue angle values (Table 24). However, chops packaged in high oxygen had higher ($p\leq0.05$) final vertebrae chroma values and lower ($p\leq0.05$) hue angle values than chops packaged in no oxygen. The high chroma values and low hue angle values, calculated from a* and b*, in vertebrae bone may be

due to hemoglobin having three more iron atoms than myoglobin. This would indicate that hemoglobin will be brighter and more vivid and have a more reddish hue than myoglobin.

There were no significant differences between packaging conditions for percent drip or percent cook loss. This was expected as Hall *et al*. (1980) reported similar results for drip loss. These authors found no significant differences in drip loss for wholesale pork loins that were either vacuum packaged or modified atmosphere packaged in 80% oxygen and 20% carbon dioxide or 60% nitrogen and 40% carbon dioxide. Chops packaged in no oxygen did have lower ($p \leq 0.05$) shear forces than chops packaged in high oxygen (Table 25). Our results contradict work by Vergara and Gallego (2001). These authors reported shear force of lamb loin chops was not significantly different between packages containing an 80% carbon dioxide and 20% oxygen gas or an 80% oxygen and 20% carbon dioxide gas.

Table 23. Final CIELAB LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different packaging conditions.

| Treatment | LD L* | LD a* | LD b* | V L* | V a* | V b* |
|---|---|---|---|---|---|---|
| HiOx | 61.80[b] | 2.74[a] | 14.50[a] | 55.59[a] | 14.06[a] | 17.26[a] |
| NoOx | 63.33[a] | 2.16[b] | 14.24[a] | 54.56[b] | 10.42[b] | 14.40[b] |
| SE | 0.727 | 0.275 | 0.909 | 2.095 | 1.616 | 0.902 |

[ab] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 24. Final chroma and hue angle LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different packaging conditions.

| Treatment | LD Chroma | LD Hue Angle | V Chroma | V Hue Angle |
|---|---|---|---|---|
| HiOx | 14.80[a] | 1.34[a] | 22.46[a] | 0.91[b] |
| NoOx | 14.49[a] | 1.27[a] | 17.89[b] | 0.96[a] |
| SE | 0.348 | 0.104 | 0.544 | 0.019 |

[ab] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 25. Percent drip loss, percent cook loss, and shear force LS Means with different packaging conditions.

| Treatment | Drip Loss, % | Cook Loss, % | Shear Force, g |
|---|---|---|---|
| HiOx | 4.35[a] | 2.06[a] | 3212.53[a] |
| NoOx | 4.67[a] | 2.13[a] | 2861.50[b] |
| SE | 0.331 | 0.812 | 103.110 |

[ab] LS Means in the same column with the same letters are not different ($p<0.05$).

There were no significant differences between display times for initial or final pH (Table 26), initial LD and vertebrae CIE L*, a*, and b* (Table 27), chroma, and hue angle values (Table 28), dipped weight (Table 29), final LD and vertebrae CIE L*, a*, and b* (Table 30), chroma, and hue angle values (Table 31), percent drip loss or percent cook loss (Table 32). No difference between days of display for initial pH, final pH, initial LD and vertebrae CIE L*, a*, and b*, chroma and hue angle values, dipped weight, percent drip loss and percent cook loss was expected and supports previous research (Mancini *et al*., 2004; Lawrence *et al*., 2003; Rees *et al*., 2002). However, other research has observed differences in final LD and vertebrae CIE L*, a*, and b*, chroma and hue angle values between differing days of display (Mancini *et al*., 2004; Lawrence *et al*., 2003; Yancey *et al*., 2002; Wheeler *et al*., 1996). The results we observed may be due to using an antioxidant dip rather than injection (Lawrence *et al*., 2003; Wheeler *et al*., 1996). These authors reported higher LD a* values and lower b* values in beef steaks injected with sodium ascorbate compared with control steaks. Chops that were displayed for 3 days had lower ($p \leq 0.05$) initial weights (Table 27) and shear force values than chops that were displayed for 6 days. The lower shear force values for chops displayed 3 days compared with 6 days cannot be explained because there were no differences in pH, pickup percent, drip loss, or cook loss with display time.

Table 26. Initial and final pH LS Means with different display times.

| Treatment | Initial pH | Final pH |
|---|---|---|
| 3d | 5.67[a] | 6.06[a] |
| 6d | 5.66[a] | 6.06[a] |
| SE | 0.015 | 0.030 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 27. Initial CIELAB LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different display times.

| Treatment | LD L* | LD a* | LD b* | V L* | V a* | V b* |
|---|---|---|---|---|---|---|
| 3d | 59.86[a] | 4.61[a] | 15.34[a] | 53.63[a] | 13.30[a] | 15.19[a] |
| 6d | 60.17[a] | 4.77[a] | 15.44[a] | 52.54[a] | 14.18[a] | 15.48[a] |
| SE | 0.727 | 0.275 | 0.909 | 2.095 | 1.616 | 0.902 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 28. Initial chroma and hue angle LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different display times.

| Treatment | LD Chroma | LD Hue Angle | V Chroma | V Hue Angle |
|---|---|---|---|---|
| 3d | 16.06[a] | 1.28[a] | 20.30[a] | 0.87[a] |
| 6d | 16.22[a] | 1.28[a] | 21.16[a] | 0.82[a] |
| SE | 0.348 | 0.104 | 0.544 | 0.019 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 29. Initial weight and dipped weight LS Means with different display times.

| Treatment | Initial weight, g | Dipped weight, g | Pickup, % |
|---|---|---|---|
| 3d | 238.69[b] | 196.78[a] | 102.53[a] |
| 6d | 252.60[a] | 202.27[a] | 102.34[a] |
| SE | 2.792 | 2.764 | 2.736 |

[ab] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 30. Final CIELAB LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different display times.

| Treatment | LD L* | LD a* | LD b* | V L* | V a* | V b* |
|---|---|---|---|---|---|---|
| 3d | 62.72[a] | 2.49[a] | 14.54[a] | 55.25[a] | 12.37[a] | 15.90[a] |
| 6d | 62.41[a] | 2.41[a] | 14.20[a] | 54.91[a] | 12.10[a] | 15.75[a] |
| SE | 0.727 | 0.275 | 0.909 | 2.095 | 1.616 | 0.902 |

[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 31. Final chroma and hue angle LS Means for *Longissimus dorsi* (LD) and lumbar vertebrae (V) with different display times.

| Treatment | LD Chroma | LD Hue Angle | V Chroma | V Hue Angle |
|---|---|---|---|---|
| 3d | 14.81[a] | 1.33[a] | 20.32[a] | 0.93[a] |
| 6d | 14.48[a] | 1.28[a] | 20.04[a] | 0.94[a] |
| SE | 0.348 | 0.104 | 0.544 | 0.019 |

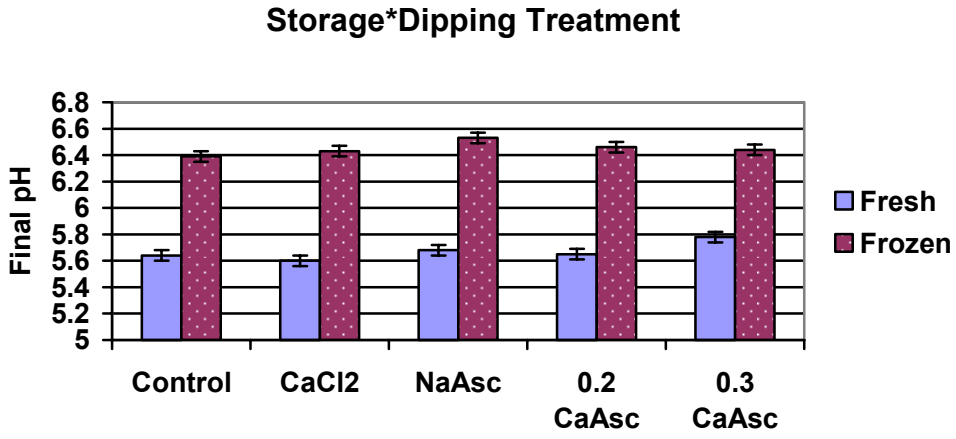
[a] LS Means in the same column with the same letters are not different ($p<0.05$).

Table 32. Percent drip loss, percent cook loss, and shear force LS Means with different display times.

| Treatment | Drip Loss, % | Cook Loss, % | Shear Force, g |
|---|---|---|---|
| 3d | 4.40[a] | 2.09[a] | 2957.01[b] |
| 6d | 4.62[a] | 2.11[a] | 3117.02[a] |
| SE | 0.331 | 0.812 | 103.110 |

[ab] LS Means in the same column with the same letters are not different ($p<0.05$).

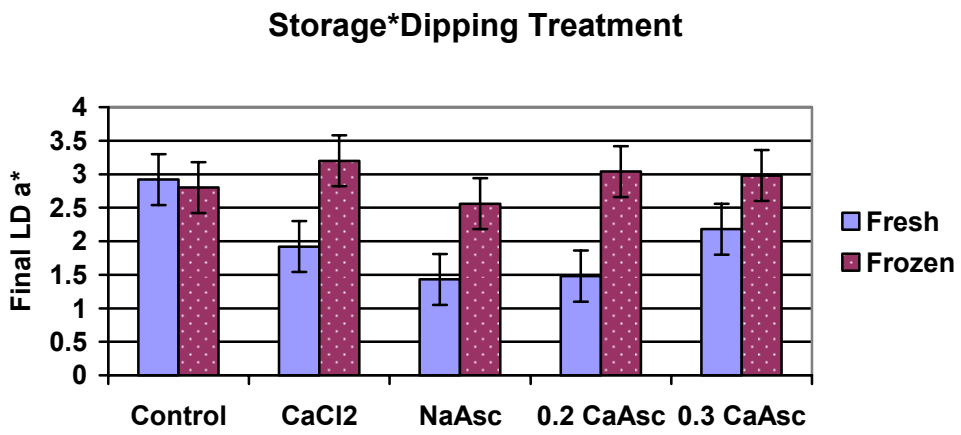
The storage*dipping treatment interaction was not significant for the variables initial pH, final LD L*, b*, hue angle, final vertebrae L*, percent drip loss, percent cook loss, and shear force. Figure 3 contains the storage*dipping treatment LS Means for the dependent variable final pH. Final pH values for dipping treatments ranged from 5.60-5.78 for the fresh group and 6.39-6.53 for the frozen group. The significance observed for the storage*dipping treatment interaction is due to higher final pH's in the frozen group than in the fresh group. Within the fresh group, chops in the control and calcium chloride groups had significantly lower final pH values than chops dipped in 0.3 M calcium ascorbate. Within the frozen group, chops in the control group had significantly lower final pH than chops dipped in sodium ascorbate. Control group final pH was not significantly different from the final pH of chops dipped in calcium chloride or 0.2 M or 0.3 M calcium ascorbate within the frozen group.




SE for differences within the fresh or frozen groups = 0.0428

Figure 3. Storage*dipping treatment interaction for final pH LS Means.

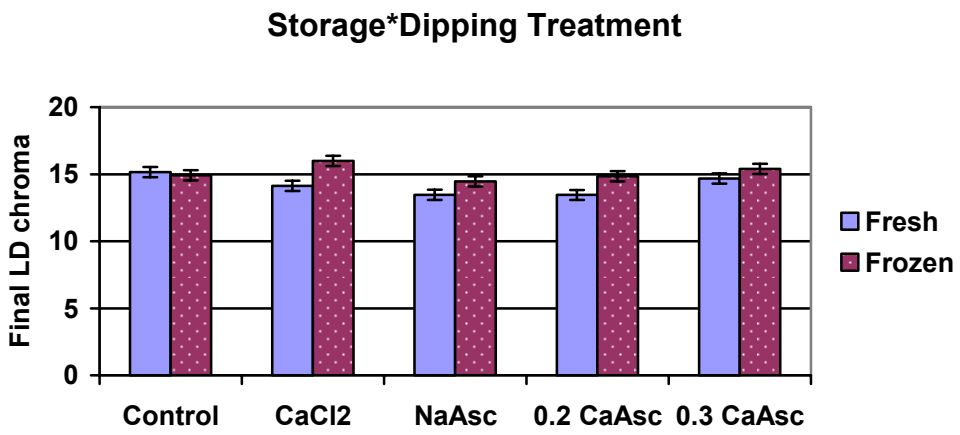
The storage*dipping treatment interaction was significant for the dependent variable final LD a*. Figure 4 contains the storage*dipping treatment LS Means for final LD a*. Final LD a* values from the frozen group were higher than the fresh group for all dipping treatments except the control group where LD a* was lower in frozen samples. These results suggest that added water and ingredient solutions coupled with frozen storage aided in maintaining reducing reactions during the thawing process, thus producing higher LD a* values than dipping chops and storing fresh. Our results support research conducted by Hoving-Bolink *et al*. (1997). These authors reported high LD a* values in pork after feeding vitamin E pre-harvest, then freezing loin chops for six days. In the fresh group, chops dipped in sodium ascorbate or 0.2 M calcium ascorbate had significantly lower final LD a* values than control chops. This was not expected because sodium ascorbate and calcium ascorbate are reducing compounds, which should have made the LD appear brighter and pinker. Wheeler *et al*. (1996) saw similar results in beef steaks that were injected with sodium ascorbate. These authors reported lower muscle a* values and higher discoloration scores when sodium ascorbate was used in concentrations of 0.25% and 4.0%. Moreover, chops dipped in 0.2 M calcium ascorbate or sodium ascorbate were not significantly different from chops dipped in calcium chloride or 0.3 M calcium ascorbate within the fresh group. Previous research on sodium and calcium ascorbate and calcium chloride are contradictory. Wheeler *et al*. (1996) reported that beef treated with sodium ascorbate produced significantly higher a* values than beef treated with calcium chloride. However, Lawrence *et al*. (2003) reported that beef steaks treated with calcium chloride or calcium ascorbate were not significantly different for LD a* values.




SE for differences within the fresh or frozen groups = 0.3888

Figure 4. Storage*dipping treatment interactions for final LD a* LS Means.

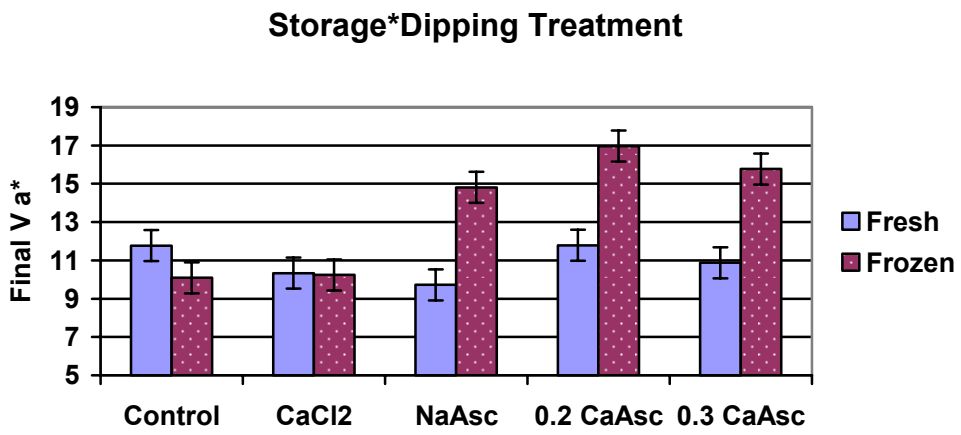
The storage*dipping treatment interaction was significant for the dependent variable final LD chroma. Figure 5 displays the storage*dipping treatment LS Means for final LD chroma. Chroma values from both storage conditions for the control group were not different while chops that were dipped in a treatment solution and stored fresh had lower chroma values than chops that were dipped and stored frozen. Final LD chroma values were lower ($p \leq 0.05$) for fresh stored chops dipped in sodium ascorbate or 0.2 M calcium ascorbate when compared with fresh stored chops from the control group. These negative results for sodium ascorbate reflect the values obtained for final LD a* and b* values. Fresh control chops were not significantly different from fresh calcium chloride or 0.3 M calcium ascorbate chops for final LD chroma. The interaction of dipping treatment and storage for final LD chroma suggest that applying a dipping solution and storing chops frozen will produce higher chroma values than storing chops fresh.




SE for differences within the fresh or frozen groups = 0.348

Figure 5. Storage*dipping treatment interactions for final LD chroma LS Means.

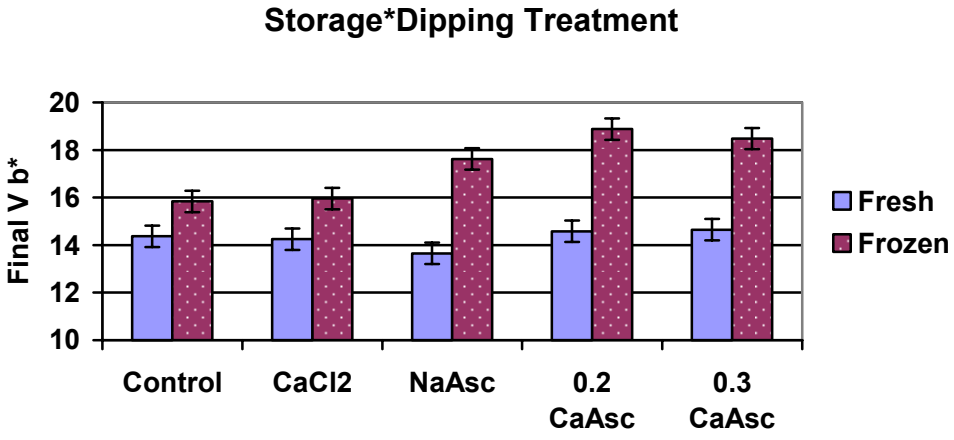
The storage*dipping treatment interaction was significant for the dependent variable final vertebrae a*. Figure 6 contains the storage by dipping treatment LS Means for final vertebrae a*. Fresh control chops had higher final vertebrae a* values than frozen control chops while chops dipped in ascorbate solutions had higher final vertebrae a* values stored frozen than stored fresh. Our data suggest that the antioxidant properties of ascorbate were not effective in reducing hemoglobin more in fresh chops than in control or calcium chloride fresh chops. No significant difference was noted between control and calcium chloride treatments within each level of storage for final vertebrae a* values. Using a 0.2 M calcium ascorbate solution may be the optimum level for achieving higher vertebrae a* values in pork vertebrae bone. These results are in agreement with Wheeler *et al*. (1996). Those authors also found a* values to be lower ($p \leq 0.05$) for steaks in the control group or dipped in calcium chloride than steaks dipped in sodium ascorbate.




SE for differences within the fresh or frozen groups = 0.8082

Figure 6. Storage*dipping treatment interactions for final vertebrae a* LS Means.

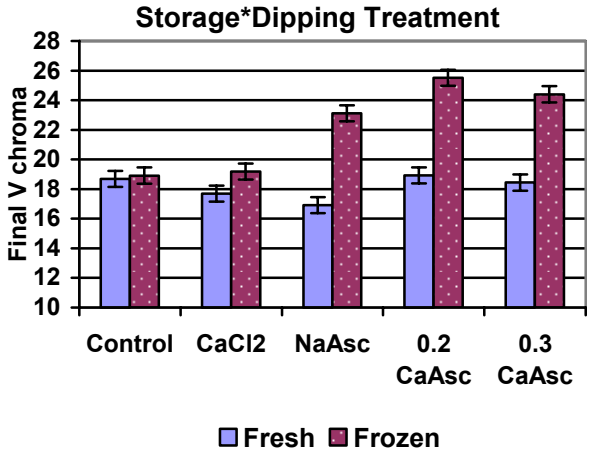
The storage*dipping treatment interaction was significant for the dependent variable final vertebrae b*. Figure 7 displays the storage*dipping treatment LS Means for final vertebrae b*. Frozen group final vertebrae b* values were higher for all dipping treatments than their corresponding values in the fresh group. The interactive effect was observed because the differences in final vertebrae b* between storage types for chops dipped in sodium or calcium ascorbate were larger than differences between storage treatment means for control or calcium chloride. The larger difference in vertebrae b* between fresh and frozen groups in those treatments may be due to a higher antioxidant activity and less pigment degradation during frozen storage.




SE for differences within the fresh or frozen groups = 0.4510

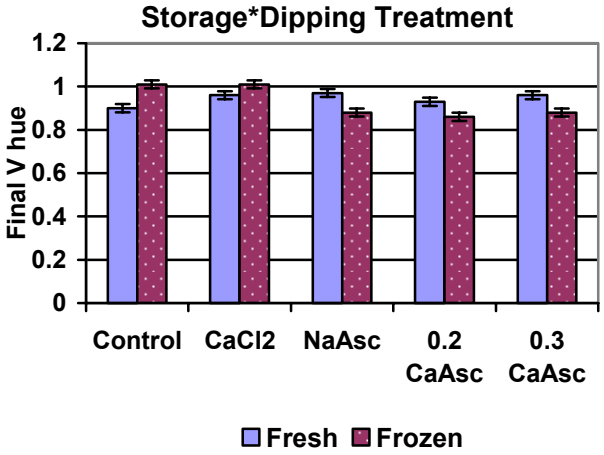
Figure 7. Storage*dipping treatment interactions for final vertebrae b* LS Means.

The storage*dipping treatment interaction was significant for the dependent variable final vertebrae chroma. Figure 8 displays the storage*dipping treatment LS Means for final vertebrae chroma. Chroma values from both storage conditions for the control group were not different, while chroma of fresh chops was less than for frozen chops in all dipped chops. Our results contradict work conducted by Lanari, Schaefer, and Scheller (1995). These authors reported significantly higher vertebrae chroma values in bone-in pork chops treated with vitamin E and stored fresh (five days at 4°C) than chops left untreated and stored fresh. Our results do agree with research conducted by Mancini *et al*. (2004). Those authors also reported significantly higher chroma values in steaks treated with ascorbic acid compared to the untreated steaks. Those authors suggested that the significantly high vertebrae chroma values were produced by the antioxidant ability of ascorbic acid. Our results were expected because of ascorbate's antioxidant ability to reduce hemoglobin iron atoms, which reflect a brighter reddish-pink color. Final vertebrae chroma was not significantly different between the fresh group ascorbate dipping treatments.




SE = 0.544

Figure 8. Storage*dipping treatment interactions for final vertebrae chroma LS Means.




SE = 0.019

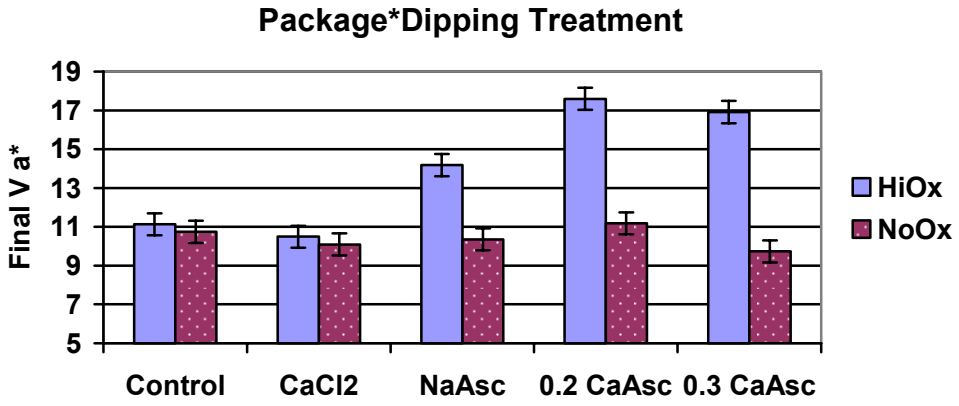
Figure 9. Storage*dipping treatment interactions for final vertebrae hue angle LS Means.

The storage*dipping treatment interaction was significant for the dependent variable final vertebrae hue angle. Figure 9 displays the storage*dipping treatment LS Means for final vertebrae hue angle. Chops that were dipped in ascorbate and stored frozen had lower final vertebrae hue angle values than fresh chops dipped in ascorbate while the opposite effect on hue angle was observed in frozen control and calcium chloride chops with higher hue angles compared with fresh chops. These results indicate that freezing chops increased ascorbate's ability to reduce iron atoms in hemoglobin during display. The results observed for final vertebrae hue angle may be due to its calculation, as the inverse tangent of b* divided by a*.

The interaction of package*dipping treatment was not significant for the dependent variables final pH, final LD L*, a*, b*, chroma, hue angle, final vertebrae L*, percent cook loss, and shear force.

The package*dipping treatment interaction was significant for the dependent variable final vertebrae a*. Figure 10 is the plot of the package*dipping treatment interaction LS Means for the dependent variable final vertebrae a*. Final vertebrae a* values were similar between the

control and calcium chloride groups packaged in high and no oxygen. However, chops dipped in an ascorbate solution and packaged in high oxygen had significantly higher vertebrae a* values than chops dipped in an ascorbate solution and packaged in no oxygen. Our results suggest that the ascorbate added to the pork chops was effective in reducing more of the heme pigments to form oxyhemoglobin when storage was in high oxygen atmospheres. These data support previous work by Mancini *et al*. (2004) and Gill *et al*. (1994). These authors reported that covering beef loin steaks with 1.5 % ascorbic acid and then packaging in high oxygen significantly increased vertebrae a* values. Chops packaged in no oxygen had numerically similar final vertebrae a* values across the five dipping treatments. This was expected since packages contained no gaseous oxygen, thus the reducing capability of ascorbate was not needed to inhibit pigment oxidation induced by reactions between hemoglobin and oxygen.

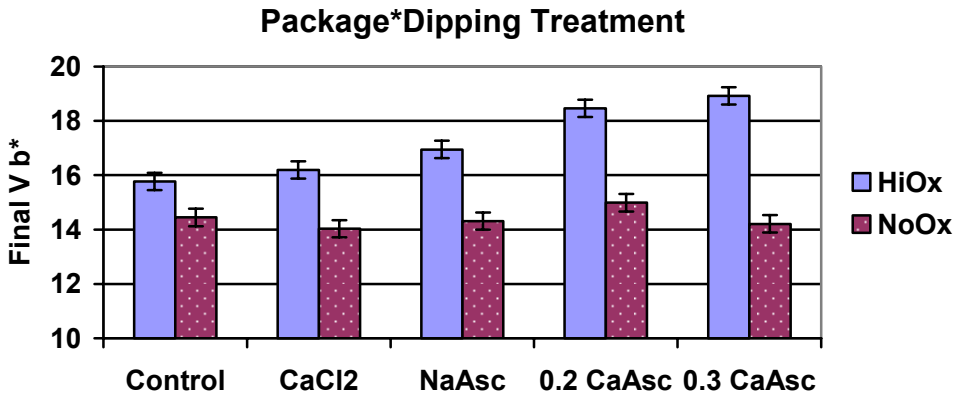



SE for differences within the high oxygen or no oxygen packages = 0.57

Figure 10. Package*dipping treatment interactions for final vertebrae a* LS Means.

The package*dipping treatment interaction was significant for the dependent variable final vertebrae b*. Figure 11 displays final vertebrae b* package*dipping treatment LS Means. Differences in final vertebrae b* between high and no oxygen treatments values were higher for all ascorbate dipping treatments than for chops in calcium chloride or control. Our data suggests

that high oxygen packaging improved vertebrae b* values for all treatment groups, but differences were more pronounced when ascorbate was added. Similar results were reported by Gill *et al*. (1994). Those authors stated that vertebrae b* values were significantly higher for steaks packaged in high oxygen when compared with steaks packaged in no oxygen or carbon dioxide. High oxygen packaging coupled with use of an antioxidant could improve b* values in vertebrae bone.



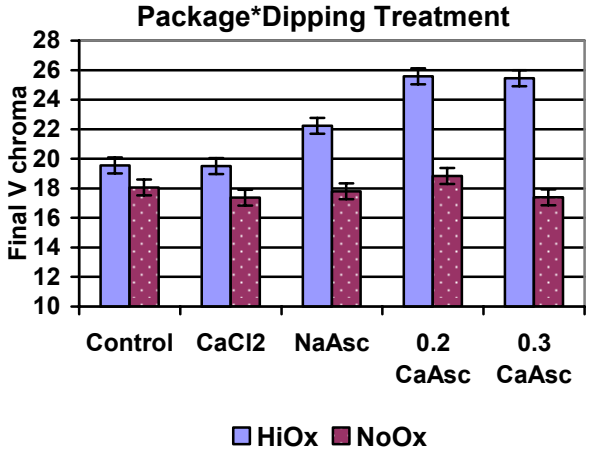

SE for differences within the high oxygen or no oxygen packages = 0.32

Figure 11. Package*dipping treatment interactions for final vertebrae b* LS Means.

The package*dipping treatment interaction was significant for the dependent variable final vertebrae chroma. Figure 12 displays the package*dipping treatment LS Means for the dependent variable final vertebrae chroma. This interaction is significant due to large differences in final vertebrae chroma between high oxygen and no oxygen packaging for acorbate dipped chops and much smaller differences between packaging types for control and calcium chloride chops. Final vertebrae chroma values were higher in the high oxygen group for chops dipped in ascorbate compared with control or calcium chloride groups, meaning that oxygenation of iron molecules can be enhanced with the use of ascorbate. Mancini *et al*. (2004) reported chroma values were significantly higher for steaks packaged in high oxygen and covered in 0.5, 1.0, or

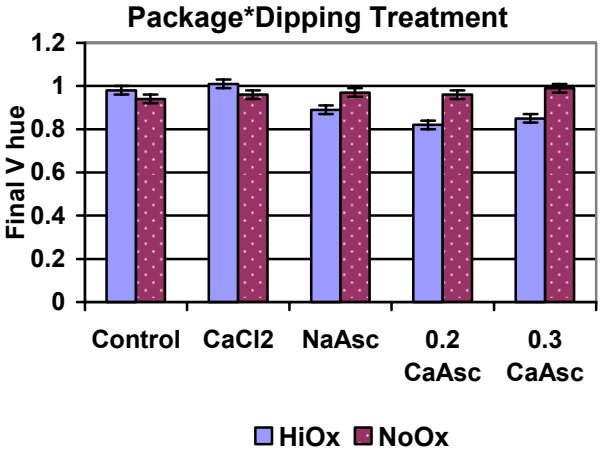
1.5 % ascorbic acid than the control, 0.05, and 0.1 % treatment groups. Chops packaged in no oxygen had similar final vertebrae chroma values across the five dipping treatments in that study.

The package*dipping treatment interaction was significant for the dependent variable final vertebrae hue angle. Figure 13 displays the package*dipping treatment LS Means for the dependent variable final vertebrae hue angle. Final vertebrae hue angle was higher for chops dipped in ascorbate and packaged in no oxygen, while final vertebrae hue angle was lower for chops in the control or calcium chloride groups packaged in no oxygen. Norman *et al*. (2003) stated that higher hue angle values represent meat color that is more true red. Our data suggest that the ascorbate added to the pork chops was effective in reducing more of the heme pigments when chops were stored in high oxygen atmospheres. This data would suggest that chops in high oxygen gas atmospheres benefit from dipping in ascorbate because the ascorbate acted as an oxygen scavenger in the package, which aided in the reduction of the hemoglobin compounds and caused the bone to appear redder.




SE = 0.54

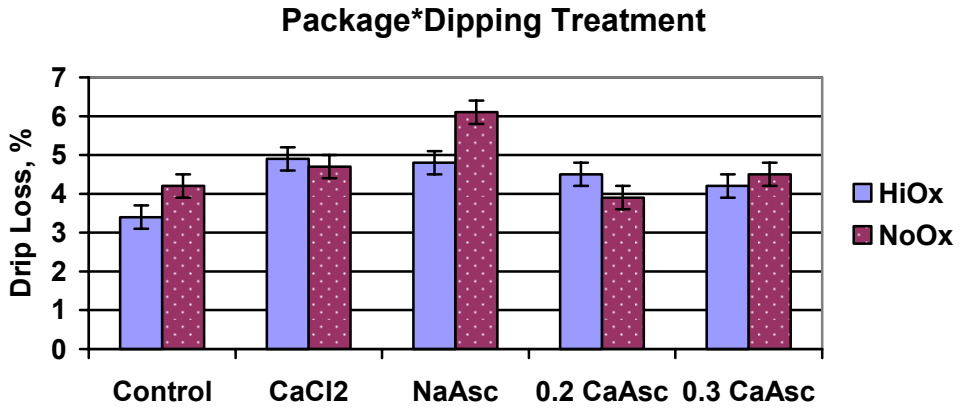
Figure 12. Package*dipping treatment interactions for final vertebrae chroma LS Means.




SE = 0.02

Figure 13. Package*dipping treatment interactions for final vertebrae hue angle LS Means.

The package*dipping treatment interaction was significant for the dependent variable percent drip loss, with variable results for each dip treatment combination. Figure 14 contains the package*dipping treatment LS Means for the dependent variable percent drip loss. In the control, sodium ascorbate, and 0.3 M calcium ascorbate groups, percent drip loss was lower for chops packaged in high oxygen compared with no oxygen. Yancey *et al*. (2002) reported similar results of high drip loss after injecting sodium ascorbate. Those authors stated that the sodium molecule in sodium ascorbate did not posses water binding properties. Livingston *et al*. (2004) reported that pork loin chops packaged in high oxygen atmospheres had less drip loss than chops packaged in no oxygen or carbon monoxide. The differences in drip loss between treatment combinations of 0.2 M or 0.3 M calcium ascorbate and high oxygen or no oxygen packaging were not significant. Higher concentrations of calcium ascorbate increased drip loss when packaged in no oxygen atmospheres, but decreased drip loss when packaged in high oxygen atmospheres. No explanation is readily available for these results. There was no significant interaction for percent cook loss or shear force for package*dipping treatment.




SE for differences within the high oxygen or no oxygen packages = 0.30

Figure 14. Package*dipping treatment interactions for percent drip loss LS Means.

The interaction of display*dipping treatment was not significant for dependent variables final pH, final LD L*, a*, b*, chroma, hue angle, final vertebrae a*, b*, chroma, hue angle, percent cook loss, and shear force.

The display*dipping treatment interaction was significant for the dependent variable final vertebrae L*. Figure 15 contains the display*dipping treatment LS Means for the dependent variable final vertebrae L*. Chops dipped in 0.2 M calcium ascorbate had the lowest final vertebrae L* values after 3 days of display and increased through 6 days of display. Chops dipped in sodium ascorbate exhibited the same trend, increasing in final vertebrae L* from 3 to 6 days of display. After 6 days of display, chops in the control, calcium chloride, and 0.3 M calcium ascorbate groups had lower final vertebrae L* values than their 3 day measurements.

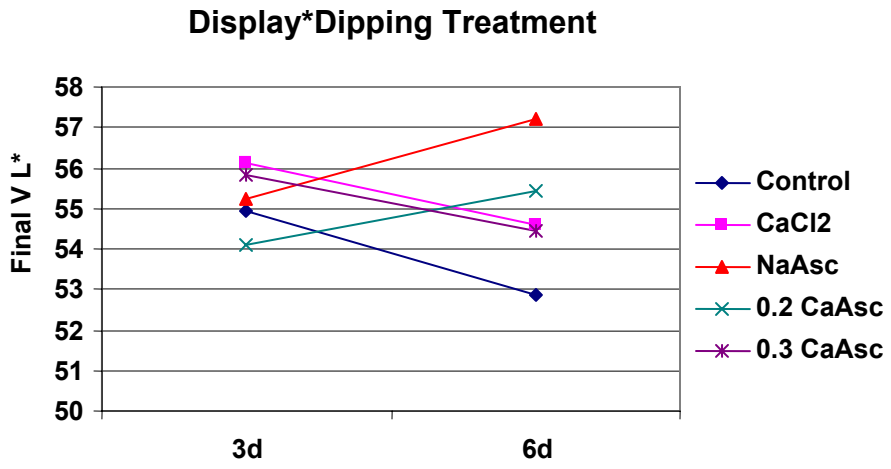



Figure 15. Display*dipping treatment interactions for final vertebrae L* LS Means.

These decreasing trends suggest that methemoglobin was beginning to accumulate in vertebrae bone. This is expected for chops in the control and calcium chloride groups since there were no additional reducing compounds present. However, chops in the 0.3 M calcium ascorbate groups experienced this same trend and this group had added ascorbate. Our results contradict

work by Mancini *et al*. (2004) who reported no difference for vertebrae L* values between ascorbic acid treatments after 18 hours of display.

The display*dipping treatment interaction was significant for the dependent variable percent drip loss. Figure 16 contains the display by dipping treatment LS Means for the dependent variables percent drip loss. Drip loss decreased with increased display time for control chops and chops dipped in 0.2 M calcium ascorbate and increased during the same time in chops dipped in calcium chloride and 0.3 M calcium ascorbate. Drip loss was unchanged with display time of chops dipped in sodium ascorbate. The increase in percent drip loss with display time for chops dipped in calcium chloride supported research by Whipple *et al*. (1992). These authors reported an increase in percent drip loss for beef steaks injected with 0.3 M calcium chloride and displayed for seven days compared with steaks that were injected with calcium chloride and displayed for 24 hours. Chops dipped in sodium ascorbate or 0.3 M calcium ascorbate exhibited no significant changes in percent drip loss over time. This data supports research conducted by Lawrence *et al*. (2003) that there were no significant differences in percent drip loss over 5 days of display for beef steaks treated with 0.3 M calcium ascorbate. Our data suggest that at 3 days of display, calcium chloride is a good binder of intracellular free water. However, as display time is increased, calcium chloride begins to lose its ionic binding ability, thus causing a purge of intracellular free water. Other research has suggested that as meat ages, the weak bond between chlorine ions and intracellular free water is broken, thus causing purge (Christen *et al*., 2000; Koohmaraie *et al*., 1990). The opposite trends over time in drip loss for chops dipped in ascorbate may be due to calcium levels. Chops dipped in 0.3 M calcium ascorbate had increased drip loss values from 3 to 6 days whereas, chops dipped in 0.2 M calcium ascorbate had decreased drip loss from 3 to 6 days. Our results contradict research conducted by Lawrence *et*

*al*. (2003). These authors reported after five days of display, beef loin steaks marinated in 0.2 M calcium ascorbate had higher drip loss than steaks marinated in 0.3 M calcium ascorbate. There was no significant interaction for percent cook loss or shear force for the display*dipping interaction effect.

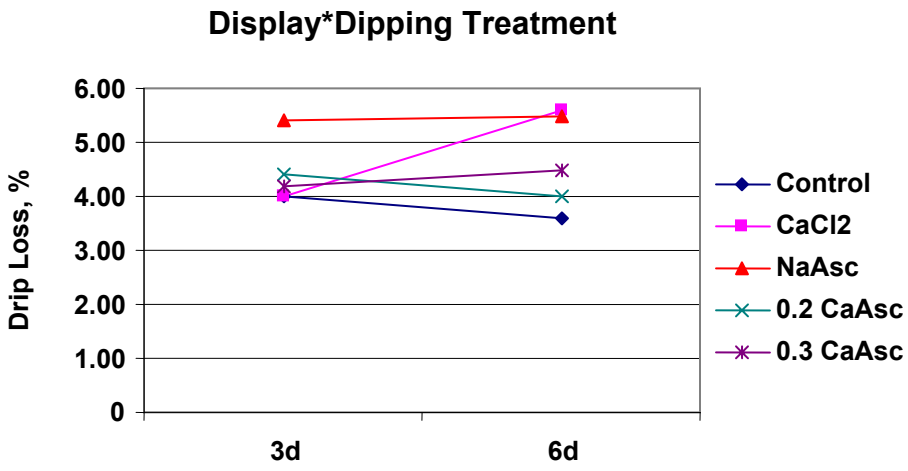
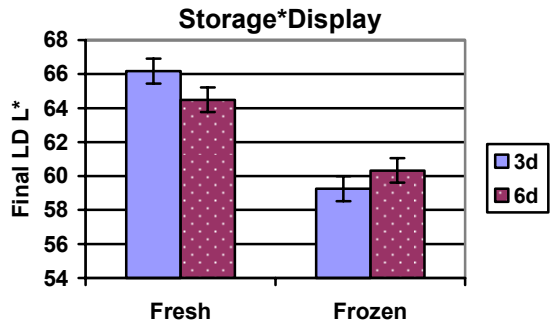



Figure 16. Display*dipping treatment interactions for drip loss percentage LS Means.

There were no significant interactions for package*display for any of the dependent variables. Four of the variables had significant storage*display interaction. Dependent variables that did not have significant storage*display interaction were final pH, final LD b*, chroma, hue angle, final vertebrae L*, hue angle, percent cook loss, and shear force.

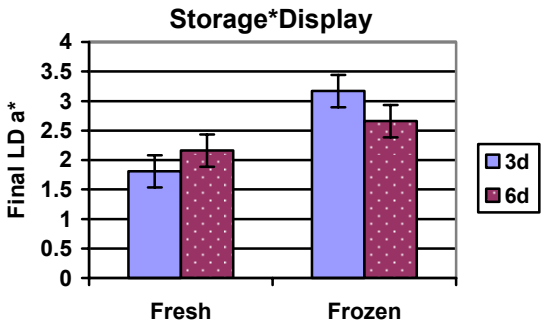
The storage*display interaction was significant for the dependent variables final LD L* and a*. In Figure 17, final LD L* values were higher for chops stored fresh for 3 days rather than 6 days while they were higher at 6 days than at 3 days for frozen chops. An explanation for these results is not readily available. Final LD a* values showed trends directly opposite from final LD L* (Figure 18). The LD a* values were higher at 3 days than at 6 days in the frozen group while 6 day values were higher than 3 day values in the fresh group. In addition, final LD a* values were higher for chops stored frozen rather than chops stored fresh for display lengths of 3 or 6

days. A possible explanation for this is that freezing inhibited pigment degradation by decreasing oxidation rate. The results in the frozen group suggest that ascorbate may work better immediately after freezing, but its antioxidant activity begins to decline after 3 days of display. This may be due to changes in oxidation-reduction potentials caused by freezing and thawing (Hanenian & Mittal, 2004).




SE = 0.73

Figure 17. Storage*display interactions for final LD L* LS Means.

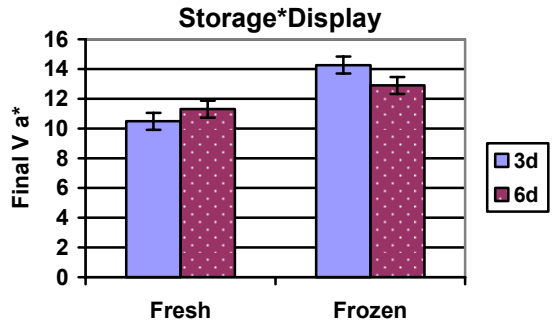



SE = 0.274

Figure 18. Storage*display interactions for final LD a* LS Means.

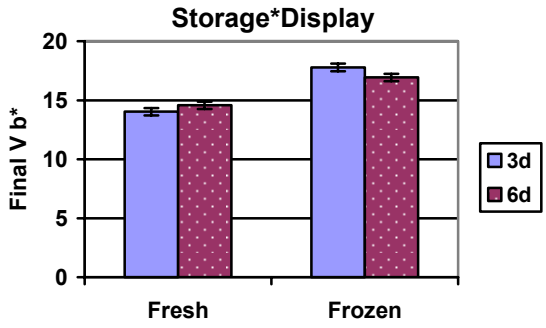
The storage*display interaction was significant for the dependent variables final vertebrae a* and b*, respectively. Figures 19 and 20 contain the storage*display LS Means for final vertebrae a* and b*. For both days of display, final vertebrae a* and b* values were higher for chops stored frozen than chops stored fresh. This was expected as evidenced by the significant differences observed for the main effects of storage and display. Final vertebrae a* values of fresh chops were higher at 6 days of display than at 3 days. This trend was reversed for the frozen group as final vertebrae a* values were higher for chops displayed for 3 days than for 6 days. These results indicate that storage condition significantly affected pigment stability in vertebrae bone. Freezing may have inhibited pigment oxidation during storage and increased antioxidant effectiveness after thawing. Vertebrae a* and b* values decreased over time for chops stored frozen. This was expected and may be due to oxidation-reduction reactions.

However, vertebrae b* values increased over time for chops stored fresh, which may be due to faster pigment oxidation. Our results for vertebrae color supports other research of adding antioxidants to pork bones, freezing, and displaying under continuous light (Nicolalde, Stetzer, Tucker, McKieth, & Brewer, 2006). Those authors reported similar vertebrae a* values (13.78) in pork loin chops after freezing for 24 hours, dipped in an antioxidant solution, and display for 8 days. However, after frozen storage and 8 days of display, Nicolalde et al. (2006) reported much lower vertebrae b* values (4.64) than values we observed.




SE = 0.571

Figure 19. Storage*display interactions for final vertebrae a* LS Means.



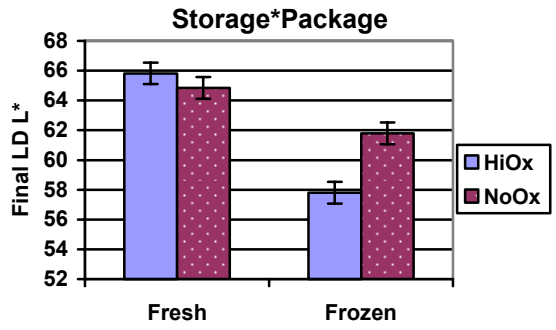

SE = 0.318

Figure 20. Storage*display interactions for final vertebrae b* LS Means.

Dependent variables that did not have significant storage*package interaction were final pH, final LD a*, chroma, hue angle, final vertebrae a*, percent drip loss, and percent cook loss. The storage*package interaction was significant for the dependent variable final LD L*. For both packaging conditions, final LD L* (Figure 21) values were lower for chops stored frozen than for chops stored fresh. This data would suggest that during frozen storage, ice crystals formed from free water may have damaged myoglobin pigments. The disruption of myoglobin may have caused the LD to appear dryer and darker.

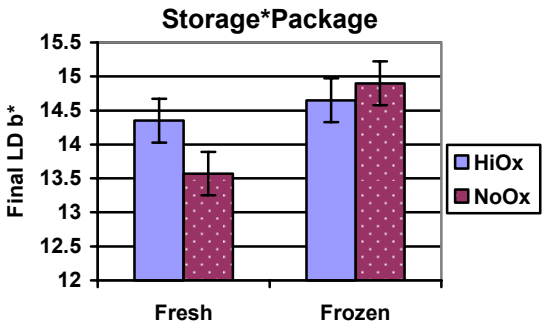
The storage*package interaction was significant for the dependent variable final LD b* (Figure 22). Frozen chops packaged in no oxygen had higher final LD b* values than in high

oxygen packages while fresh chops had higher b* values in high oxygen than in no oxygen. Other research has shown that packaging pork chops in no oxygen packaging produced higher trained color panel discoloration scores than chops packaged in high oxygen (Hall *et al*., 1980). However, in the frozen group, chops packaged in no oxygen had higher final LD b* values than chops packaged in high oxygen. Jeremiah (2001) found that packaging fresh meats in high oxygen atmospheres had less trained color panel discoloration scores in muscle and bone compared with meat packaged on foam trays and wrapped with polyethylene film when displayed.




SE = 0.73

Figure 21. Storage*package interactions for final LD L* LS Means.

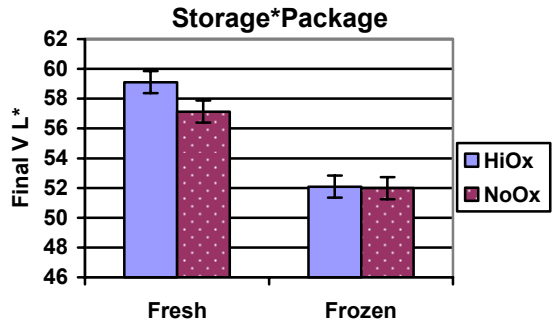



SE = 0.321

Figure 22. Storage*package interactions for final LD b* LS Means.

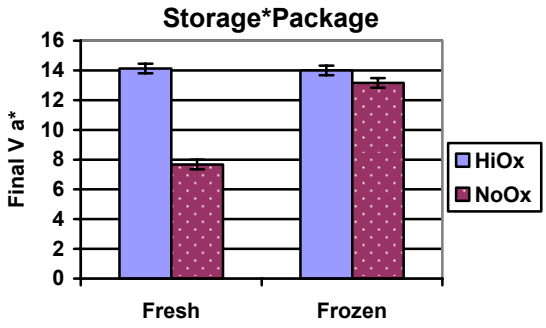
The storage*package interaction was significant for the dependent variable final vertebrae L*. For both packaging conditions, final vertebrae L* values (Figure 23) were lower for chops stored frozen than chops stored fresh. Our results supported work by Livingston *et al*. (2004) and Mancini, Hunt, Hachmeister, Kropf, and Johnson (2005). Those authors reported higher vertebrae L* values for chops packaged in high oxygen compared with chops packaged in no oxygen when stored fresh (Mancini *et al*., 2005). Within the fresh group, chops packaged in no oxygen had lower final vertebrae L* values than chops packaged in high oxygen, but there was no significant difference between packaging conditions for final vertebrae L* values for

chops in the frozen group. Other research has reported that exclusion of oxygen from MAP packages and the addition of low concentrations of CO lowered L* values and minimized beef rib and lumbar vertebrae discoloration compared with high-oxygen MAP (Mancini *et al*., 2005). In addition, Mancini's results suggest that bone darkening may have occurred during the frozen storage. Muscle and bone L* values for chops stored fresh appeared brighter than chops stored frozen. The extended storage time for chops stored frozen may have resulted in greater oxidation of myoglobin and hemoglobin causing the chops to appear darker. In the frozen storage group, chops packaged in no oxygen had brighter muscle appearance than chops packaged in high oxygen. The brighter appearance may be due to reduced oxidation reaction rates during the frozen storage plus lack of oxygen in the package may have prevented myoglobin from oxidizing faster. However, this effect was not observed in bone for chops stored frozen because of a lower percentage of moisture on bone cut surfaces. Since muscle is made up of approximately 70-80% water, ice crystals can form during freezing, which may cause destruction of myoglobin pigments. However, moisture levels are not high enough in bone marrow to cause major destruction of hemoglobin pigments during freezing. Smith and Pearson (1985) reported moisture content of pork rib bones was less than 1%. Even with the use of a dip system, moisture levels must not have reached high enough levels to cause hemoglobin destruction from ice crystals during freezing. Extended frozen storage time with both types of packaging could not reduce bone darkening in chops.




SE = 0.741

Figure 23. Storage*package interactions for final vertebrae L* LS Means.




SE = 0.321

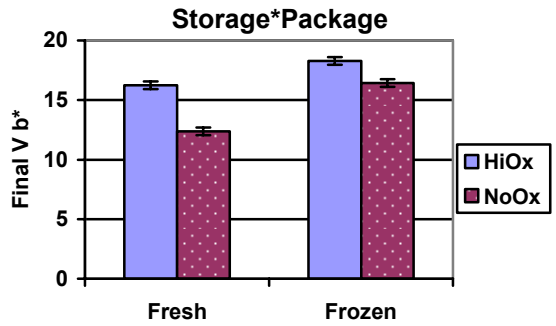
Figure 24. Storage*package interactions for final vertebrae a* LS Means.

The storage*package interaction was significant for the dependent variables final vertebrae a* and b*. Final vertebrae a* (Figure 24) and b* (Figure 25) were higher for both types of storage for chops packaged in high oxygen. However, final vertebrae a* and b* values in chops packaged in high oxygen and stored frozen were not significantly different from chops packaged in no oxygen and stored frozen. A large difference in vertebrae a* between storage conditions was observed in chops packaged in no oxygen. Chops packaged in no oxygen and stored fresh had the lowest vertebrae a* values. This data suggest that oxidation of hemoglobin was greater at fresh temperatures and since no gaseous oxygen was available, hemoglobin was less able to be re-oxygenated. There were no differences observed in vertebrae a* between storage conditions for chops packaged in high oxygen. High vertebrae a* values for chops in no oxygen stored frozen suggest that frozen storage inhibited hemoglobin oxidation causing bone to appear redder for a longer period of time. Hemoglobin may have been frozen in a reduced and oxygenated form and may have remained unchanged during the freezing process. These results of higher vertebrae a* values for chops packaged in high oxygen support the work of Livingston *et al*. (2004). These authors also found higher vertebrae a* values for fresh or frozen chops packaged in high oxygen.

The storage*package interaction was significant for the dependent variable final vertebrae b* (Figure 25). This interaction may be significant due to the magnitude of differences for vertebrae b* in the treatment combinations. For both storage conditions, chops packaged in high oxygen had higher final vertebrae b* values than in no oxygen packages. Other research has shown that packaging pork chops in no oxygen packaging produces higher discoloration scores than chops packaged in high oxygen (Hall *et al*., 1980). Results for final vertebrae b* were similar to final LD b* for both types of packaging in the fresh group. However, the results were opposite for final LD and vertebrae b* in the frozen group. Muscle and bone b* value trends were the same for chops stored fresh. Chops stored fresh and packaged in high oxygen had higher LD and vertebrae b* values than chops packaged in no oxygen. However, vertebrae b* values differed between the LD and vertebrae for chops stored frozen. These results may be due to moisture content differences in bone and muscle. Since muscle has higher moisture content than bone (Smith *et al*., 1985), freezing may have caused ice crystals to form, which may have caused damage to myoglobin. During thawing, the moisture in the muscle may have been lost in the package causing the LD surface to appear darker and dryer.

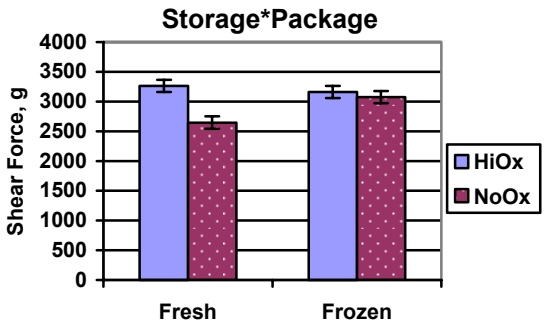
The storage*package interaction was significant for the dependent variable shear force. Shear force values were lower for chops packaged in no oxygen than in high oxygen for both conditions of storage (Figure 26). Shear force values for chops packaged in high oxygen were similar for both storage conditions. However, chops packaged in no oxygen and stored fresh had significantly lower shear force values than chops packaged in no oxygen and stored frozen. Our data contradicts work by Legaretta *et al*. (1988). These authors reported slight decreases in shear force values for pork sausage patties packaged in high oxygen and stored frozen for 14 days compared with patties packaged in no oxygen and stored frozen for 14 days. Our results of lower

shear force values might insinuate that structural protein degradation may have occurred faster for chops packaged in no oxygen and stored fresh than chops packaged in high or no oxygen and stored frozen. In addition, degradation of structural proteins from calcium activated CDP's and chloride ions may have been increased for chops packaged in no oxygen and stored fresh.




SE = 0.318

Figure 25. Storage*package interactions for final vertebrae b* LS Means.




SE = 103.11

Figure 26. Storage*package interactions for shear force LS Means.

Storage*package*display, dipping treatment*package*display, storage*dipping treatment*package, and storage*dipping treatment*display interactions were considered significant at $p \leq 0.05$. No dependent variables had significant storage*package*display interaction.

The only dependent variable that had a significant dipping treatment*package*display interaction was shear force. Chops dipped in calcium chloride, packaged in high or no oxygen, and displayed for 3 or 6 days had lower shear force values than chops in the other dip, package, and display combinations. This significant interaction may be due to calcium chloride being significantly different in shear force for the main effect of dip treatment. The two factor interactions of dip*package, package*display, and dip*display were not significant for shear force. These results indicate that the addition of a calcium chloride solution to pork loin chops may reduce shear force values by activating CDP-I or CDP-II, which aids in the breakdown of

the myofibril (Rees *et al*., 2002). Since calcium levels were the same for chops dipped in calcium chloride and calcium ascorbate (Table 33), the reduced shear force values may be a result of chlorine concentration. Calcium ascorbate does not contain salt compounds that aid in the breakdown of myofibrillar proteins, thus, calcium chloride dipped chops may have had more breakdown in myofibrillar and cytoskeletal proteins than calcium ascorbate dipped chops.

Dependent variables that had significant storage*dipping treatment*package interaction were final LD a* and hue angle, final vertebrae a*, chroma, hue angle, and shear force. Final LD a* values were higher for chops stored frozen rather than fresh for chops packaged in either packaging condition, regardless of the five dipping treatments. Within the frozen group, final LD a* values were higher for chops packaged in high oxygen rather than no oxygen for any of the dipping treatments. Significant differences in LD a* values were not observed for the two factor interactions of storage*package or package*dipping treatment. Therefore, these results suggest that freezing had more influence on pigment stability than the antioxidant dip treatments.

In addition to LD a* values, LD hue angle was significant for chops stored fresh compared to frozen. Chops in the fresh group had lower final LD hue angle values than chops in the frozen group, regardless of packaging condition or dipping treatment. Chops dipped in sodium ascorbate, stored fresh, and packaged in no oxygen had the lowest final LD hue angle values. The significant p-value observed for this interaction may be due to the type of storage condition, which was also significant for main effects and the two factor interaction of storage*dipping treatment.

Final vertebrae a* values were higher for chops stored frozen rather than fresh for chops packaged in either packaging condition, regardless of the five dipping treatments. The same results in a* were observed for LD and vertebrae. Chops in the fresh group that were packaged in

high oxygen had significantly higher final vertebrae a* values than chops packaged in no oxygen, regardless of dipping treatment. The higher a* values for frozen chops compared with fresh chops and high oxygen compared with no oxygen in the fresh group may explain the significant p-value associated with this three-way interaction for final vertebrae a*. The main effects and the two factor interactions of storage*dip treatment, package*dip treatment, and storage*package were also significant for vertebrae a*. Treatment with ascorbate, high oxygen, and frozen storage resulted in the highest final vertebrae a* of all treatment combinations.

Chops stored frozen, dipped in 0.2 M or 0.3 M calcium ascorbate, and packaged in high oxygen had higher final vertebrae chroma values than other dipping, packaging, and storage treatment combinations. These results indicate that chops stored frozen, packaged in high oxygen, and dipped in an antioxidant solution will have a brighter red color in bone marrow than chops that were stored fresh, packaged in no oxygen, and absence of an antioxidant ingredient. Significance observed for final vertebrae chroma may be due to the differences observed between high oxygen and no oxygen packaging within each storage group and for each dipping treatment.

Within each storage condition, chops dipped in calcium chloride had significantly lower shear force values than chops from the control, sodium ascorbate, 0.2 M or 0.3 M calcium ascorbate groups in both packaging conditions. Chops that had the highest shear force values were dipped in sodium ascorbate, packaged in high oxygen or no oxygen, and stored frozen. However, chops that were dipped in 0.2 M or 0.3 M calcium ascorbate, packaged in high oxygen or no oxygen, and stored frozen had lower shear force values than control chops stored fresh, packaged in high or no oxygen. However, shear force values for frozen and fresh group chops dipped in calcium ascorbate and packaged in high or no oxygen were not as low as chops from

the calcium chloride treatment combinations. Our data suggest that calcium in calcium chloride and calcium ascorbate had some effect on lowering shear force values, but the effect was small. Freezing chops appeared to have more effect of lowering shear force values in chops.

Dependent variables that had significant storage*dipping treatment*display interaction were final pH, and final vertebrae a* and b*. Final pH was higher for chops dipped in ascorbate, stored frozen, and displayed for 3 or 6 days than chops in the other treatment combinations. Within the fresh group, there were no differences in final pH regardless of dipping treatment or days of display. Final pH was higher for chops stored frozen than chops stored fresh, regardless of dipping treatment or days of display. The significant p-value observed for final pH was due to the large differences in pH between ascorbate dipped chops and the other dipping treatments within the frozen group.

Within the frozen group, final vertebrae a* and b* values were higher for chops dipped in ascorbate, and displayed for 3 days compared with the other dipping treatment groups that were displayed for 3 or 6 days. Chops that were stored fresh and dipped in an antioxidant solution had higher vertebrae a* and b* values through 6 days of display compared with 3 days of display. The significant p-value observed for this interaction may be due to differences observed in the storage*dip treatment interaction. Main effects were significantly different for dip treatment and storage, but not for display. In addition, the two factor interactions of display*dip treatment and storage*display were not significant for vertebrae a* and b*.

The interaction of dip treatment*package*storage*display was significant for few dependent variables. Just like the main effects and two factor and three factor interactions, final vertebrae a* and b* values were significant for the four factor interaction. For final vertebrae a*, the dip treatment effect may be why the four factor interaction is significant. Chops from the

frozen group dipped in ascorbate had higher vertebrae a* values than chops in the control or calcium chloride groups for both types of packaging and both days of display. For final vertebrae b*, a packaging effect may be why the four factor interaction is significant. Higher final vertebrae b* values were observed for all dipping treatments for both storage groups after 3 or 6 days of display with the use of high oxygen packaging. Chops from the five dipping treatments that were stored fresh or frozen, displayed for 3 or 6 days, and packaged in no oxygen had lower vertebrae b* values than chops packaged in high oxygen..

A mineral analysis was conducted on ten LD core samples, two from each dip treatment group. The mineral analysis was conducted to validate levels of calcium, sodium, and other minerals among the differing dip treatments. The samples that were available for determining the mineral analysis were chops stored frozen and displayed for 3 days. The two cores analyzed from each dip treatment were from separate loins. In addition, one core from the frozen storage, 3d display, and specific dip treatment came from a package with high oxygen and the other core from the frozen storage, 3d display, and specific dip treatment came from a package with no oxygen. This process was used to evaluate mineral differences in high and no oxygen packaging. The percent calcium levels were increased in dip treatments of calcium chloride and 0.2 M and 0.3 M calcium ascorbate compared with control and sodium ascorbate treatments. Thus, this data confirms the elevated levels of calcium for their respective dip treatments. Higher levels of calcium support our results for decreased shear force values in chops that were dipped in calcium chloride and 0.2 M calcium ascorbate. However, since calcium levels were similar for chops dipped in calcium chloride and calcium ascorbate, the lower shear force values observed in calcium chloride dipped chops may be due chloride degrading myosin filaments. Sodium levels varied throughout the dipping treatments. However, chops dipped in sodium ascorbate did not

exhibit higher sodium levels than other dip treatments. Since the sodium-potassium pump may have ceased postmortem, the ionization gradient may have been polarized, not allowing sodium to bind within meat compounds, thus being lost in the drip loss in the package. Magnesium, phosphorus, and potassium percentages remained relatively the same for all dipping treatment combinations. Boron, copper, and manganese parts per million were constant for their respective element across all dipping treatment combinations. Iron and zinc parts per million varied across the dipping treatment combinations. This may be due to different mineral absorption and deposition or usage rates in each animal.

Table 33. Mineral analysis for chops from the frozen storage, 3d display group.

| Treatment | Package | Ca, % | Na, % | Mg, % | P, % | K, % |
|---|---|---|---|---|---|---|
| Control | NoOx | 0.021 | 0.063 | 0.035 | 0.266 | 0.486 |
| Control | HiOx | 0.015 | 0.050 | 0.033 | 0.252 | 0.435 |
| $CaCl_2$ | NoOx | 0.045 | 0.051 | 0.033 | 0.251 | 0.395 |
| $CaCl_2$ | HiOx | 0.038 | 0.053 | 0.030 | 0.235 | 0.394 |
| NaAsc | NoOx | 0.015 | 0.061 | 0.031 | 0.244 | 0.409 |
| NaAsc | HiOx | 0.018 | 0.059 | 0.032 | 0.249 | 0.476 |
| 0.2 CaAsc | NoOx | 0.034 | 0.039 | 0.022 | 0.187 | 0.304 |
| 0.2 CaAsc | HiOx | 0.048 | 0.059 | 0.031 | 0.239 | 0.410 |
| 0.3 CaAsc | NoOx | 0.046 | 0.046 | 0.031 | 0.241 | 0.402 |
| 0.3 CaAsc | HiOx | 0.041 | 0.054 | 0.025 | 0.226 | 0.372 |

Ca = calcium; Na = sodium; Mg = magnesium; P = phosphorus; K = potassium

| Treatment | Package | B, ppm | Cu, ppm | Fe, ppm | Mn, ppm | Zn, ppm |
|---|---|---|---|---|---|---|
| Control | NoOx | < 14 | < 4 | 62.4 | < 0.6 | 26.3 |
| Control | HiOx | < 14 | < 4 | 20.0 | < 0.6 | 39.7 |
| $CaCl_2$ | NoOx | < 14 | < 4 | 14.2 | < 0.6 | 25.9 |
| $CaCl_2$ | HiOx | < 14 | < 4 | 39.1 | < 0.6 | 35.6 |
| NaAsc | NoOx | < 14 | < 4 | 17.0 | < 0.6 | 22.1 |
| NaAsc | HiOx | < 14 | < 4 | 19.7 | < 0.6 | 26.0 |
| 0.2 CaAsc | NoOx | < 14 | < 4 | 32.3 | < 0.6 | 25.0 |
| 0.2 CaAsc | HiOx | < 14 | < 4 | 47.3 | < 0.6 | 42.9 |
| 0.3 CaAsc | NoOx | < 14 | < 4 | 20.0 | < 0.6 | 33.1 |
| 0.3 CaAsc | HiOx | < 14 | < 4 | 31.5 | < 0.6 | 29.9 |

B = boron; Cu = copper; Fe = iron; Mn = manganese; Zn = zinc

# CHAPTER 4. SUMMARY AND CONCLUSIONS

The objective of this study was to compare calcium ascorbate with calcium chloride for tenderization and with sodium ascorbate for color enhancement of pork muscle under different storage conditions and at simulated display periods in case-ready packaging. Two hundred forty pork center loin chops from twelve loins were used to evaluate the effects of dipping in various calcium and sodium solutions in conjunction with different modified atmosphere packaging conditions (MAP), storage conditions, and display times. Dipping treatments included control (no dip), 0.3 M calcium chloride ($CaCl_2$), 2.0% sodium ascorbate (NaAsc), 0.2 M calcium ascorbate (0.2 M CaAsc), and 0.3 M calcium ascorbate (0.3 M CaAsc). MAP conditions consisted of 80% $O_2$ / 20% $CO_2$ or 80% $N_2$ / 20% $CO_2$. Chop storage conditions were fresh temperatures (4°C) for 7 days or at frozen temperatures (-18°C) for 21 days. Chops were displayed for 3 or 6 days after fresh or frozen storage.

Our observations of this study suggest that dipping of pork chops in ingredient baths may enhance color traits of bone and muscle, but tenderization of muscle was minimal, even using calcium chloride. Using an ascorbate dip reduced color changes in muscle and bone that might have been due to pigment oxidation. Calcium ascorbate significantly increased a* values in vertebrae bone, giving bone a brighter red color, thus reducing the amount of bone darkening. Our work with pork supports other research on beef.

Tenderization was achieved to a small extent in chops dipped calcium chloride, but not with the use of calcium ascorbate. Differences we observed for shear force in chops dipped in calcium chloride were not as significant as results of injection or infusion with calcium chloride reported in previous research (Koohmaraie *et al*., 1988; Koohmaraie *et al*., 1990; Rees *et al*.,

2001). Injection of calcium ascorbate might have shown lower shear force values than dipping chops, as has been shown in other research studies.

Short marination times or dipping of pork loin chops in sodium ascorbate or calcium ascorbate at 0.069 ppm and packaging in high oxygen atmospheres will result in bright red color in cut bone surfaces through 6 days of display. It is recommended that calcium chloride, in sufficient levels, can lower drip loss and shear force values more than use of calcium ascorbate. Since calcium levels were the same in calcium chloride and calcium ascorbate dipped chops, chlorine ions may have had an effect in degrading salt soluble myofibrillar proteins. Alone, calcium ascorbate cannot replace usage of individual amounts of calcium chloride and sodium ascorbate. However, usage of calcium ascorbate and calcium chloride may enhance color and tenderness in pork loin chops to desired degrees.

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## APPENDIX A: ANOVA TABLES FOR DEPENDENT VARIABLES

Appendix Table 1. Analysis of Variance for initial pH

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 0.04 | 6.99 | <0.0001 |
| Storage*Treat | 4 | 0.003 | 0.49 | 0.75 |
| Pack | 1 | 0.01 | 1.79 | 0.18 |
| Storage*Pack | 1 | 0.001 | 0.12 | 0.73 |
| Treat*Pack | 4 | 0.001 | 0.13 | 0.97 |
| Storage*Treat*Pack | 4 | 0.003 | 0.57 | 0.68 |
| Display | 1 | 0.002 | 0.29 | 0.59 |
| Storage*Display | 1 | 0.02 | 3.14 | 0.08 |
| Treat*Display | 4 | 0.003 | 0.63 | 0.64 |
| Stor*Treat*Display | 4 | 0.002 | 0.44 | 0.78 |
| Pack*Display | 1 | 0.002 | 0.33 | 0.57 |
| Stor*Pack*Display | 1 | 0.002 | 0.31 | 0.58 |
| Treat*Pack*Display | 4 | 0.004 | 0.66 | 0.62 |
| Stor*Treat*Pack*Disp | 4 | 0.001 | 0.10 | 0.98 |
| **Error** | **190** | **0.01** | | |
| Storage | 1 | 0.01 | 0.43 | 0.53 |
| Error(Storage) | 10 | 0.03 | | |
| Total Error | 239 | | | |

Appendix Table 2. Analysis of Variance for final pH

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 0.11 | 4.87 | 0.001 |
| Storage*Treat | 4 | 0.08 | 3.49 | 0.009 |
| Pack | 1 | 0.23 | 10.31 | 0.002 |
| Storage*Pack | 1 | 0.04 | 1.70 | 0.19 |
| Treat*Pack | 4 | 0.03 | 1.27 | 0.28 |
| Storage*Treat*Pack | 4 | 0.04 | 1.70 | 0.15 |
| Display | 1 | 0.003 | 0.12 | 0.73 |
| Storage*Display | 1 | 0.06 | 2.56 | 0.11 |
| Treat*Display | 4 | 0.002 | 0.07 | 0.99 |
| Stor*Treat*Display | 4 | 0.06 | 2.72 | 0.03 |
| Pack*Display | 1 | 0.06 | 2.70 | 0.10 |
| Stor*Pack*Display | 1 | 0.01 | 0.37 | 0.55 |
| Treat*Pack*Display | 4 | 0.02 | 0.99 | 0.41 |
| Stor*Treat*Pack*Disp | 4 | 0.03 | 1.31 | 0.27 |
| **Error** | **190** | **0.02** | | |
| Storage | 1 | 36.67 | 571.45 | <0.0001 |
| Error(Storage) | 10 | 0.06 | | |
| Total Error | 239 | | | |

Appendix Table 3. Analysis of Variance for initial *Longissimus dorsi* L* color value

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 162.40 | 9.95 | <0.0001 |
| Storage*Treat | 4 | 10.87 | 0.67 | 0.62 |
| Pack | 1 | 17.80 | 1.09 | 0.30 |
| Storage*Pack | 1 | 8.47 | 0.52 | 0.47 |
| Treat*Pack | 4 | 27.62 | 1.69 | 0.15 |
| Storage*Treat*Pack | 4 | 3.71 | 0.23 | 0.92 |
| Display | 1 | 5.65 | 0.35 | 0.56 |
| Storage*Display | 1 | 10.13 | 0.62 | 0.43 |
| Treat*Display | 4 | 10.21 | 0.63 | 0.64 |
| Stor*Treat*Display | 4 | 6.63 | 0.41 | 0.80 |
| Pack*Display | 1 | 1.19 | 0.07 | 0.79 |
| Stor*Pack*Display | 1 | 6.60 | 0.40 | 0.53 |
| Treat*Pack*Display | 4 | 14.32 | 0.88 | 0.48 |
| Stor*Treat*Pack*Disp | 4 | 7.08 | 0.43 | 0.78 |
| **Error** | **190** | **16.32** | | |
| Storage | 1 | 13.40 | 0.08 | 0.78 |
| Error(Storage) | 10 | 165.68 | | |
| Total Error | 239 | | | |

Appendix Table 4. Analysis of Variance for initial *Longissimus dorsi* a* color value

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 4.53 | 2.20 | 0.07 |
| Storage*Treat | 4 | 6.32 | 3.07 | 0.02 |
| Pack | 1 | 0.05 | 0.02 | 0.88 |
| Storage*Pack | 1 | 0.30 | 0.15 | 0.70 |
| Treat*Pack | 4 | 0.80 | 0.39 | 0.82 |
| Storage*Treat*Pack | 4 | 0.78 | 0.38 | 0.82 |
| Display | 1 | 1.39 | 0.68 | 0.41 |
| Storage*Display | 1 | 7.38 | 3.59 | 0.06 |
| Treat*Display | 4 | 4.58 | 2.23 | 0.07 |
| Stor*Treat*Display | 4 | 1.00 | 0.49 | 0.75 |
| Pack*Display | 1 | 3.05 | 1.48 | 0.23 |
| Stor*Pack*Display | 1 | 5.62 | 2.73 | 0.10 |
| Treat*Pack*Display | 4 | 0.73 | 0.36 | 0.84 |
| Stor*Treat*Pack*Disp | 4 | 0.21 | 0.10 | 0.98 |
| **Error** | **190** | **2.06** | | |
| Storage | 1 | 3.33 | 0.21 | 0.66 |
| Error(Storage) | 10 | 15.80 | | |
| Total Error | 239 | | | |

Appendix Table 5. Analysis of Variance for initial *Longissimus dorsi* b* color value

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 20.02 | 7.41 | <0.0001 |
| Storage*Treat | 4 | 10.02 | 3.71 | 0.01 |
| Pack | 1 | 0.77 | 0.28 | 0.60 |
| Storage*Pack | 1 | 2.37 | 0.88 | 0.35 |
| Treat*Pack | 4 | 10.19 | 3.77 | 0.01 |
| Storage*Treat*Pack | 4 | 1.66 | 0.62 | 0.65 |
| Display | 1 | 0.69 | 0.26 | 0.61 |
| Storage*Display | 1 | 4.12 | 1.53 | 0.22 |
| Treat*Display | 4 | 11.00 | 4.07 | 0.003 |
| Stor*Treat*Display | 4 | 1.48 | 0.55 | 0.70 |
| Pack*Display | 1 | 9.32 | 3.45 | 0.06 |
| Stor*Pack*Display | 1 | 3.18 | 1.18 | 0.28 |
| Treat*Pack*Display | 4 | 2.36 | 0.87 | 0.48 |
| Stor*Treat*Pack*Disp | 4 | 0.90 | 0.33 | 0.86 |
| **Error** | **190** | **2.70** | | |
| Storage | 1 | 0.79 | 0.04 | 0.84 |
| Error(Storage) | 10 | 17.84 | | |
| Total Error | 239 | | | |

Appendix Table 6. Analysis of Variance for initial *Longissimus dorsi* chroma

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 14.67 | 4.09 | 0.003 |
| Storage*Treat | 4 | 14.01 | 3.91 | 0.005 |
| Pack | 1 | 0.50 | 0.14 | 0.71 |
| Storage*Pack | 1 | 2.60 | 0.72 | 0.40 |
| Treat*Pack | 4 | 10.75 | 3.00 | 0.02 |
| Storage*Treat*Pack | 4 | 2.08 | 0.58 | 0.68 |
| Display | 1 | 1.41 | 0.39 | 0.53 |
| Storage*Display | 1 | 7.60 | 2.12 | 0.15 |
| Treat*Display | 4 | 13.88 | 3.87 | 0.005 |
| Stor*Treat*Display | 4 | 1.98 | 0.55 | 0.70 |
| Pack*Display | 1 | 12.32 | 3.44 | 0.07 |
| Stor*Pack*Display | 1 | 6.21 | 1.73 | 0.19 |
| Treat*Pack*Display | 4 | 2.97 | 0.83 | 0.51 |
| Stor*Treat*Pack*Disp | 4 | 0.89 | 0.25 | 0.91 |
| **Error** | **190** | **3.58** | | |
| Storage | 1 | 1.86 | 0.08 | 0.78 |
| Error(Storage) | 10 | 23.30 | | |
| Total Error | 239 | | | |

Appendix Table 7. Analysis of Variance for initial *Longissimus dorsi* hue angle

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 0.04 | 8.95 | <0.0001 |
| Storage*Treat | 4 | 0.01 | 2.20 | 0.07 |
| Pack | 1 | 0.001 | 0.20 | 0.66 |
| Storage*Pack | 1 | 0.0001 | 0.03 | 0.86 |
| Treat*Pack | 4 | 0.002 | 0.38 | 0.82 |
| Storage*Treat*Pack | 4 | 0.002 | 0.40 | 0.81 |
| Display | 1 | 0.001 | 0.27 | 0.61 |
| Storage*Display | 1 | 0.01 | 2.89 | 0.09 |
| Treat*Display | 4 | 0.01 | 1.46 | 0.21 |
| Stor*Treat*Display | 4 | 0.002 | 0.52 | 0.72 |
| Pack*Display | 1 | 0.001 | 0.27 | 0.60 |
| Stor*Pack*Display | 1 | 0.01 | 2.59 | 0.11 |
| Treat*Pack*Display | 4 | 0.001 | 0.26 | 0.90 |
| Stor*Treat*Pack*Disp | 4 | 0.001 | 0.25 | 0.91 |
| **Error** | **190** | **0.004** | | |
| Storage | 1 | 0.01 | 0.29 | 0.60 |
| Error(Storage) | 10 | 0.04 | | |
| Total Error | 239 | | | |

Appendix Table 8. Analysis of Variance for initial weight

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 6732.75 | 14.40 | <0.0001 |
| Storage*Treat | 4 | 340.05 | 0.73 | 0.57 |
| Pack | 1 | 95.18 | 0.20 | 0.65 |
| Storage*Pack | 1 | 806.89 | 1.73 | 0.19 |
| Treat*Pack | 4 | 649.64 | 1.39 | 0.24 |
| Storage*Treat*Pack | 4 | 533.89 | 1.14 | 0.34 |
| Display | 1 | 11607.06 | 24.82 | <0.0001 |
| Storage*Display | 1 | 1778.23 | 3.80 | 0.05 |
| Treat*Display | 4 | 3719.07 | 7.95 | <0.0001 |
| Stor*Treat*Display | 4 | 170.46 | 0.36 | 0.83 |
| Pack*Display | 1 | 1482.15 | 3.17 | 0.08 |
| Stor*Pack*Display | 1 | 163.85 | 0.35 | 0.55 |
| Treat*Pack*Display | 4 | 521.44 | 1.12 | 0.35 |
| Stor*Treat*Pack*Disp | 4 | 358.00 | 0.77 | 0.55 |
| **Error** | **190** | **467.61** | | |
| Storage | 1 | 883.97 | 0.05 | 0.84 |
| Error(Storage) | 10 | 19414.72 | | |
| Total Error | 239 | | | |

Appendix Table 9. Analysis of Variance for dipped weight

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 604776.84 | 1014.56 | <0.0001 |
| Storage*Treat | 4 | 280.711 | 0.47 | 0.76 |
| Pack | 1 | 264.03 | 0.44 | 0.51 |
| Storage*Pack | 1 | 643.96 | 1.08 | 0.30 |
| Treat*Pack | 4 | 370.25 | 0.62 | 0.65 |
| Storage*Treat*Pack | 4 | 458.86 | 0.77 | 0.55 |
| Display | 1 | 1811.21 | 3.04 | 0.08 |
| Storage*Display | 1 | 1666.32 | 2.80 | 0.10 |
| Treat*Display | 4 | 907.46 | 1.52 | 0.20 |
| Stor*Treat*Display | 4 | 296.47 | 0.50 | 0.74 |
| Pack*Display | 1 | 1130.61 | 1.90 | 0.17 |
| Stor*Pack*Display | 1 | 9.24 | 0.02 | 0.90 |
| Treat*Pack*Display | 4 | 376.14 | 0.63 | 0.64 |
| Stor*Treat*Pack*Disp | 4 | 214.54 | 0.36 | 0.84 |
| **Error** | **190** | **596.10** | | |
| Storage | 1 | 877.95 | 0.07 | 0.80 |
| Error(Storage) | 10 | 13384.96 | | |
| Total Error | 239 | | | |

Appendix Table 10. Analysis of Variance for percent pickup

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 100147.68 | 69061.0 | <0.0001 |
| Storage*Treat | 4 | 1.06 | 0.73 | 0.57 |
| Pack | 1 | 0.001 | 0.00 | 0.98 |
| Storage*Pack | 1 | 0.47 | 0.33 | 0.57 |
| Treat*Pack | 4 | 1.15 | 0.80 | 0.53 |
| Storage*Treat*Pack | 4 | 1.02 | 0.70 | 0.59 |
| Display | 1 | 1.86 | 1.28 | 0.26 |
| Storage*Display | 1 | 2.48 | 1.71 | 0.19 |
| Treat*Display | 4 | 1.24 | 0.86 | 0.49 |
| Stor*Treat*Display | 4 | 0.61 | 0.42 | 0.79 |
| Pack*Display | 1 | 1.35 | 0.93 | 0.34 |
| Stor*Pack*Display | 1 | 1.52 | 1.05 | 0.31 |
| Treat*Pack*Display | 4 | 2.90 | 2.00 | 0.10 |
| Stor*Treat*Pack*Disp | 4 | 1.25 | 0.86 | 0.06 |
| **Error** | **190** | **1.45** | | |
| Storage | 1 | 1.20 | 0.45 | 0.52 |
| Error(Storage) | 10 | 2.66 | | |
| Total Error | 239 | | | |

Appendix Table 11. Analysis of Variance for final *Longissimus dorsi* L* color value

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 40.02 | 3.15 | 0.02 |
| Storage*Treat | 4 | 4.85 | 0.38 | 0.82 |
| Pack | 1 | 139.13 | 10.96 | 0.001 |
| Storage*Pack | 1 | 372.06 | 29.30 | <0.0001 |
| Treat*Pack | 4 | 14.52 | 1.14 | 0.34 |
| Storage*Treat*Pack | 4 | 21.17 | 1.67 | 0.16 |
| Display | 1 | 5.49 | 0.43 | 0.51 |
| Storage*Display | 1 | 115.05 | 9.06 | 0.003 |
| Treat*Display | 4 | 8.38 | 0.66 | 0.62 |
| Stor*Treat*Display | 4 | 10.53 | 0.83 | 0.51 |
| Pack*Display | 1 | 1.31 | 0.10 | 0.75 |
| Stor*Pack*Display | 1 | 18.90 | 1.49 | 0.22 |
| Treat*Pack*Display | 4 | 11.89 | 0.94 | 0.44 |
| Stor*Treat*Pack*Disp | 4 | 6.11 | 0.48 | 0.75 |
| **Error** | **190** | **12.70** | | |
| Storage | 1 | 1842.96 | 21.44 | 0.0009 |
| Error(Storage) | 10 | 85.97 | | |
| Total Error | 239 | | | |

Appendix Table 12. Analysis of Variance for final *Longissimus dorsi* a* color value

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 5.27 | 2.90 | 0.02 |
| Storage*Treat | 4 | 4.96 | 2.74 | 0.03 |
| Pack | 1 | 20.31 | 11.20 | 0.001 |
| Storage*Pack | 1 | 0.73 | 0.40 | 0.53 |
| Treat*Pack | 4 | 2.84 | 1.57 | 0.19 |
| Storage*Treat*Pack | 4 | 7.08 | 3.90 | 0.005 |
| Display | 1 | 0.36 | 0.20 | 0.66 |
| Storage*Display | 1 | 10.88 | 6.00 | 0.02 |
| Treat*Display | 4 | 1.86 | 1.03 | 0.39 |
| Stor*Treat*Display | 4 | 3.29 | 1.82 | 0.13 |
| Pack*Display | 1 | 7.07 | 3.90 | 0.06 |
| Stor*Pack*Display | 1 | 2.08 | 1.14 | 0.29 |
| Treat*Pack*Display | 4 | 1.80 | 0.99 | 0.41 |
| Stor*Treat*Pack*Disp | 4 | 1.37 | 0.76 | 0.56 |
| **Error** | **190** | **1.81** | | |
| Storage | 1 | 51.93 | 5.57 | 0.04 |
| Error(Storage) | 10 | 9.32 | | |
| Total Error | 239 | | | |

Appendix Table 13. Analysis of Variance for final *Longissimus dorsi* b* color value

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 11.28 | 4.55 | 0.002 |
| Storage*Treat | 4 | 5.67 | 2.29 | 0.06 |
| Pack | 1 | 4.19 | 1.69 | 0.20 |
| Storage*Pack | 1 | 15.80 | 6.38 | 0.01 |
| Treat*Pack | 4 | 3.72 | 1.50 | 0.20 |
| Storage*Treat*Pack | 4 | 3.35 | 1.35 | 0.25 |
| Display | 1 | 6.76 | 2.73 | 0.10 |
| Storage*Display | 1 | 1.21 | 0.49 | 0.49 |
| Treat*Display | 4 | 4.53 | 1.83 | 0.13 |
| Stor*Treat*Display | 4 | 0.58 | 0.24 | 0.92 |
| Pack*Display | 1 | 3.27 | 1.32 | 0.25 |
| Stor*Pack*Display | 1 | 6.35 | 2.56 | 0.11 |
| Treat*Pack*Display | 4 | 1.57 | 0.64 | 0.64 |
| Stor*Treat*Pack*Disp | 4 | 1.70 | 0.69 | 0.60 |
| **Error** | **190** | **2.48** | | |
| Storage | 1 | 40.07 | 2.55 | 0.14 |
| Error(Storage) | 10 | 15.68 | | |
| Total Error | 239 | | | |

Appendix Table 14. Analysis of Variance for final *Longissimus dorsi* chroma

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 14.31 | 4.92 | 0.0009 |
| Storage*Treat | 4 | 7.51 | 2.58 | 0.04 |
| Pack | 1 | 5.81 | 2.00 | 0.16 |
| Storage*Pack | 1 | 13.94 | 4.79 | 0.03 |
| Treat*Pack | 4 | 2.45 | 0.84 | 0.50 |
| Storage*Treat*Pack | 4 | 5.28 | 1.82 | 0.13 |
| Display | 1 | 6.64 | 2.28 | 0.13 |
| Storage*Display | 1 | 3.72 | 1.28 | 0.26 |
| Treat*Display | 4 | 4.98 | 1.71 | 0.15 |
| Stor*Treat*Display | 4 | 1.40 | 0.48 | 0.75 |
| Pack*Display | 1 | 6.83 | 2.35 | 0.13 |
| Stor*Pack*Display | 1 | 6.85 | 2.35 | 0.13 |
| Treat*Pack*Display | 4 | 2.33 | 0.80 | 0.53 |
| Stor*Treat*Pack*Disp | 4 | 2.04 | 0.70 | 0.59 |
| **Error** | **190** | **2.91** | | |
| Storage | 1 | 53.63 | 2.89 | 0.12 |
| Error(Storage) | 10 | 18.54 | | |
| Total Error | 239 | | | |

Appendix Table 15. Analysis of Variance for final *Longissimus dorsi* hue angle

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 0.40 | 1.55 | 0.19 |
| Storage*Treat | 4 | 0.31 | 1.20 | 0.31 |
| Pack | 1 | 0.24 | 0.93 | 0.34 |
| Storage*Pack | 1 | 0.13 | 0.52 | 0.47 |
| Treat*Pack | 4 | 0.42 | 1.64 | 0.17 |
| Storage*Treat*Pack | 4 | 0.81 | 3.15 | 0.02 |
| Display | 1 | 0.15 | 0.59 | 0.45 |
| Storage*Display | 1 | 0.03 | 0.12 | 0.73 |
| Treat*Display | 4 | 0.19 | 0.72 | 0.58 |
| Stor*Treat*Display | 4 | 0.56 | 2.17 | 0.07 |
| Pack*Display | 1 | 1.84 | 7.11 | 0.10 |
| Stor*Pack*Display | 1 | 0.55 | 2.13 | 0.15 |
| Treat*Pack*Display | 4 | 0.37 | 1.44 | 0.22 |
| Stor*Treat*Pack*Disp | 4 | 0.11 | 0.42 | 0.80 |
| **Error** | **190** | **0.26** | | |
| Storage | 1 | 0.68 | 1.67 | 0.23 |
| Error(Storage) | 10 | 0.41 | | |
| Total Error | 239 | | | |

Appendix Table 16. Analysis of Variance for initial vertebrae L* color value

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 101.03 | 4.53 | 0.002 |
| Storage*Treat | 4 | 33.69 | 1.51 | 0.20 |
| Pack | 1 | 97.68 | 4.38 | 0.04 |
| Storage*Pack | 1 | 35.79 | 1.60 | 0.21 |
| Treat*Pack | 4 | 52.57 | 2.36 | 0.06 |
| Storage*Treat*Pack | 4 | 12.17 | 0.55 | 0.70 |
| Display | 1 | 71.52 | 3.21 | 0.08 |
| Storage*Display | 1 | 78.93 | 3.54 | 0.06 |
| Treat*Display | 4 | 52.90 | 2.37 | 0.05 |
| Stor*Treat*Display | 4 | 22.79 | 1.02 | 0.40 |
| Pack*Display | 1 | 71.56 | 3.21 | 0.07 |
| Stor*Pack*Display | 1 | 4.20 | 0.19 | 0.67 |
| Treat*Pack*Display | 4 | 38.60 | 1.73 | 0.15 |
| Stor*Treat*Pack*Disp | 4 | 4.69 | 0.21 | 0.93 |
| **Error** | **190** | **22.31** | | |
| Storage | 1 | 7.38 | 0.07 | 0.80 |
| Error(Storage) | 10 | 104.11 | | |
| Total Error | 239 | | | |

Appendix Table 17. Analysis of Variance for initial vertebrae a* color value

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 46.13 | 2.57 | 0.04 |
| Storage*Treat | 4 | 27.51 | 1.53 | 0.20 |
| Pack | 1 | 14.15 | 0.79 | 0.38 |
| Storage*Pack | 1 | 24.00 | 1.33 | 0.25 |
| Treat*Pack | 4 | 28.08 | 1.56 | 0.19 |
| Storage*Treat*Pack | 4 | 8.42 | 0.47 | 0.76 |
| Display | 1 | 46.39 | 2.58 | 0.11 |
| Storage*Display | 1 | 89.00 | 4.95 | 0.03 |
| Treat*Display | 4 | 43.37 | 2.41 | 0.05 |
| Stor*Treat*Display | 4 | 22.41 | 1.25 | 0.29 |
| Pack*Display | 1 | 28.24 | 1.57 | 0.21 |
| Stor*Pack*Display | 1 | 12.78 | 0.71 | 0.40 |
| Treat*Pack*Display | 4 | 18.72 | 1.04 | 0.39 |
| Stor*Treat*Pack*Disp | 4 | 24.06 | 1.34 | 0.26 |
| **Error** | **190** | **17.98** | | |
| Storage | 1 | 1.96 | 0.03 | 0.86 |
| Error(Storage) | 10 | 62.53 | | |
| Total Error | 239 | | | |

Appendix Table 18. Analysis of Variance for initial vertebrae b* color value

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 4.17 | 0.60 | 0.66 |
| Storage*Treat | 4 | 2.88 | 0.42 | 0.80 |
| Pack | 1 | 3.44 | 0.50 | 0.48 |
| Storage*Pack | 1 | 0.14 | 0.02 | 0.89 |
| Treat*Pack | 4 | 1.21 | 0.18 | 0.95 |
| Storage*Treat*Pack | 4 | 3.74 | 0.54 | 0.71 |
| Display | 1 | 5.18 | 0.75 | 0.39 |
| Storage*Display | 1 | 30.40 | 4.40 | 0.04 |
| Treat*Display | 4 | 21.97 | 3.18 | 0.01 |
| Stor*Treat*Display | 4 | 11.92 | 1.73 | 0.15 |
| Pack*Display | 1 | 2.07 | 0.30 | 0.58 |
| Stor*Pack*Display | 1 | 13.41 | 1.94 | 0.17 |
| Treat*Pack*Display | 4 | 2.20 | 0.32 | 0.87 |
| Stor*Treat*Pack*Disp | 4 | 14.26 | 2.06 | 0.09 |
| **Error** | **190** | **6.91** | | |
| Storage | 1 | 0.87 | 0.07 | 0.79 |
| Error(Storage) | 10 | 12.12 | | |
| Total Error | 239 | | | |

Appendix Table 19. Analysis of Variance for initial vertebrae chroma

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 29.40 | 1.43 | 0.23 |
| Storage*Treat | 4 | 22.00 | 1.07 | 0.37 |
| Pack | 1 | 12.40 | 0.60 | 0.44 |
| Storage*Pack | 1 | 10.76 | 0.52 | 0.47 |
| Treat*Pack | 4 | 15.15 | 0.74 | 0.57 |
| Storage*Treat*Pack | 4 | 11.43 | 0.56 | 0.69 |
| Display | 1 | 44.51 | 2.17 | 0.14 |
| Storage*Display | 1 | 103.96 | 5.06 | 0.03 |
| Treat*Display | 4 | 57.04 | 2.78 | 0.03 |
| Stor*Treat*Display | 4 | 31.57 | 1.54 | 0.19 |
| Pack*Display | 1 | 22.31 | 1.09 | 0.30 |
| Stor*Pack*Display | 1 | 23.09 | 1.12 | 0.29 |
| Treat*Pack*Display | 4 | 13.68 | 0.67 | 0.62 |
| Stor*Treat*Pack*Disp | 4 | 36.63 | 1.78 | 0.13 |
| **Error** | **190** | **20.55** | | |
| Storage | 1 | 0.03 | 0.00 | 0.98 |
| Error(Storage) | 10 | 51.97 | | |
| Total Error | 239 | | | |

Appendix Table 20. Analysis of Variance for initial vertebrae hue angle

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 0.03 | 0.74 | 0.57 |
| Storage*Treat | 4 | 0.07 | 1.96 | 0.10 |
| Pack | 1 | 0.01 | 0.30 | 0.59 |
| Storage*Pack | 1 | 0.003 | 0.08 | 0.78 |
| Treat*Pack | 4 | 0.08 | 2.21 | 0.07 |
| Storage*Treat*Pack | 4 | 0.05 | 1.33 | 0.26 |
| Display | 1 | 0.13 | 3.50 | 0.06 |
| Storage*Display | 1 | 0.00003 | 0.00 | 0.98 |
| Treat*Display | 4 | 0.02 | 0.52 | 0.72 |
| Stor*Treat*Display | 4 | 0.04 | 1.25 | 0.29 |
| Pack*Display | 1 | 0.13 | 3.49 | 0.06 |
| Stor*Pack*Display | 1 | 0.04 | 1.02 | 0.31 |
| Treat*Pack*Display | 4 | 0.03 | 0.76 | 0.55 |
| Stor*Treat*Pack*Disp | 4 | 0.06 | 1.67 | 0.16 |
| **Error** | **190** | **0.04** | | |
| Storage | 1 | 0.12 | 0.58 | 0.46 |
| Error(Storage) | 10 | 0.03 | | |
| Total Error | 239 | | | |

Appendix Table 21. Analysis of Variance for final vertebrae L* color value

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 35.09 | 2.67 | 0.03 |
| Storage*Treat | 4 | 13.22 | 1.00 | 0.41 |
| Pack | 1 | 64.44 | 4.89 | 0.03 |
| Storage*Pack | 1 | 54.15 | 4.11 | 0.04 |
| Treat*Pack | 4 | 15.07 | 1.14 | 0.34 |
| Storage*Treat*Pack | 4 | 12.13 | 0.92 | 0.45 |
| Display | 1 | 7.04 | 0.53 | 0.47 |
| Storage*Display | 1 | 31.25 | 2.37 | 0.13 |
| Treat*Display | 4 | 40.83 | 3.10 | 0.02 |
| Stor*Treat*Display | 4 | 18.06 | 1.37 | 0.25 |
| Pack*Display | 1 | 0.05 | 0.00 | 0.95 |
| Stor*Pack*Display | 1 | 20.11 | 1.53 | 0.22 |
| Treat*Pack*Display | 4 | 6.97 | 0.53 | 0.71 |
| Stor*Treat*Pack*Disp | 4 | 8.82 | 0.67 | 0.61 |
| **Error** | **190** | **13.17** | | |
| Storage | 1 | 2221.03 | 29.10 | 0.0003 |
| Error(Storage) | 10 | 76.34 | | |
| Total Error | 239 | | | |

Appendix Table 22. Analysis of Variance for final vertebrae a* color value

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 135.44 | 17.28 | <0.0001 |
| Storage*Treat | 4 | 130.91 | 16.70 | <0.0001 |
| Pack | 1 | 795.95 | 101.55 | <0.0001 |
| Storage*Pack | 1 | 472.38 | 60.27 | <0.0001 |
| Treat*Pack | 4 | 123.97 | 15.82 | <0.0001 |
| Storage*Treat*Pack | 4 | 51.18 | 6.53 | <0.0001 |
| Display | 1 | 4.45 | 0.57 | 0.45 |
| Storage*Display | 1 | 70.84 | 9.04 | 0.003 |
| Treat*Display | 4 | 6.69 | 0.85 | 0.49 |
| Stor*Treat*Display | 4 | 34.24 | 4.37 | 0.002 |
| Pack*Display | 1 | 5.23 | 0.67 | 0.41 |
| Stor*Pack*Display | 1 | 15.30 | 1.95 | 0.16 |
| Treat*Pack*Display | 4 | 9.77 | 1.25 | 0.29 |
| Stor*Treat*Pack*Disp | 4 | 1.49 | 0.19 | 0.94 |
| **Error** | **190** | **7.84** | | |
| Storage | 1 | 430.50 | 11.76 | 0.006 |
| Error(Storage) | 10 | 36.61 | | |
| Total Error | 239 | | | |

Appendix Table 23. Analysis of Variance for final vertebrae b* color value

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 29.12 | 11.93 | <0.0001 |
| Storage*Treat | 4 | 21.86 | 8.96 | <0.0001 |
| Pack | 1 | 490.52 | 200.97 | <0.0001 |
| Storage*Pack | 1 | 61.19 | 25.07 | <0.0001 |
| Treat*Pack | 4 | 20.03 | 8.21 | <0.0001 |
| Storage*Treat*Pack | 4 | 3.90 | 1.60 | 0.18 |
| Display | 1 | 1.38 | 0.56 | 0.45 |
| Storage*Display | 1 | 29.35 | 12.03 | 0.0006 |
| Treat*Display | 4 | 2.64 | 1.08 | 0.37 |
| Stor*Treat*Display | 4 | 10.38 | 4.25 | 0.003 |
| Pack*Display | 1 | 0.93 | 0.38 | 0.54 |
| Stor*Pack*Display | 1 | 5.60 | 2.30 | 0.13 |
| Treat*Pack*Display | 4 | 2.55 | 1.05 | 0.38 |
| Stor*Treat*Pack*Disp | 4 | 7.86 | 3.22 | 0.01 |
| **Error** | **190** | **2.44** | | |
| Storage | 1 | 560.13 | 88.75 | <0.0001 |
| Error(Storage) | 10 | 6.31 | | |
| Total Error | 239 | | | |

Appendix Table 24. Analysis of Variance for final vertebrae chroma

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 127.88 | 18.01 | <0.0001 |
| Storage*Treat | 4 | 107.79 | 15.18 | <0.0001 |
| Pack | 1 | 1255.24 | 176.76 | <0.0001 |
| Storage*Pack | 1 | 342.03 | 48.17 | <0.0001 |
| Treat*Pack | 4 | 96.51 | 13.59 | <0.0001 |
| Storage*Treat*Pack | 4 | 32.74 | 4.61 | 0.001 |
| Display | 1 | 4.61 | 0.65 | 0.42 |
| Storage*Display | 1 | 92.72 | 13.06 | 0.0004 |
| Treat*Display | 4 | 5.73 | 0.81 | 0.52 |
| Stor*Treat*Display | 4 | 37.16 | 5.23 | 0.0005 |
| Pack*Display | 1 | 0.69 | 0.10 | 0.76 |
| Stor*Pack*Display | 1 | 17.74 | 2.50 | 0.12 |
| Treat*Pack*Display | 4 | 9.53 | 1.34 | 0.26 |
| Stor*Treat*Pack*Disp | 4 | 5.54 | 0.78 | 0.54 |
| **Error** | **190** | **7.10** | | |
| Storage | 1 | 1004.52 | 33.79 | 0.0002 |
| Error(Storage) | 10 | 29.73 | | |
| Total Error | 239 | | | |

Appendix Table 25. Analysis of Variance for final vertebrae hue angle

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 0.065 | 7.71 | <0.0001 |
| Storage*Treat | 4 | 0.107 | 12.73 | <0.0001 |
| Pack | 1 | 0.188 | 22.44 | <0.0001 |
| Storage*Pack | 1 | 0.665 | 79.32 | <0.0001 |
| Treat*Pack | 4 | 0.101 | 12.07 | <0.0001 |
| Storage*Treat*Pack | 4 | 0.043 | 5.18 | 0.0006 |
| Display | 1 | 0.001 | 0.12 | 0.73 |
| Storage*Display | 1 | 0.016 | 1.90 | 0.17 |
| Treat*Display | 4 | 0.007 | 0.88 | 0.48 |
| Stor*Treat*Display | 4 | 0.018 | 2.20 | 0.07 |
| Pack*Display | 1 | 0.012 | 1.42 | 0.23 |
| Stor*Pack*Display | 1 | 0.003 | 0.33 | 0.57 |
| Treat*Pack*Display | 4 | 0.006 | 0.73 | 0.58 |
| Stor*Treat*Pack*Disp | 4 | 0.008 | 0.92 | 0.45 |
| **Error** | **190** | **0.008** | | |
| Storage | 1 | 0.018 | 0.56 | 0.47 |
| Error(Storage) | 10 | 0.030 | | |
| Total Error | 239 | | | |

Appendix Table 26. Analysis of Variance for blotted weight

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 7106.75 | 15.08 | <0.0001 |
| Storage*Treat | 4 | 289.97 | 0.62 | 0.65 |
| Pack | 1 | 124.59 | 0.26 | 0.61 |
| Storage*Pack | 1 | 1035.84 | 2.20 | 0.14 |
| Treat*Pack | 4 | 391.61 | 0.83 | 0.51 |
| Storage*Treat*Pack | 4 | 642.27 | 1.36 | 0.25 |
| Display | 1 | 9914.80 | 21.04 | <0.0001 |
| Storage*Display | 1 | 2341.38 | 4.97 | 0.03 |
| Treat*Display | 4 | 3935.06 | 8.35 | <0.0001 |
| Stor*Treat*Display | 4 | 241.53 | 0.51 | 0.73 |
| Pack*Display | 1 | 1473.62 | 3.13 | 0.08 |
| Stor*Pack*Display | 1 | 278.60 | 0.59 | 0.44 |
| Treat*Pack*Display | 4 | 664.93 | 1.41 | 0.23 |
| Stor*Treat*Pack*Disp | 4 | 381.67 | 0.81 | 0.52 |
| **Error** | **190** | **471.18** | | |
| Storage | 1 | 10.15 | 0.00 | 0.98 |
| Error(Storage) | 10 | 18124.39 | | |
| Total Error | 239 | | | |

Appendix Table 27. Analysis of Variance for percent drip loss

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 0.002 | 10.23 | <0.0001 |
| Storage*Treat | 4 | 0.0002 | 1.21 | 0.31 |
| Pack | 1 | 0.0006 | 3.36 | 0.07 |
| Storage*Pack | 1 | 0.0003 | 1.77 | 0.18 |
| Treat*Pack | 4 | 0.0007 | 3.73 | 0.006 |
| Storage*Treat*Pack | 4 | 0.0003 | 1.37 | 0.25 |
| Display | 1 | 0.0003 | 1.58 | 0.21 |
| Storage*Display | 1 | 0.003 | 14.65 | 0.0002 |
| Treat*Display | 4 | 0.0008 | 4.22 | 0.003 |
| Stor*Treat*Display | 4 | 0.0003 | 1.81 | 0.13 |
| Pack*Display | 1 | 0.0006 | 3.20 | 0.08 |
| Stor*Pack*Display | 1 | 0.0000002 | 0.00 | 0.97 |
| Treat*Pack*Display | 4 | 0.0004 | 2.36 | 0.06 |
| Stor*Treat*Pack*Disp | 4 | 0.0001 | 0.53 | 0.72 |
| **Error** | **190** | **0.0002** | | |
| Storage | 1 | 0.008 | 4.51 | 0.06 |
| Error(Storage) | 10 | 0.002 | | |
| Total Error | 239 | | | |

Appendix Table 28. Analysis of Variance for cooked weight

| Source | Df | Mean Square | F-value | Pr > F |
|---|---|---|---|---|
| Dip Treatment | 4 | 5752.85 | 16.20 | <0.0001 |
| Storage*Treat | 4 | 117.08 | 0.33 | 0.86 |
| Pack | 1 | 10.41 | 0.03 | 0.86 |
| Storage*Pack | 1 | 265.78 | 0.75 | 0.38 |
| Treat*Pack | 4 | 307.14 | 0.86 | 0.49 |
| Storage*Treat*Pack | 4 | 283.91 | 0.80 | 0.53 |
| Display | 1 | 5679.60 | 15.99 | <0.0001 |
| Storage*Display | 1 | 716.43 | 2.02 | 0.16 |
| Treat*Display | 4 | 1458.45 | 4.11 | 0.003 |
| Stor*Treat*Display | 4 | 111.87 | 0.32 | 0.87 |
| Pack*Display | 1 | 1752.84 | 4.94 | 0.30 |
| Stor*Pack*Display | 1 | 14.44 | 0.04 | 0.84 |
| Treat*Pack*Display | 4 | 633.03 | 1.78 | 0.13 |
| Stor*Treat*Pack*Disp | 4 | 421.37 | 1.19 | 0.32 |
| **Error** | **190** | **355.10** | | |
| Storage | 1 | 783.80 | 0.07 | 0.80 |
| Error(Storage) | 10 | 11157.65 | | |
| Total Error | 239 | | | |

Appendix Table 29. Analysis of Variance for percent cook loss

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 0.014 | 2.03 | 0.09 |
| Storage*Treat | 4 | 0.009 | 1.29 | 0.28 |
| Pack | 1 | 0.003 | 2.03 | 0.16 |
| Storage*Pack | 1 | 0.002 | 0.96 | 0.33 |
| Treat*Pack | 4 | 0.001 | 0.11 | 0.98 |
| Storage*Treat*Pack | 4 | 0.007 | 1.06 | 0.38 |
| Display | 1 | 0.0003 | 0.16 | 0.69 |
| Storage*Display | 1 | 0.002 | 1.35 | 0.25 |
| Treat*Display | 4 | 0.017 | 2.42 | 0.05 |
| Stor*Treat*Display | 4 | 0.001 | 0.16 | 0.96 |
| Pack*Display | 1 | 0.002 | 0.93 | 0.34 |
| Stor*Pack*Display | 1 | 0.001 | 0.67 | 0.42 |
| Treat*Pack*Display | 4 | 0.003 | 0.44 | 0.78 |
| Stor*Treat*Pack*Disp | 4 | 0.009 | 1.29 | 0.28 |
| **Error** | **190** | 0.002 | | |
| Storage | 1 | 0.016 | 12.57 | 0.005 |
| Error(Storage) | 10 | 0.001 | | |
| Total Error | 239 | | | |

Appendix Table 30. Analysis of Variance for shear force

| **Source** | **Df** | **Mean Square** | **F-value** | **Pr > F** |
|---|---|---|---|---|
| Dip Treatment | 4 | 858923.32 | 3.37 | 0.01 |
| Storage*Treat | 4 | 301438.77 | 1.18 | 0.32 |
| Pack | 1 | 7393200.79 | 28.97 | <0.0001 |
| Storage*Pack | 1 | 4214891.36 | 16.52 | <0.0001 |
| Treat*Pack | 4 | 308833.54 | 1.21 | 0.31 |
| Storage*Treat*Pack | 4 | 612643.11 | 2.40 | 0.05 |
| Display | 1 | 1536120.00 | 6.02 | 0.02 |
| Storage*Display | 1 | 19246.98 | 0.08 | 0.78 |
| Treat*Display | 4 | 295947.24 | 1.16 | 0.33 |
| Stor*Treat*Display | 4 | 71488.18 | 0.28 | 0.89 |
| Pack*Display | 1 | 781784.81 | 3.06 | 0.08 |
| Stor*Pack*Display | 1 | 84797.40 | 0.33 | 0.57 |
| Treat*Pack*Display | 4 | 978058.24 | 3.83 | 0.05 |
| Stor*Treat*Pack*Disp | 4 | 132340.21 | 0.52 | 0.722 |
| **Error** | **190** | **255160.38** | | |
| Storage | 1 | 1588562.14 | 0.88 | 0.37 |
| Error(Storage) | 10 | 1800308.98 | | |
| Total Error | 239 | | | |

## APPENDIX B: STANDARD ERROR TABLES FOR DEPENDENT VARIABLES

Appendix Table 31. Standard Error (SE) for differences between individual cell means within fresh or frozen groups

| Dependent Variable | SE | Dependent Variable | SE |
|---|---|---|---|
| Initial pH | 0.009596718 | Final pH | 0.085530833 |
| Initial LD L* avg. | 0.521613442 | Final LD L* avg. | 2.057366683 |
| Initial LD a* avg. | 0.185197368 | Final LD a* avg. | 0.777590552 |
| Initial LD b* avg. | 0.212255345 | Final LD b* avg. | 0.908625115 |
| Initial LD Chroma | 0.244395376 | Final LD Chroma | 0.984721467 |
| Initial LD Hue Angle | 0.008522773 | Final LD Hue Angle | 0.293370505 |
| Initial V L* avg. | 0.609793845 | Final V L* avg. | 2.094910499 |
| Initial V a* avg. | 0.547482922 | Final V a* avg. | 1.616345673 |
| Initial V b* avg. | 0.339281569 | Final V b* avg. | 0.901978566 |
| Initial V Chroma | 0.585173265 | Final V Chroma | 1.538531551 |
| Initial V Hue Angle | 0.024445668 | Final V Hue Angle | 0.052861391 |
| Initial Weight | 2.791685572 | Dipped Weight | 2.764365982 |
| Percent Pickup | 0.155461678 | | |
| Blotted Weight | 12.53233285 | % Drip Loss | 0.007811957 |
| Cooked Weight | 10.87960171 | % Cook Loss | 0.023831702 |
| Shear Force | 291.6392635 | | |

## APPENDIX C: LS MEAN TABLES FOR TWO FACTOR INTERACTIONS

Appendix Table 32. Storage*dipping treatment LS Means.

| Storage | Dip | Initial pH | Final pH | Initial weight, g | Dipped weight, g |
|---|---|---|---|---|---|
| Fresh | Control | 5.70 | 5.64 | 250.83 | 0.00 |
| Fresh | $CaCl_2$ | 5.65 | 5.60 | 240.19 | 245.01 |
| Fresh | NaAsc | 5.69 | 5.68 | 234.49 | 238.72 |
| Fresh | 0.2 CaAsc | 5.63 | 5.65 | 233.12 | 236.94 |
| Fresh | 0.3 CaAsc | 5.69 | 5.78 | 259.99 | 267.41 |
| Frozen | Control | 5.70 | 6.39 | 249.28 | 0.00 |
| Frozen | $CaCl_2$ | 5.63 | 6.43 | 251.61 | 256.59 |
| Frozen | NaAsc | 5.66 | 6.53 | 233.61 | 238.23 |
| Frozen | 0.2 CaAsc | 5.63 | 6.46 | 237.41 | 240.88 |
| Frozen | 0.3 CaAsc | 5.67 | 6.44 | 265.91 | 271.51 |
| Standard Error | | 0.15 | 0.03 | 4.41 | 2.35 |

Appendix Table 33. Initial LD color measurement LS Means for storage*dipping treatment.

| Storage | Dip | I LD L* | I LD a* | I LD b* | I LD chroma | I LD hue |
|---|---|---|---|---|---|---|
| Fresh | Control | 60.33 | 4.96 | 16.28 | 17.09 | 1.28 |
| Fresh | $CaCl_2$ | 61.98 | 4.02 | 15.55 | 16.08 | 1.32 |
| Fresh | NaAsc | 61.26 | 5.04 | 15.75 | 16.58 | 1.27 |
| Fresh | 0.2 CaAsc | 59.96 | 4.93 | 15.01 | 15.84 | 1.26 |
| Fresh | 0.3 CaAsc | 57.74 | 5.10 | 14.65 | 15.55 | 1.24 |
| Frozen | Control | 59.68 | 3.69 | 14.83 | 15.33 | 1.33 |
| Frozen | $CaCl_2$ | 60.73 | 4.79 | 16.64 | 17.35 | 1.30 |
| Frozen | NaAsc | 62.09 | 4.67 | 15.90 | 16.62 | 1.29 |
| Frozen | 0.2 CaAsc | 60.10 | 4.77 | 14.92 | 15.72 | 1.27 |
| Frozen | 0.3 CaAsc | 56.30 | 4.94 | 14.37 | 15.24 | 1.25 |
| Standard Error | | 0.82 | 0.29 | 0.34 | 0.39 | 0.01 |

Appendix Table 34. Initial vertebrae color measurement LS Means for storage*dipping treatment.

| Storage | Dip | I V L* | I V a* | I V b* | I V chroma | I V hue |
|---|---|---|---|---|---|---|
| Fresh | Control | 53.42 | 13.69 | 15.18 | 20.54 | 0.85 |
| Fresh | $CaCl_2$ | 53.91 | 12.67 | 15.19 | 19.82 | 0.88 |
| Fresh | NaAsc | 53.95 | 13.63 | 15.62 | 20.80 | 0.86 |
| Fresh | 0.2 CaAsc | 53.01 | 13.22 | 14.53 | 19.82 | 0.87 |
| Fresh | 0.3 CaAsc | 50.25 | 15.96 | 15.86 | 22.62 | 0.80 |
| Frozen | Control | 54.77 | 12.86 | 15.20 | 20.00 | 0.88 |
| Frozen | $CaCl_2$ | 54.50 | 12.87 | 15.20 | 20.18 | 0.78 |
| Frozen | NaAsc | 54.23 | 12.71 | 15.45 | 20.13 | 0.89 |
| Frozen | 0.2 CaAsc | 50.60 | 15.48 | 15.51 | 22.03 | 0.78 |
| Frozen | 0.3 CaAsc | 52.19 | 14.34 | 15.63 | 21.36 | 0.86 |
| Standard Error | | 0.96 | 0.87 | 0.54 | 0.93 | 0.04 |

Appendix Table 35. Final LD color measurement LS Means for storage*dipping treatment.

| Storage | Dip | F LD L* | F LD a* | F LD b* | F LD chroma | F LD hue |
|---|---|---|---|---|---|---|
| Fresh | Control | 65.35 | 2.92 | 14.84 | 15.15 | 1.38 |
| Fresh | $CaCl_2$ | 66.08 | 1.92 | 13.95 | 14.13 | 1.18 |
| Fresh | NaAsc | 66.21 | 1.43 | 13.35 | 13.46 | 1.07 |
| Fresh | 0.2 CaAsc | 64.43 | 1.48 | 13.35 | 13.45 | 1.46 |
| Fresh | 0.3 CaAsc | 64.61 | 2.18 | 14.32 | 14.67 | 1.16 |
| Frozen | Control | 60.56 | 2.80 | 14.60 | 14.91 | 1.39 |
| Frozen | $CaCl_2$ | 61.11 | 3.20 | 15.59 | 15.99 | 1.38 |
| Frozen | NaAsc | 59.93 | 2.56 | 14.19 | 14.46 | 1.39 |
| Frozen | 0.2 CaAsc | 58.54 | 3.04 | 14.49 | 14.84 | 1.37 |
| Frozen | 0.3 CaAsc | 58.84 | 2.98 | 15.02 | 15.40 | 1.26 |
| Standard Error | | 0.72 | 0.27 | 0.32 | 0.35 | 0.10 |

Appendix Table 36. Final vertebrae color measurement LS Means for storage*dipping treatment.

| Storage | Dip | F V L* | F V a* | F V b* | F V chroma | F V hue |
|---|---|---|---|---|---|---|
| Fresh | Control | 56.16 | 11.77 | 14.37 | 18.69 | 0.90 |
| Fresh | $CaCl_2$ | 58.93 | 10.33 | 14.25 | 17.69 | 0.96 |
| Fresh | NaAsc | 59.72 | 9.72 | 13.65 | 16.91 | 0.97 |
| Fresh | 0.2 CaAsc | 57.80 | 11.79 | 14.58 | 18.93 | 0.93 |
| Fresh | 0.3 CaAsc | 57.98 | 10.88 | 14.65 | 18.44 | 0.96 |
| Frozen | Control | 51.62 | 10.09 | 15.84 | 18.91 | 1.01 |
| Frozen | $CaCl_2$ | 51.81 | 10.24 | 15.96 | 19.18 | 1.01 |
| Frozen | NaAsc | 52.74 | 14.81 | 17.62 | 23.12 | 0.88 |
| Frozen | 0.2 CaAsc | 51.73 | 16.97 | 18.88 | 25.51 | 0.86 |
| Frozen | 0.3 CaAsc | 52.27 | 15.77 | 18.48 | 24.40 | 0.88 |
| Standard Error | | 0.74 | 0.57 | 0.32 | 0.54 | 0.01 |

Appendix Table 37. Storage*dipping treatment LS Means.

| Storage | Dip | Drip loss, % | Cook loss, % | Shear Force, g |
|---|---|---|---|---|
| Fresh | Control | 3.11 | 21.25 | 2902.51 |
| Fresh | $CaCl_2$ | 3.92 | 20.54 | 2730.84 |
| Fresh | NaAsc | 4.92 | 20.23 | 3065.65 |
| Fresh | 0.2 CaAsc | 3.91 | 19.54 | 2988.36 |
| Fresh | 0.3 CaAsc | 3.72 | 19.24 | 3090.92 |
| Frozen | Control | 4.50 | 21.70 | 3244.25 |
| Frozen | $CaCl_2$ | 5.62 | 23.02 | 2961.42 |
| Frozen | NaAsc | 5.96 | 20.94 | 3306.39 |
| Frozen | 0.2 CaAsc | 4.46 | 23.11 | 2938.85 |
| Frozen | 0.3 CaAsc | 5.00 | 20.09 | 3140.95 |
| Standard Error | | 0.30 | 0.80 | 103.11 |

Appendix Table 38. Storage*package LS Means.

| Storage | Package | Initial pH | Final pH | Initial weight, g | Dipped weight, g |
|---|---|---|---|---|---|
| Fresh | HiOx | 5.68 | 5.69 | 194.93 | 241.26 |
| Fresh | NoOx | 5.66 | 5.65 | 200.30 | 246.19 |
| Frozen | HiOx | 5.66 | 6.50 | 202.03 | 248.77 |
| Frozen | NoOx | 5.65 | 6.41 | 200.85 | 246.36 |
| Standard Error | | 0.15 | 0.03 | 4.41 | 2.35 |

Appendix Table 39. Initial LD color measurement LS Means for storage*package.

| Storage | Package | I LD L* | I LD a* | I LD b* | I LD chroma | I LD hue |
|---|---|---|---|---|---|---|
| Fresh | HiOx | 60.17 | 4.86 | 15.49 | 16.29 | 1.27 |
| Fresh | NoOx | 60.34 | 4.76 | 15.40 | 16.17 | 1.28 |
| Frozen | HiOx | 59.32 | 4.55 | 15.18 | 15.90 | 1.29 |
| Frozen | NoOx | 60.24 | 4.59 | 15.49 | 16.20 | 1.29 |
| Standard Error | | 0.82 | 0.29 | 0.34 | 0.39 | 0.01 |

Appendix Table 40. Initial vertebrae color measurement LS Means for storage*package.

| Storage | Package | I V L* | I V a* | I V b* | I V chroma | I V hue |
|---|---|---|---|---|---|---|
| Fresh | HiOx | 53.16 | 13.91 | 15.18 | 20.71 | 0.85 |
| Fresh | NoOx | 52.66 | 13.76 | 15.37 | 20.74 | 0.86 |
| Frozen | HiOx | 54.28 | 13.09 | 15.25 | 20.30 | 0.83 |
| Frozen | NoOx | 52.23 | 14.21 | 15.54 | 21.18 | 0.85 |
| Standard Error | | 0.96 | 0.87 | 0.54 | 0.93 | 0.04 |

Appendix Table 41. Final LD color measurement LS Means for storage*package.

| Storage | Package | F LD L* | F LD a* | F LD b* | F LD chroma | F LD hue |
|---|---|---|---|---|---|---|
| Fresh | HiOx | 65.82 | 2.33 | 14.35 | 14.57 | 1.31 |
| Fresh | NoOx | 64.85 | 1.64 | 13.57 | 13.78 | 1.20 |
| Frozen | HiOx | 57.79 | 3.15 | 14.65 | 15.03 | 1.37 |
| Frozen | NoOx | 61.80 | 2.68 | 14.90 | 15.20 | 1.35 |
| Standard Error | | 0.72 | 0.27 | 0.32 | 0.35 | 0.10 |

Appendix Table 42. Final vertebrae color measurement LS Means for storage*package.

| Storage | Package | F V L* | F V a* | F V b* | F V chroma | F V hue |
|---|---|---|---|---|---|---|
| Fresh | HiOx | 59.11 | 14.12 | 16.24 | 21.61 | 0.86 |
| Fresh | NoOx | 57.13 | 7.68 | 12.37 | 14.65 | 1.03 |
| Frozen | HiOx | 52.08 | 14.00 | 18.28 | 23.32 | 0.95 |
| Frozen | NoOx | 51.99 | 13.16 | 16.43 | 21.13 | 0.90 |
| Standard Error | | 0.74 | 0.57 | 0.32 | 0.54 | 0.02 |

Appendix Table 43. Storage*package LS Means.

| Storage | Package | Drip loss, % | Cook loss, % | Shear Force, g |
|---|---|---|---|---|
| Fresh | HiOx | 3.87 | 19.52 | 3263.69 |
| Fresh | NoOx | 3.96 | 20.80 | 2647.62 |
| Frozen | HiOx | 4.83 | 21.65 | 3161.36 |
| Frozen | NoOx | 5.38 | 21.89 | 3075.38 |
| Standard Error | | 0.20 | 0.80 | 103.11 |

Appendix Table 44. Storage*display LS Means.

| Storage | Display | Initial pH | Final pH | Initial weight, g | Dipped weight, g |
|---|---|---|---|---|---|
| Fresh | 3d | 5.68 | 5.69 | 192.23 | 234.05 |
| Fresh | 6d | 5.66 | 5.65 | 203.00 | 253.40 |
| Frozen | 3d | 5.65 | 6.44 | 201.33 | 243.33 |
| Frozen | 6d | 5.66 | 6.46 | 201.55 | 251.79 |
| Standard Error | | 0.15 | 0.03 | 4.41 | 2.35 |

Appendix Table 45. Initial LD color measurement LS Means for storage*display.

| Storage | Display | I LD L* | I LD a* | I LD b* | I LD chroma | I LD hue |
|---|---|---|---|---|---|---|
| Fresh | 3d | 60.31 | 4.56 | 15.26 | 15.97 | 1.28 |
| Fresh | 6d | 60.20 | 5.06 | 15.63 | 16.48 | 1.26 |
| Frozen | 3d | 59.42 | 4.67 | 15.41 | 16.15 | 1.28 |
| Frozen | 6d | 60.14 | 4.47 | 15.26 | 15.95 | 1.29 |
| Standard Error | | 0.82 | 0.29 | 0.34 | 0.39 | 0.01 |

Appendix Table 46. Initial vertebrae color measurement LS Means for storage*display.

| Storage | Display | I V L* | I V a* | I V b* | I V chroma | I V hue |
|---|---|---|---|---|---|---|
| Fresh | 3d | 54.03 | 12.79 | 14.78 | 19.63 | 0.88 |
| Fresh | 6d | 51.79 | 14.88 | 15.78 | 21.81 | 0.83 |
| Frozen | 3d | 53.23 | 13.82 | 15.61 | 20.97 | 0.86 |
| Frozen | 6d | 53.29 | 13.48 | 15.19 | 20.52 | 0.82 |
| Standard Error | | 0.96 | 0.87 | 0.54 | 0.93 | 0.04 |

Appendix Table 47. Final LD color measurement LS Means for storage*display.

| Storage | Display | F LD L* | F LD a* | F LD b* | F LD chroma | F LD hue |
|---|---|---|---|---|---|---|
| Fresh | 3d | 66.18 | 1.81 | 14.06 | 14.22 | 1.29 |
| Fresh | 6d | 64.49 | 2.16 | 13.86 | 14.13 | 1.21 |
| Frozen | 3d | 59.25 | 3.17 | 15.02 | 15.41 | 1.37 |
| Frozen | 6d | 60.33 | 2.66 | 14.54 | 14.83 | 1.34 |
| Standard Error | | 0.73 | 0.27 | 0.32 | 0.35 | 0.10 |

Appendix Table 48. Final vertebrae color measurement LS Means for storage*display.

| Storage | Display | F V L* | F V a* | F V b* | F V chroma | F V hue |
|---|---|---|---|---|---|---|
| Fresh | 3d | 58.65 | 10.49 | 14.03 | 17.65 | 0.95 |
| Fresh | 6d | 57.59 | 11.31 | 14.57 | 18.62 | 0.94 |
| Frozen | 3d | 51.84 | 14.26 | 17.78 | 22.98 | 0.92 |
| Frozen | 6d | 52.22 | 12.90 | 16.93 | 21.46 | 0.94 |
| Standard Error | | 0.74 | 0.57 | 0.32 | 0.54 | 0.02 |

Appendix Table 49. Storage*display LS Means.

| Storage | Display | Drip loss, % | Cook loss, % | Shear Force, g |
|---|---|---|---|---|
| Fresh | 3d | 4.14 | 19.75 | 2884.61 |
| Fresh | 6d | 3.69 | 20.58 | 3026.70 |
| Frozen | 3d | 4.66 | 21.97 | 3029.41 |
| Frozen | 6d | 5.55 | 21.57 | 3207.32 |
| Standard Error | | 0.30 | 0.80 | 103.11 |

Appendix Table 50. Package*dipping treatment LS Means.

| Package | Dip | Initial pH | Final pH | Initial weight, g | Dipped weight, g |
|---|---|---|---|---|---|
| HiOx | Control | 5.71 | 6.09 | 253.49 | 0.00 |
| HiOx | $CaCl_2$ | 5.65 | 6.02 | 248.85 | 253.82 |
| HiOx | NaAsc | 5.68 | 6.13 | 232.07 | 236.05 |
| HiOx | 0.2 CaAsc | 5.64 | 6.09 | 232.76 | 237.45 |
| HiOx | 0.3 CaAsc | 5.68 | 6.14 | 257.90 | 265.08 |
| NoOx | Control | 5.70 | 5.94 | 246.63 | 0.00 |
| NoOx | $CaCl_2$ | 5.63 | 6.01 | 242.95 | 247.78 |
| NoOx | NaAsc | 5.67 | 6.08 | 236.03 | 240.89 |
| NoOx | 0.2 CaAsc | 5.63 | 6.03 | 237.77 | 240.37 |
| NoOx | 0.3 CaAsc | 5.67 | 6.09 | 267.99 | 273.85 |
| Standard Error | | 0.15 | 0.03 | 4.41 | 2.35 |

Appendix Table 51. Initial LD color measurement LS Means for package*dipping treatment.

| Package | Dip | I LD L* | I LD a* | I LD b* | I LD chroma | I LD hue |
|---|---|---|---|---|---|---|
| HiOx | Control | 59.46 | 4.23 | 15.31 | 15.96 | 1.30 |
| HiOx | $CaCl_2$ | 60.55 | 4.54 | 15.98 | 16.64 | 1.30 |
| HiOx | NaAsc | 62.13 | 4.96 | 16.15 | 16.98 | 1.28 |
| HiOx | 0.2 CaAsc | 58.96 | 4.67 | 14.27 | 15.07 | 1.26 |
| HiOx | 0.3 CaAsc | 57.62 | 5.07 | 14.95 | 15.83 | 1.25 |
| NoOx | Control | 60.56 | 4.36 | 15.80 | 16.46 | 1.31 |
| NoOx | $CaCl_2$ | 62.16 | 4.27 | 16.21 | 16.79 | 1.32 |
| NoOx | NaAsc | 61.22 | 4.75 | 15.50 | 16.22 | 1.27 |
| NoOx | 0.2 CaAsc | 61.10 | 5.04 | 15.67 | 16.49 | 1.26 |
| NoOx | 0.3 CaAsc | 56.41 | 4.97 | 14.06 | 14.97 | 1.24 |
| Standard Error | | 0.82 | 0.29 | 0.34 | 0.39 | 0.01 |

Appendix Table 52. Initial vertebrae color measurement LS Means for package*dipping treatment.

| Package | Dip | I V L* | I V a* | I V b* | I V chroma | I V hue |
|---|---|---|---|---|---|---|
| HiOx | Control | 55.07 | 13.06 | 15.10 | 20.11 | 0.88 |
| HiOx | $CaCl_2$ | 54.75 | 12.38 | 14.95 | 19.60 | 0.78 |
| HiOx | NaAsc | 55.79 | 11.97 | 15.40 | 19.61 | 0.92 |
| HiOx | 0.2 CaAsc | 50.72 | 15.28 | 15.16 | 21.60 | 0.78 |
| HiOx | 0.3 CaAsc | 52.26 | 14.82 | 15.48 | 21.61 | 0.84 |
| NoOx | Control | 53.12 | 13.48 | 15.29 | 20.44 | 0.86 |
| NoOx | $CaCl_2$ | 53.66 | 13.17 | 15.44 | 20.40 | 0.88 |
| NoOx | NaAsc | 52.39 | 14.38 | 15.67 | 21.32 | 0.83 |
| NoOx | 0.2 CaAsc | 52.89 | 13.42 | 14.89 | 20.26 | 0.87 |
| NoOx | 0.3 CaAsc | 50.17 | 15.49 | 16.01 | 22.37 | 0.82 |
| Standard Error | | 0.96 | 0.87 | 0.54 | 0.93 | 0.04 |

Appendix Table 53. Final LD color measurement LS Means for package*dipping treatment.

| Package | Dip | F LD L* | F LD a* | F LD b* | F LD chroma | F LD hue |
|---|---|---|---|---|---|---|
| HiOx | Control | 62.30 | 3.23 | 14.61 | 14.98 | 1.36 |
| HiOx | $CaCl_2$ | 63.44 | 2.94 | 14.78 | 15.10 | 1.38 |
| HiOx | NaAsc | 61.95 | 2.46 | 13.79 | 14.03 | 1.39 |
| HiOx | 0.2 CaAsc | 59.98 | 2.64 | 14.05 | 14.34 | 1.39 |
| HiOx | 0.3 CaAsc | 61.35 | 2.44 | 15.28 | 15.56 | 1.16 |
| NoOx | Control | 63.61 | 2.48 | 14.83 | 15.09 | 1.41 |
| NoOx | $CaCl_2$ | 63.75 | 2.19 | 14.76 | 15.01 | 1.17 |
| NoOx | NaAsc | 64.19 | 1.53 | 13.74 | 13.89 | 1.07 |
| NoOx | 0.2 CaAsc | 62.99 | 1.88 | 13.79 | 13.95 | 1.44 |
| NoOx | 0.3 CaAsc | 61.35 | 2.72 | 14.07 | 14.51 | 1.26 |
| Standard Error | | 0.73 | 0.27 | 0.32 | 0.35 | 0.10 |

Appendix Table 54. Final vertebrae color measurement LS Means for package*dipping treatment.

| Package | Dip | F V L* | F V a* | F V b* | F V chroma | F V hue |
|---|---|---|---|---|---|---|
| HiOx | Control | 54.26 | 11.13 | 15.77 | 19.55 | 0.98 |
| HiOx | $CaCl_2$ | 56.17 | 10.49 | 16.19 | 19.51 | 1.01 |
| HiOx | NaAsc | 57.58 | 14.18 | 16.95 | 22.22 | 0.89 |
| HiOx | 0.2 CaAsc | 54.80 | 17.59 | 18.46 | 25.59 | 0.82 |
| HiOx | 0.3 CaAsc | 55.16 | 16.91 | 14.99 | 25.45 | 0.85 |
| NoOx | Control | 53.52 | 10.74 | 14.45 | 18.05 | 0.94 |
| NoOx | $CaCl_2$ | 54.57 | 10.09 | 14.03 | 17.36 | 0.96 |
| NoOx | NaAsc | 54.88 | 10.35 | 14.31 | 17.80 | 0.97 |
| NoOx | 0.2 CaAsc | 54.72 | 11.18 | 14.99 | 18.84 | 0.96 |
| NoOx | 0.3 CaAsc | 55.09 | 9.73 | 14.21 | 17.40 | 0.99 |
| Standard Error | | 0.74 | 0.57 | 0.32 | 0.54 | 0.02 |

Appendix Table 55. Package*dipping treatment LS Means.

| Package | Dip | Drip loss, % | Cook loss, % | Shear Force, g |
|---|---|---|---|---|
| HiOx | Control | 3.42 | 20.95 | 3161.10 |
| HiOx | $CaCl_2$ | 4.88 | 21.25 | 2973.57 |
| HiOx | NaAsc | 4.77 | 20.54 | 3332.68 |
| HiOx | 0.2 CaAsc | 4.46 | 20.91 | 3247.18 |
| HiOx | 0.3 CaAsc | 4.23 | 19.29 | 3348.10 |
| NoOx | Control | 4.19 | 22.00 | 2985.66 |
| NoOx | $CaCl_2$ | 4.66 | 22.31 | 2718.69 |
| NoOx | NaAsc | 6.11 | 20.63 | 3039.35 |
| NoOx | 0.2 CaAsc | 3.91 | 21.74 | 2680.04 |
| NoOx | 0.3 CaAsc | 4.49 | 20.05 | 2883.76 |
| Standard Error | | 0.30 | 0.80 | 103.11 |

Appendix Table 56. Display*dipping treatment LS Means.

| Display | Dip | Initial pH | Final pH | Initial weight, g | Dipped weight, g |
|---|---|---|---|---|---|
| 3d | Control | 5.71 | 6.02 | 228.87 | 0.00 |
| 3d | $CaCl_2$ | 5.65 | 6.02 | 247.51 | 252.17 |
| 3d | NaAsc | 5.67 | 6.10 | 232.34 | 236.96 |
| 3d | 0.2 CaAsc | 5.62 | 6.06 | 230.30 | 234.99 |
| 3d | 0.3 CaAsc | 5.69 | 6.12 | 254.42 | 259.77 |
| 6d | Control | 5.69 | 6.01 | 271.25 | 0.00 |
| 6d | $CaCl_2$ | 5.64 | 6.01 | 244.29 | 249.42 |
| 6d | NaAsc | 5.68 | 6.11 | 235.76 | 239.98 |
| 6d | 0.2 CaAsc | 5.64 | 6.05 | 240.23 | 242.82 |
| 6d | 0.3 CaAsc | 5.67 | 6.11 | 271.47 | 279.15 |
| Standard Error | | 0.15 | 0.03 | 4.41 | 2.35 |

Appendix Table 57. Initial LD color measurement LS Means for display*dipping treatment.

| Display | Dip | I LD L* | I LD a* | I LD b* | I LD chroma | I LD hue |
|---|---|---|---|---|---|---|
| 3d | Control | 60.91 | 3.98 | 15.26 | 15.83 | 1.32 |
| 3d | $CaCl_2$ | 61.80 | 4.78 | 16.85 | 17.54 | 1.30 |
| 3d | NaAsc | 61.45 | 4.95 | 15.78 | 16.59 | 1.27 |
| 3d | 0.2 CaAsc | 59.90 | 4.71 | 14.49 | 15.27 | 1.26 |
| 3d | 0.3 CaAsc | 57.00 | 4.66 | 14.31 | 15.09 | 1.26 |
| 6d | Control | 60.84 | 4.66 | 15.85 | 16.60 | 1.30 |
| 6d | $CaCl_2$ | 60.91 | 4.03 | 15.34 | 15.89 | 1.32 |
| 6d | NaAsc | 61.90 | 4.76 | 15.87 | 16.60 | 1.28 |
| 6d | 0.2 CaAsc | 59.90 | 5.00 | 15.45 | 16.29 | 1.26 |
| 6d | 0.3 CaAsc | 57.04 | 5.38 | 14.71 | 15.71 | 1.23 |
| Standard Error | | 0.82 | 0.29 | 0.34 | 0.39 | 0.01 |

Appendix Table 58. Initial vertebrae color measurement LS Means for display*dipping treatment.

| Display | Dip | I V L* | I V a* | I V b* | I V chroma | I V hue |
|---|---|---|---|---|---|---|
| 3d | Control | 55.98 | 11.84 | 14.48 | 18.83 | 0.90 |
| 3d | $CaCl_2$ | 54.45 | 13.64 | 16.12 | 21.19 | 0.88 |
| 3d | NaAsc | 54.93 | 12.90 | 15.63 | 20.40 | 0.89 |
| 3d | 0.2 CaAsc | 50.80 | 14.29 | 14.58 | 20.50 | 0.83 |
| 3d | 0.3 CaAsc | 51.97 | 13.85 | 15.14 | 20.59 | 0.85 |
| 6d | Control | 52.21 | 14.71 | 15.90 | 21.72 | 0.83 |
| 6d | $CaCl_2$ | 53.96 | 11.90 | 14.27 | 18.80 | 0.78 |
| 6d | NaAsc | 53.25 | 13.45 | 15.44 | 20.54 | 0.86 |
| 6d | 0.2 CaAsc | 52.81 | 14.41 | 15.47 | 21.36 | 0.83 |
| 6d | 0.3 CaAsc | 50.46 | 16.45 | 16.35 | 23.40 | 0.82 |
| Standard Error | | 0.96 | 0.87 | 0.54 | 0.93 | 0.04 |

Appendix Table 59. Final LD color measurement LS Means for display*dipping treatment.

| Display | Dip | F LD L* | F LD a* | F LD b* | F LD chroma | F LD hue |
|---|---|---|---|---|---|---|
| 3d | Control | 62.43 | 2.74 | 14.36 | 14.65 | 1.39 |
| 3d | $CaCl_2$ | 63.63 | 2.85 | 15.19 | 15.51 | 1.39 |
| 3d | NaAsc | 63.57 | 2.15 | 14.04 | 14.25 | 1.29 |
| 3d | 0.2 CaAsc | 61.80 | 2.32 | 14.18 | 14.44 | 1.42 |
| 3d | 0.3 CaAsc | 62.15 | 2.38 | 14.93 | 15.21 | 1.16 |
| 6d | Control | 63.48 | 2.74 | 15.09 | 15.42 | 1.38 |
| 6d | $CaCl_2$ | 63.55 | 2.27 | 14.36 | 14.61 | 1.16 |
| 6d | NaAsc | 62.56 | 1.84 | 13.50 | 13.67 | 1.18 |
| 6d | 0.2 CaAsc | 61.18 | 2.20 | 13.66 | 13.85 | 1.41 |
| 6d | 0.3 CaAsc | 61.29 | 2.77 | 14.41 | 14.86 | 1.26 |
| Standard Error | | 0.73 | 0.27 | 0.32 | 0.35 | 0.10 |

Appendix Table 60. Final vertebrae color measurement LS Means for display*dipping treatment.

| Display | Dip | F V L* | F V a* | F V b* | F V chroma | F V hue |
|---|---|---|---|---|---|---|
| 3d | Control | 54.92 | 10.69 | 14.92 | 18.55 | 0.93 |
| 3d | $CaCl_2$ | 56.14 | 10.45 | 15.47 | 18.80 | 0.99 |
| 3d | NaAsc | 55.25 | 12.79 | 15.54 | 20.26 | 0.90 |
| 3d | 0.2 CaAsc | 54.10 | 14.87 | 16.99 | 22.74 | 0.89 |
| 3d | 0.3 CaAsc | 55.84 | 13.08 | 16.60 | 21.23 | 0.93 |
| 6d | Control | 52.86 | 11.17 | 15.30 | 19.05 | 0.95 |
| 6d | $CaCl_2$ | 54.61 | 10.13 | 14.74 | 18.07 | 0.99 |
| 6d | NaAsc | 57.21 | 11.74 | 15.72 | 19.76 | 0.95 |
| 6d | 0.2 CaAsc | 55.43 | 13.90 | 16.46 | 21.69 | 0.89 |
| 6d | 0.3 CaAsc | 54.42 | 13.57 | 16.53 | 21.62 | 0.91 |
| Standard Error | | 0.74 | 0.57 | 0.32 | 0.54 | 0.02 |

Appendix Table 61. Display*dipping treatment LS Means.

| Display | Dip | Drip loss, % | Cook loss, % | Shear Force, g |
|---|---|---|---|---|
| 3d | Control | 3.99 | 20.45 | 3035.89 |
| 3d | $CaCl_2$ | 3.98 | 22.80 | 2634.88 |
| 3d | NaAsc | 5.42 | 21.33 | 3094.02 |
| 3d | 0.2 CaAsc | 4.37 | 20.60 | 2948.30 |
| 3d | 0.3 CaAsc | 4.25 | 19.12 | 3071.97 |
| 6d | Control | 3.62 | 22.51 | 3110.88 |
| 6d | $CaCl_2$ | 5.56 | 20.76 | 3057.39 |
| 6d | NaAsc | 5.46 | 19.83 | 3278.01 |
| 6d | 0.2 CaAsc | 4.00 | 22.05 | 2978.92 |
| 6d | 0.3 CaAsc | 4.48 | 20.22 | 3159.90 |
| Standard Error | | 0.30 | 0.80 | 103.11 |

Appendix Table 62. Package*display LS Means.

| Package | Display | Initial pH | Final pH | Initial weight, g | Dipped weight, g |
|---|---|---|---|---|---|
| HiOx | 3d | 5.68 | 6.11 | 197.90 | 240.54 |
| NoOx | 3d | 5.66 | 6.02 | 195.66 | 236.83 |
| HiOx | 6d | 5.67 | 6.07 | 199.06 | 249.48 |
| NoOx | 6d | 5.66 | 6.04 | 205.49 | 255.71 |
| Standard Error | | 0.15 | 0.03 | 4.41 | 2.35 |

Appendix Table 63. Initial LD color measurement LS Means for package*display.

| Package | Display | I LD L* | I LD a* | I LD b* | I LD chroma | I LD hue |
|---|---|---|---|---|---|---|
| HiOx | 3d | 59.66 | 4.74 | 15.48 | 16.25 | 1.28 |
| NoOx | 3d | 60.07 | 4.49 | 15.20 | 15.88 | 1.29 |
| HiOx | 6d | 59.83 | 4.67 | 15.19 | 15.95 | 1.28 |
| NoOx | 6d | 60.51 | 4.87 | 15.70 | 16.49 | 1.28 |
| Standard Error | | 0.82 | 0.29 | 0.34 | 0.39 | 0.01 |

Appendix Table 64. Initial vertebrae color measurement LS Means for package*display.

| Package | Display | I V L* | I V a* | I V b* | I V chroma | I V hue |
|---|---|---|---|---|---|---|
| HiOx | 3d | 54.81 | 12.72 | 14.98 | 19.77 | 0.88 |
| NoOx | 3d | 52.44 | 13.89 | 15.40 | 20.83 | 0.85 |
| HiOx | 6d | 52.63 | 14.28 | 15.46 | 21.24 | 0.80 |
| NoOx | 6d | 52.44 | 14.08 | 15.51 | 21.09 | 0.85 |
| Standard Error | | 0.96 | 0.87 | 0.54 | 0.93 | 0.04 |

Appendix Table 65. Final LD color measurement LS Means for package*display.

| Package | Display | F LD L* | F LD a* | F LD b* | F LD chroma | F LD hue |
|---|---|---|---|---|---|---|
| HiOx | 3d | 61.88 | 2.95 | 14.79 | 15.14 | 1.27 |
| NoOx | 3d | 63.55 | 2.03 | 14.29 | 14.49 | 1.39 |
| HiOx | 6d | 61.73 | 2.53 | 14.22 | 14.47 | 1.40 |
| NoOx | 6d | 63.10 | 2.29 | 14.19 | 14.49 | 1.16 |
| Standard Error | | 0.73 | 0.27 | 0.32 | 0.35 | 0.10 |

Appendix Table 66. Final vertebrae color measurement LS Means for package*display.

| Package | Display | F V L* | F V a* | F V b* | F V chroma | F V hue |
|---|---|---|---|---|---|---|
| HiOx | 3d | 55.75 | 14.34 | 17.27 | 22.66 | 0.90 |
| NoOx | 3d | 54.74 | 10.41 | 14.54 | 17.98 | 0.97 |
| HiOx | 6d | 55.44 | 13.78 | 17.24 | 22.27 | 0.92 |
| NoOx | 6d | 54.37 | 10.43 | 14.26 | 17.81 | 0.96 |
| Standard Error | | 0.74 | 0.57 | 0.32 | 0.54 | 0.02 |

Appendix Table 67. Package*display LS Means.

| Package | Display | Drip loss, % | Cook loss, % | Shear Force, g |
|---|---|---|---|---|
| HiOx | 3d | 4.09 | 20.22 | 3075.45 |
| NoOx | 3d | 4.72 | 21.50 | 2838.57 |
| HiOx | 6d | 4.62 | 20.95 | 3349.60 |
| NoOx | 6d | 4.63 | 21.20 | 2884.43 |
| Standard Error | | 0.003 | 0.008 | 103.11 |

## VITA

Dennis Michael Price was born on February 14, 1980, in Thibodaux, Louisiana. Dennis is the elder of two sons raised by JoAnne and Majesta Price. He graduated from Thibodaux High School in May of 1998 and began an undergraduate program at Nicholls State University. He then transferred to Louisiana State University in the spring of 2000 and became interested in the field of meat science. Dennis conducted two undergraduate research projects, where he worked on understanding and improving pork quality. After graduating with a bachelor of science degree in animal science (Louisiana State University) in 2002, he was employed by Manda Fine Meats, Inc., as a supervisor and quality assurance technician. Dennis began his research and coursework in the Department of Animal Sciences at Louisiana State University in January 2003. He will graduate with a master of science degree in animal and dairy sciences in May 2006.