EFFECT OF SUPPLEMENTAL DIETARY VITAMIN E ON THE COLOR AND CASE-LIFE OF GROUND BEEF PATTIES AND TOP LOIN STEAKS IN VARIOUS CASE READY RETAIL PACKAGING SYSTEMS

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This thesis is dedicated to the loving memory of my father Ace Stubbs who always dreamed of something better for his family. His spirit gives me strength in everything I do. Thank you Dad. Your dreams will come true.

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FORMAT OF THESIS

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

CHAPTER I

INTRODUCTION

Over the past several years, the face of the retail meat counter has changed significantly. Changes such as the progression from carcass beef to boxed beef, the addition of packer trimmed meat products and home meal replacements, and a step toward labor reduction and enhanced food safety by utilizing "case-ready" fresh poultry, fish, and pork items have redefined today's retail meat case. To maintain and improve its market share, the beef industry must find better ways to compete as well as merchandise its product(s) (Hollingsworth, 1996). Since 1966, the beef industry has been loosing market share to other competing protein sources (USDA, 1997). If the current trend continues, the beef industry will have only 26% on the entire U.S. consumption industry market by the year 2005 (Purcell, 1997).

Currently all poultry and most pork products arrive at retail stores as "case-ready" and require minimal handling and processing prior to retail display. These value-added sections can easily be kept fully stocked and very presentable with limited labor as well as minimal oversight by the meat merchandisers. These advantages help make poultry and pork more attractive and convenient to consumers. Fabrication and packaging of beef, on the other

hand, requires the majority of the time and labor in today's retail meat department.

It appears that the main limiting factor in the production of "case-ready" beef is lean color (Schut, 1998). Due to elevated myoglobin content, relative to other muscle foods, beef color stability is much more a concern to the retailer. Consumers associate bright cherry red lean color with meat freshness (Kropf, 1980). The natural bright, cherry red lean color is due to the oxygenation of myoglobin in the muscle fibers to oxymyoglobin. Once the product has bloomed, (i.e., turned bright cherry red), meat begins to oxidize to metmyoglobin and once 70% of the product reaches this stage it becomes a brown color and is discounted or discarded (Daun et al., 1971). Oxygenation of meat occurs approximately 30 minutes after the cut surface is exposed to oxygen and normally lasts in a normal retail situation approximately 3 d (Smith et al., 1996). In order for beef to utilize a case-ready program, overcoming the lean color dilemma and prevention of oxidation of myoglobin to metmyoglobin must be achieved (Effertz, 1997). The use of vitamin E as an antioxidant has been shown by several studies to limit lipid and muscle pigment oxidation resulting in longer case-life in meats.

Addition of vitamin E to the diet of finishing steers improves the case-life of "normal" beef products as shown in the Domestic Shelf Life Alliance Study (Westcott et. al., 1997). The use of vitamin E in branded "case-ready" programs could potentially help the packer provide a consistent, made to order, longer-lasting product to the retailer which could be used to reduce out of stock items.

Addition of vitamin E and the built-in advantage of packer sanitation in centralized cutting programs could potentially help their product actually out perform products fabricated at local markets. This study is designed to investigate the additive ability of dietary vitamin E supplementation to increase the performance of ground beef and beef top loin steaks in case-ready applications through reduction of lipid and muscle pigment oxidation.

CHAPTER II

LITERATURE REVIEW

CONSUMERS AND MEAT QUALITY

Foods are essential in providing nutrients needed to sustain life, and must be consumed to realize this value (Pearson, 1994). It is important that products not only meet a consumers nutritional needs, but they must also be aesthetically pleasing while maintaining acceptable quality levels which meet consumer sensory needs. The quality of any product is measured as a degree of excellence (St. Angelo, 1996). A consumer not only considers nutritive value, edibility, wholesomeness and freedom from disease when purchasing a food product, but they also consider aesthetic properties (Pearson, 1994). In meat products, many factors are used to evaluate overall quality. Consumers use appearance texture and flavor when judging the acceptability of cooked meats (Liu et al., 1995). Of the sensory qualities, appearance is the primary factor by which consumers judge fresh meat quality during retail display (Green et al., 1971). In beef products, color is an extremely important component of appearance and is known to substantially influence the purchase decision (Sherbeck et al., 1995). Through experience, consumers have learned that the color of fresh beef is bright cherry red and when a product does not meet this

standard a level of consumer unacceptability is created (Kropf, 1980). Unfortunately the acceptable color of fresh beef products is short lived (Liu et al., 1995). In a typical retail environment, discolored meat products are often either discounted, or discarded resulting in a loss of product value. It is important to note that loss of visual properties (i.e. appearance) does not indicate a loss of nutrient value (Faustman and Chen, 1994). Although the consumer uses color as an index of quality, the correlation between color and of overall meat nutrient quality is limited (Daun et al., 1971). Beef products can maintain nutritive value and wholesomeness even after a decline in appearance as a result of pigment oxidation and a loss of acceptable color.

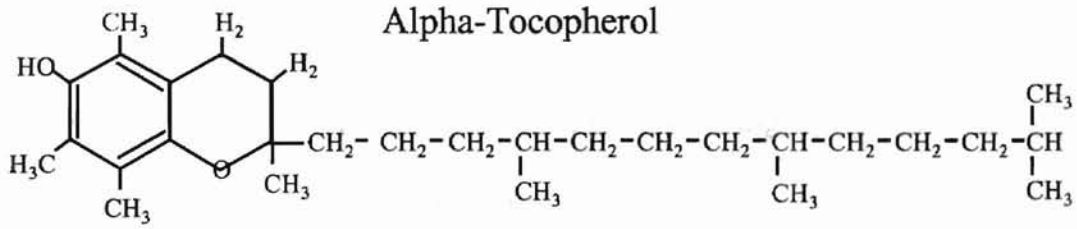
Consumer attitudes towards beef have changed in the past several years (Eastwood, 1994). Health concerns, price : value relationship, aggressive competition from other protein sources and changes in consumer lifestyle have all led to a decline in beef market share (Eastwood, 1994; Hollingsworth, 1997; Schmitz et al., 1993). This decline in beef consumption has led to the analysis of the beef industry from the producer to the consumer (Eastwood, 1994). In an effort to determine strategies aimed at regaining market share, the National Cattlemen's Beef Association (NCBA) introduced the "Brand-Like Initiative" which focused on producing quality products that consumers would associate with the word "beef". Since the responsibility of creating and maintaining quality would fall on all segments of the industry, the change of industry focus has led to the application of several innovations in production, fabrication, and marketing that are aimed at improving beef quality.

Because fresh beef color is so important to the consumer, any improvements associate with product color stability and subsequently product shelf life would improve the marketability of beef products as well as decrease the waste of a wholesome nutrient source (Faustman & Chen, 1994). Shelf life extension could have a great economic impact on the beef industry as a whole. Williams and colleagues (1992) determined that the economic benefit of extending product shelf life for one to two days would create savings for the beef industry of approximately $175 million to $1 billion annually. Thus, any product, strategy, or interaction that can enhance retail case life of meat products has the potential of not only improving beef quality but also improving beef's market share and economic status.

VITAMIN E: STRUCTURE AND PHYSICAL PROPERTIES

Vitamin E is the generic name given to all toco and tocotrienol compounds that exhibit the activity of α-tocopherol (Buckley and Morrissey, 1992; Roche, 1991). Tocols are represented as having a saturated phytol side chain, while trienols contain double bonds in the 3', 7' and 11' positions (Buckley and Morrissey, 1992 ; see Figure 2.1). Natural vitamin E activity in foods is derived from a series of eight compounds found in plants and includes four tocopherols and four tocotrienols. The most biologically active form of these compounds is α-tocopherol which also is the most common form found in feedstuffs (Roche, 1991). Of the isometric forms *dl* α-tocopheryl acetate (Figure 2.1) is accepted as the international standard with a potency of 1 mg equivalent to 1 international

unit (IU) (Roche, 1991). This is the synthetic form of vitamin E, when in its free tocopherol form, *dl* α-tocopherol, has a potency of 1.1 IU/mg (McDowell, 1989). Comparatively the naturally occurring form *d*-α-tocopherol has a potency of 1.49 IU/mg and the potency of its esterfied acetate, *d*-α-tocopheryl acetate, is 1.36 IU/mg (McDowell, 1989). The esterfied form, ∝-tocopheryl acetate, which is not as susceptible to destruction by oxidation as the alcohol form, is most commonly used in commercially available supplements for mixing in dry feeds (Liu et al., 1995)



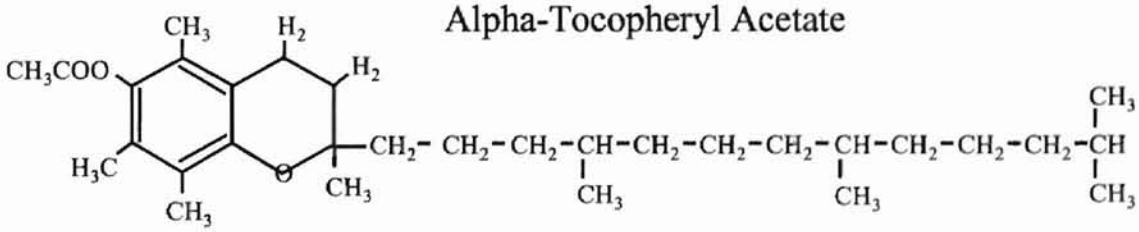


Figure 2.1: Structure of α-tocopherol and α-tocopheryl acetate (McDowell, 1989).

VITAMIN E: METABOLISM

Ruminants are unable to synthesize vitamin E, and therefore must achieve needed concentrations from their diets (Roche, 1991). Being a fat soluble vitamin, absorption is related to fat digestion and is facilitated by bile and

pancreatic lipase in the small intestine (Roche, 1991; McDowell, 1989). Transportation of vitamin E *in vivo* takes place via the lymph system and is delivered to the liver for where it is resecreted (Buckley and Morrissey, 1992) by chylomicrons and lipoproteins to the tissues (Reported in Faustman et al., 1998). Regardless if the free alcohol form or the ester is presented, the majority of dietary vitamin E is absorbed as an alcohol (McDowell, 1989). Because the alcohol form is subject to some destruction in the rumen, the ester form is more widely used in commercial applications. During digestion, the acetate is cleaved in the intestinal wall where the alcohol is reformed and then absorbed (McDowell, 1989). The use of vitamin E in the alcohol form by body tissues allows for its function as an antioxidant. Any vitamin E that is obtained from the diet and digested is eventually converted to the alcohol form by the liver (Buckley and Morrissey, 1992).

Of the eight compounds that exhibit the activity of vitamin E, the α-form is the most active, best absorbed and is assumed to be the most prevalent form in animal tissue (Roche, 1989). Concentrations of α-tocopherol within membranes is tissue and organ dependent (Faustman et al., 1998). Relatively little storage in the body occurs in contrast to other vitamins such as vitamin A (McDowell, 1989). The liver is not a proficient storage organ for vitamin E and although it contains high concentrations compared to other body tissues, it contains only a small amount of the total body storage (Roche, 1989). Over time, tissue concentrations of α-tocopherol are depleted. This indicates the importance of

continual feeding of vitamin E to maintain necessary or desired levels in muscle or lipid tissues (Faustman et al., 1994). Vitamin E is regularly found in all tissues of the body and concentrated mostly in fatty tissues where fractional amounts can persist over long periods of time. It is important to note that destruction of vitamin E through lipid oxidation is accelerated in tissues containing high concentrations of polyunsaturated fatty acids (Roche, 1989; Wood and Enser, 1997).

VITAMIN E: FUNCTION

Vitamin E functions as a chain breaking antioxidant that prevents lipid oxidation by scavenging free radicals. Its reaction with lipid radicals converts them to more stable products (Gordon, 1990). Vitamin E is the major lipid soluble antioxidant in animal tissue that acts post-mortem to delay oxidative deterioration of meat (Wood and Enser, 1997). This oxidative deterioration includes the combined effect of both lipid and pigment oxidation which have been shown to be coupled (Williams et al., 1992; Greene, 1969). By delaying lipid oxidation in fresh meat pigment oxidation is also delayed allowing for the extension of shelf life (Sherbeck et al., 1995). Vitamin E studies in meats have focused on its ability to reduce oxidation, as well as improve color stability and moisture retention (Faustman et al., 1998).

LEAN QUALITY CHANGES IN MEAT

Quality deterioration in meat occurs due to the effects of lipid and muscle pigment oxidation (Smith et al., 1996). Numerous studies have reported the

ability of antioxidants to decrease the rate of quality deterioration in beef products (Greene, 1969 ; Faustman et al., 1989 ; Sanders et al., 1997). To consider the role of antioxidants in improving case life we must first explore these processes.

Lipid Oxidation

The spontaneous reaction of atmospheric oxygen and organic compounds yields degradative changes effecting the case life of a product (Gordon, 1990). One such reaction is that of lipid oxidation which occurs in stored and displayed meat products. Lipid compounds act as storage depots for energy needed by living systems. When lipids are oxidized, primary and secondary products are formed. These products adversely effect the properties of lipids and lead to undesirable characteristics in meat products (Williams et al., 1992). Harvesting of animals causes injury to cells which allow oxidative processes to be favored (Kanner, 1994). Oxygen mediated oxidation in food systems is referred to as autoxidation, and involves free radical reactions (St. Angelo, 1996). Reduction of oxygen yields several products including superoxide radical ($O_2^{\bullet}$), perhydroxyl radical ($HO_2^{\bullet}$), hydrogen peroxide (H_2O_2), and a hydroxyl radical ($HO^{\bullet}$) all of which can participate in lipid oxidation in meat products (Kanner, 1994). Lipid oxidation leads to hydroperoxides that are very unstable and degraded to secondary reaction products (Lillard, 1987; St. Angelo, 1996). These secondary reaction products adversely affect meat flavor and quality, and are associated with the term oxidative rancidity (St. Angelo, 1996)

Polyunsaturated fatty acids (PUFA) in meat products are highly susceptible to autoxidation (Wood and Enser, 1997; St. Angelo, 1996; Solomons, 1992). This is important because PUFA make up the phospholipids in muscle cell membranes (Klis, 1993). Solomons (1992) describes the oxygen mediated autoxidation of a PAFU:

1. In such a fatty acid a radical product attacks the hydrogen of $-CH_2-$ group between double bonds creating resonance hybrid radical.
2. The radical formed in step one reacts with O_2 to form an oxygen-containing radical.
3. This radical abstracts a hydrogen from another PUFA resulting in a hydroperoxide and a free radical that can bring the repetition of step 2.

Any reaction that prevents the propagation of peroxidation or removes free radicals from the oxidative process is capable of terminating such a process (Simic and Taylor, 1987). Antioxidants are very effective in inhibiting this process. For example vitamin E is capable of acting as a radical trap preventing cell damage and improving lipid stability (Solomons, 1992).

Meat Color

When considering beef color, understanding the common heme pigment relationships of fresh meat is improtant. The first pigment is responsible for the color of meat that is unexposed to O_2 is reduced (ferrous) myoglobin. This purple color is also the color of vacuum packaged fresh meat. By eliminating the available oxygen in vacuum packaging systems any oxymyoglobin is reduced to

deoxymyoglobin. Addition of O_2 or increasing oxygen pressure to an exposed surface in the reduced state causes the meat to bloom or become a bright cherry red which is associated with the desirable color of fresh beef (Liu et al., 1995). The reduced myoglobin can also be transformed to the oxidized metmyoglobin (ferric) state which is brown and undesirable color associated with meat that has been exposed or displayed for some amount of time and usually occurs at low partial oxygen pressures (pO_2) (Price and Schweigert, 1971). Initial formation of metmyoglobin is independent of microbial growth (Daun et al., 1971). The oxidation of reduced myoglobin in the presence of reducing agents results in the two green pigments sulfmyoglobin and cholemyoglobin which cause undesirable colors. These two green pigments are most often observed as a result of bacterial action and are quickly converted by further oxidation and protein denaturation to free and oxidized porphyrins. In some cases sulfmyoglobin may be converted back to reduced myoglobin but cholemyoglobin is quickly broken down into globin, iron, and a tetrapyrrole (Price and Schweigert, 1971).

Oxymyoglobin is the major pigment form in fresh displayed retail beef (Kanner, 1994). Oxidation of oxymyoglobin results in the ferric metmyoglobin state associated with discolored meat that has been displayed for longer periods. As previously mentioned lipid and pigment oxidation have been found to be closely linked (Greene et al., 1971; Faustman et al., 1989; Liu et al., 1995). Free radical products of lipid oxidation act in oxidizing the heme of deoxymyoglobin to metmyoglobin (Greene, 1969). This mechanism is most notably affected by the use of dietary antioxidants such as vitamin E (Arnold et al., 1993a, 1993b).

Feeding feedlot cattle vitamin E as a dietary supplement allows this fat soluble vitamin to incorporate itself into the lipid membrane of the cell. Vitamin E enhances the reductant (antioxidant) pool within the muscle which minimizes the oxidation of oxymyoglobin to the metmyoglobin state providing for a more optimum fresh beef color (Faustman et al., 1989b).

When considering meat color it is also important to understand the relationship of oxygen partial pressure (pO_2) and pigment chemical states. There are both short term and long term effects of atmospheric exposure that are dependent on pO_2. As discussed above, the absence of O_2 causes a purple color in beef products as a result of reduced myoglobin holding the greatest percentage of total pigment as seen in uncut beef. Once a product is fabricated several things can happen. If allowed to be openly exposed to an atmosphere with a high $p0_2$ the product will "bloom" and oxymyoglobin will become the dominant pigment (Smith et al., 1996). This is demonstrated as the pressure of O_2 increases over ~80 mm. This is the normal response of exposed surface of meat in current retail applications. If only a small amount O_2 is present the oxidation of oxymyoglobin is favored resulting in metmyoglobin (the oxidized Ferric state) being the dominant color pigment causing a brown color (reported in Faustman et al., 1998). This is evident when a piece of meat is set in a retail display tray where the amount of oxygen on the down surface is limited and will eventually become permanently brown until the product is fully reduced as in vacuum storage. This can also occur in paper wrapped meat or other low oxygen permeable packaging materials.

We can examine the interaction of the various pigment states with the related pO_2 over time in fresh cut products. If a fresh steak were cut and we instantly stopped time, the color of the product would be purple due to the previously uncut surface being in the reduced, ferrous state. If we then started time for an instant, and stopped it again, we would have allowed just a slight amount of the O_2 pressure in the atmosphere to come in contact with the meat. The surface would then look brown due to the oxidized metmyoglobin (ferric) state being the dominant pigment. This is due to oxidative enzymatic activity at the surface of the steak that consumes the available O_2. When only a small amount of O_2 has been allowed to come in contact with the steak, the relative pO_2 would be low to provide enough O_2 for oxygenation to oxymyoglobin and the oxidative enzymatic activity would favor metmyoglobin formation. If we start time again, the surface will come in contact with a greater amount of oxygen pressure and is allowed to bloom. As O_2 penetrates the surface of the product metmyoglobin is initially formed at the level of deepest O_2 penetration and over time spreads toward the surface eventually effecting the overall meat appearance (Madhavi and Carpenter, 1993). The point of deepest penetration can be considered a "Met-Line" and is important in the rate of discoloration in case ready packaging systems (M-TEK, 1997). As the pO_2 increases it penetrates the further in to the meat causing the met-line to fall further from the meat surface. This met-line is at a point at which atmospheric oxygen penetrates at a low pO_2 and metmyoglobin is formed (Schuler, 1990). This is important in the concept that the metmyoglobin state rises from the inside of the

meat and discoloration occurs at a 70% of metmyoglobin as a surface pigment (Daun et al., 1971). Although Greene et al. (1971) found that consumer panels could detect initial meat discoloration at 30% to 40% surface metmyoglobin. In high oxygen case ready packaging systems, the environment during storage allows for greatest oxygen penetration and is aimed at giving the product an advantage when it is exposed to air and displayed (M-TEK, 1997). In such systems the deeper met-line would theoretically take longer to reach the surface resulting in extended cut meat storage and display life assuming no adverse interaction from other pigment stressors such as the interaction of lipid oxidation after long periods of storage in such a pro-oxidant atmosphere.

The met-line theory is also evident in ground beef. Trinkaus (1995) performed an informal study to determine shoppers' attitudes toward ground beef. He found that shoppers viewed ground beef that was red on the outside and red on the inside to be fresh. Ground beef that was brown on the outside and brown on the inside was considered as yesterday's meat, and any product that was red on the outside and brown in the middle was considered to be yesterday's meat wrapped in today's meat. The actual process relates to the pO_2 during processing. Fresh ground beef is usually ground and immediately placed on retail trays. Grinding allows for all of the meat to come in direct contact with some oxygen. Once wrapped the meat surface blooms and so does approximately the first cm or so due to penetration of atmospheric oxygen. The internal ground beef that has encountered enough O_2 to leave the reduced state for the met state during grinding never receives enough O_2 to reach the oxy state

becoming a brown color. The depth of the oxygen penetration in this ground product is influenced by storage time (Feldhausen, et al., 1995). The Trinkaus study showed a misconception on the part of the consumer. He concluded that of 50 respondents 31 recognized differences in ground beef color. Of these 31 people, 87% believed that new ground beef was placed over old ground beef in retail meat departments using a special machine in the back of the store. In actuality, meat that was red on the outside and brown in the middle was the freshest of the products considered.

CASE-LIFE OF MEAT PRODUCTS

Case-life is defined as the amount of time retail cuts can maintain an attractive red color and be acceptable in the eyes of the consumer (Smith et al., 1996). In addition to the oxidative effects described above, factors including light, temperature, metmyoglobin reducing ability (MRA) and bacterial load are also important in determining retail case-life (Kropf, 1980; Faustman and Cassens, 1990; Walker, 1980).

In a study in part to determine the effects of lighting type on metmyoglobin formation, Satterlee and Hansmeyer (1974) found that more intense lights, such as soft white florescent, cause increased autoxidation rates of beef when compared to less intense lighting such as incandescent. This research also helped to determine that under high intensity light the initial color loss is due to light oxidation and not bacterial load. This research was supported when it was discovered that UV (254 nm) light was more than 4000 times more

efficient at oxidizing oxymyoglobin to the metmyoglobin state (Bertelsen and Skibsted, 1987). This leads to the conclusion that lighting intensities and conditions are an important factor in retail meat case-life.

Some muscles discolor more rapidly due to metmyoglobin reducing activity (MRA). Increased MRA allows a muscle to maintain its original appearance longer due to the ability to maintain myoglobin in its reduced state that allows greater penetration of oxygen in to the meat (Madhavi and Carpenter, 1993). Faustman and Cassens (1990) found that beef longissimis muscle had greater MRA than did glutius medius in a pro-oxidant atmosphere. Madhavi and Carpenter (1993) suggested that both MRA and oxygen consumption rates (OCR) were involved in muscle color stability. Supporting research has shown that OCR of muscle mitochondria could account for muscle differences in color stability (Lanari and Cassens, 1991).

Bacterial load also impacts case-life of meat products. Ayres (1960) concluded that the critical value for slime production in displayed beef was 10^7 colony forming units (CFU). Increased exposure to oxygen acts as a catalyst for bacterial growth in displayed meat products. Saterlee and Hansmeyer (1970) found that metmyoglobin is reduced to myoglobin under high bacterial loads. This was due to lack of O_2 on the surface of meat products. This reduced myoglobin can react with bacterial byproducts (H_2S and H_2O_2) to form the sulfmyoglobin and choleglobin states associated with the green color in spoiled meat. Although microbial growth over long periods of time does indeed have some effect on meat case life, it was determined that visual appearance rather

than microbial spoilage is the limiting factor (Bell et al., 1996a). Cabredo and co-workers (1998) also found that unacceptability due to pigment oxidation occurs prior to bacterial spoilage in retail displayed meat.

COLORIMETRIC AND VISUAL ANALYSIS IN MEAT

Meat color is a phenomenon of an opaque non-metallic object that refracts light at several angels producing a diffuse reflectance (Hunt, 1980). Using objective methods for analysis of meat color give a convenient and rapid method for determining the color content of meat (Arnold et al., 1992a). Hunt (1980) suggested that spectrophotometric methods that determine the amounts of myoglobin forms present are better at determining subtle color changes in meat than are colormetric methods. However, colormetric methods allow the researcher to numerically quantify the color of an object with more uniform color differences in relation to visual differences (Minolta, 1994). Colormetric observations can also be used in determining changes in the actual color of an object not discernible to the human eye. Brewer and Wu (1993) determined the correlation between instrumental methods of color assessment was present in the evaluation of display, frozen storage and packaging effects on ground beef. Their research showed that "a" values were correlated (0.85) to red color percentage contributed by oxymyoglobin. One of the most widely used methods of colorimetery is the use of the L, a*, and b* (CIELAB) color space where the L* value represents lightness to darkness, the a* and b* values are the chromaticity coordinates (red to green, and yellow to blue, respectively) (Minolta, 1994). In

meat the a* value is of greatest importance because of its representation of the red color. Liu and co-workers (1996b) utilized a Minolta colorimeter in researching color coordinates for the assessment of effects of dietary vitamin E on color stability. Using CIELAB scores they found that vitamin E supplementation caused retention of redness (a*) and decreased yellowness (b*) which when combined to produce a value of color saturation represented a more desirable product than controls. It is important to note that objective color in meat can not be properly utilized with out considering subjective human color measurements. Measuring human perception of meat color acceptability is critical when determining factors that could effect meat color display life (Arnold et al., 1992a). Determination of myoglobin forms presents valuable incite to the changing color properties of meat, but the determinant factor in beef quality is the consumers visual and subjective perception of lean color. Using colormetric measurements to complement visual perceptions of meat color researchers can effectively evaluate changes in color that affect consumer acceptance of the product.

CASE READY PACKAGING SYSTEMS

In order for a case ready system to work in today's environment it must provide a bright red, display ready, product with a long storage life (Down, 1997). New packaging innovations are currently being applied to enhance shelf life and microbial safety in meat products (AMI, 1997). There are four types of packaging systems available for case ready fresh meats: 1) vacuum packaging,

2) high oxygen modified atmosphere packaging (MAP), 3) low oxygen MAP, and 4) oxygen free saturated carbon dioxide controlled atmosphere packaging (CAP) (Down, 1997). Concerns for fresh beef color eliminate the use of CAP systems in case ready beef due to browning of the product. However these systems have been found effective in pork (Sorheim et al., 1996). High CO_2 packaging provides superior control of microbial growth, but has been shown to have no effect on color stability (Bell et al., 1996a). Some work has been done utilizing carbon monoxide (CO) in high CO_2 systems to enhance beef color. Luno and co-workers (1998) found that by adding 1% CO to a gas mixture containing 50% CO_2 the microbiological advantage was realized without compromise to lean color. This color stability is due to the formation of carboxymyoglobin which provides a bright red color and is more stable than oxymyoglobin, but such use of CO is not currently available due to restrictions concerning health risks (Luno et al., 1998). Color concerns also mandate the use of low oxygen systems for display ready products. Low oxygen MAP systems are mainly used in storage and bulk packaging of lamb products but would not be suitable for display purposes due to an undesirable lean color. Systems for display ready fresh beef products currently utilize either vacuum technology, and present the product in the reduced myoglobin state, or high oxygen MAP systems that present the product in the oxymyoglobin state (Church and Parsons, 1995).

Enriched oxygen atmospheres are an adequate means of extending the color life of beef products (Daun et al., 1971). The most widely used form of case ready meat is modified atmosphere packaging (MAP) utilizing an 80% O_2

and 20% CO_2 atmosphere (AMI, 1997). Modified atmosphere packaging is defined as the enclosure of fresh products in gas-barrier materials, in which the gaseous environment has been changed in order to inhibit spoilage agents and therefore extend the shelf life of a food product (Church and Parsons, 1995). High oxygen MAP systems exploit the spoilage microfloras sensitivity to carbon dioxide and the muscles need for oxygen to retain bloom (Down, 1997). Oxygen inclusion is important in red meat packaging to maintain desirable red lean color of fresh beef (Church and Parsons, 1995). The high oxygen content is related to color retention by providing a high pO_2 (as described in a previous section of this review). An adverse effect of these systems is their tendency to promote lipid oxidation (Houben et al., 1998). The high oxygen atmosphere of these systems provide free oxygen which is used in the formation of free radicals and the propagation of autoxidation. The CO_2 component of the gas mixture is important in inhibiting bacterial growth. Microbial growth was shown to be reduced with increased concentration of carbon dioxide in MAP packaged pork chops (Sorheim et al., 1996). The effectiveness of carbon dioxide as a bacterial growth inhibitor is determined by the growth phase of the organisms where in CO_2 increases the length of the lag phase and decreases the growth rate during the exponential phase (Church and Parsons, 1995). Sorheim and co-workers (1996) also observed benefits in bacterial inhibition once a product was removed from MAP packaging and displayed traditionally. In beef products the optimum CO_2 concentration is less then 40%, where higher concentrations cause souring and surface bleaching (Church and Parsons, 1995). The advantage of high

oxygen MAP systems is shelf life extension. It has been reported that storage life of products is often doubled over conventional methods and can be from 7 to 10 days (Down, 1997). Supporting research by Daun et al. (1971) found that beef packaged in oxygen enriched atmospheres reached unacceptable color levels after 10 days compared to 6 days for conventionally wrapped controls.

Vacuum package technology is also a viable means of case life extension. Vacuum package technology is the oldest and most widely used form of alternative packaging. It is used extensively in the production of boxed beef although not a widely accepted form of retail packaging even though the shelf life of vacuum packaged beef products can be extended up to 21 days (AMI, 1997). In a study designed to test the effects of packaging on the relationship of lipid oxidation, and color in frozen ground beef Brewer and Wu (1993) looked for differences in vacuum packaged vs. oxygen permeable vs. oxygen impermeable/light impermeable packaging systems. They discovered that in fresh ground beef that was displayed for 24 hrs under simulated retail conditions, TBA numbers were not different ($P>0.05$) among the three packaging types. This would suggest that display alone resulted in lipid oxidation when compared to non displayed controls. Comparatively, oxygen permeable systems had greater loss of red color and constantly received lower acceptability scores. This suggests oxygen availability greatly affects pigment oxidation. Differences in pigment oxidation observed when oxygen permeable packaged products were compared to vacuum packaged products would suggests that light alone did not result in lean color changes. Although the combination of light and oxygen

availability in traditionally wrapped ground beef resulted in lipid oxidation and significant changes in pigment oxidation during short-term retail display. Church and Parsons (1995) noted that in vacuum packaging residual air to meat volume is critical where smaller cuts are more prone to oxidative effects due to an increase in this ratio. It is also important to note that vacuum package technology is limited by characteristics such as color, loss of shape and increased drip loss (Church and Parsons, 1995).

As discussed earlier MAP relies on the bacteriastatic effects of CO_2, where vacuum package technology maintains an oxygen deficient environment denying bacteria the ability to proliferate freely (Church and Parsons, 1995; Down, 1997). This introduces some concerns as to microbial activity in case ready packaging. Church and Parsons (1995) suggested that the ability of MAP and vacuum packaging to inhibit *Psedomonas* bacteria allow for dominance of *Lactoacillus* organisms. This was verified in a personal communication with Russ Kelso of Kroger Foods who experienced this problem in test marketing Cryovac® Peelable VSP packaging. Bell and co-workers (1996b) also found that in CAP systems off odor associated with lactic acid bacterial dominance was present prior to bacterial levels associated with spoilage. Venugopal and others (1993) found that the majority (56%) of isolates (n=734) form aerobic plate counts of MAP products were lactic acid cocci. This research suggests that the effects of CO_2 reduce most, but not all spoilage bacteria.

The key to case ready success is consumer acceptance. In a study by

Pelzer and others (1991) it was discovered that consumers discriminate against the most stable form of case ready, vacuum skin packed (VSP) steaks. They also determined that consumers were more willing to purchase VSP roasts when informed of the protection aspects of these products. Eastwood and co-workers (1994) found similar discrimination patterns in a marketing study involving several beef cuts at retail outlets that had been using both traditional and case ready packaging. Using a questionnaire to compare consumer attitudes of VSP and polyvinyl chloride tray wrapped ribeye steaks, Schmitz and others (1993) found that development of new beef products would have to capitalize on the desirable attributes of fresh beef. The color problem has obviously hindered acceptance of VSP in the retail case, but new VSP technologies have been developed to overcome this. Cryovac® Peelable VSP film is one example of this. This system involves a two piece Peelable Film layer over the top of the meat, which is heat bonded to barrier film tray. The top layer can be removed at the time the product is placed in the case and the under layer is oxygen permeable allowing for the product to bloom (Schut, 1998). The advantage of such a product is reduced labor and enhanced safety of centralized cutting while retaining the desired ability to "bloom" when the cut is presented in the retail case.

"Case ready" meat offers consumers a fresh, consistently cut, and attractive product (AMI, 1997). These systems allow retailers to carry items that are frequently out of stock or troublesome to prepare. In a 1997 article that

appeared in Beef Today Magazine, Keith DeHaan then of Beef America was quoted as saying that case ready cuts "Are the same fresh beef cuts in longer shelf-life packaging and they will eventually become the new commodity," (Effertz, 1997).

SUPPLEMENTAL VITAMIN E TO IMPROVE BEEF QUALITY

One use of vitamin E that has been extensively studied over the past several years is the use of its antioxidant properties to improve beef quality. The primary mechanisms that cause quality deterioration of meat are lipid and pigment oxidation (Williams et al., 1992). Any improvement in lipid and color stability would have great economic impact on the $1.1 billion a year beef industry (Hermel, 1993). This improvement would focus on the ability of vitamin E, as an antioxidant, to retain beef's its bright cherry red color over extended periods of display thus extending its case-life.

Some of the earlier work done utilizing antioxidants to improve meat color focused on the use of exogenous products added to postmortem ground beef products (Greene, 1969; Greene et al., 1971). Greene (1969) found that by using the synthetic antioxidants butylated hydoxyanisol (BHA) and propyl gallate (PG), the odor due to lipid oxidation (determined by sensory panel) of ground beef stored 2 or eight days was significantly reduced. This reduction in rancid odor was a result of reduced lipid oxidation in antioxidant treated samples as expressed by significantly lower TBA values. When determining the effects of anaerobic packaging, results suggested that the addition of antioxidants

eliminated the need for such packaging by equally reducing lipid oxidation and retarding metmyoglobin formation. It was determined that antioxidants exert their effect on meat color by protecting reducing enzymes as well as heme pigments from being damaged due to lipid oxidation intermediates. In a subsequent study, Greene and others (1971) found a synergetic effect by also adding ascorbate, the natural antioxidant. They found less overall pigment loss and the presence of less ferric pigment when synthetic antioxidants were added in combination with ascorbate. This research was important in determining the relative amount of ferric pigments rather than pigment concentration is the deciding factor in color acceptability.

In a similar study, Mitsumoto and co-workers (1991) tested the effects of postmortem addition of vitamins E, in the form of α-tocopherol, and or vitamin C, in the form of sodium ascorbate, on the improvement of pigment and lipid stability of ground beef stored for 1, 3, 5, or 7 days. They discovered significant treatment by day effects ($p < 0.0001$) in the reduction of pigment and lipid oxidation. Control samples showed large increases of surface (24.2% to 57.6%) and extract (38.3% to 73.4%) metmyoglobin percentages as well as increases in TBA values (1.18 to 4.34) when compared to treated samples. Vitamin E addition reduced pigment oxidation for surface (22.5% to 42.2%) and extract (12.0% to 46.9%) as well as reduced lipid oxidation (0.47 to 2.16) over the retail display life. They concluded that post-mortem addition of low concentration vitamin E (6 ppm) was effective in retarding lipid oxidation. Additionally, it was noted that

high concentrations (> 7,600 ppm) had a pro-oxidant effect and could cause greater pigment oxidation than control samples. A limit of 3,800 ppm was suggested to capitalize on antioxidant effects.

In an attempt to compare dietary versus post-mortem supplementation of vitamin E on pigment and lipid stability, Mitsumoto and others (1993) fed cattle supplemental α-tocopherol at a level of 1500 IU/hd/d for 232 or 252 consecutive days. The concentration of post-mortem added α-tocopherol was sufficient to equal the mean difference of α-tocopherol concentrations between supplemented and control fed cattle. They found that endogenous vitamin E improved pigment and lipid stability much better than exogenous vitamin E. They further concluded that dietary vitamin E supplementation would be a more effective and safer method for retarding pigment and lipid oxidation in beef than was post-mortem addition. This was important because exogenous antioxidant addition in raw meat is no longer permitted in most countries.

Acting on the conclusion that beef produced from Holstein steers was inferior in case life to that produced from beef-bred steers, Faustman and co-workers (1989b) developed a study to determine the effects of dietary vitamin E supplementation on improving pigment and lipid stability. They first discovered that when supplemented at the rate of 370 IU/head/day through out the feeding period tissue α-tocopherol concentrations were twice that of control steers ($P<0.05$). Several other researchers have demonstrated the efficacy of dietary vitamin E supplementation on increasing muscle tissue concentrations (Sanders

et al., 1997 ; Garber et al., 1995 ; Sherbeck et al., 1995 ; Westcott et al.,1997). This increase in tissue α- tocopherol concentration led to a significant reduction ($P<0.05$) in metmyoglobin formation on days 0 and 6 of simulated retail display and tended to decrease ($P<0.10$) formation on days 2 and 4. They also discovered a significant reduction in lipid oxidation on days 2, 4, and 6. They determined that α-tocopherol supplementation stabilized muscle pigments and lipids by allowing greater amount of vitamin E to be incorporated into the cellular membranes where it utilizes antioxidant properties to resist pigment and lipid oxidation. Alpha-tocopherol maintains oxymyoglobin indirectly by its direct inhabition of lipid oxidation (Faustman et al., 1998).

One of the major advantages of supplemental vitamin E is the reduction of lipid oxidation in displayed meat. Oxidation of lipids in beef products leads to the production of free radials associated with off flavors in cooked products (St. Angelo, 1996). Vitamin E has the ability to "capture free radicals and reduce the development of malondialdahyde in beef products (Liu et al., 1996). Liu and coworkers (1996) found that thiobarbituric acid reactive substances (TBARS) were more closely related and suppressed by vitamin E supplementation than was metmyoglobin formation by oxidation of oxymyoglobin. They found that across 14 d of display TBARS were different ($P<0.001$) for control fed steers (3.99) verses steers supplemented with 250 IU/d (2.77), 500 IU/d (2.07) and 2000 IU/d (.96) of vitamin E. This suggests that lipid oxidation was more suppressed in cattle that received higher doses of vitamin E.

Garber and co-workers (1995) also studied dose response effects of vitamin E on feedlot performance, carcass characteristics, and meat quality. These researchers assigned 75 beef steers and 60 Holstein steers to one of five vitamin E dietary treatment groups: E0 (no supplemental vitamin E), E250, E500, E1000, and E2000 (250, 500, 1000, and 2000 IU/hd/day respectively) for 119 to 153 days. They found that in steaks form beef steers lipid oxidation was decreased by 46.3, 60.5, 66.1, and 72.9% respectively for the E treatments when compared to controls. Beef from vitamin E fed Holstein steers showed a reduction in lipid oxidation of 42.9, 39.2, and 40.0% respectively when compared to controls. This data suggests that their was no advantage in feeding Holstein steers >500 IU/hd/d although some advantage was realized in steaks from beef steers. This study determined that 4.1 μg of α-tocopherol / g of muscle tissue was the threshold value for improvement of lipid oxidation in Holstein steers with no benefit beyond this point. Faustman and co-workers (1989b) similarly determined that maintaining a tissue concentration of 3.0 μg/g was critical in capitalizing on vitamin E's effects. They found minimal advantage to concentrations higher than 3.0 μg/g but did see reduction in beneficial effects under this concentration.

Another study by Arnold and coworkers (1993), discovered that different tissues in the body accumulate α-tocopherol at different rates. They found that by feeding dl-α-tocopheryl acetate at various levels for various time periods, saturation occurred first in the plasma and liver (<6 weeks), then the muscle (12

to 18 weeks). They first determined that the critical concentration in muscle was 3.3 μg/g similar to Faustman et al. (1989b). This level, it was determined, could be reached by feeding 1,300 IU/head/day for 44 days. Augmentation of time on feed inversely correlated with dose of vitamin E (300 IU for 266 days, 1140 IU for 67 days, or 1200 IU for 38 days) showed similar ability in case-life extension (Arnold et al., 1992b). It was also discovered that depletion of tissue α-tocopherol concentrations being slow, reduction in vitamin E intake immediately prior to slaughter would not effect its properties if critical concentrations had been met. Although over long periods of refrigerated storage, vitamin E concentrations have been shown to be depleted (Garber et al., 1995; Faustman et al., 1998)

Consumer response is vital to the success of exported beef products. In an attempt to determine the importance of meat color to Japanese consumers and the effect of dietary vitamin E on retail characteristics, Sanders and others (1997) fed no supplemental vitamin E (CON), 1000 (E1000) or 2000(E2000) IU/hd/day for 100 d to crossbred steers. Rib-eye rolls and strip loins were stored for either 40, 60, 80, or 100 days at 2^0 C, transported to Japan and then fabricated into steaks. After arriving in Japan, steaks were conventionally wrapped and displayed under retail conditions for 3 d. After the retail display period, steaks were moved to a food show placed under retail display conditions. Utilizing a survey the researchers were able to determine that 87% of the food show participants were able to notice a difference in lean color between vitamin

E supplemented (VITE) steaks and control steaks, 79% of these participants attributed this to the red color of the VITE meat. The concurrent lab work on product from the same animals showed that VITE steaks brighter in color than controls. This shows the efficacy of supplementation on the color of beef stored over long periods of time. Lipid oxidation was also reduced during storage where in control beef had higher TBA values on the initial of display then did supplemented steaks.

Taking this technology further, Zerby and others (1997) supplemented cattle with 1,000 IU/hd/d for 100 days and determined the case-life and economic benefit of vitamin E supplementation in true retail environments in Japan. The cattle were conventionally fed, slaughtered, and exported to Japan via sea freighter. They found that for ribeye steaks, 16% of all control product was discounted in price, while only 6.4% of vitamin E product was discounted due to lean color discoloration. Similarly for chuck roll steaks 12% and 3% of the products (control and vitamin E, respectively) were discounted after retail display. They determined that this had an economic impact of 23.6 cents per kg savings at the retail level by utilizing vitamin E supplemented steers.

In a similar retail study performed in the U S, Westcott and others (1997) fed approximately 235,000 head of cross bred steers a diet containing either 0 or 500 IU/hd/day of α-tocopheryl acetate in conventional feed yards in three geographical regions of the U.S. The steers were conventionally harvested at major meat processers, and followed traditional distribution chains to four major

retailers in different metropolitan cities. Approximately eight retail cuts were tracked for display performance, discount percentages and economic value of case-life. It was determined that for closely-trimmed cuts 19.53% of all control product was either discounted or discarded at the retail level due to discoloration compared to only 13.63% for vitamin E supplemented beef. The economic value of such a reduction in discounts was determined to be $28.67 per carcass equivalent based on average packer yields. This substantial impact shows the efficacy of vitamin E in "real-world" applications.

Discovery of any masking of the undesirable characteristics associated with bacterial spoilage is critical to the commercial use of vitamin E to improve beef quality. Cabedo and others (1998) designed a study to determine the microbiological status of E supplemented ground beef. They discovered that when ground beef was displayed under normal conditions (4^0 C), aerobic plate counts increased similarly for controls vs. 1000 IU/hd/day and 2000 IU/hd/d supplementation levels. Patties made from high E beef were found to be visually unacceptable after 6 to 7 days of display where they were microbiologicly unacceptable after 6 to 8 days. This suggests that visual spoilage will occur before bacterial populations reach unacceptable levels. Gerber and others (1995) found similar results in cores from top sirloin steaks from cattle not supplemented or supplemented with vitamin E. They found that there was no treatment effect and by day eight of display, bacterial concentrations had not reached undesirable levels. Greene and co-workers also discovered that postmortem antioxidant treatments had no effect on bacterial loads.

The most important attribute associated with vitamin E supplementation is the extension of color life or improvement of color stability. Although the mechanism of protection is not fully understood a link between lipid oxidation and oxymyoglobin sees to be demonstrated by supplementation (Faustman et al., 1998). Schafer and others (1995) suggested a model for the oxidation reduction relationships in fresh beef muscle. They suggest that the relationship between redox state of myoglobin and PAFU reflects a balance between anti- and prooxidative forces. The proposed model suggests that if lipid peroxyl radicals are not quenched by α-tocopherol oxidized fatty acids become water soluble products by decomposition and travel across the sarcoplasma where myoglobin exisits. Therefor the direct suppression of lipid oxidation indirectly reduces the amount of pigment oxidation, but the direct stabilization of myoglobin has yet to be determined.

Currently the beef processors are utilizing MAP packaging systems to help improve myoglobin stability during storage and display. The synergistic effects of case life extension in MAP packaging systems in combination with vitamin E supplementation has not yet been fully researched in beef. Houben and others (1998) investigated the relationship between lean color and lipid stability of minced pork from animals fed vitamin E and packaged in a conventional manor (WRAP) or in MAP packaging containing 66% O_2, 27% CO_2 and 7% N (GAS). They found that in the pro-oxidative atmosphere (GAS) control samples were more susceptible to lipid oxidation that were control samples

wrapped conventional (TBA = 0.24 vs. 1.2 after 11 days of display). When comparing packaging types for vitamin E enriched samples they determined that the pro-oxidant atmosphere had no effect on TBA values (TBA= 0.17 WRAP and 0.10 GAS for 11 days of display). This suggests the powerful antioxidant ability of vitamin E to protect against lipid oxidation in a pro-oxidant atmosphere. Their study also found a pronounced positive effect on the color stability of the red color component of fresh pork in MAP packaging but found no added effect with vitamin E supplementation. Cannon et al. (1996) also found this lack of effect on color stability in pork. This research indicates an advantage for vitamin E supplemented pork in case ready systems in the reduction of lipid oxidation. Further research would be valuable in determining if supplemental vitamin E can enhance the color stability of beef in case ready systems.

CHAPTER III

EFFECT OF SUPPLEMENTAL DIETARY VITAMIN E ON THE COLOR AND CASE-LIFE OF TOP LOIN STEAKS AND GROUND CHUCK PATTIES IN MAP CASE-READY RETAIL PACKAGING SYSTEMS

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ABSTRACT

Ground chuck and top loin steaks from cattle supplemented with either 0 (CON), or 500 (VITE) IU/hd/day of α-tocopheryl acetate were packaged utilizing a modified atmosphere case-ready beef packaging system (MAP). Random samples were taken from the strip loins and bulk ground chuck of each treatment at fabrication in order to determine the α-tocopherol concentrations in the products. Cuts were stored at 4^0 C +/- 1^0 C for 0, 2, 4, 6, 8, 10, 12, or 14 d. Following storage, products were displayed in a retail case at 2^0 to 6^0 C for 8 d. Twice daily, objective and subjective measures of display color properties were obtained. Lipid oxidation (TBARS) was measured on display days 0, 4, and 8 for each supplementation by storage group combination.

Analysis of retail samples revealed a higher ($P<0.01$) concentration of α-tocopherol in VITE when compared to CON products for both top loin steaks and ground chuck patties. Lipid oxidation was significantly ($P<0.01$) reduced during

both storage and display with VITE supplementation. CON products displayed increased ($P<0.01$) TBARS values during the display period after 2 or more days of storage in MAP packaging. Irregardless of display, VITE steaks stored 10 d or less and ground chuck stored 6 d or less exhibited stable lipid properties. VITE products to maintained their red color over the display period for most storage periods. CON ground chuck samples exhibited complete brown surface color if stored more than 6 d, where VITE ground chuck was able to maintain displayable red color after 10 d of storage.

Both VITE top loin steaks and VITE ground chuck patties maintained more acceptable visual scores for lean color, percent discoloration, and overall appearance, for a greater portion of the display period than did their CON counterparts. Fat color in steaks was unaffected ($P>0.05$) by supplementation, but improved in ground chuck patties. Maximum display life, when averaged across all storage days, was improved by approximately 3 d and 0.9 d with VITE supplementation for top loin steaks and ground chuck patties, respectively. This study suggests that VITE supplementation would be beneficial in improving lipid and color stability of beef products stored in high oxygen MAP packaging systems.

INTRODUCTION

Over the past several years, many changes in retail meat products have occurred. One such change has been the progressive movement toward the reduction of labor and enhanced food safety by utilizing "case-ready" fresh

poultry, fish, and pork products. Currently all poultry and most pork products arrive at retail stores as "case-ready" requiring minimal handling and processing prior to retail display. These value-added sections can easily be kept fully stocked and very presentable with limited labor as well as minimal oversight by the meat merchandisers. These advantages help make poultry and pork products more attractive and convenient to consumers then conventionally fabricated beef items. Fabrication and packaging of beef, on the other hand, requires the majority of the time and labor in today's retail meat department.

It appears that the main limiting factor in the production of "case-ready" beef products is unstable lean color (Effertz, 1997; Schut, 1998). Due to elevated myoglobin content associated with beef muscle, its relative color stability is much more of a concern than that of poultry products. Consumers associate a bright, cherry red lean color with beef freshness (Kropf, 1980). This color is due to the oxygenation of myoglobin in the muscle fibers of beef to oxymyoglobin. After the product has "bloomed", (i.e. oxygenated to bright cherry red), muscle pigments begin to oxidize to metmyoglobin. Once approximately 70% of the myoglobin population becomes oxidized beef becomes a brown color and is discounted or even discarded (Daun et al., 1971). Oxygenation of meat occurs approximately 30 minutes after the cut surface is exposed to oxygen and normally lasts for approximately 3 d in retail applications (Smith et al., 1996).

A successful case-ready beef packaging system must provide a bright red, display ready product with a long storage life (Down, 1997). Of all case-ready meat packaging systems, modified atmosphere packaging (MAP) utilizing

an 80% O_2 and 20% CO_2 gas atmosphere is the most widely used (AMI, 1997). MAP packaging involves enclosing perishable products in gas-barrier materials, in which the gaseous environment has been changed in order to inhibit spoilage agents and extend the storage life of the product. Enriched oxygen atmospheres are an adequate means of extending the color life of beef products during storage (Daun et al., 1971). These systems exploit the spoilage microfloras sensitivity to CO_2 and the muscles need of O_2 to retain bloom (Down, 1997). Often storage life of MAP products can be doubled when compared to traditional packaging (Down, 1997). An adverse effect of these systems is their tendency to promote lipid oxidation (Houben et al., 1998). The high oxygen atmosphere of these systems provides the O_2 needed to form oxygen-containing radicals involved in the propagation and chain reactions of lipid oxidation. Lipid oxidation leads to secondary reaction products that adversely affect meat flavor and quality, and are associated with the term oxidative rancidity (St. Angelo, 1996). In order for beef to better utilize the benefits of MAP packaging, it must first overcome the associated increase in lipid oxidation during the storage period.

Addition of vitamin E to the diet of finishing steers improves the retail case-life of "normal" beef products as shown in the Domestic Shelf Life Alliance Study (Westcott et. al., 1997). Vitamin E is also helpful in reducing lipid oxidation by acting as a free radical quencher (Faustman et al., 1998). The use of vitamin E in MAP "case-ready" programs could potentially help the packer/processor provide a more consistent, made to order, longer-lasting product to the retailer and eventually to the ultimate consumer. If effective, the addition of vitamin E

could help centralized cutting programs that utilize MAP packaging create products with added quality and extended storage stability. This study was designed to investigate the additive ability of dietary vitamin E supplementation to increase the performance of ground chuck patties and beef top loin steaks in MAP applications through reduction of lipid and muscle pigment oxidation.

Experimental Procedures

Meat Samples

Boxed beef subprimals, strip loins (IMPS #180a) and neck-off chuck rolls (IMPS #116), were obtained from beef cattle that were supplemented with either 0 (CON), or 500 (VITE) IU/hd/d for a minimum of the last 100 d of the finishing period,.of dietary vitamin E in the form of *dl*-α- tocopheryl acetate (Roche Vitamins, Nutley NJ). Approximately ten top loin steaks (2.5 cm thick) were obtained using a sanitized knife from each of five strip loins for each treatment group (n = 48 / treatment). Steaks were placed on 17s foam meat trays (Tenneco Packaging, Smyrna, GA) containing Dry-loc meat pads (Sealed Air Corp., Patterson, NC). Whole neck-off chuck rolls were ground once through a 1.27 cm plate and twice through a 0.32 cm plate to ensure equal fat distribution. After grinding and mixing, patties (approximately 113 g each) were hand formed with a plastic patty former for each treatment group separately (n = 48 / treatment). Ground beef patties were then placed on 1s foam trays (Tenneco Packaging, Smyrna, GA) without meat pads. Both steak and ground chuck samples were then packaged utilizing a MAP packaging system.

Random samples (n=14) were taken from strip loins of each treatment group and from the bulk ground chucks (n=4) of each treatment for laboratory analysis of α-tocopherol acetate concentration (Liu et al., 1996) by the Soil and Plant Analysis Laboratory at the University of Wisconsin, Madison.

Packaging

Within 20 min of retail fabrication, meat samples were packaged. Individual trays containing either top loin steaks or ground beef patties were wrapped in MAPAC-M stretch packaging film (AEP/Borden, North Andover, MA). This is a 72 gage stretch polyvinyl chloride (PVC) film designed for high oxygen modified atmosphere applications with an oxygen permeability rated at 1500 cc O_2 / 645 cm^2 in 24 hrs. Packages within each treatment group were then randomly assigned an identification number that corresponded to a particular storage and display time. One VITE and one CON package with matching storage and display times were placed into a 30.48 X 40.64 cm barrier film packaging bag (ALEC Enterprises, Burnsville, MN). A modified atmosphere package (MAP) was created using a Corr-vac Mark-IV flexible MAP system (M-TEK, Elgin, IL) that contained a gas mixture of 80% O_2 and 20% CO_2. Two MAP packages were then placed into individual cardboard boxes for storage.

Storage and Display

MAP packages were stored in cardboard boxes in the absence of light for 0, 2, 4, 6, 8, 10, 12, or 14 d at 2^0 C +/- 1^0 C. After their designated storage time was achieved, individual packages were removed from their MAP bags and

placed in a commercial retail display case for 0, 4, or 8 d under cool-white florescent light (1600 to 1900 lux) at 2 to 4^0 C. Packages were rotated randomly in the case once daily and new packages were added to random locations in the case. Products were removed after 0, 4, or 8 days for analysis of lipid oxidation.

Color Assessment

Twice daily retail display products were objectively evaluated for lean color using a Minolta CR-300 colorimeter (Minolta Co. Ltd., Osaka, Japan). L, a*, and b* values were recorded for each sample until its designated removal day. Measurements were taken at medial, central and lateral positions of each steak. These color measurements were of the lean color only, and precaution was taken to avoid any intramuscular fat. Four measurements were taken from each ground chuck patty at each observation time. A template was used to take these measures at each quarter section of the patty in approximately the same location for each observation. All samples, top loin steaks and ground chuck patties, were also visually evaluated twice daily by a three member trained panel for lean color (8 = bright cherry-red, 1 = extremely dark-brown), fat color (8 = creamy white, 1= dark-brown or green), percent discoloration (7 = none, 4= 26 to 50%, 1 = complete), and overall appearance (7 = Extremely desirable, 1 = Extremely undesirable) (Sanders et al., 1997). Overall appearance represented the combined effects of lean color, fat color and percent discoloration and was utilized an indicator of the acceptability of the retail product.

Thiobarbituric Acid Analysis

On days 0, 4, and 8 of retail display duplicate samples for each treatment by storage group combination were removed from the case and frozen at -20^0 C until further analyzed. Thiobarbituric Acid (TBA) analysis was performed using the test procedure described by White et al. (1970) with the following modifications: a 10 g sample was used in the extraction step, and 30 ml of the resulting slurry was centrifuged at 3000 RPM for 30 minutes prior to filtration. Results were reported as thiobarbituric acid reactive substances (TBARS) representing mg malondialdehyde (MDA) equivalents per kg of fresh meat.

Statistical Analyses

The Least Squares Means option of the General Linear Model procedure of SAS (SAS Institute Inc., Cary, NC) was used to compare means for treatment (TRT) by storage group (STORE) by display interactions. Objective color and visual panel data were analyzed with a split plot design with TRT, STORE and assigned display period before removal (0, 4, or 8 d) (DAY) in the main-plot utilizing STEAK(TRT*STORE*DAY) as the error term, and display as a repeated measure in the sub-plot utilizing residual error. Trends in a* values, lean color, fat color, percent discoloration, overall appearance, and TBARS over display time were fitted via regression. First, second, and third order regressions were fitted for all factors and the best fit regression was defined as having significant ($P<0.05$) model and parameter estimates. In cases where more than one order of regression for a given factor had significant model and parameter estimates,

the highest R^2 value determined the best-fit line. Dummy variables were used to test if data from adjacent storage days within a treatment had statistically similar regression lines. If these regression lines were not statistically different (P>0.05) the data was then pooled and a single line was fit as described above. This occurred only for the TBARS variable. Visual acceptance data ranges were calculated by solving regression equations to determine at which level of display a given factor became unacceptable. Unacceptability was defined as the point on the visual scale where a panelist would determine a factor unacceptable (i.e. <4.5 on an 8-point scale). Overall benefit for the visual panel factors was calculated as the average of the treatment differences over all storage days and reported with resulting standard deviations. Overall acceptability scores were used in this manner to determine maximum display life of products. Dummy variables were also used to associate treatments with each regression coefficient, and F-tests were then used to determine if differences existed in slopes and intercepts of the fitted lines.

RESULTS AND DISCUSSION

Alpha-tocopherol Concentrations

Analysis of randomly selected samples from MAP top loin steaks revealed that tissue α-tocopherol concentrations of VITE samples were 92.9% higher than were the concentrations of CON samples (2.95 +/- 0.56 μg/g vs. 1.53 +/- 0.61 μg/g, respectively; P=0.0007). Similarly it was found that α-tocopherol concentrations in VITE ground chuck samples were 77.0% greater then controls

(5.36 +/- 0.12 μg/g vs. 3.03 +/- 0.21 μg/g, respectively; P=0.005). Steak tissue α-tocopherol concentrations were found to be significantly lower (P<0.01) than the tissue concentrations of ground beef samples, when analyzed in the absence of treatment effects (2.24 +/- 0.93 μg/g vs. 4.19 +/- 1.35 μg/g, respectively). Differences in α-tocopherol concentrations between cuts could be attributed to differences in α-tocopherol accumulation rates of their muscles of origin (Arnold et al.,1993a, b). Liu and co-workers (1996) suggested that there is no clear explanation for such differences. Because vitamin E is a fat-soluble vitamin, it is also possible that the relative fat content differences of these products may have contributed to the observed variation in α-tocopherol levels.

Lipid Oxidation

Lipid oxidation, as indicated by thiobarbituric acid reactive substances (TBARS), was found to be markedly reduced in MAP packaged VITE top loin steaks when compared to CON. Storage in the high oxygen MAP system was found to have no effect (P>0.05) on TBARS accumulation in VITE top loin steaks stored up to 12 d (Fig 3.1). Conversely MAP packaging was found to significantly increase (P<0.01) lipid oxidation in CON top loin steak stored more than 2 d prior to display. Unexpected reductions in TBARS were observed in CON steaks at d 10 and 12 of storage. These reductions yielded TBARS values that were not different (P>0.1) than products stored 4 d.

TBARS accumulation was also unaffected (P>0.05) during the storage of MAP packaged VITE ground chuck patties stored for up to 10 d (Fig. 3.2).

Storage d 12 was found to have significantly higher TBARS than d 0 or 2 and storage day 14 exhibited a higher ($P>0.1$) TBARS value than all other storage periods. Storage of CON ground chuck patties in MAP packaging for more than 2 d was shown to significantly increase ($P<0.01$) lipid oxidation. The effect of storage in the high oxygen atmosphere of MAP packaging was found to be much more detrimental to the lipid stability of CON products than to VITE products. For all products stored more than 2 d, both VITE top loin steaks and VITE ground chuck patties exhibited significantly less ($P<0.01$) TBARS accumulation than did their CON counterparts. This would suggest that VITE could be used as an effective means of improving the lipid stability of MAP stored beef products.

The effect of display on the TBARS value of top loin steaks is presented in Table 1. No significant differences ($P>0.05$) were observed over the 8 d display period within VITE top loin steaks that were stored for up to 10 d. When one considers the overall age of these products (18 d) and the pro-oxidative conditions of MAP storage, the overwhelming antioxidant power of VITE is revealed. Conversely TBARS accumulation within CON steaks was significantly increased ($P<0.05$) over the display period after only 2 d of storage. When compared to CON products, VITE supplementation significantly reduced ($P<0.01$) the accumulation of TBARS over the display period. Comparisons of TBARS means over all storage days revealed reductions of 343.2%, 417.6% and 470.4% for display d 0, 4, and 8, respectively.

Effects of retail display on the TBARS value of MAP packaged ground chuck patties are presented in Table 3.2. Values not represented are due to the

removal of ground chuck products that displayed undesirable display characteristics prior to TBARS evaluation. Display for up to 4 d did not effect ($P>0.05$) TBARS accumulation within VITE ground chuck patties that were stored up to 6 d, where display period increases in TBARS accumulation were observed within CON products stored 2 or more days ($P<0.05$). Significant TRT differences ($P<0.01$) were also observed over the display period in products stored 2 or more days. Lipid oxidation in MAP packaged ground chuck was reduced by an average of 320.0%, 141.7% and 76.2% after 0, 4, and 8 d of display, respectively. Analysis of this data indicates that VITE supplementation would be very effective in reducing the occurrence of lipid oxidation in displayed beef products after storage in MAP packaging systems.

Lean Color

The effect of storage in MAP packaging on the Minolta a* value of top loin steaks prior to retail display is presented in Figure 3.3. MAP packaging significantly increased ($P<0.01$) the red color of both VITE and CON steaks after 2 d of storage when compared to non MAP packaged steaks. Both VITE and CON steaks were able to maintain this increase over the 14 d storage period. These findings are in agreement with Okayama (1987) who reported acceptable color stability in CON and antioxidant dip treated steaks that were stored for up to 13 d in high oxygen MAP packaging. Treatment differences in red color were not detected over the storage period with the exception of d 2 and 4, where VITE steaks exhibited increased ($P<0.01$) a* values. Differences within treatments

were not observed (P>0.05) after 6 d of storage for CON products, and after 8 d of storage of VITE products. This data would suggest that VITE would provide improved lean color in MAP packaged top loin steaks stored less than 6 d.

Storage in MAP packaging significantly decreased (P<0.05) the Minolta a* value of ground chuck patties stored for extended periods of time (Fig. 3.4). CON patties exhibited a steady decrease (P<0.01) in a* value between d 2 and 6 of storage, and a dramatic drop in a* value between d 6 and 8 of storage. CON product stored 8 or more days were gray-brown in color when removed from their MAP package and were unfit for retail display. VITE patties also exhibited a steady decline in a* value over the 14 d storage period, but were able to maintain a displayable red color through 10 d of storage. Treatment differences (P<0.03) in red color were observed at all levels of storage. CON products had significantly higher a* values prior to retail display in patties stored for up to 6d, after which VITE patties maintained a higher (P<0.01) level of red color.

Comparisons of a* values over the 8 d display period for MAP stored top loin steaks are represented in Figure 3.5. VITE steaks exhibited significantly higher a* values over the entire 8 d of display when averaged across all storage days. CON steaks discolored at a much faster rate than did VITE steaks (P<0.05). VITE steaks were not different from each other in red color when displayed for up to 3 d. Conversely, CON steaks exhibited differences in red color after only 1 d of display. These findings suggest that the antioxidant attributes of VITE supplementation was extended to the display period even after storage in the pro-oxidative atmosphere of high O_2 MAP packaging.

Comparisons of a* values of ground chuck patties stored up to 6 d are represented in Figure 3.6. Comparisons beyond this point were not considered due to lack of red color in CON samples stored for more than 6 d. It is important to note that VITE samples did exhibit red color, and were displayed after being stored for up to 10 d. VTE ground chuck patties had higher ($P<0.05$) a* values between d 1 and 5 of display. CON patties were found to discolor at a faster rate ($P<0.01$) over the 8 d display period after all storage periods. Analysis of the a* values of ground chuck patties would suggest that both the 14 d storage period and the 8 d display period are inappropriate for the stability of these products. Currently retailers use a total life (storage plus display) of 6 to 10 days for MAP stored ground beef (Maskel, personal communication). The current study would suggest that CON products could achieve a total life of 4 d, and color stability could be extended to 8 or more days with the use of VITE.

Subjective color analysis

Storage in MAP packaging for 2 or more days significantly reduced ($P<0.05$) the initial lean color of VITE steaks prior to display. Similar reductions were seen in CON steaks stored more than 6d. Both VITE and CON steaks exhibited highly significant ($P<0.01$) reductions in lean color scores after 10 days of storage. Although lean color of VITE steaks did improve after this decline to a level that was not different ($P>0.05$) than observations made after 8 d of storage. VITE steaks maintained higher degrees of lean color for an extended portion of the display period after all storage days with the exception of d 10 (Fig. 3.7).

The greatest differences in acceptable display period occurred at d 12 and 14. After these storage periods, VITE steaks maintained acceptable lean color for the entire display period where CON products failed to achieve acceptable display for more than 0.2 d. When all storage days were considered, VITE steaks had extended lean color lives compared to CON steaks. VITE steaks maintained an average lean color display life of 7.73 +/- 1.08 d where CON steaks were found unacceptable after an average of 3.77 +/- 2.88 d. This leads to the conclusion that VITE supplementation could extend the acceptable lean color of top loin steaks by up to 3.96 d.

Visual assessment of percent discoloration demonstrated that VITE supplementation was also effective in maintaining a more uniform surface color over an extended portion of the display period (Fig. 3.8). All VITE steaks exhibited acceptable discoloration scores for at least 8 d of display. CON steaks reached unacceptable surface discoloration earlier in the display period with the exception of day 8 where no difference was observed. Regression analysis was unable to determine the acceptable discoloration life of either treatment after 10 d of storage. When all storage days were considered, VITE maintained acceptable percent discoloration scores for 8.29 +/- 0.09d compared to 5.59 +/- 2.70 d for CON steaks. This would indicate a delay in the rate of discoloration of up to 2.7 d with VITE supplementation.

Fat color differences between treatments were observed in all MAP stored top loin steaks (Fig. 3.9). These differences were not uniform in nature in that CON products exhibited higher fat color ratings after 3 of the MAP storage

periods and VITE steaks had more acceptable fat color after 4 of the MAP storage periods. Previous research by Sanders an co-workers (1997) found that VITE had no effect on the stabilization of fat color over the display period. Observed differences in this study could be in part to individual steak differences.

Maximum display life of top loin steaks was calculated utilizing overall appearance scores (Fig. 3.10). Days of display to reach unacceptable overall appearance decreased as the storage period increased for CON steaks. However there was an unexpected increase in acceptability of CON steaks stored 10 d. This increase in CON top loin steaks acceptability after 10 d of storage was also discovered in a parallel study conducted weeks after the current study utilizing an alternative packaging system. No explanation can be given for such a phenomenon. VITE was effective in increasing the display life of top loin steaks. Mean treatment overall appearance scores were significantly higher ($P<0.01$) than CON. CON steaks did however exhibit improved acceptability when compared to VITE steaks after 2 and 10 d of storage. It appears that decreased lean color and fat color scores limited the acceptance of VITE steaks stored in MAP for 2 d. When all storage days were considered, maximum display life was an average of 6.80 +/-1.63 d for VITE steaks and 3.51 +/- 2.79 days for CON steaks. Greatest differences occurred after 8 d of storage. Since most retailers utilize a sell by date of 3 to 5 days for beef products, it is important to consider a products ability to meet this demand after storage in MAP. The current study suggests that VITE top loin steaks could be stored for up to 14 days in map systems and still achieve 4 d of acceptable

display. Moreover, VITE steaks after all storage periods, with the exception of d 2 and 10, achieved greater than 5 days of acceptable display. Conversely, CON top loin steaks would not be expected to achieve more than 3 d of retail display life if stored more than 6 d in high oxygen MAP systems.

MAP storage had no effect ($P>0.05$) on the lean color of VITE ground chuck patties stored up to 8 d prior to display when compared to patties stored 0 d in MAP packaging. CON products exhibited significant reductions ($P<0.05$) in lean color after only 2 d of storage. As discussed earlier, CON ground chuck patties exhibited a total loss of red color if stored more than 6 d. As expected VITE patties received significantly higher lean color scores than CON past 6 d of storage. VITE patties maintained acceptable lean color over a greater portion of the display period than did CON patties after all MAP storage periods (Fig. 3.11). However CON patties did maintain higher lean color scores for 0.19 d longer than VITE patties stored 0d in MAP packaging. When storage d 0 through 6 were considered VITE steaks maintained acceptable lean color for an average of 3.09 +/- 0.63 d. CON products discolored at a much faster rate and had an average of 1.97 +/- 1.66 d of acceptable display after storage from 0 to 6 d. This would account for an increase in the period of acceptable lean color display of 1.12 d by utilizing VITE ground chuck patties.

Visual assessment of percent discoloration over the storage period also yielded similar results (Fig. 3.12). No differences ($P>0.05$) were found between treatments prior to display on the percent discoloration of products stored up to 6 d. These products were also not different ($P>0.05$) in discoloration than products

stored 0 d in MAP. VITE was effective in reducing the amount of discoloration over the display period. When products stored up to 6 d in MAP are considered, days of display until unacceptable discoloration were 3.96 +/- 1.2 d and 2.08 +/- 1.5 d for VITE and CON patties, respectively. Additionally VITE was able to maintain acceptable percent discoloration after 1.93 and 1.60 d of display in products stored 8 or 10 d, respectively. If these observations were added to the above comparison, VITE patties would maintain acceptable discoloration for an average of 3.22 d after being stored for up to 10 d.

VITE patties also maintained fat color for extended portions of the display period (Fig. 3.13). Storage in MAP packaging did not affect ($P>0.05$) the fat color of products stored up to 6 d. No treatment differences during storage ($P>0.05$) were observed until 8 d of storage where CON patties lost their color. VITE patties were able to maintain acceptable fat color for an average of 3.85 +/- 1.39 d where CON patties were acceptable in fat color for an average of 2.25 +/- 1.71 d. This would indicate the ability of VITE to maintain higher fat color scores for 1.6 additional days of display.

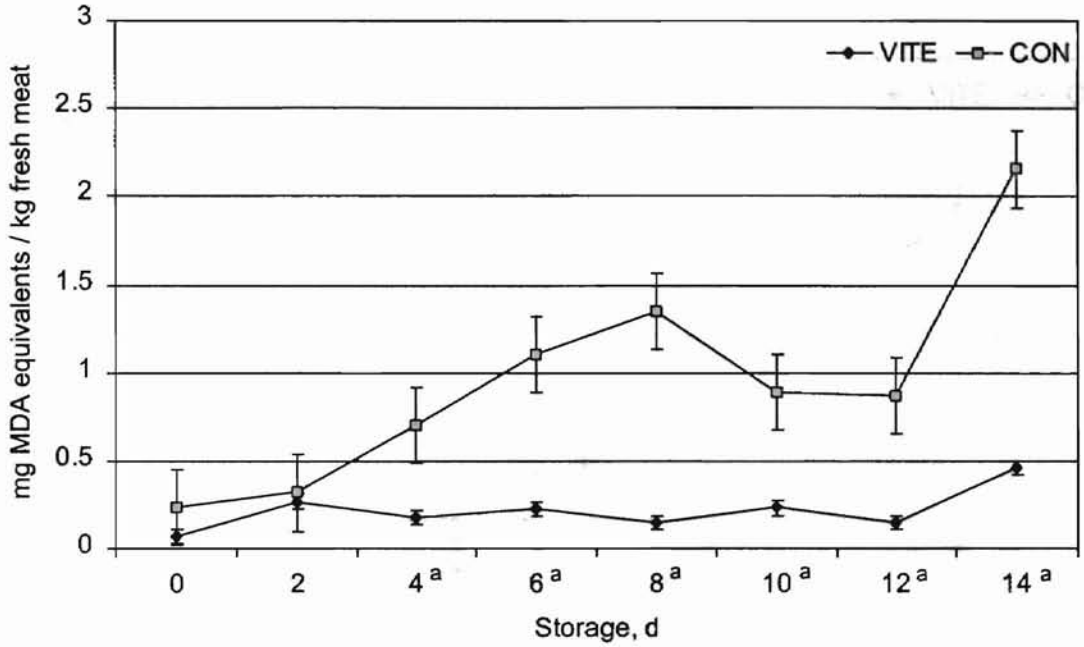
Days of display to reach unacceptable overall appearance decreased as the storage period increased for both VITE and CON patties (Fig 3.14). CON patties stored 0 d were able to maintain extended display life when compared to VITE patties. VITE was effective in increasing the display life of ground chuck patties on all other storage days. CON patties did exhibit higher ($P<0.01$) initial overall acceptance scores prior to display after 0, 4 or 6 d of storage. When d 0 through 6 of storage days were considered, maximum display life was 2.74 +/-

0.66 d for VITE steaks and 1.87 +/- 1.44 d for CON patties. An extension of .87 d was achieved with VITE supplementation. It would be important to note that VITE products stored for 8 d in MAP packaging did achieve an acceptable display life of 1.41 d. This research suggests that VITE would be beneficial in extending the color stability and display life of ground chuck patties stored in MAP packaging.

IMPLICATIONS

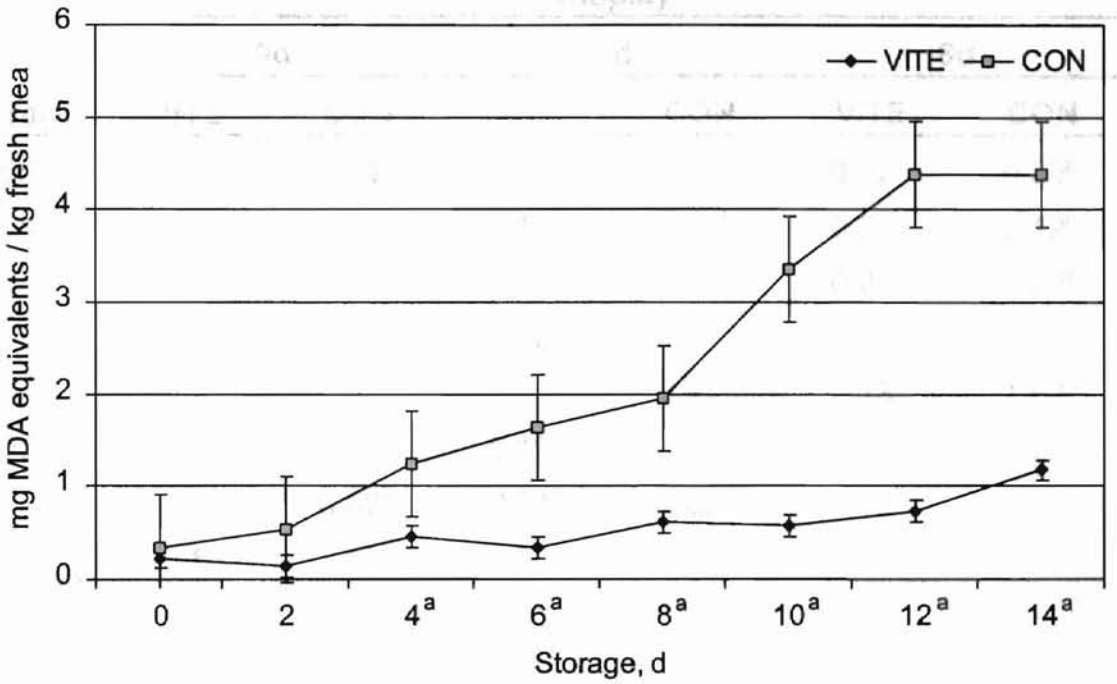
Case ready packaging is one way beef can better compete with other protein sources in today's retail environment. However the true benefit of these case ready systems has not yet been realized. The problems of lipid oxidation and reduced display stability associated with storage in high oxygen prevent beef from taking full advantage of this system's true potential. The present study shows that addition of vitamin E to the diets of beef steers would help improve the lipid and color stability of top loin steaks and ground chuck patties during MAP storage and subsequent retail display. By improving the storage and display stability of these products vitamin E can help to provide a higher quality beef product that would be more flexible at the retail level.

Figure 3.1: Effect of storage on the TBARS value of VITE and CON MAP packaged top loin steaks. Standard error bars indicated.



[a]Significantly different ($P<0.05$)

Figure 3.2: Effect of storage on the TBARS value of VITE and CON MAP packaged ground chuck patties. Standard error bars indicated.



[a]Significantly different ($P<0.05$)

Table 3.1: Effect of retail display on the TBARS value of MAP packaged top loin steaks.

	Display					
	0d		4d		8d	
Storage	VITE	CON	VITE	CON	VITE	CON
0d	0.07[a]	0.24[ab]	0.13[a]	0.33[b]	0.22[a]	0.39[b]
2d	0.27[a]	0.31[a]	0.13[a]	1.15[b]	0.23[a]	2.12[c]
4d	0.18[a]	0.70[b]	0.19[a]	1.23[c]	0.27[a]	2.20[d]
6d	0.22[a]	1.10[b]	0.28[a]	1.52[c]	0.41[a]	2.51[d]
8d	0.14[a]	1.35[b]	0.23[a]	2.27[c]	0.13[a]	1.62[d]
10d	0.23[a]	0.89[b]	0.19[a]	1.29[c]	0.15[a]	1.84[d]
12d	0.14[a]	0.87[b]	0.61[c]	2.32[d]	0.69[b, c]	3.03[e]
14d	0.46[a]	2.16[b]	0.74[c]	2.81[d]	0.89[c]	3.51[e]

[abcde]Means within the same row are significantly different ($P<0.05$) if letters differ.

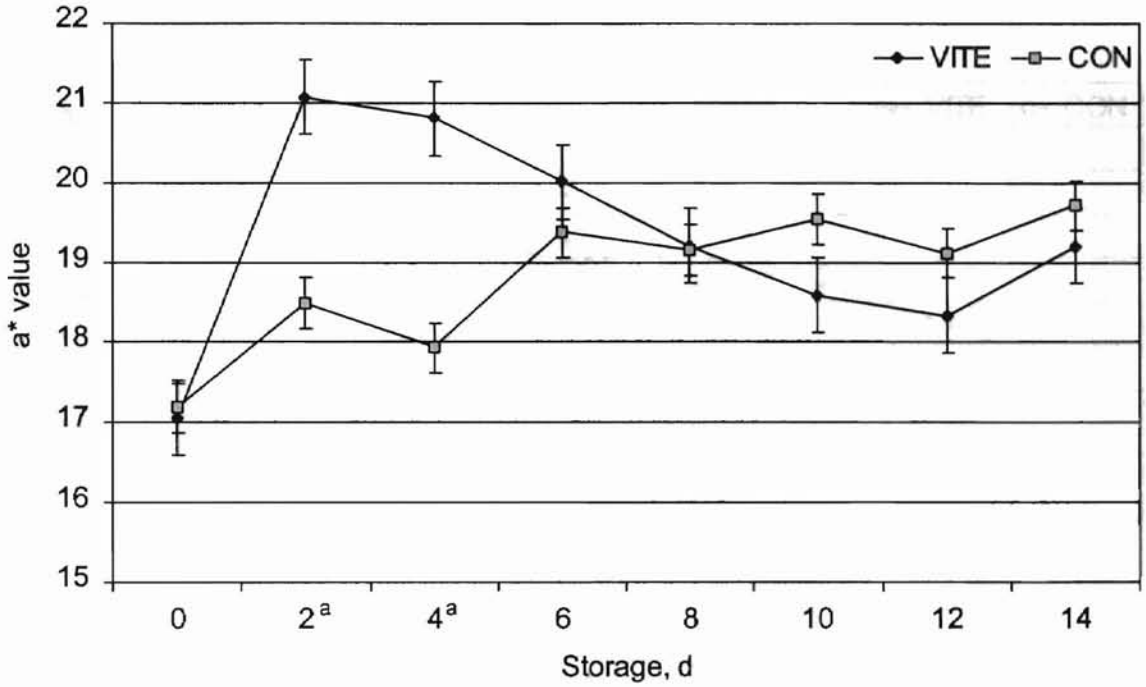
Table 3.2: Effect of retail display on the TBARS value of MAP packaged ground chuck patties.

	Display					
	0d		4d		8d	
Storage	VITE	CON	VITE	CON	VITE	CON
0d	0.23[a]	0.34[a]	0.29[a]	0.71[a]	0.49[a]	2.02[b]
2d	0.14[a]	0.53[b]	0.09[a]	0.94[c]	***	***
4d	0.45[a]	1.23[b]	0.60[a]	2.15[c]	***	***
6d	0.34[a]	1.63[b]	0.52[a]	***	***	***
8d	0.60[a]	1.96[b]	1.53[b]	***	***	***
10d	0.57[a]	3.43[b]	1.77[c]	***	***	***
12d	0.73[a]	4.37[b]	2.62[c]	***	***	***
14d	1.18[a]	4.38[b]	***	***	***	***

[abc]Means within the same row are significantly different ($P<0.05$) if letters differ.

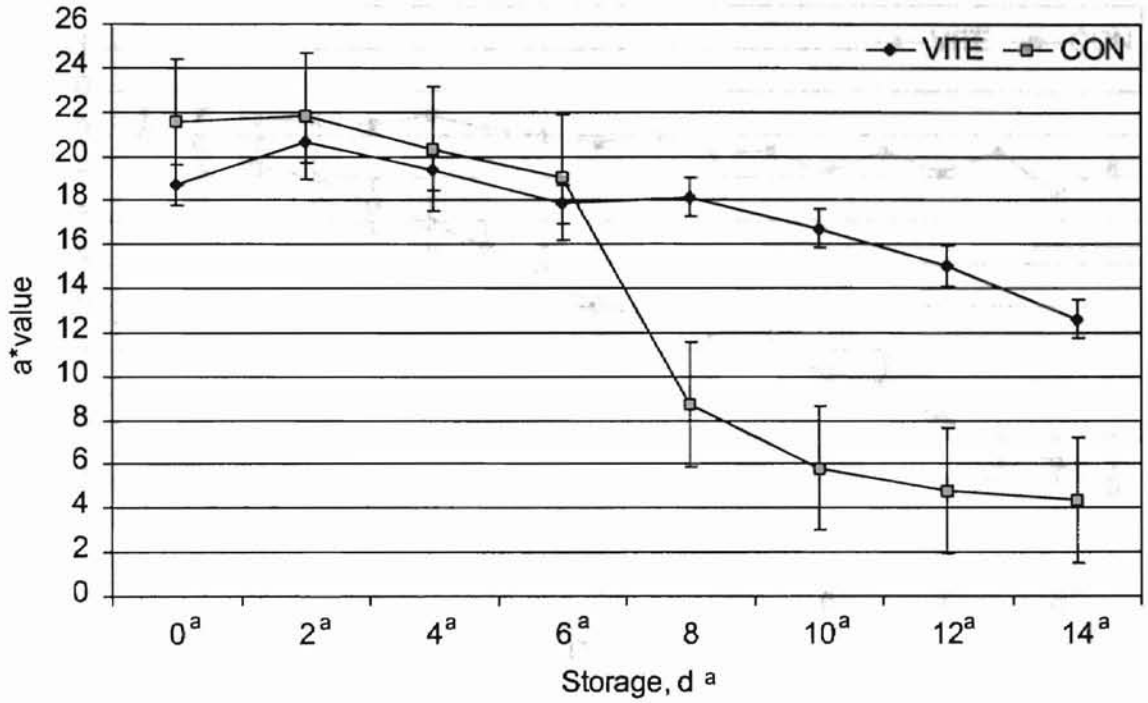
***Product removed from study prior to this observation due to color characteristics.

Figure 3.3: Effect of storage on the initial Minolta a *value of VITE and CON MAP packaged top loin steaks. Standard error bars indicated.



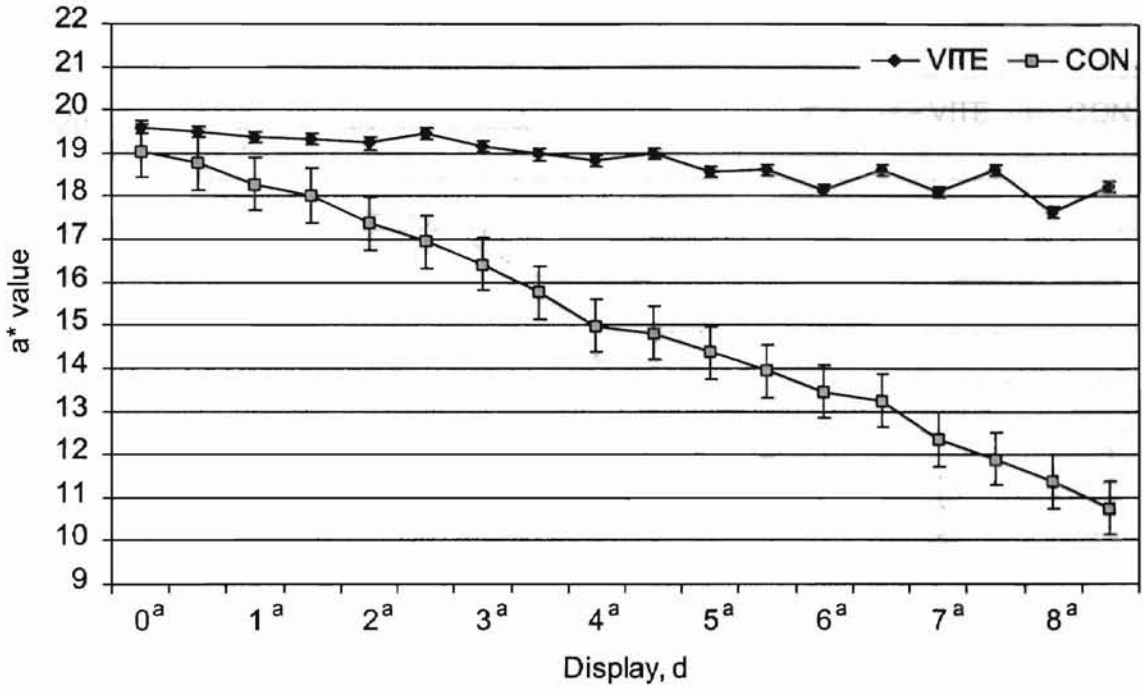
[a]Significantly different (P<0.05)

Figure 3.4: Effect of storage on the initial Minolta a *value of VITE and CON MAP packaged ground chuck patties. Standard error bars indicated.



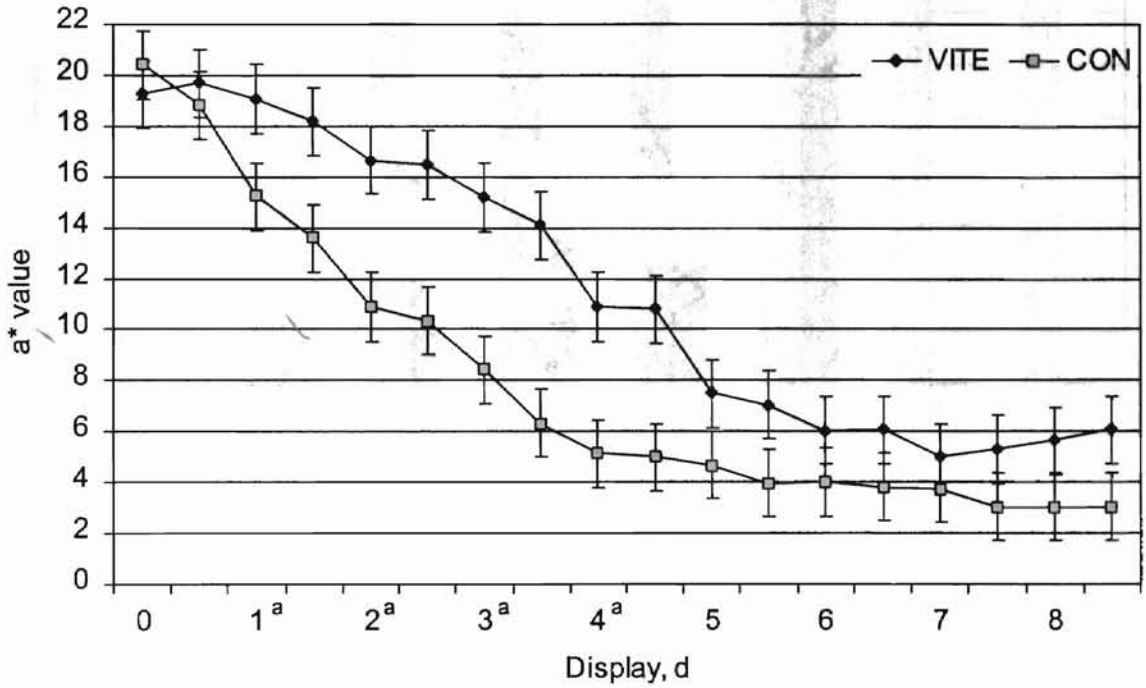
[a]Significantly different (P<0.05)

Figure 3.5: Effect of display on the Minolta a *value of MAP packaged top loin steaks averaged across all storage days. Standard error bars indicated.



[a]Significantly different (P<0.05)

Figure 3.6: Effect of display on the Minolta a *value of MAP packaged ground chuck averaged across all storage days. Standard error bars indicated.



[a]Significantly different (P<0.05)

Figure 3.7: Comparison of lean color scores for MAP packaged top loin steaks represented as days of display to reach unacceptable score.

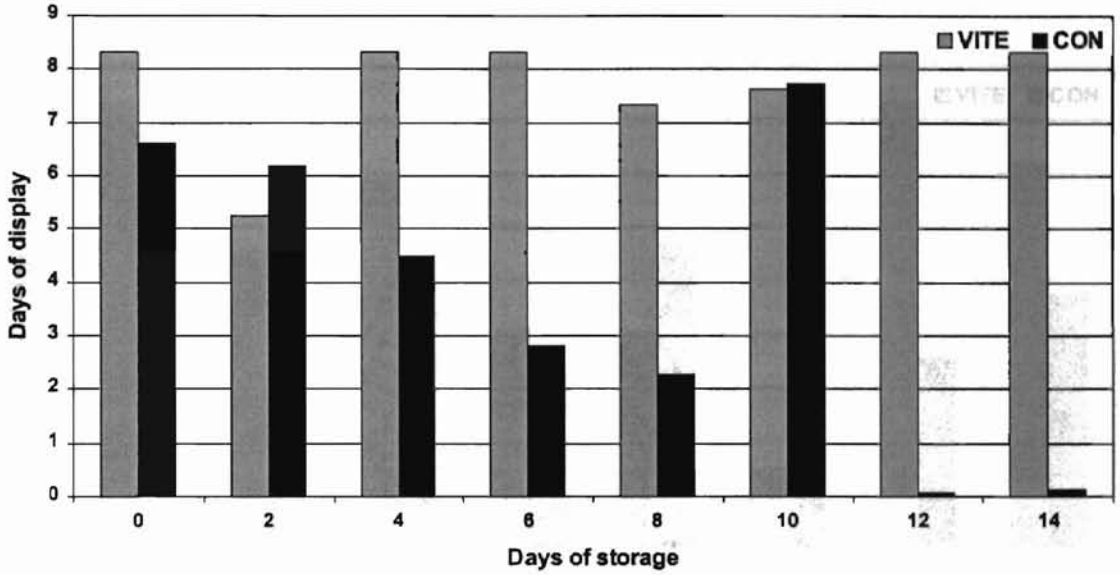


Figure 3.8: Comparison of percent discoloration scores for MAP packaged top loin steaks represented as days of display to reach unacceptable score.

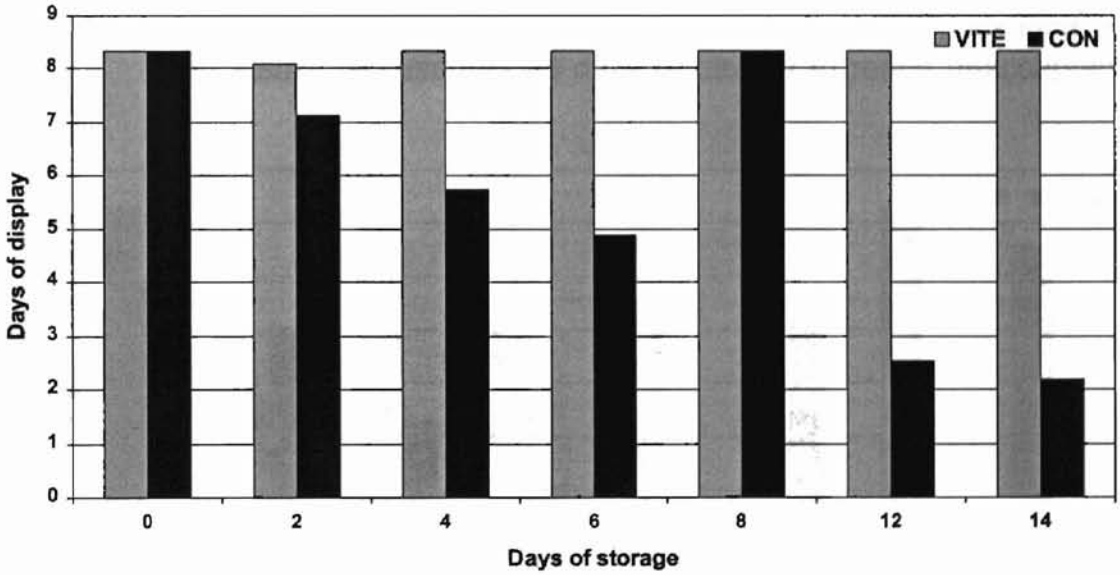


Figure 3.9: Comparison of fat color scores for MAP packaged top loin steaks represented as days of display to reach unacceptable score.

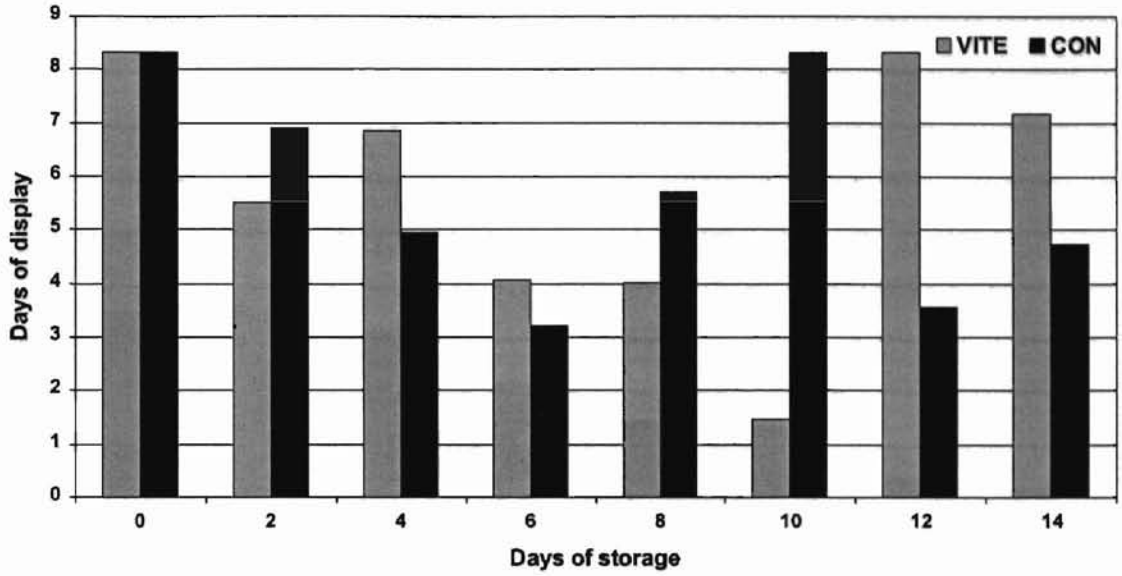


Figure 3.10: Comparison of overall acceptance scores for MAP packaged top loin steaks represented as days of display to reach unacceptable score.

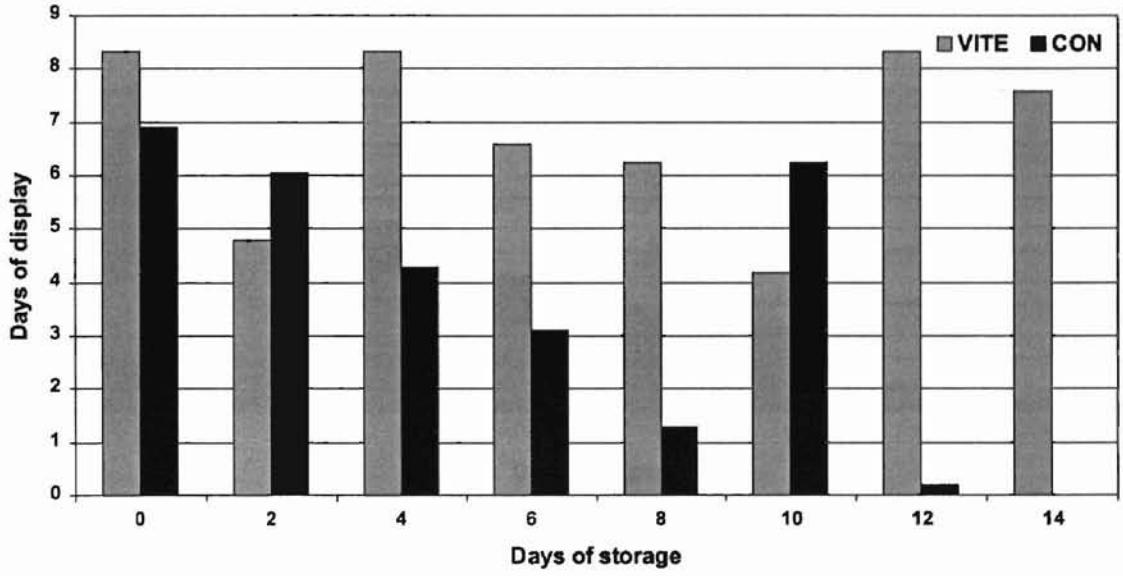


Figure 3.11: Comparison of lean color scores for MAP packaged ground chuck patties represented as days of display to reach unacceptable score.

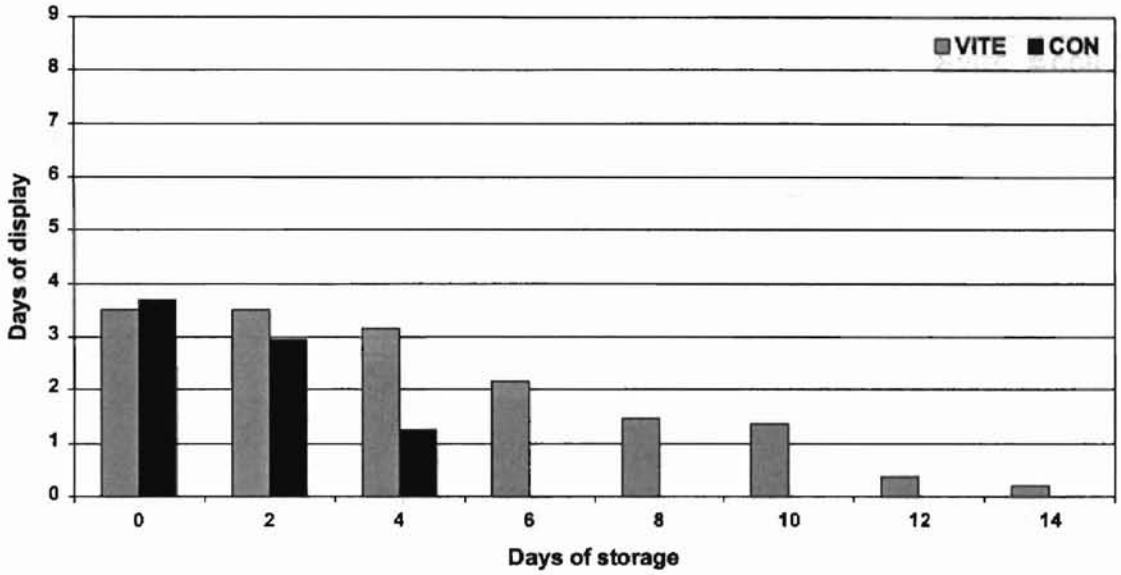


Figure 3.12: Comparison of percent discoloration scores for MAP packaged ground chuck patties represented as days of display to reach unacceptable score.

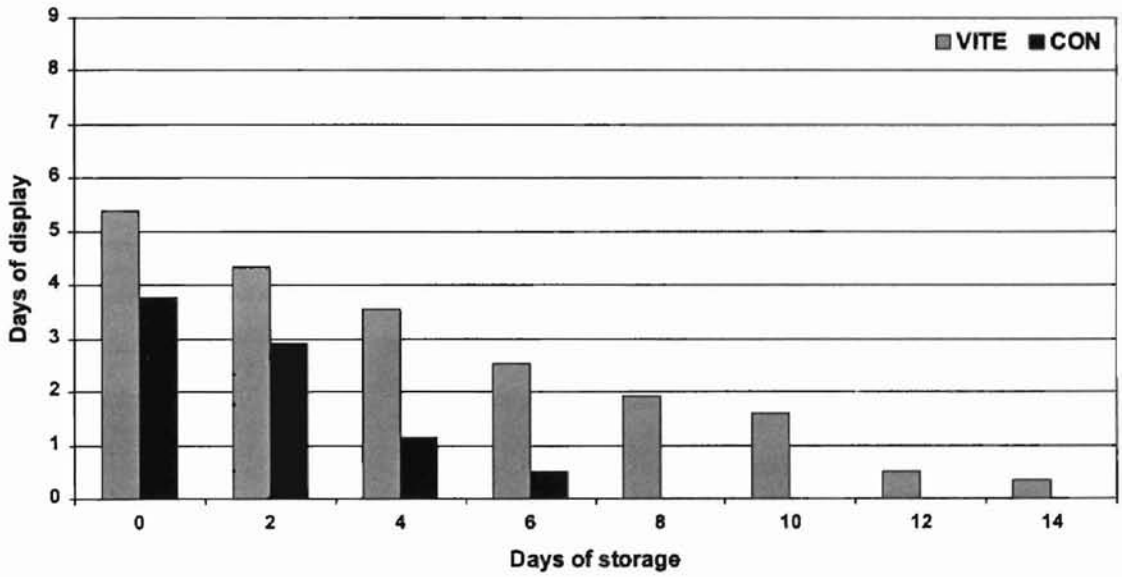


Figure 3.13: Comparison of fat color scores for MAP packaged ground chuck patties represented as days of display to reach unacceptable score.

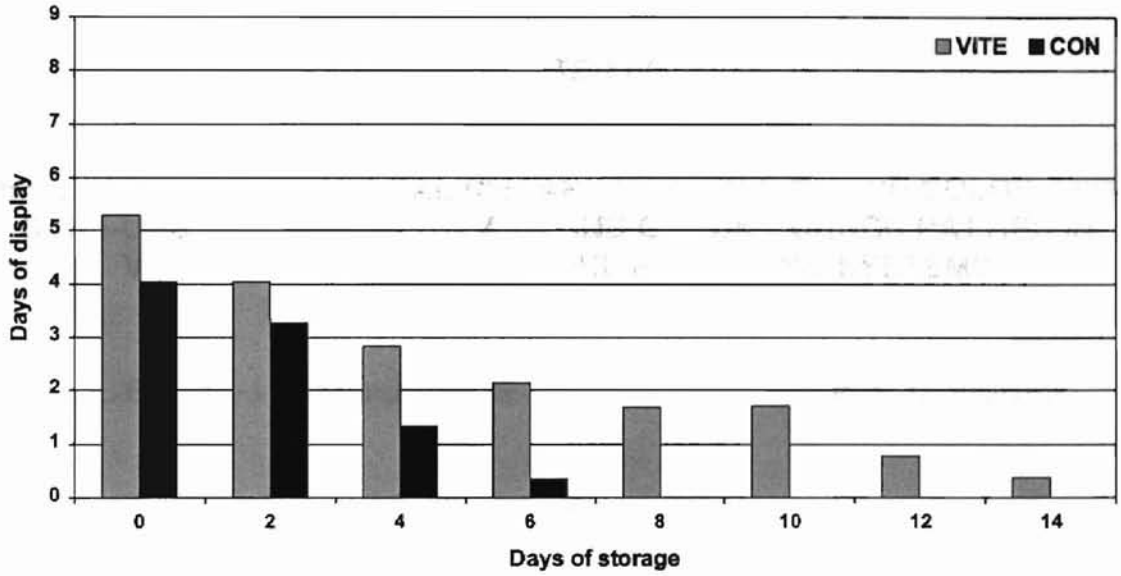
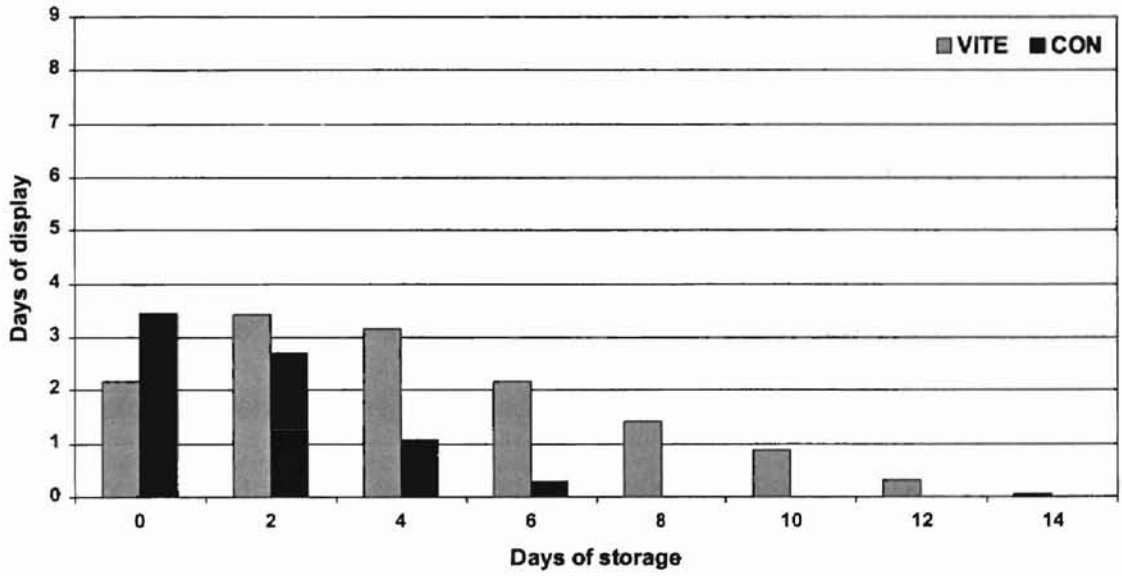


Figure 3.14: Comparison of overall acceptance scores for MAP packaged ground chuck patties represented as days of display to reach unacceptable score.



CHAPTER IV

EFFECT OF SUPPLEMENTAL DIETARY VITAMIN E ON THE COLOR AND CASE-LIFE OF TOP LOIN STEAKS AND GROUND CHUCK PATTIES IN VARIOUS CASE-READY RETAIL PACKAGING SYSTEMS

R. L. Stubbs, J. B. Morgan, H. G. Dolezal, F. K. Ray and S. E. Williams

ABSTRACT

Ground chuck and top loin steaks from cattle supplemented with either 0 (CON) or 500 (VITE) IU/hd/d for at least 100 d, of α-tocopheryl acetate were packaged utilizing two case-ready beef packaging systems. Random samples were taken from each sub-primal at fabrication in order to determine the α-tocopherol concentrations in the products. Cuts were stored at 4^0 C +/- 1^0 C for 0, 2, 4, 6, 8, 10, 12, or 14 d for ground chuck samples and additionally for 16, 18, 20, and 22 d for top loin samples. After storage, products were displayed in a retail case at 2 to 6^0 C for 8 d. Twice daily, objective and subjective measures of display color properties were obtained. Lipid oxidation (TBARS) was measured on display d 0, 4, and 8 for each supplementation by storage group combination. A higher ($P<0.03$) concentration of α-tocopherol existed in VITE than in CON products for both case-ready package types. Lipid oxidation was markedly reduced ($P<0.01$) across the display period for both VITE top loin steaks and

ground chuck patties compared to controls. Storage did not affect lipid oxidation of steaks from either TRT group however, VITE reduced ($P<0.05$) lipid oxidation during the storage of ground chuck patties. CON steaks responded better ($P<0.05$) than VITE steaks during a 2h bloom period after being stored more than 6d as indicated by higher a* values. VITE steaks were shown to retain red color more consistently throughout the display period for most storage days. VITE increased ($P<0.05$) color retention when displayed 3 d or more. Fat color of top loin steaks was unaffected by supplementation. Maximum display life increased with VITE by approximately 3 d and 1.3 d for top loin steaks and ground chuck patties, respectively. This study suggests that vitamin E would be very useful in overcoming the oxidative problems associated with case-ready retail beef systems by providing extended periods of storage and display.

INTRODUCTION

Over the past several years, many changes in retail meat products have occurred. One such change has been the progressive movement toward the reduction of labor and enhanced food safety by utilizing "case-ready" fresh poultry, fish, and pork products. Currently all poultry and most pork products arrive at retail stores as "case-ready" requiring minimal handling and processing prior to retail display. These value-added sections can easily be kept fully stocked and very presentable with limited labor as well as minimal oversight by the meat merchandisers. These advantages help make poultry and pork products more attractive and convenient to consumers then conventionally

fabricated beef items. Fabrication and packaging of beef, on the other hand, requires the majority of the time and labor in today's retail meat department.

It appears that the main limiting factor in the production of "case-ready" beef products is unstable lean color (Effertz, 1997; Schut, 1998). Due to elevated myoglobin content associated with beef muscle, its relative color stability is much more of a concern than that of poultry products. Consumers associate a bright, cherry red lean color with beef freshness (Kropf, 1980). This color is due to the oxygenation of myoglobin in the muscle fibers of beef to oxymyoglobin. After the product has "bloomed", (i.e. oxygenated to bright cherry red), muscle pigments begin to oxidize to metmyoglobin. Once approximately 70% of the myoglobin population becomes oxidized beef becomes a brown color and is discounted or even discarded (Daun et al., 1971). Oxygenation of meat occurs approximately 30 minutes after the cut surface is exposed to oxygen and normally lasts for approximately 3 d in retail applications (Smith et al., 1996).

Currently most case-ready systems involve the utilization of either vacuum or modified atmosphere (MAP) packaging systems. Vacuum packaging systems do not allow for beef products to bloom during retail display, and retail cuts thus are presented in their deoxygenated myoglobin state. The resulting purple lean color of deoxygenated beef products has been found to be less acceptable to consumers (Pelzer et al., 1991). High oxygen MAP packaging systems are effective in retaining the red color of beef products by maintaining myoglobin in the oxygenated state (Daun et al. 1971). One draw back to high oxygen MAP systems is an increase in lipid oxidation as a result of the pro-oxidant

atmosphere created (Houben et al., 1998). Lipid oxidation products have been shown to reduce color display life of conventionally packaged retail beef products (Schaefer et al., 1995), and create an undesirable warmed-over flavor in cooked beef products (St. Angelo, 1996). In order for beef merchandisers to effectively utilize current case-ready systems, the oxidative processes that reduce the quality of these products must be overcome.

Addition of vitamin E to the diet of finishing steers improves the case-life of "normal" beef products as shown in the Domestic Shelf Life Alliance Study (Westcott et. al., 1997). Vitamin E is also helpful in reducing lipid oxidation by acting as a free radical quencher (Faustman et al. 1998). The utilization of vitamin E in branded "case-ready" programs could potentially help the packer/processor provide a more consistent, made to order, longer-lasting product to the retailer and eventually to the ultimate consumer. If effective, the addition of vitamin E and the built-in advantage of packer sanitation in centralized cutting programs could potentially help their product actually out perform the product fabricated at local retail markets. This study is designed to investigate the additive ability of dietary vitamin E supplementation to increase the performance of ground chuck and beef top loin steaks in case-ready applications through reduction of lipid and muscle pigment oxidation.

Experimental Procedures

Meat Sample Preparation

Boxed beef subprimals, strip loins (IMPS #180a) and neck-off chuck rolls

(IMPS #116), were obtained from beef cattle that were supplemented with either 0 (CON) or 500 (VITE) IU/hd/d of dietary vitamin E in the form of *dl*-α-tocopheryl acetate (Roche Vitamins, Nutley, NJ). Approximately twelve top loin steaks (1.54 cm thick) were hand cut with a sanitized knife from each of six strip loins for each treatment group (n = 66 / treatment). Steaks were placed on sanitized metal trays and covered with butcher paper for transfer to the packaging room. Whole neck off chuck rolls were ground once through a 1.27 cm plate and twice through a 0.32 cm plate to ensure equal fat distribution. After grinding and mixing, patties (approximately 113 g each) were formed with a Hollymatic Super Patty Molding Machine (Hollymatic Corp., Chicago, IL) for each treatment group separately (n = 42 / treatment). Two ground chuck patties were then placed in to individual Cryovac® Barrier Foam Trays (Cryovac, Duncan, SC) with Dry-loc meat pads (Sealed Air Corp., Patterson, NC). These two patties were stacked to provide an acceptable meat to head space ratio and all analyses were performed on the top patty. Both top loin steaks and ground chuck patties were then packaged in Cryovac® Peelable Vacuum Skin Packs or Cryovac® Barrier Foam Packs, respectively.

Random samples were taken from strip loins (n= 10) from each treatment and from the bulk ground chuck (n=4) from each treatment for laboratory analysis for α-tocopherol acetate concentration (Liu et al., 1996) by the Soil and Plant Analysis Laboratory at the University of Wisconsin, Madison.

Packaging

Within 20 min of retail fabrication meat samples were packaged. Individual top loin steaks were placed on a Multi-vac R5-70-CDP roll stock Vacuum Skin Package (VSP) machine and packaged using Cryovac® Peelable VSP film (Cryovac, Duncan, SC). This film is a two part system that utilizes a barrier film heat shrunk over-wrap on a heat formed barrier tray. The over-wrap layer can be removed, exposing an oxygen permeable layer, to allow the product to bloom for retail display. Cryovac® Barrier Foam Trays containing ground chuck patties were packaged using a Ross INPACK 3320 and utilizing Cryovac® Lid 550 barrier film (Cryovac, Duncan, SC). This created a self contained modified atmosphere package (MAP) containing 80 % oxygen and 20 % carbon dioxide. All packages were identified by treatment and packaged into ice chests for shipment to the Oklahoma Food and Agricultural Products Research and Technology Center (FAPC) on the Oklahoma State University campus via next day air express for storage and display. Once at FAPC, packages within each treatment group were randomly assigned an identification number that corresponded to a particular storage and display time. Six ground chuck patties (3 per TRT) or twelve top loin steaks (6 per TRT) were placed in individual cardboard boxes for storage.

Storage and Display

Individual packages were stored in cardboard boxes in the absence of light for 2, 4, 6, 8, 10, 12, or 14 d at 2^0 C +/- 1^0 C for ground chuck and

additionally for 16, 18, 20, and 22 d for top loin steaks. After their designated storage time was achieved, individual packages were removed from their boxes and placed in a commercial retail display case for 0, 4, or 8 d under cool-white florescent light (1600 to 1900 lux) at 2 to 4^0 C. Top loin steak packages were "peeled" to remove the barrier layer, allowing the product to contact oxygen immediately prior to display. Packages were rotated randomly in the case once daily and new packages were added to random locations in the case. Products were removed after 0, 4 or 8 d of display for analysis of lipid oxidation.

Bloom Response Assessment

After 2, 4, 6, 8, 10 ,12 ,14, 16 ,18, 20, and 22 d of storage, bloom response of Peelable VSP packaged top loin steaks was determined using a Minolta CR-300 colorimeter (Minolta Co. Ltd. Osaka, Japan). Three L, a*, b* readings per steak were taken every 15 min for 2 h immediately following removal of the barrier layer from the package as described above. For each storage d 2 randomly chosen steaks from each treatment group were utilized for these bloom response comparisons.

Color Assessment

Twice daily retail display products were objectively evaluated for lean color using a Minolta CR-300 colorimeter (Minolta Co. Ltd. Osaka, Japan). L, a*, b* values were recorded for each sample until its designated removal day. Measurements were taken at medial, central and lateral positions of the steak. These color measurements were of the lean color only, and precaution was

taken to avoid any intramuscular fat. Four measures were taken from each ground chuck patty at each observation time. Measurements were taken at each quarter section of the patty by inverting the package to allow the meat to come in contact with the film. All samples, ground chuck and top loin steaks, were also visually evaluated twice daily by a three member trained panel for lean color (8 = bright cherry-red, 1 = extremely dark-brown), fat color (8 = creamy white, 1= Dark-brown or green), percent discoloration (7 = none, 4= 26 to 50%, 1 = complete), and overall appearance (7 = extremely desirable, 1 = extremely undesirable) according to the procedures outlined in Sanders et al, 1997. Due to independent bloom response evaluations, all color and acceptance variables for top loin steaks were measured starting at the p.m. observation time of d 0.

Lipid Oxidation

On d 0, 4, and 8 of retail display duplicate samples for each treatment by storage group combination were removed from the case and frozen at -20^0 C until further analyzed. Thiobarbituric Acid (TBA) analysis was performed using the test procedure described by White et al. (1970) with the following modifications: a 10 g sample was used in the extraction step, and 30 ml of the resulting slurry was centrifuged at 3000 RPM for 30 minutes prior to filtration. Results were reported as thiobarbituric acid reactive substances (TBARS) representing mg malondialdehyde (MDA) equivalents per kg of fresh meat.

Statistical Analyses

The Least Squares Means option of the General Linear Model procedure

of SAS (SAS Institute Inc., Cary, NC) was used to compare means for treatment (TRT) by storage group (STORE) by display interactions. Objective color and visual panel data were analyzed with a split plot design with TRT, STORE and assigned display period before removal (0, 4, or 8 d) (DAY) in the main-plot utilizing STEAK(TRT*STORE*DAY) as the error term, and display as a repeated measure in the sub-plot utilizing residual error. Trends in a* values, lean color, fat color, percent discoloration, overall appearance, and TBARS over display time were fitted via regression. First, second, and third order regressions were fitted for all factors and the best fit regression was defined as having significant ($P<0.05$) model and parameter estimates. In cases where more than one order of regression for a given factor had significant model and parameter estimates, the highest R^2 value determined the best-fit line. Dummy variables were used to test if data from adjacent storage days within a treatment had statistically similar regression lines. If these regression lines were not statistically different ($P>0.05$) the data was then pooled and a single line was fit as described above. This occurred only for the TBARS variable. Visual acceptance data ranges were calculated by solving regression equations to determine at which level of display a given factor became unacceptable. Unacceptability was defined as the point on the visual scale where a panelist would determine a factor unacceptable (i.e. <4.5 on an 8-point scale). Overall benefit for the visual panel factors was calculated as the average of the treatment differences over all storage days and reported with resulting standard deviations. Overall acceptability scores were used in this manner to determine maximum display life of products. Dummy

variables were also used to associate treatments with each regression coefficient, and F-tests were then used to determine if differences existed in slopes and intercepts of the fitted lines.

RESULTS AND DISCUSSION

Alpha-tocopherol Concentrations

Tissue concentration analysis for α-tocopherol in randomly selected samples from top loin steaks revealed that α-tocopherol levels in VITE samples were 64.0% higher than were the levels in CON samples (2.69 μg/g vs. 1.64 μg/g, respectively) (P=0.03). Similarly it was found that α-tocopherol concentrations in VITE ground chuck samples were 61.5% higher than for controls (5.96 μg/g vs. 3.70 μg/g, respectively) (P=0.02). Steak tissue α-tocopherol concentrations were found to be significantly lower (P<0.01) than tissue concentrations of ground chuck samples, when analyzed in the absence of treatment effects (2.17 μg/g vs. 4.83 μg/g, respectively). Differences in concentrations between steaks and ground chuck could be attributed to differences in α-tocopherol accumulation rates of their muscles of origin (Arnold et al.,1993a, b). Liu and co-workers (1996) suggested that there is no clear explanation for such differences. Because vitamin E is a fat-soluble vitamin, it is possible that the relative fat content differences may contribute to the observed variation in α-tocopherol levels between ground chuck patties and top loin steaks.

Lipid Oxidation

Lipid oxidation over the entire storage period for Peelable VSP packaged top loin steaks, as indicated by thiobarbituric acid reactive substances (TBARS) accumulation, was not significantly affected by TRT ($P>0.05$) (Fig. 4.1). Least squares means comparisons revealed that TBARS values immediately after storage and prior to display were not different ($P>0.1$) between TRT for all storage periods with the exception of d 6 and d 20. Further analysis revealed that differences on these days were attributed to uncharacteristically high TBARS values in CON products. VITE top loin steaks demonstrated no significant ($P>0.1$) increase in TBARS accumulation immediately prior to display during the entire 22d storage period. Similarly no differences ($P>0.1$) were exhibited in TBARS accumulation during storage of CON steaks, with the noted exceptions at d 6 and 20. These analyses suggest that the anaerobic conditions of Peelable VSP packaging is sufficient in retarding lipid oxidation during storage of top loin steaks for up to 22 d. This could be expected due to lack of O_2 needed in the initiation and propagation of lipid oxidation reactions.

Regression analysis of TBARS accumulation in Peelable VSP packaged top loin steaks over the display period is represented in Figure 4.2 where statistically similar regression lines within treatments are pooled to show trends. Lipid oxidation occurred at similar rates in VITE steaks stored for up to 16 d ($P>0.05$). VITE steaks stored 20 or 22 exhibited a similar rate of TBARS accumulation up to 4 d of display but demonstrated more dramatic increases of TBARS later in the display period than VITE steaks stored up to 16 d. VITE

steaks stored 18 d (not represented graphically) exhibited higher than expected values after 4 d of display (0.97 TBARS) when compared to values at d 0 (0.07 TBARS) and d 8 (0.03 TBARS). CON steaks exhibited trends in TBARS accumulation rates when stored between 2 and 4 d. As seen in VITE samples, CON products accumulated TBARS at a similar rate up to 4 d of display after all storage periods, but exhibited more dramatic increases in the later display period if stored between 8 and 22 d. Comparisons across treatments revealed that VITE supplementation was able to significantly reduce the occurrence of lipid oxidation after 4 or 8 d of display by 42.3% and 51.3%, respectively.

Analysis of TBARS data for Barrier Foam packaged ground chuck revealed significant TRT effects during both storage and display ($P<0.01$). The effect of storage on the TBARS value of ground chuck patties prior to display are represented in Figure 4.3. VITE patties demonstrated significant reductions ($P<0.01$) in lipid oxidation when compared to CON over the entire storage period, with the exception of d 6 where no differences ($P>0.05$) were found. VITE TBARS values at d 6 were untraditionally high. Noting this exception, no significant difference ($P>0.05$) was observed within individual treatments until the storage period reached 10 d or more where both VITE and CON patties exhibited increases in TBARS accumulation ($P<0.05$).

The effect of display on the TBARS accumulation in ground chuck patties is presented in Table 4.1. When similar storage and display periods are considered, VITE patties were able to maintain significantly lower ($P<0.05$) TBARS values at all but 2 comparisons, where VITE samples were numerically

lower than CON patties. Comparisons of least squares means within individual treatments across all storage days indicate that no differences were present (P=0.65) between 0 and 4 d of display for VITE ground chuck patties. This was not found in CON patties. In fact, the mean TBARS values for all storage periods indicated that VITE patties displayed 8d had less (P<0.01) average lipid oxidation than CON products displayed 0 d (1.32 vs. 1.86, respectively). This suggests the overwhelming benefit of vitamin E supplementation in the reduction of lipid oxidation of ground chuck patties packaged in these systems. Faustman and co-workers (1989) have also reported the ability of vitamin E supplementation to reduce lipid oxidation during display of ground sirloin patties packaged using conventional methods. Houben and others (1998) also discovered that high oxygen gas packaging did not influence lipid oxidation in VITE minced pork when compared to conventionally wrapped VITE products. The current study suggests that vitamin E would be invaluable in protecting ground chuck patties against lipid oxidation when utilized in high oxygen Barrier Foam packaging applications.

Bloom Response

Analysis of bloom response in the absence of treatment effects revealed significant differences (P<0.01) in a* values between storage days over the display period. Peelable VSP packaged steaks bloomed, became more red, faster as the storage period increased. This was evident until d 20 and 22 where reductions in bloom response were observed. The highest a* value during the

bloom period was achieved after 18 d of storage and 2h of display (a* = 20.98). The lowest end point a* value after the 2h of bloom period occurred at 2d of storage and was significantly different ($P<0.05$) than all other storage day end points. Utilizing relationships between partial pressures of oxygen (pO_2) and lean pigment color, it could be suggested that storage in Peelable VSP film for periods less than 2 d would be undesirable due inadequate myoglobin reduction time. Low pO_2 is known to favor oxidation of oxymyoglobin to metmyoglobin (Price and Schweigert, 1971). Faustman and co-workers (1998) reported that for anoxic storage of beef products to be effective, complete reduction of myoglobin must be achieved. The current study suggests that storage times greater than 2d would be effective in reducing myoglobin prior to display.

Differences in TRT Least squares means for a* values over the storage period are represented in Figure 4.4. No significant TRT differences ($P>.05$) were observed in top loin steaks stored for up to 6 d. CON steaks had higher ($P<0.05$) a* values (were more red) after 8 through 22d of storage, with the exception of d 10 where no differences were observed and d 16 where VITE a* values were significantly ($P<0.01$) higher than CON. Regression analysis of bloom response over the entire storage period showed that initial a* values (storage d 2) were not different ($P>0.1$) for treatments and CON steaks achieved higher ($P<0.05$) a* values than did VITE steaks as the storage period increased. The current study suggests that CON steaks would have an advantage in bloom response over the 2 h bloom period in this packaging system. This advantage seemed to be more evident as the storage period increased.

Lean Color

Storage effects on the lean color of Peelable VSP packaged top loin steaks are presented in Figure 4.5. These comparisons are of the least squares means from the first observation following the bloom period. CON and VITE steaks were found to be of the same red color (P>0.05) after all storage periods with the exception of d 2 and 8 where CON steaks were able to maintain higher initial red values. When one considers the differences observed during the bloom phase, this data would indicate that after a reasonable equilibration time these differences would be nullified. As the storage period increased initial a* values also seemed to slowly increase to a maximum point between 16 and 18 d of storage. Extended periods of storage (> 18 d), revealed a decreasing trend in the ability to retain red color for both treatments. Reductions after d 10 and 12 were confounding yet similar for both treatments.

Comparisons of a* values over the 8 d display period averaged across all storage days are presented in Figure 4.6. CON top loin steaks displayed 2 d or more were found to lose there color at a much faster rate than VITE steaks (P<0.01). No color differences were observed (P>0.1) at both observations of d 1, and CON steaks were higher in red color at the initial observation (P<0.01) of d 0. This data would suggest that VITE retained the ability to limit pigment oxidation during aerobic display after anaerobic storage in Peelable VSP packaging. Regression analysis of individual storage days confirmed the ability VITE steaks to maintain higher a* values (P<0.01) and discolor at a significantly less rapid rate (P<0.01) over the display period when stored 4 d or more.

However analysis of storage d 10 exhibited no difference (P=0.25) in mean a* value over the display period between treatments. CON steaks stored 10 d did not discolor as rapidly when compared to CON steaks from adjacent storage days. In a parallel study conducted weeks before the current study, CON top loin steaks packaged in high oxygen MAP systems were also found to exhibit uncharacteristic increases in color stability at 10 d of storage. No previously reviewed literature has reported this phenomenon. Further investigation could be warranted to determine if such a response could be consistently repeated.

The effect of storage of ground chuck patties in Barrier Foam packaging on the initial a* value immediately prior to display is represented in Figure 4.7. CON products stored either 2 or 8 d exhibited significantly higher ($P<0.05$) initial a* values, while VITE patties stored 12 d were significantly more red ($P<0.05$) than controls. No differences were observed after 4, 6, 10, or 14 d of storage. Both VITE and CON patties were able to maintain similar red color when stored up to 10 d. Reductions in a* values ($P<0.05$) were observed in both treatments after storage for 12 or 14 d. The lack of a uniform color stability advantage would suggest that the intended mechanism of this packaging system was equally capable of maintaining red color during the storage period regardless of treatment. By maintaining high partial pressures of O_2, Barrier Foam packaging limits pigment oxidation by retaining oxymyoglobin has the dominant pigment (Renerre,1990). However, differences in the ability to maintain red color during display were observed between treatments (Fig. 4.8). VITE ground chuck patties exhibited higher ($P<0.05$) a* values than CON ground chuck patties when

displayed 3 d or more. Though both treatments did show significant decreases in a* values over the 8 d display period.

Subjective color analysis

VITE top loin steaks showed extended display acceptability for lean color scores on d 6, 8, 12, 14, 18, 20, and 22 of storage (Fig. 4.9). No differences were observed on d 2, 4, and 10. The maximum lean benefit was achieved on d 18 where lean color for VITE steaks was acceptable throughout the display period and CON steaks discolored after only 1.07 d of display. When all storage days were considered, VITE steaks retained acceptable lean color for an average of 7.58 +/- 1.06 d while CON steaks retained acceptable lean color for an average of only 4.12 +/- 3.1 d. Percent discoloration data for top loin steaks (Fig. 4.10) also revealed significant ($P<0.01$) differences between treatments. It was found that VITE Steaks maintained higher acceptability levels over a greater portion of the display period for all storage days except d 2, 4, and 10, where no differences were observed. VITE steaks maintained acceptable discoloration for an average of 7.99 +/- 0.61 d of display while CON steaks were acceptable for only 5.24 +/- 2.28 d of display. These results suggest that VITE steaks were better able to retain red color and prevent discoloration for a greater portion of the display period after storage in Peelable VSP packaging.

Comparison of fat color for top loin steaks (Fig. 4.11) showed no TRT differences ($P>0.1$) between storage days. The average benefit for VITE steaks was 0.84 (+/-1.78) d which also suggests that fat color was similar for both

treatments. Comparisons of Least squares means showed no difference (P>0.1) between storage days until d 18 and 20 where average acceptability was higher (P<0.01) for VITE steaks. Significant TRT differences (P<0.05) over the display period were observed, where VITE fat color was found to be more acceptable on display d 5 through 8 when averaged across all storage periods. Sanders and others (1997) found vitamin E supplementation to have no effect on visual panel fat color acceptance scores. The current study would suggest that during a traditional 3 to 5 day retail display period, VITE steaks would not demonstrate improved fat color.

The maximum display life for VITE steaks was increased by an average of 3.08 (+/-2.18) d of display (Fig. 4.12). No differences (P>0.10) in overall acceptability were present at d 2 and 4 of storage. An increase in display life of over 2.5 d occurred after all other storage periods except for d 14 where it seems fat color limited overall acceptance (Fig. 4.11). This would suggest that by supplementing cattle with VITE gains could be made by extending display life of Peelable VSP packaged top loin steaks. For all storage days VITE steaks remained acceptable for over 5 d of display except on d 14 (1.99 d) and 20 (4.21 d). Since retailers utilize a sell by date of 3 to 5 d for fresh beef products this research indicates that VITE supplementation would allow for traditional display life for products stored up to 22 d. Along these lines CON products achieved a display life of less than 3 d if stored 10 d or more. This suggests in order to achieve traditional display life in retail applications CON products in Peelable VSP film should not be stored longer than 10 d, while the storage period of

Peelable VSP packaged top loin steaks could be extended to 22 d. By utilizing vitamin E beef in this system, a retailer could benefit from added flexibility of the product. By extending the storage stability of these products, it would enable the retailer to have more "on hand" product which could help reduce lost sales due to out of stock items during periods of unpredictably high demand.

As expected acceptance for all visual variables of ground chuck patties decreased ($P<0.01$) as storage the storage time increased. TRT differences existed over all factors resulting in VITE supplemented ground chuck maintaining higher levels of acceptability for a greater portion of the display period. When all storage days were considered, lean color acceptance was improved by an average of 1.65 +/- 0.54d with vitamin E supplementation. VITE patties showed improved lean color acceptability over CON patties after all storage periods. Lean color gradually decreased over the storage period for both TRT (Fig. 4.13), except for an non uniform increase at d 10 for VITE patties. Similar trends were exhibited in fat color and percent discoloration (Fig. 4.14,4.15) which were improved by VITE supplementation by 1.29 +/- 0.53d and 1.39 +/- 0.62d, respectively. The noted difference after 10 d of storage was also seen in these factors.

Maximum display life was increased by an average of 1.34 (+/-0.45) d with VITE supplementation when considered across all storage periods (Fig. 4.16). Overall acceptance scores were found to be different ($P<0.05$) between treatments over the display period but were not different ($P>0.1$) over the storage period. This, in combination with the significant ($P<.01$) storage by display

reduction noted above, would suggest a similar VITE advantage after all storage d. As observed in top loin steaks, VITE ground chuck patties exhibited traditional retail display life (1.5d) after all storage periods. Both treatments did however exhibit dramatic declines in maximum display life if stored more than 10 d. CON products were unable to maintain acceptable overall scores for at least one day of display if stored 12 d or more. This would suggest that the storage periods longer than 10 d would be inappropriate for CON ground chuck patties. The noticeable reductions in display acceptability of VITE products after 12 d or more of storage suggest that display stability is compromised. Even though 1 d or more of display can be achieved after extended periods of storage, to ensure a quality product that will retain desirable visual appeal in the consumers home VITE products should also not be stored more than 10 d. In the case of extended storage VITE would be assumed to have more benefit in providing visual appeal after the sale, as opposed to trying to achieve an extra day or two of storage.

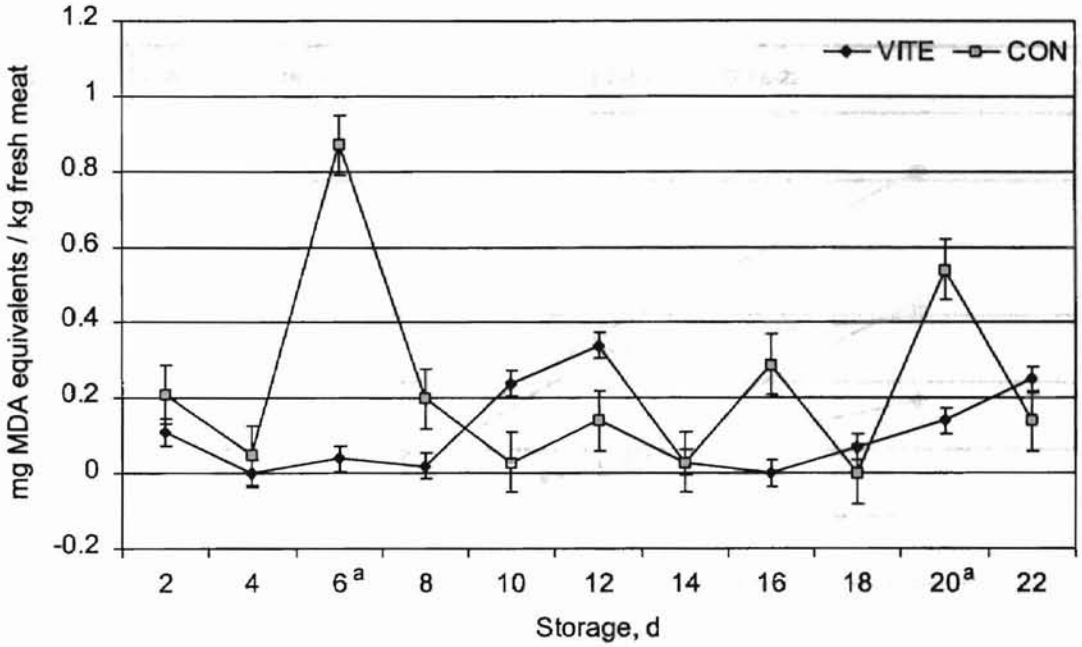
This study indicates the ability of vitamin E supplementation to provide extended storage and display stability of both Barrier Foam packaged ground chuck and Peelable VSP packaged top loin steaks. This in turn provides the retailer with a long lasting, bright red, display ready product.

IMPLICATIONS

This research shows that vitamin E supplementation has significant effects in reducing the oxidative processes that create undesirable

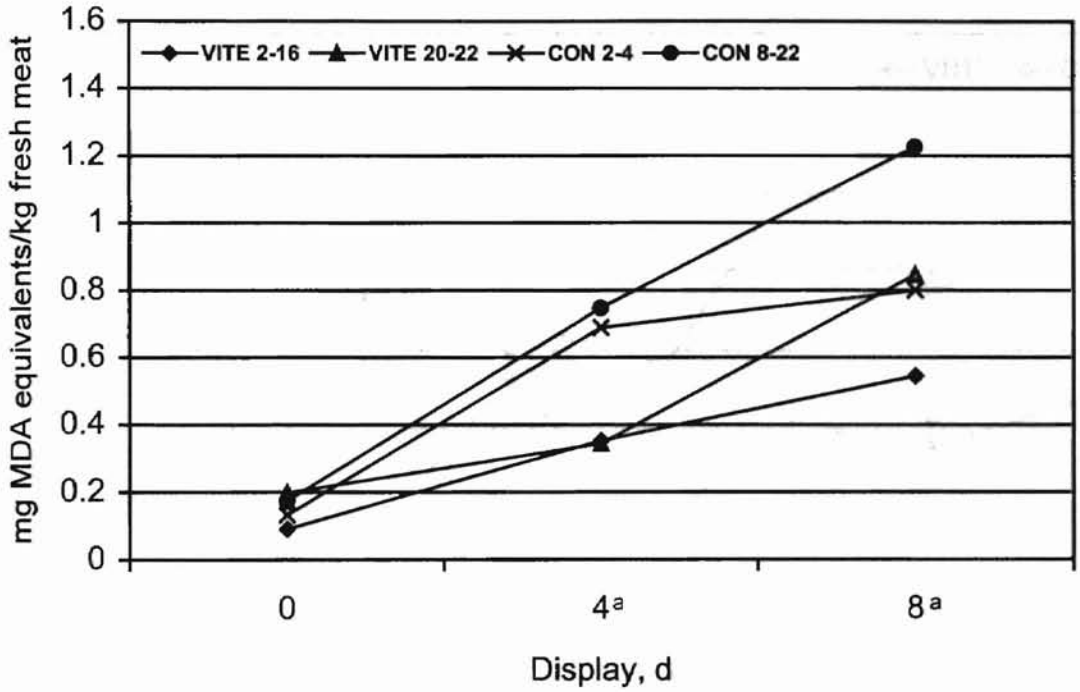
characteristics in case-ready beef. Vitamin E supplementation was shown to maintain color and visual acceptance scores for longer periods of display in both Peelable VSP packaged top loin steaks and Barrier Foam packaged ground chuck patties. Extending the storage and display life of case-ready beef products, vitamin E has the potential to help beef better compete with other case-ready protein sources. The combination of case-ready packaging and vitamin E supplementation can help beef products become more appealing and convenient to today's retail consumer.

Figure 4.1: Effect of storage on TBARS accumulation in top loin steaks packaged in Peelable VSP systems. Standard error bars are indicated.



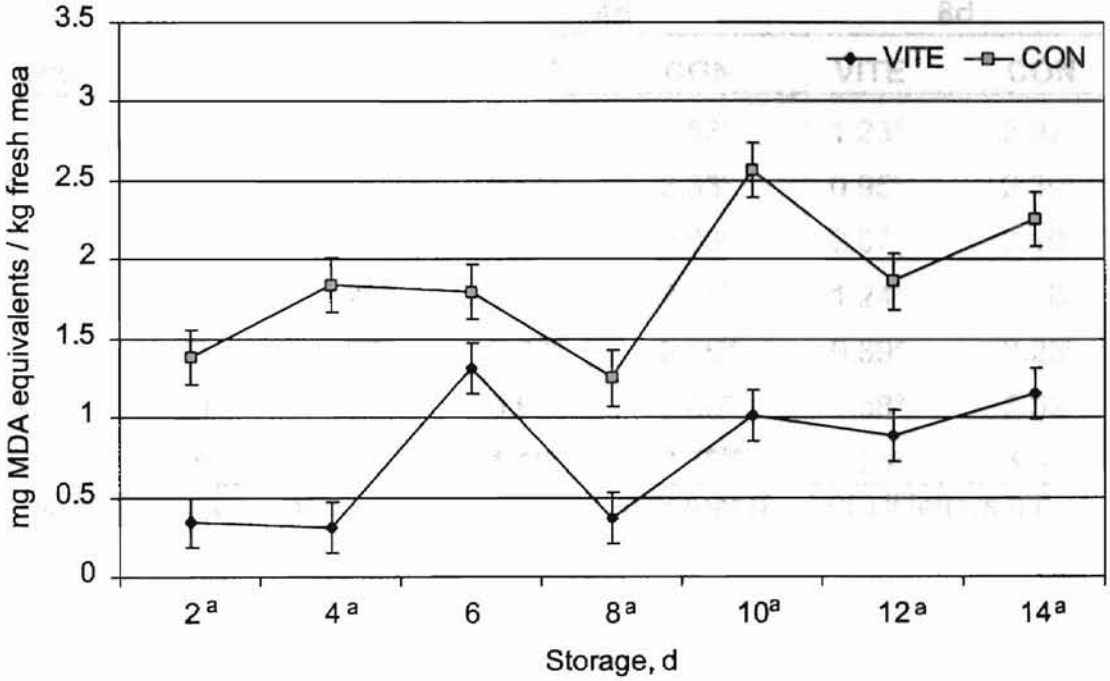
[a]Significantly different ($P<0.05$)

Figure 4.2: Effects of dietary vitamin E supplementation on TBARS accumulation during display of Peelable VSP packaged top loin steaks for pooled storage days.



[a]Significantly different (P<0.05)

Figure 4.3: Effect of storage on TBARS accumulation in ground chuck patties packaged in high oxygen Barrier Foam systems. Standard error bars are indicated.



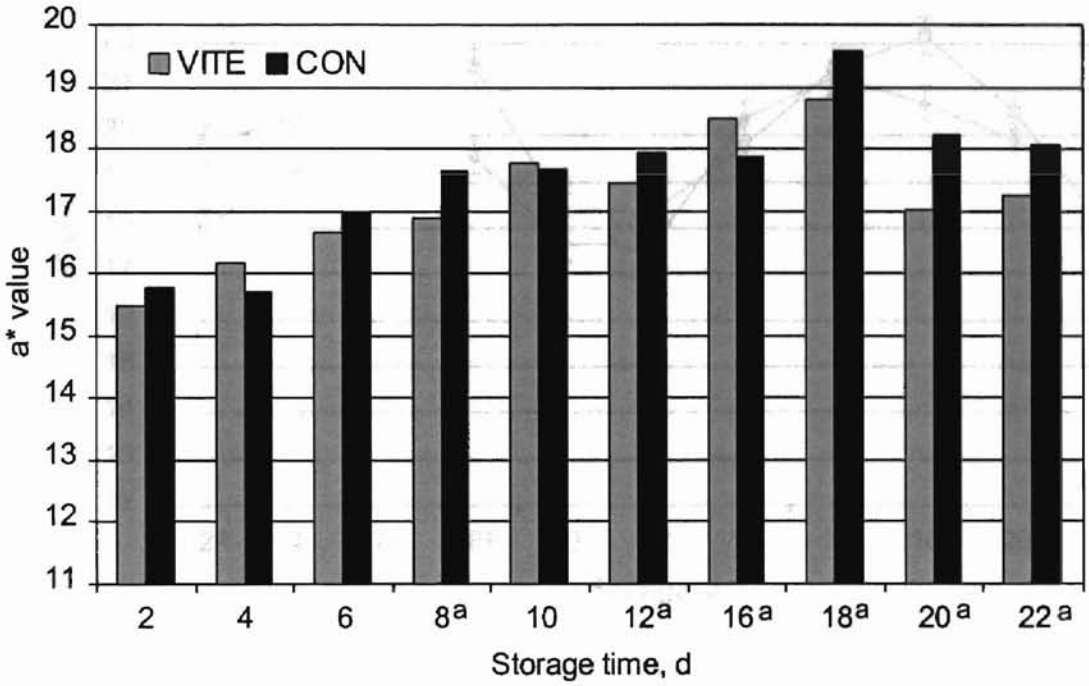
[a]Significantly different (P<0.05)

Table 4.1: Effect of retail display on TBARS accumulation in Barrier Foam packaged ground chuck patties.

	Display					
	0d		4d		8d	
Storage	VITE	CON	VITE	CON	VITE	CON
2d	0.34[a]	1.38[b]	1.11[b]	1.53[b]	1.23[b]	2.92[c]
4d	0.31[a]	1.84[b]	0.61[a]	2.33[b]	0.95[c]	2.39[b]
6d	1.31[ab]	1.80[bc]	0.75[a]	2.03[c]	2.07[c]	3.19[d]
8d	0.38[a]	1.25[b]	0.57[a]	2.58[c]	1.24[d]	3.18[e]
10d	1.01[a]	2.58[b]	0.72[a]	2.76[bc]	0.89[a]	3.23[c]
12d	0.90[a]	1.87[b]	0.86[a]	2.80[d]	1.58[b]	3.52[d]
14d	1.15[a]	2.26[b]	1.16[a]	2.75[bc]	1.23[a]	3.33[c]

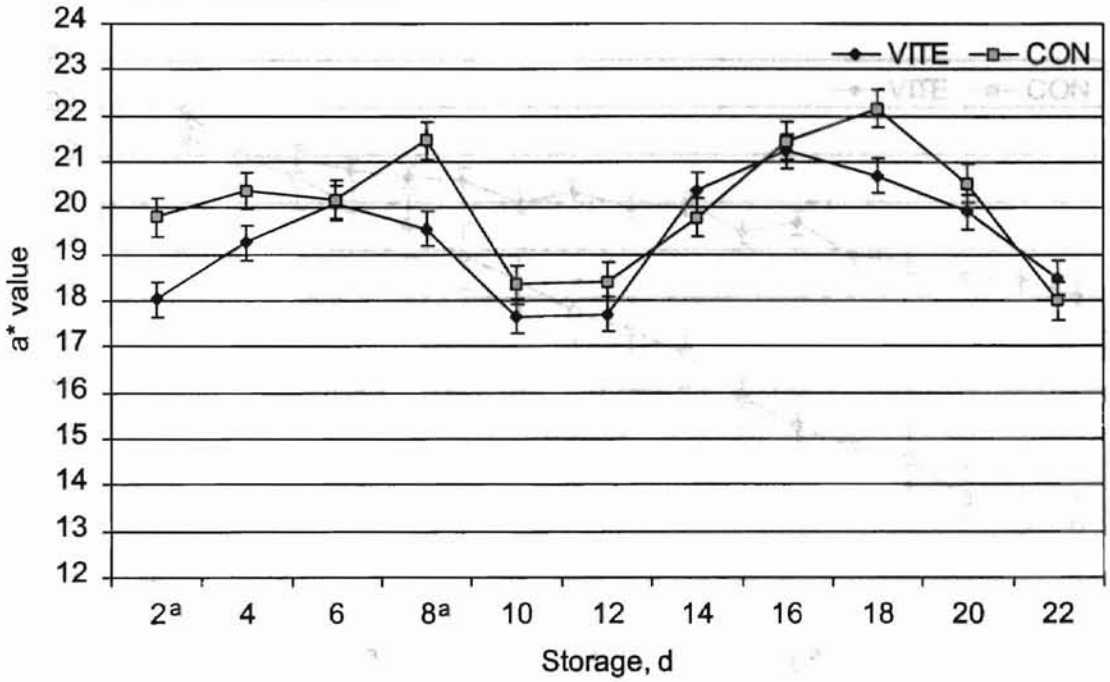
[abcd]Means within the same row are significantly different ($P<0.05$) if letters differ.

Figure 4.4: Representation of treatment x storage Least squares means for bloom response Minolta a* values for top loin steaks packaged in Peelable VSP systems.



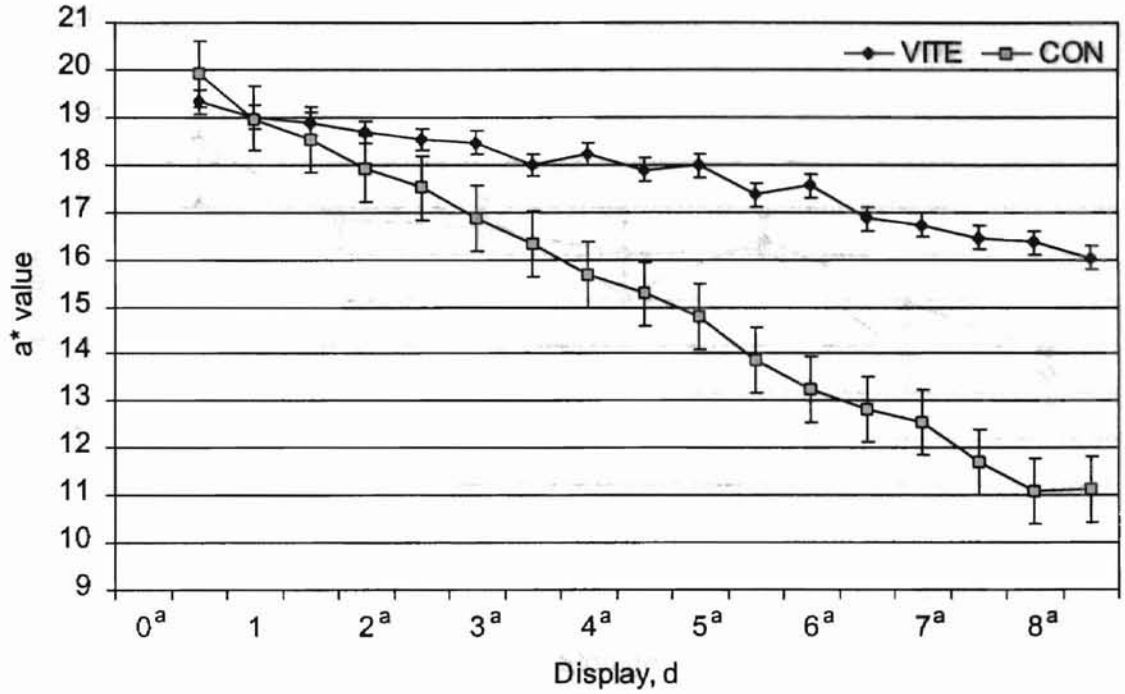
[a]Significantly different (P<0.05)

Figure 4.5: Effect of storage in Peelable VSP packaging on the Minolta a* value of top loin steaks. Standard error bars are indicated.



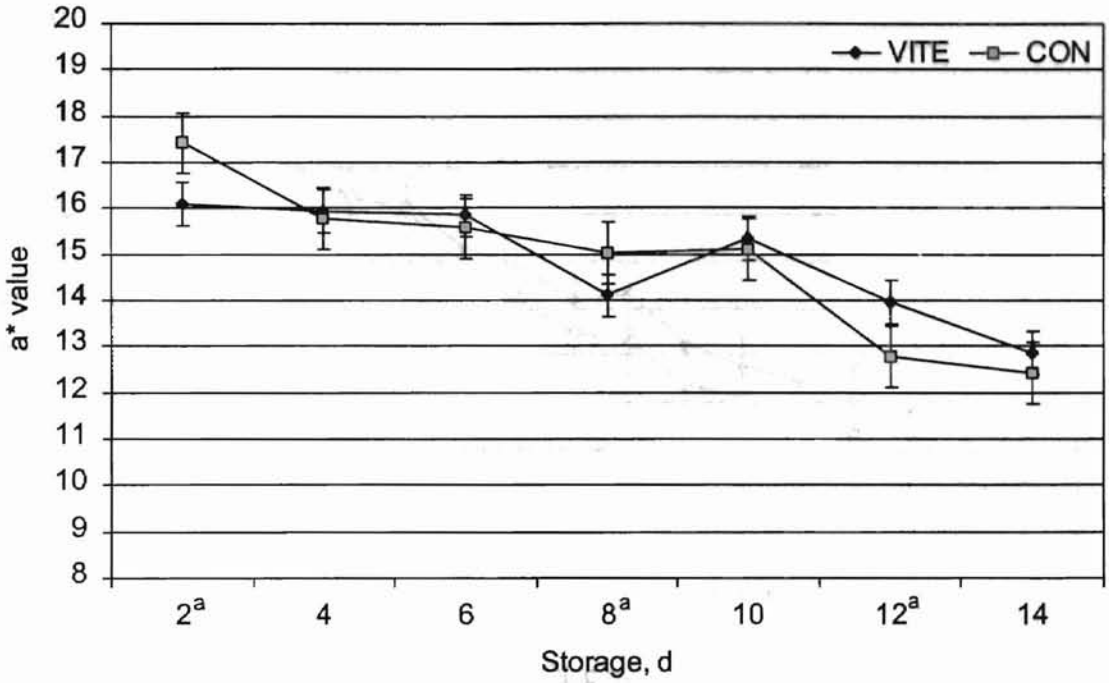
[a]Significantly different (P<0.05)

Figure 4.6: Comparison of mean display Minolta a* values of Peelable VSP packaged top loin steaks across all storage days. Standard error bars are indicated.



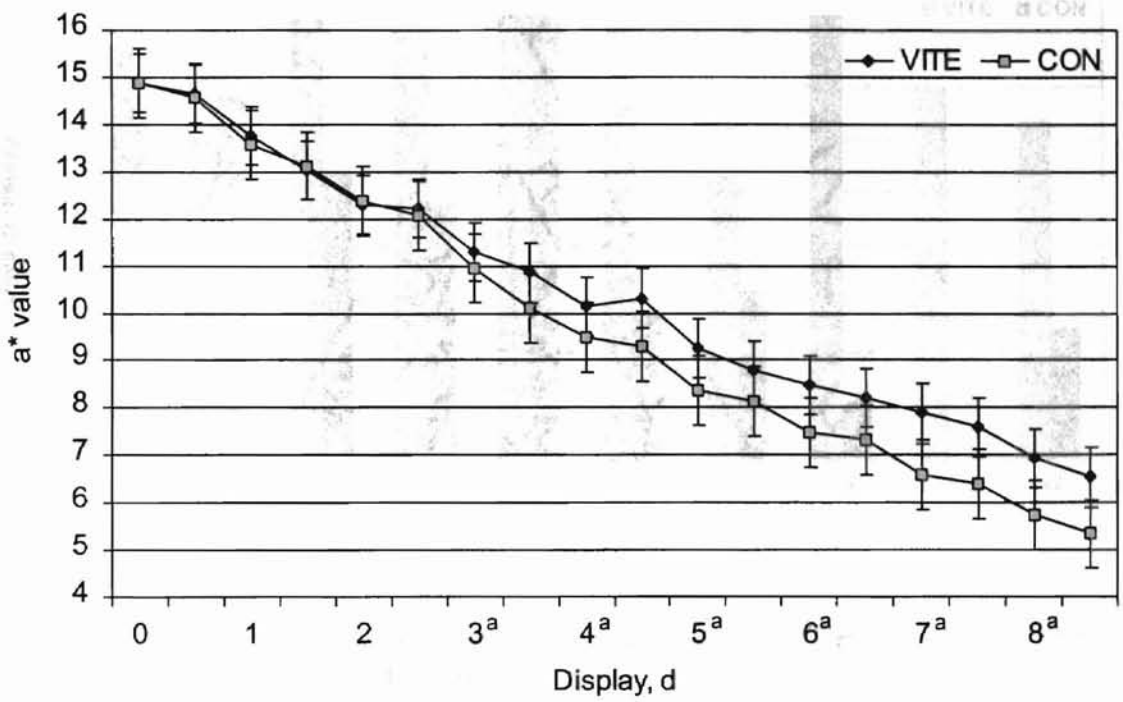
[a]Significantly different (P<0.05)

Figure 4.7: Effect of storage in Barrier Foam packaging on the Minolta a* value of ground chuck patties immediately prior to display. Standard error bars are indicated.



[a]Significantly different (P<0.05)

Figure 4.8: Comparison of mean display Minolta a* values of Barrier Foam packaged ground chuck patties across all storage days. Standard error bars are indicated.



[a]Significantly different (P<0.05)

Figure 4.9: Comparison of lean color scores for Peelable VSP packaged top loin steaks represented as days of display to reach unacceptable score.

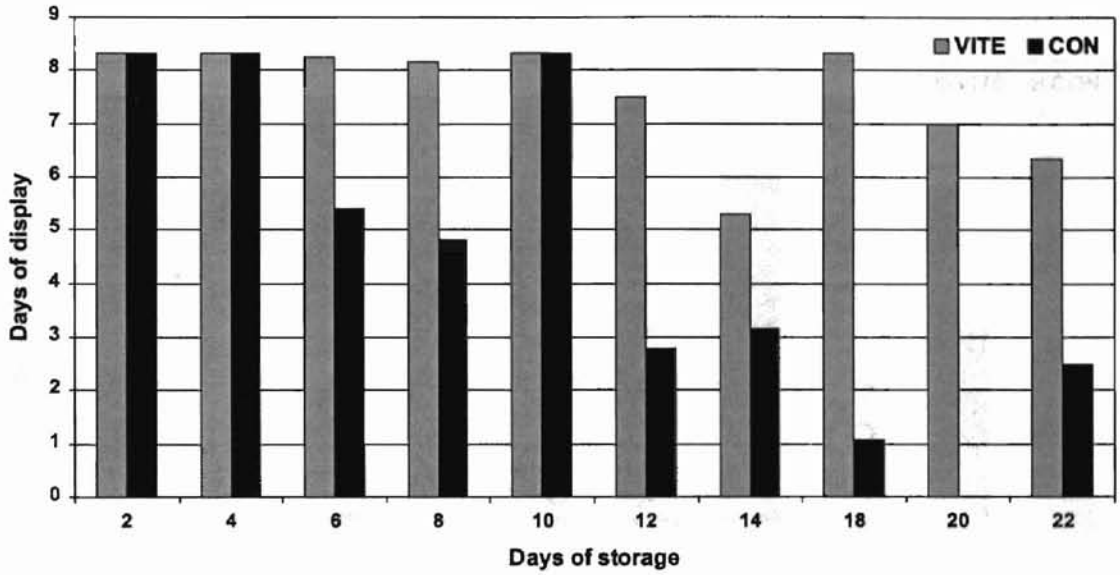


Figure 4.10: Comparison of fat color scores for Peelable VSP packaged top loin steaks represented as days of display to reach unacceptable score.

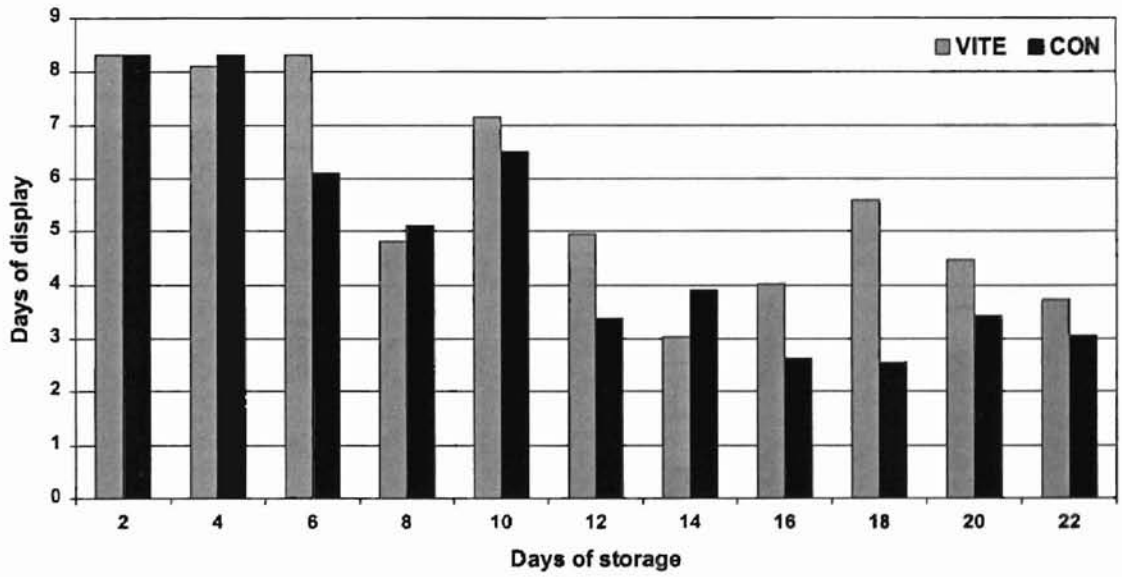


Figure 4.11: Comparison of percent discoloration scores for Peelable VSP packaged top loin steaks represented as days of display to reach unacceptable score.

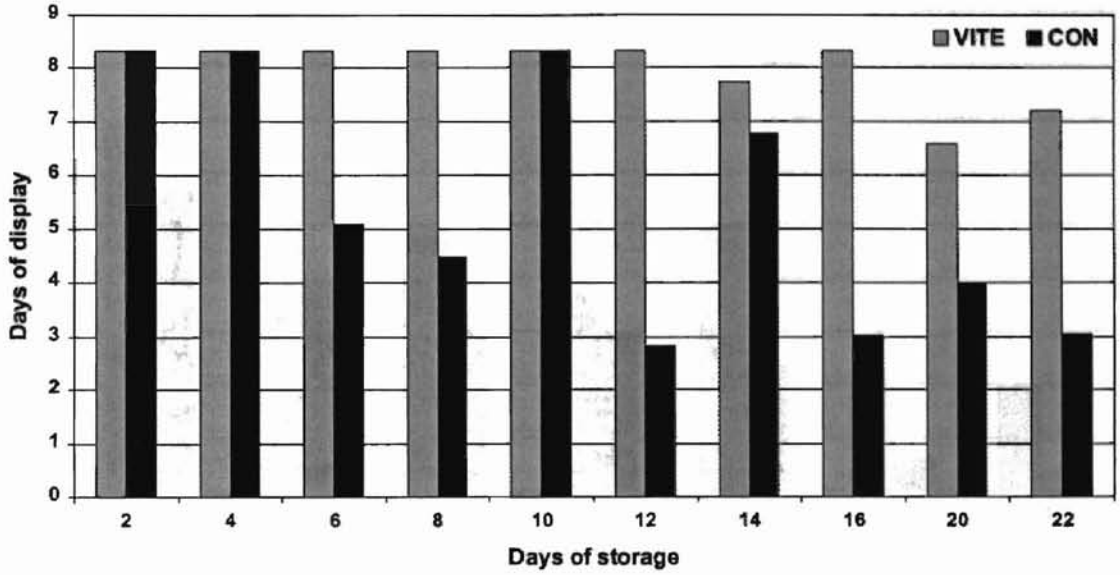


Figure 4.12: Comparison of overall acceptance scores for Peelable VSP packaged top loin steaks represented as days of display to reach unacceptable score.

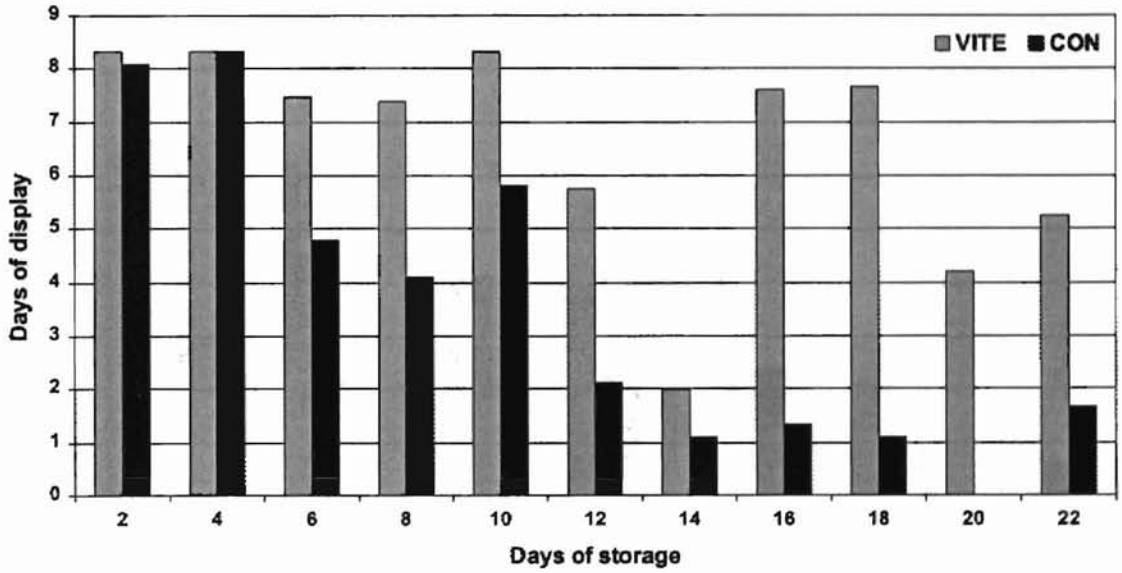


Figure 4.13: Comparison of lean color scores for Barrier Foam packaged ground chuck patties presented as days of display to reach unacceptable score.

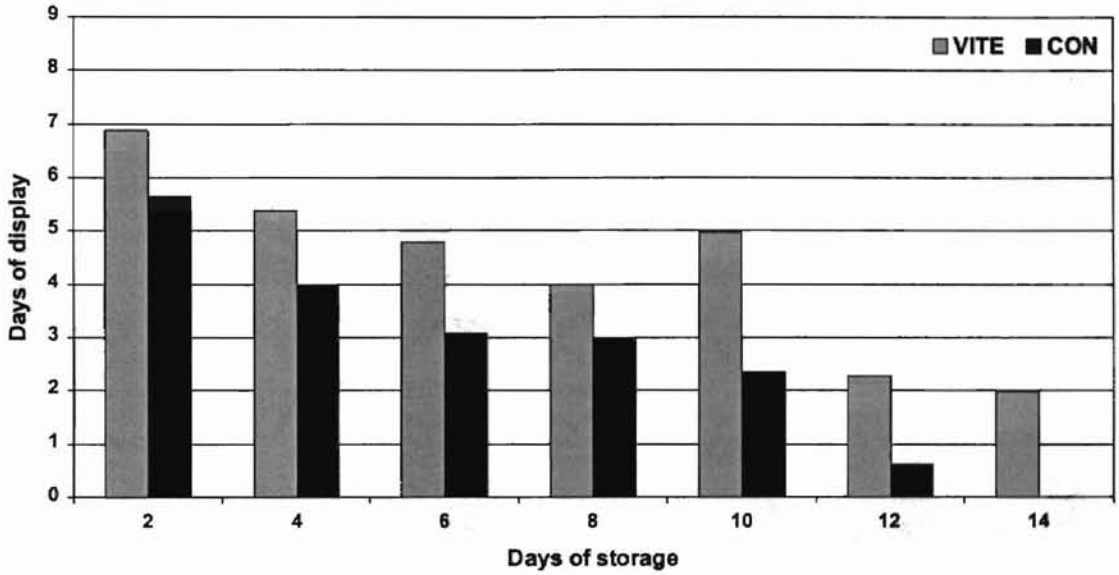


Figure 4.14: Comparison of fat color scores for Barrier Foam packaged ground chuck patties represented as days of display to reach unacceptable score.

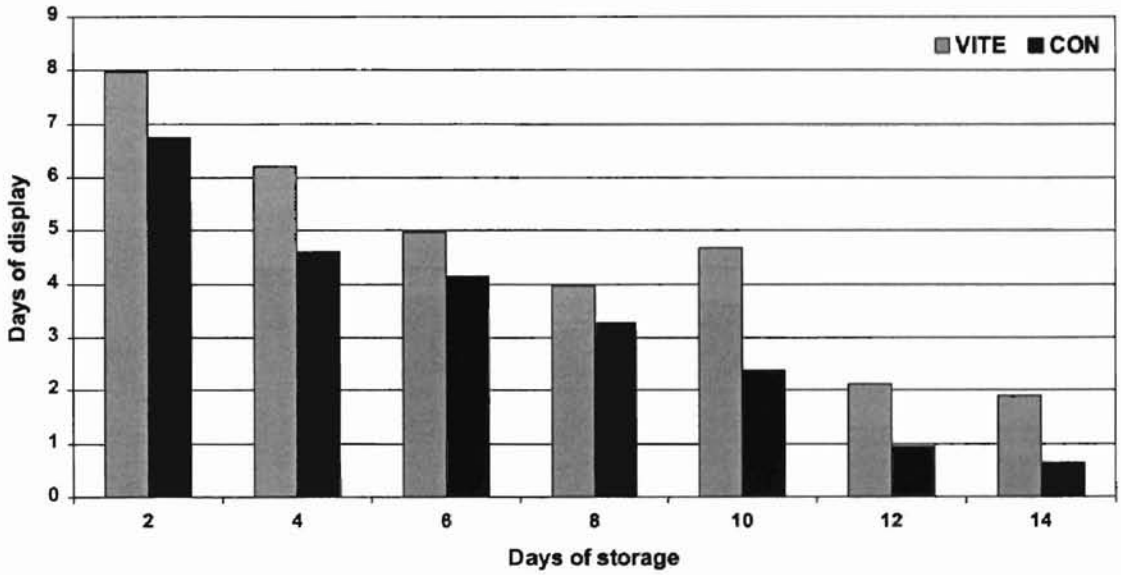


Figure 4.15: Comparison of percent discoloration scores for Barrier Foam packaged ground chuck patties represented as days of display to reach unacceptable score.

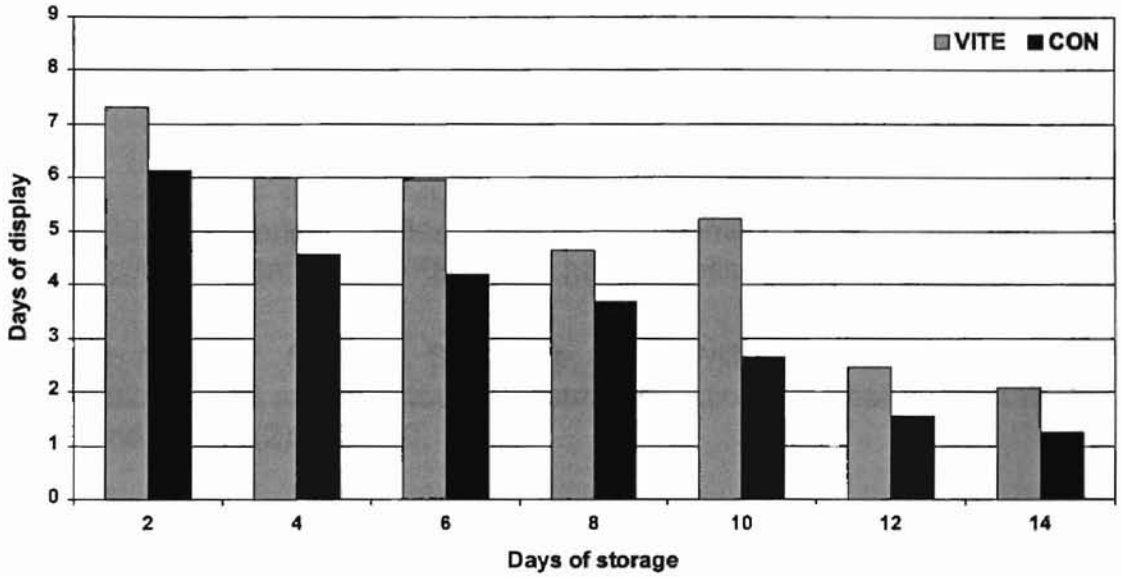
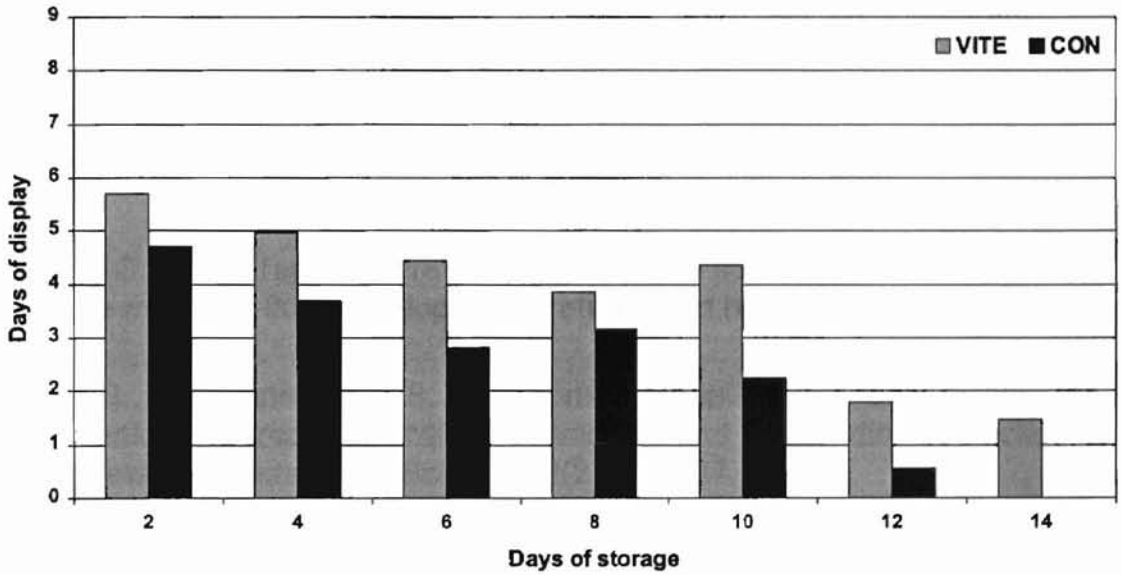


Figure 4.16: Comparison of overall acceptance scores for barrier foam packaged ground chuck patties represented as days of display to reach unacceptable score.



CHAPTER V

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