VITAMIN E: AN ASSESSMENT OF THE "QUALITY & ECONOMIC" GAINS ACHIEVED THROUGH SUPPLEMENTATION OF α-TOCOPHERYL ACETATE IN FEEDLOT STEERS

By

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DEDICATION

This thesis is dedicated to those who have given me the strength and wisdom to attempt my every dream; To my father Marvin, my mother Vicki and my sister and brother Shawna and Shane.

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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

Of the many challenges that the U. S. beef industry must address, customer satisfaction and approval remain a top priority. Profitability in the retail beef sector functions on a narrow profit margin with a large percentage of the monetary loss being due to unacceptable product color. In fact, the National Cattleman's Beef Association (1993) estimated a loss of approximately $520 million annually due to discoloration of retail beef products (Wheeler et al., 1996). Customers associate fresh beef with a bright cherry red color, and any variation can lead to an unsatisfied consumer and thus a "bad experience" (Kropf, 1980). At the point in which beef products begin to darken, a retailer is forced to do one of three things: 1) discount or mark down the price of the product, 2) convert the product to a new product of lesser value (ex. grinding to hamburger) or 3) discard the product at a 100% loss. Discoloration of beef products is not only a concern within the U. S. beef market but, within the global market as well. In 1994, the International Beef Quality Audit (Morgan et al., 1994) found that inadequate caselife was the fifth most concern of all foreign buyers of U.S. beef products and was the largest problem identified by Japanese retailers. In turn, U.S. beef market share will continue to grow internationally if improvements are made in this area.

The color of retail beef products is principally associated with myoglobin levels in the muscle. Myoglobin and hemoglobin are heme-protein complexes responsible for the transportation and storage of oxygen in the muscle of live animals, these proteins are then utilized in the conversion of metabolites to energy (Zerby et al., 1997). In turn, postmortem factors such as increased exposure to oxygen, light, microbial growth, a change in pH and(or) temperature will affect the rate of oxidation of myoglobin and product discoloration (Faustman & Cassens, 1990; Saterlee & Hansmeyer, 1974). The rate of discoloration in retail beef products is primarily due to the formation of metmyoglobin on the surface of the muscle, this process is called pigment oxidation. The mechanism of pigment oxidation begins with the introduction of oxygen to the deoxymyoglobin on the surface area of the muscle, yielding oxymyoglobin and thus, altering the muscle shade from a deep purple to a bright cherry red. The bright cherry red color is associated with fresh beef products and is the color customers most desire. Conversion of oxymyoglobin to metmyoglobin occurs after approximately 40 to 60% of the oxymyoglobin is oxidized, resulting in a change of muscle pigment to an undesirable shade of brown (formation of metmyoglobin). A brown spot, the size of a mere dime has been found to negatively influence the customer and prevent him/her from buying the product.

Caselife is defined as the number of days and hours that a meat product can be displayed prior to discounting or removal from the case. Increasing display time of beef products is accomplished through minimizing the formation of metmyoglobin. Vitamin E is an antioxidant, by definition antioxidants are lipid soluble substances that can delay the onset of oxidation or degeneration of tissue membranes (McDowell, 1989). The most active form of vitamin E is α-tocopherol acetate and upon supplementation it can protect the muscle cell membranes from oxygen thus slowing the formation of metmyoglobin. The α-tocopheryl acetate (ester form) is accepted as the International Standard and is currently the most common type of vitamin E supplemented in feedlot diets (McDowell 1989; Liu et al., 1995). Previous research has shown benefits from supplementation of antioxidant vitamins such as, vitamin E on carcass characteristics of swine (Yamauchi et. al., 1980), poultry (Bartov and Bornstein, 1977) and lamb (Wulf et. al., 1995). Enhancement of caselife in beef products was first reported by Faustman et al. (1989a, 1989b) where Holsteins were fed 370 IU E/head/day for approximately 300 days. Those studies revealed, improved objective lean color scores and decreased production of metmyoglobin during simulated retail display conditions. Since that time, many other researchers have confirmed these findings (Arnold et al., 1992; Liu et al., 1992, Schaefer et al., 1995). Due to the fact that ruminant animals can not synthesize vitamin E and because high concentrate feedyard diets can deplete the α-tocopherol concentrations in the muscles of cattle through lower levels of α-tocopheryl and anti-oxidant destruction in the rumen, several scientific literature reviews have suggested feeding 500 to 1,000 IU E/head/day for approximately 100 days to achieve a vitamin E concentration of 3.0 μg/g in muscle tissue which is needed to enhance the caselife of the retail beef products (Liu et al., 1995; Schaefer et al., 1995; Smith et al., 1996). In the study by Faustman et al. (1989b) they found that any amount of vitamin E < 3.0 μg/g muscle tissue would decrease the stabilizing affects of the vitamin. Sanders et al. (1993) placed vitamin E product in two grocery stores and monitored the products color and display life. The results of the study revealed improved visual color scores for the vitamin E supplemented product and increased caselife.

The beef sector is amidst a market share battle with both the poultry and swine industries and the first step in winning this battle is providing a high quality product which can please the customer. Improving and extending the time frame that retail beef cuts remain a fresh desirable color will play a significant role in the beef industries quest for a customer satisfaction. As John Story, director of deli and meat purchasing for Fairway Foods, located in Minneapolis, Minnesota suggested, "Increased caselife will not only improve the appearance and quality of the meat case but, it will increase the customer retailer relationship by keeping the product looking fresh in the home" (Hermal, 1997).

The objective of this study was to not only to determine the efficacy of supplementing cattle with vitamin E in order to extend the color display life of beef retail cuts but, to analyze the monetary losses at a retail level for control versus vitamin E supplemented beef and to ultimately provide any information on economical benefits of caselife extension in "real-world" retail applications.

CHAPTER II

VITAMIN E AND CASELIFE ENHANCEMENT: A REVIEW

Meat Quality: Consumers and Color

"The performance is the product; the performance is what the customer buys" (Berry, 1991). The perception of a product, or its "quality" is strongly influenced by appearance and each consumer has been trained to connect the bright cherry red color of beef products with freshness (Faustman & Cassens, 1990; Kropf, 1980). It is critical that the beef industry meet the demands of the consumer and eliminate "bad experiences" with its beef and beef products. The tendency for red meat to discolor prior to spoilage is due to the oxidation of oxymyoglobin within the muscle resulting in the formation of metmyoglobin, not bacteria or mold. However, because the perception between the bright cherry red color and freshness has already been established, it is unlikely that it will change. In turn, when a product discolors, it has to be discounted in price to be sold or discarded from the case entirely. According to research by Williams et al. (1992) an increase in caselife of 1-2 days will save the beef industry between $175 million to $1 billion annually. John Story, senior director of the meat and deli sectors for Fairway Foods in Minneapolis, Minnesota believes an increase in the display time of beef products will enhance the customer-retailer relationship by providing a product which maintains a brighter fresher color after several days of storage in the home (Hermal, 1997). Therefore, a method the stabilizes the pigment of muscle for an extended period of time would not only be economically feasible but extremely beneficial from a customer service aspect.

Oxidative Processes in Meat

Oxidative processes, such as lipid peroxidation, usually consist of a "free radical chain reaction" which can ultimately affect muscle pigment, carbohydrates, proteins, lipids and oxidizable vitamins, resulting in poor overall food quality (Kanner, 1994). Lipid and color oxidation are interrelated (Greene et al., 1969; Faustman et al., 1989; Liu et al., 1995); however, the method behind this relationship is not fully understood. Polyunsaturated fatty acids (PUFA) make up the phospholipids in muscle cell membranes and are highly susceptible to oxidation (Klis, 1993). In a regular scenario, oxygen (O_2) has two unpaired electrons providing a triplet ground state which is incapable of reacting with the single state of PUFA (Kanner et al., 1985); however, hydrogen ($H\bullet$) has a single electron allowing a reaction to occur with any unpaired electron on any molecule (Kanner, 1994). In the case of beef and other meat products, increased exposure to oxygen, beyond what is needed for blooming purposes or disruption of the cellular system, by grinding or restructuring causes a reduction of oxygen yielding several $H\text{-}O_2$ free radicals can occur (Kanner, 1994; Pearson et al., 1977). The electron reduction of O_2 can create the following products: hydroxyl radical ($HO\bullet$), hydrogen peroxide (H_2O_2), perhydroxyl radical ($HO_2\bullet$) and superoxide anion radical ($O_2\bullet$), all of which are lipid peroxides (Kanner, 1994). Any of the previous radicals have the ability to initiate several different types of lipid oxidation, but H_2O_2 appears to be highly correlated with the discoloration in beef products and (or) pigment oxidation. In addition to O_2, metal compounds such as iron (Fe) are involved in oxidative processes. The ferric (Fe^{3+}) and ferrous (Fe^{2+}) ion states of myoglobin and hemoglobin can both be activated by H_2O_2, possibly initiating oxidation (Kanner & Harel, 1985; Brown et al., 1963). The ferritin form of iron, which is stored in the protein cells of muscle tissue (Kanner, 1994), also interacts with the free radical products such as H_2O_2 and can lead to muscle pigment damage.

Research by Hunt & Hedrick (1977) found a difference in the "aerobic potential" of varying muscles types. The muscle type and its aerobic potential are listed in descending order: psoas major (PM) > inside semitendinosus (IST) > longissimus dorsi (LD) > gluteus medius (GM) > outside semimembranosus (OSM) > inside semimembranosus (ISM) > outside semitendinosus (OST). Currently, it is not known to what extent the different muscles are affected by oxidation; however, a correlation between the aerobic potential and the diversity of α-tocopherol concentrations among muscle types is an interesting concept, that should possibly be further investigated. As previously stated, the formation of the free radicals, lipid oxidation and oxidation of myoglobin have a detrimental effect on muscle pigment (Haurowitz et al., 1941; Greene et al., 1971; Kanner, 1994); though, the relationship is not entirely understood, research by Green et al. (1971) suggests that the free radicals of lipid oxidation first oxidize the heme to metmyoglobin instead of damaging the globin first. Anderson et al. (1990) and Anderson & Skibsted (1991) reported that photooxidation of muscle pigment and photosensitized lipid oxidation support the theory that pigment oxidation may be the initiator of lipid oxidation. However, Anderson et al. (1990) and Anderson & Skibsted (1991) note that two processes of lipid oxidation metal or light catalyzed; can be occurring simultaneously in a synergistic relationship. A proposed model of the oxidation-reduction relationship in beef by Schaefer et al. (1995) can be seen in figure 1. Currently, the role of antioxidants and their ability to improve pigment and lipid oxidation is of great interest in the beef industry (Williams et al., 1992).

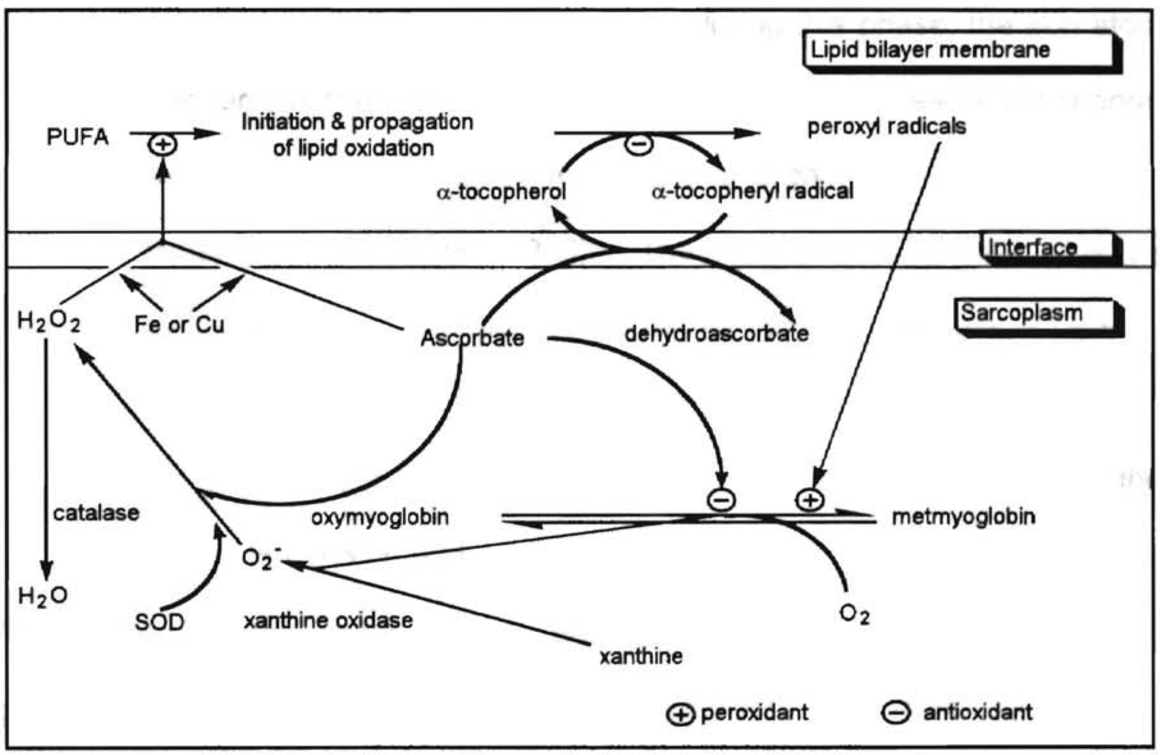

Figure 1: A suggested model of the Oxidation-Reduction relationship. The course of action for phospholipid and myoglobin oxidation (Schaefer et al., 1995).

Meat Color: Muscle Pigment Oxidation

Hemoglobin (Hb) and myoglobin (Mb) are the two primary pigments associated with muscle tissue color. Hemoglobin is a large molecule located in blood that remains a purple color until exposed to oxygen (O_2); O_2 causes the a color to change to red. Myoglobin is a smaller molecule located inside the muscle fibers and consists of three varying pigments. In living tissue and in freshly cut beef, deoxymyoglobin or the reduced form of myoglobin is present. Deoxymyoglobin is purple in color and contains iron in the ferrous state (Fe^{2+}). Upon being exposed, to O_2, deoxymyoglobin is oxygenated to form oxymyoglobin (OMb); a bright cherry red color, during this phase, the iron atom remains in the ferrous state (Cross et al., 1986). The time it takes for the change in color to occur is approximately 30 minutes, and is called the "bloom time" in the beef industry (Smith et al., 1996). The next phase of color change, associated with the loss of an electron from the Fe^{2+} ion and the loss of O_2 from oxymyoglobin yields metmyoglobin (MMb) (Kanner, 1994); which causes a change in the absorption rates of the muscle this damage results in the formation of Fe^{3+} ion and an undesirable dark brown color. A hydrogen peroxide (H_2O_2) molecule then replaces the O_2 and binds to oxymyoglobin. Sixty percent of the surface area of a beef retail cut that has been oxygenated to form MMb will show signs of pigment discoloration (Lawrie, 1966). The following figure looks at pigment oxidation which can occur when OMb is exposed to free radicals, high temperature or low pH causing the loss of oxygen or autoxidation of MMb.

$$Fe^{2+}-O_2 \longrightarrow Fe^{2+} + O_2$$

$$Fe^{2+}-O_2 \longrightarrow Fe^{3+} + O_2^{\cdot -}$$

$$O_2^{\cdot -} + O_2^{\cdot -} \longrightarrow H_2O_2 + O_2$$

$$Fe^{2+} + H_2O_2 \longrightarrow Fe^{4+}{=}O + H_2O$$

Figure 2: Autoxidation reactions: Oxymyoglobin and Myoglobin and oxygen producing H_2O_2 , O_2-, ferryl compounds (Fe^{2+}) and metmyoglobin (Satoh & Shikama, 1981; Wallace et al., 1982; Kanner et al., 1987).

The rate of discoloration in retail beef products can vary due to different concentrations of metmyoglobin reducing activity (MRA) and other reducing equivalents ($NADH_2$). Thus, the reduced state of iron in myoglobin and (or) OMb remains longer (Smith et al., 1996) resulting in an extended bright red color. After the formation of MMb, further oxygenation due to bacteria and enzymes produce dark compounded that are brown and green color.

Caselife: Factors Affecting Oxidation of Meat

The length of time a fresh retail cut will maintain its bright cherry red color before surface browning, causing a discount in price or discardment of the product is defined as retail caselife. There are many catalysts for oxidation which ultimately affect the caselife of a product, some examples are: diet, retail lighting, temperature, pH, packaging types and microorganisms.

Dietary Affects

The dietary contents of a ration can dictate the composition and concentration of PUFA in the animal tissue. Larick & Turner (1989) studied low energy forage finishing diets vs. high concentrate diets in a comparison of the phospholipid composition and individual fatty acids within the phospholipids of lean beef muscle. They found an increase in linoleic and linolenic PUFA levels and a decrease in saturated fatty acids (oleic acid) in the muscle tissue for cattle fed a high forage diet. These findings support previous research by Melton et al. (1982) on ground beef characteristics of grass fed cattle. An increase in PUFA, as previously mentioned, can promote the possibility of oxidative processes occurring. Therefore, the grain fed diet may not only provide a greater balance of essential fatty acids (Marmer et al., 1984; Forest, 1981) but, it may also decrease the rate of lipid oxidation that occurs in lean muscle.

Light and Temperature Affects

The exposure of meat to light and varying temperatures can be detrimental to color stability. Hood (1980) reported that the primary factor affecting rate of discoloration when exposed to oxygen is the muscle type. According to Hood (1980), the psoas major (PM) had the least stable muscle pigment while the LD had the most stable. GM and SM were intermediate but not different from each other; GM and SM had similar muscle pigment stability. However Hood (1980) noted that the discoloration rate can be greatly affected by variation in light as well as temperature fluctuations. When oxymyoglobin is exposed to light, photooxidation can occur speeding up the formation of metmyoglobin. Kropf (1980) reported that display lighting effects on muscle pigment are altered by temperature fluctuations, photochemical effects or different light wavelengths. Bertlsen & Skebsted (1987) determined the conversion rate of oxymyoglobin to metmyoglobin in beef extract solution exposed to different wavelengths of UV light. Steaks from the semitendinosus muscle were cut and frozen for 2 to 12 days, after which liquid extracts from the thawed steaks were irradiated with a monochromic light and monitored at regular intervals with a spectrophotometric meter. Calculations were made using degree of conversion rates from OMb to MMb and revealed that UV light with a wavelength of 245 nanometers was 4,000 times more harmful to muscle pigment than visible light. These findings support the work of Anderson et al., 1988; 1989; and Hood, 1980, which found that the degree of photooxidation, which accelerates the discoloration of fresh and minced beef and ham products, was dependent on the wavelength composition of light. In a study by Bertlelsen & Skebsted (1987) temperature was found to display a minimal effect on the rate of discoloration when associated with different light sources and wavelengths. This conclusion implies that, the "energy of activation" for photooxidation is higher than that of thermal oxidation (Anderson et al., 1989). Hood (1980) also investigated the effects of temperature on prepackaged beef. Storage of beef products for 96 hours at temperatures ranging from 0, 5 to 10 °C showed significant ($P < .0001$) rates of muscle discoloration as temperature increased. A muscle type by temperature interaction was evident ($P < .05$) as PM muscles discolored more quickly then the longissimus lumborum (LL) at the same temperature. O'Keefe & Hood (1980) found the effect of temperature on meat color stability to be substantial and complicated. Surface meat discoloration due to an increase in temperature is a repercussion of lower oxygen solubility levels (Morley, 1971) and an increase in the number of oxygen utlizers (Urbin & Wilson, 1961; Snyder, 1964). Many researchers have reported the rate of autoxidation of OMb and deoxygenated myoglobin increases with higher temperatures (George & Stratmann, 1952; Snyder & Ayres, 1961; Walters, 1974). The complication arises with the observation that MMb reduction is increased with increasing temperatures (Stewart et al., 1965). The effect of temperature on color stability documented by O'Keefe & Hood (1980) revealed a rapid increase in beef color instability with an increase in temperature from -1°C to +5°C ($P < .001$) during normal air storage conditions. After aging PM, GM and SM muscles for 4 weeks, O'Keefe & Hood (1980) and Hood (1980) found a difference in the rate of discoloration between each muscle type 41, 32 and 35% respectively. However, the time required for pigment discoloration to occur within the temperature parameters was similar for all muscle types. Interestingly, the authors found temperature fluctuations can augment the rate of discoloration suggesting, controlled climates can decrease the rate of discoloration (O'Keefe & Hood; 1980).

Heating of muscle tissue can also involve lipid oxidation. For example, high temperatures can cause the cleavage of myoglobin in lean muscle tissue releasing oxygen from OMb which yields H_2O_2 and creates an unstable form of myoglobin that is easily transformed to MMb (Kanner, 1994; Walters, 1974). Anderson et al., (1989) described the connection between light and temperature oxidation through comparisons of the rate of autoxidation. It appears that at low temperatures suppression of thermal oxidation occurs without hampering photooxidation but, the rate of both is dependent upon the light wavelength (Figure 3).

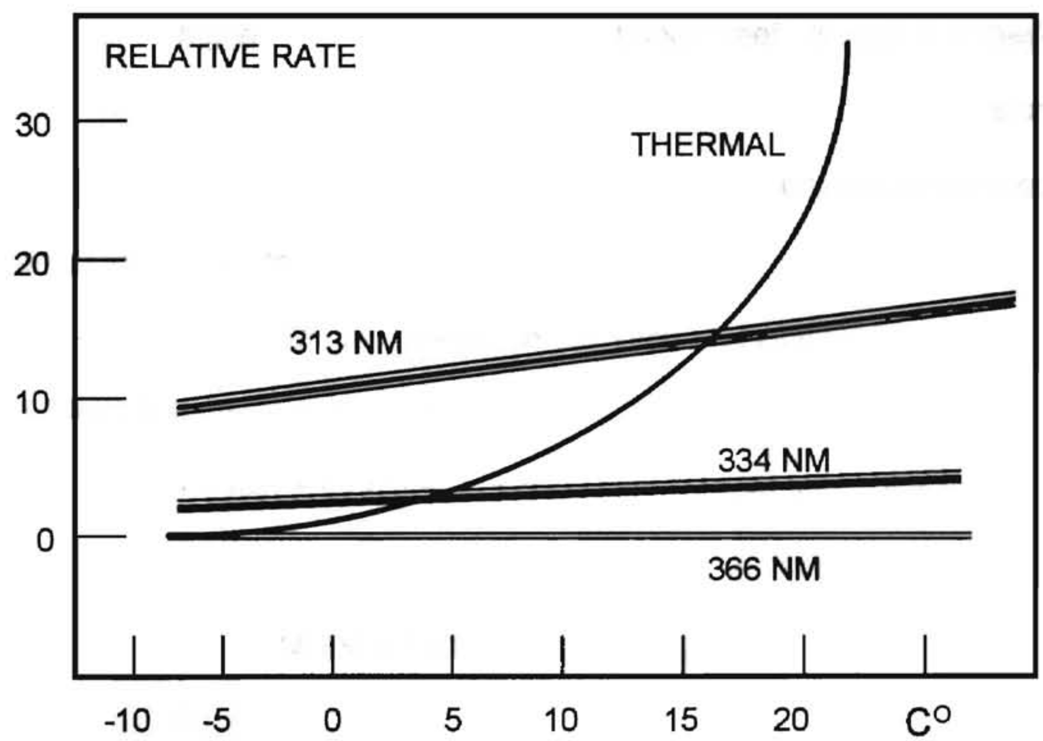

Figure 3: A comparison of the rate of thermal and photooxidation at three different light wavelengths (Anderson et al., 1989).

pH Affects

The pH of normal fresh meat ranges from 5.4 to 5.8 (Hood, 1980) and anything below 5.2 is acidic and can cause oxidation of the lipids in muscle. Interestingly, acids are known oxidizing agents (Stryer, 1988), and the process by which oxidation occurs is similar to that of thermal oxidation. Cleavage or denaturation of the myoglobin molecule at decreased pH levels causes the iron atom to become oxygenated yielding MMb. In a study by Anderson et al. (1990) the color stability of frozen and hot processed minced beef was tested under different storage conditions. In this study, the pH of the hot deboned beef was significantly higher than that of the cold deboned beef. Included in these results was improved color quality for the hot deboned meat during frozen storage and less color sensitivity when salt was added. As a result, the authors concluded that improved oxidative and color stability occurs in hot deboned minced beef with or without the addition of salt. In the 1980 study by Hood, pH had no effect on discoloration of muscle tissue or oxidation of myoglobin. These results conflict with research by George & Stratmann (1954) who reported accelerated effects at low pH levels in minced product. The lack of pH effect on beef discoloration may be explained by the limited range of pH levels between the whole muscle types utilized in the Hood (1980) study.

Packaging Affects

Packaging of fresh meat products is primarily used for ease of storage, protection of the product -- either physically, microbially or chemically -- and to attract consumers. Though packaging varies among retail chains, the majority of the product wrap is oxygen permeable, which may increase the occurrence of lipid oxidation and(or) discoloration of lean muscle tissue (Kropf, 1980). A study by O'Keefe & Hood (1980) researched the differences in the rate of discoloration between air permeable retail wrap and storage in anaerobic conditions (in the presence of nitrogen) at varying temperatures. They found that storage of beef products in an anaerobic environment for longer than one week produced rapid discoloration rates upon exposure to oxygen more so than product stored in aerobic conditions. However, O'Keefe & Hood, noted that because the anaerobic case ready product does not undergo routine fabrication prior to display, the decreased color stability will not be a pertinent factor. Oxygen free packaging enhanced the rate of discoloration above that of oxygen sensitive packaging for the muscle types with less color stability which had an enhanced rate of discoloration over the more stable types (PM < GM < SM < LD) (O'Keefe & Hood, 1980). Anderson et al. (1989) reported similar results, revealing significant decreases in meat discoloration due to UV light when light impermeable polyethylene wrap was used in freezer conditions.

Bacteria Affect

Bacterial contamination can alter lean muscle color. Increased exposure of fresh meat to oxygen can act as a catalyst for aerobic bacterial growth, ultimately leading to discoloration of the product. Certain aerobic bacteria will produce H_2O_2 and hydrogen sulfide (H_2S) following oxygen utilization (Morgan et al., 1993; Smith et al., 1996). These two compounds are then "attracted" to the free binding site of the reduced OMb, resulting in the formation of choleglobin and sulfmyoglobin, respectively. Choleglobin and sulfmyoglobin yield Fe^{3+} ion and produce a metallic green color associated with bacterial growth.

Tocopherol: The Role of an Antioxidant

In the beef industry, there are two methods of maintaining or increasing caselife; one involves controlling environmental factors such as: storage conditions, sanitation, retail handling, lighting and temperature. The second involves the use of antioxidants. Vitamin E is a naturally occurring lipid-antioxidant, with its primary role being neutralization of free radicals, thus preventing the degradation of phospholipids (McCay & King, 1980). By definition, antioxidants are any substance which can delay the onset of oxidation of autoxidizable materials (McDowell, 1989). α-tocopherol is a free radical scavenger, in that it prevents lipid peroxidation by binding with a free radical in its initial stage yielding an non-reactive or non-radical product. The α-tocopherol donates a $H^{\cdot}$ atom from the phytol side chain to bind with the unpaired electron of the free radical molecule, this movement also causes the α-tocopherol to its quinone form (McCay & King, 1980: Liu et. al. 1995).

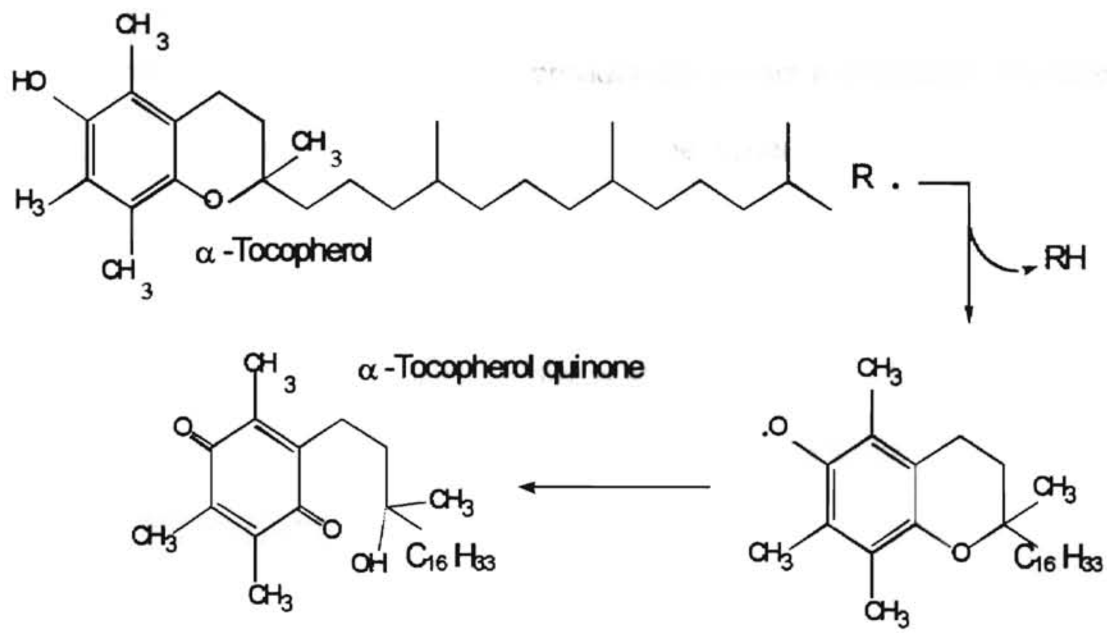

Figure 4 : The donation of a hydrogen atom yielding a non-radical product and the α-tocopherol quinone product (McCay & King, 1980).

Factors behind α-tocopherols ability to protect membrane stability include: the natural localization of Vitamin E in the membrane where lipid peroxidation mainly occurs, the molecules ability to move laterally making it more accessible for electron donation, plus the extra advantage of meeting these requirements below toxic levels (Machlin, 1980; McCay & King, 1980; Gomez-Fernandez et. al., 1989). Protection of PUFA from lipid peroxidation and the relationship with pigment oxidation play an important role in the discoloration and overall quality of meat products.

VITAMIN E: CASELIFE ENHANCEMENT OF RETAIL MEAT

Other Meat Products: A Review

The appearance of any meat product will impact a consumer and strongly affect his/her decision to buy or by-pass the product (Morgan et al., 1993; Sanders et al., 1993). Demand for lamb meat is limited within the United States partially due to its short caselife, which makes it difficult to market; a large concern within the lamb industry (Williams et al., 1991). In 1971, Jeremiah et al. reported that in lean lamb products the primary cause of a short caselife in fresh retail lamb was discoloration. A study by Hidiroglou (1987) found that mega-doses (1,000 IU's) of vitamin E 24 to 72 hours prior to harvesting resulted in significantly increased levels of α-tocopherol in the muscle of sheep. In a more recent study by Wulf et al. (1995), 30 whether lambs were not supplemented (CON), supplemented 500 IU E/head/day (V500) or 1000 IU E/head/day (V1000) of α-tocopheryl acetate for 56 days prior to harvest. The product was displayed under simulated retail store conditions with observations made daily for days 0 through 7. Vitamin E tissue levels were significantly higher for vitamin E supplemented whethers than CON carcasses. Identification of lipid oxidation in meat can be determined through thiobarbituric acid values (TBA), which are measured using a muscle tissue sample. Retail cuts from the round of the vitamin E supplemented carcasses had greater oxidation and poorer lean color than the vitamin E supplemented loin retail cuts. In the comparison of CON versus vitamin E muscle samples, lipid oxidation was decreased for the vitamin E product, as determined by lower TBA values for the vitamin E product. Caselife was extended by four additional days for the vitamin E product throughout the study but, there was no difference between the level of supplemented vitamin E. Carcass traits, performance and carcass fat color were not improved when vitamin E was fed (Wulf et al., 1995; Spillane & L'Estrange, 1977).

Supplementation of swine with vitamin E appears to reduce lipid oxidation of meat products. However, no improvement in lean color or caselife extension has been reported (Cannon et al., 1996; Yamauchi et al., 1980). A study by Monahan et al. (1989) evaluated the effects of vitamin E on the stability of raw and cooked pork. The results of this study revealed α-tocopherol stabilized fat and membrane lipids, postponing lipid peroxidation in cooked, raw deboned or processed pork products, which coincides with research by Buckley et al. (1988). There have been several other studies which found vitamin E to be very effective in reducing lipid oxidation in restructured or ground pork. For example, Miles et al. (1986) reported that lipid oxidation was reduced for restructured pork supplemented with 200 mg of α-tocopheryl acetate, while Benedict et al. (1975) found that as little as 50 mg of α-tocopheryl acetate/kg would decrease the rate of lipid oxidation. In a recent study by Cheah et al. (1995), stabilization of muscle integrity was confirmed when 500 mg/kg vitamin E was supplemented to the diet for the last 46 days of feeding. The research focused on drip loss and prevention of pale, soft and excuvative (PSE) conditions in pork. PSE is a meat quality problem which plagues the pork industry today. It involves stress prior to slaughter which causes the product to become watery and pale in color. The two muscles utilized were the longissimus thoracis (LT) and the major masseter (MM) which consist of mainly white muscle fibers, and red muscle fibers, respectively. Researchers found that vitamin E concentration was higher in the MM muscle ($P < .01$) (red fibers) than in the LT muscle (white fibers) and that drip loss was seven-fold less for the red versus the white muscle fibers. However, results varied among breed type with the Landrace x Large White red muscle fiber products having higher drip loss values than the white muscle products. The opposite occurred for the Landrace and Pietrain breeds. Additionally, when 1000 mg/kg of vitamin E was supplemented to the diet for 46 days, potential PSE animals were returned to "normal conditioned" animals. This was identified in a postmortem biopsy that revealed normal pH levels and increases in Ca^{2+} release within the muscle of the supplemented animals. Ca^{2+} and pH are primary indicators used to predict PSE and the possibility that vitamin E can aid in the prevention of PSE, would greatly benefit the pork industry as a whole (Cheah et al., 1995).

Extensive research in the poultry industry to improve lipid stability of retail products has been conducted in recent years. As previously mentioned, high PUFA concentrations in muscle causes increased lipid oxidation. Pearson et al (1977) reported that PUFA levels in meat species vary in concentration, shown here in increasing order: lamb < beef < pork < poultry < fish. Webb et al. (1972) supplemented or injected 40 turkeys with vitamin E and compared them to control turkeys on a standard diet. They reported that the turkeys injected with vitamin E were more stable, thus early rancidity was prevented as compared to control and supplemented turkeys. These results support other research by Uebersax et al. (1978) and Bartov et al. (1983). Asghar et al. (1990) reported vitamin E supplementation increased levels of α-tocopherol in poultry muscle tissue and enhanced membranal lipid stability. Similar trends were found results in earlier research by Bartov & Bornstein (1977) where the meat from broiler chickens was found to benefit from supplementation of α-tocopheryl acetate in preventing lipid oxidation; however, as the carcass fat increased the benefit from the vitamin decreased).

Beef Products: A Review

The standard form of vitamin E for supplementation in a beef feedyard is the dl (racemic) α-tocopheryl acetate (Liu et al., 1995). The ester acetate form of the vitamin is deesterfied and absorbed as α-tocopherol throughout the lymph system (Chylomicrons) to the liver which excretes the α-tocopherol into the plasma (lipoproteins) which is then transferred to several different tissues including the muscle (Gallo-Torres, 1980; Liu et al., 1995). It has been suggested that once the vitamin E reaches the muscle it is incorporated into the cellular membranes (Mitsumoto et al. 1991). Hidiroglou et al. (1988) studied the different types of supplemental vitamin E for a 28 day feeding period and found that the "non-racemic" (rac or dl) and the "racemic" (d) forms of both the alcohol and ester vitamin E compounds were highly available to bovine tissues. The study concluded, feeding the rac-α-tocopherol and(or) rac-α-tocopheryl acetate provided acceptable concentrations of the vitamin E in muscle tissue. Length of supplementation, and supplementation level of vitamin E has been studied extensively; low levels of α-tocopheryl acetate supplementation, ranging from 300-500 IU E/head/day with extended days on feed (100 to 126 days on feed) or high levels ranging from 1000-3000 IU/head/day with short feeding intervals (20 to 100 days on feed); (Arnold et al., 1992; 1993a; 1993b; 1989b). Arnold et al. (1993b) researched the color display life of muscles following a 7 day aging period of beef from cattle supplemented with 360 IU E/head/day or 1290 IU E/head/day for 252 days and found no difference in caselife enhancement. However, with an increase in aging to 21 days the higher supplementation level had a longer caselife when compared to the 360 IU E/head/day. Conflicting research by Liu et al. (1996) found supplementation with 486 IU E/head/day for 126 days increased caselife over non-supplemented cattle for 14 and 28 day aging periods. This would appear to be adequate caselife enhancement for retailers due to the fact that aging periods range from 10 to 30 days in the US (Morgan et al., 1990). The primary concern when supplementing α-tocopheryl acetate is the α-tocopherol muscle tissue concentration with a level of $\geq$ 3.0 μg/g in the muscle tissue providing a sufficient amount to increase caselife (Arnold et al., 1993a; Faustman et al., 1989a; Mitsumoto et al., 1991). Another finding in the Arnold et al. (1993a) study suggested that lower concentrations of vitamin E are beneficial when supplemented for longer feeding periods. The same study reported that the α-tocopherol content of the Longissimus lumborum (LL) equilibrated with the intake after approximately 12 weeks of supplementation. Faustman et al. (1989b) found that any amount of α-tocopherol less than 3.0 μg/g would reduce the vitamin's ability to slow down meat discounts due to discoloration and lipid oxidation. The effects of vitamin E on feedlot performance (rate of gain and feed efficiency) appear to be negligible (Arnold et al., 1993; Secrist et al., 1995), along with no benefits being seen in carcass characteristics such as quality or yield grades (Arnold et al., 1992). Nockels et al. (1996) looked at the effects of stress on vitamin E concentrations in serum, plasma, various organs and muscle tissue by supplementing the animals with 1,000 IU's for 28 days. They concluded that after stressful situations cattle show a tendency to utilize stores of vitamin E in different tissues but not in muscle tissues selected for the study.

The initial studies on vitamin E and its effect on discoloration and lipid peroxidation of Holstein beef products were performed by researchers at the University of Wisconsin. Faustman et al. (1989b) reported that the lean muscle from Holstein cattle is highly susceptible to discoloration, perhaps even more so than beef from traditional breeds. In one of the first Faustman studies (1989b), 22 Holstein steers were supplemented with 370 IU/head/day for approximately

250 to 300 days or until the cattle reached a harvest weight of 545 kg. Faustman et al. 1989b) concluded that supplementation not only increased the vitamin E concentration of muscle tissue but provided enhanced caselife of the treated ground sirloin product. The same study researched the prevention of off-flavors, which often occur in pre-cooked beef products, with vitamin E resulting in a delay of the unwanted off-flavor in cooked sliced sirloin. In another study, Faustman et al. (1989a) identified a significant improvement with vitamin E supplemented product ($P < .01$) in preventing discoloration in retail cuts on storage days 2, 4, 6 and 8 at 4°C, this work coincides with a 1993 study by Arnold et al. which found supplementation of vitamin E extended caselife by 2 to 5 days. The same study found no significant improvement in caselife of animals that were supplemented with amounts > 500 IU E/head/day. Engeseth et al. (1992) found that supplementation of Holstein calves with 500 mg of vitamin E for approximately 12 weeks improved the oxidative stability by delaying the production of H_2O_2 and ultimately delaying the formation of metmyoglobin in veal meat. Interestingly, they also found that supplementation can improve the stability of muscle and cholesterol lipids in young ruminants.

A trial by Mitsumoto et al. (1991) evaluated the effects of supplementing vitamin E as well as the comparison between Holstein and crossbred steers. High α-tocopherol concentrations decreased MMb levels on day seven and bacteria counts on day one, while increasing OMb concentration on day ten of retail display. When comparing the Holstein steers to the crossbred steers, Mitsumoto et al. (1991) revealed that the α-tocopherol content of the LL in the crossbred steers was higher than that of the Holstein steers. They concluded that the Holstein steer carcasses did not respond as well to the vitamin E supplementation as the crossbred steers. As evidenced by higher MMb concentrations and lower OMb. These results coincide with research by Faustman and Cassens in 1991 but they conflict with those of Arnold et al. in 1992 and 1993a who reported breed differences ($P > .01$) were nonexistent for caselife extension. Another study by Mitsumoto et al. in 1993 evaluated the impact of vitamin E supplementation on drip and cooking loss of Holstein steers. In this study, the product from supplemented animals had a lower drip loss and higher cooking loss than control product. These finding suggest a benefit to the retailer, the amount of "liquid" or drip loss is reduced during retail display decreasing the amount of purge in the package. Several other researchers have looked at the ability of vitamin E to protect cooked or cured beef products from color and lipid oxidation. Beerman et al (1995) and O'Donnell et al. (1995) looked at the viability of VITE in cooked cured and uncured briskets. Beerman et al. (1995) found a decrease in TBA values from .38, .18 to .13 for control, 1000 and 2000 IU treatments, respectively. However, they also concluded that there were no protective effects from vitamin E as far as pigment discoloration in cooked and cured briskets which coincide with research by O'Donnell et al. (1995). In a trial looking at the stability of ground beef, 12 Holstein steers were treated with α-tocopheryl acetate or not treated and the Longissimus muscle was ground into hamburger. The poor lipid and color stability of ground products is due to the grinding itself, which exposes more surface area causing increased exposure to air and bacterial contamination (Mitsumoto et al., 1993). The researchers found that vitamin E decreased the MMb percentage and bacteria levels on day 9 of display in ground beef ($P < .0001$) (Mitsumoto et al., 1993). Previously Greene et al. (1971) found that if MMb was present at levels of >30% on the surface of meat products, consumers would find it unacceptable. In the Mitsumoto et al. (1993) study, it was not until day 8 of display that vitamin E ground beef exceeded the 30% MMb threshold reported by Greene et al. (1971).

Lanari et al. (1993a, 1993b, 1994) worked on several projects testing the effects of vitamin E on frozen beef products. In 1993, Lanari et al. looked at the LL and semimembranosus (SM) muscles from 6 Holstein steers (3 vitamin E treatment and 3 control or non-treatment) the muscles were cut into strip loin and top round steaks, wrapped in standard polyethylene or vacuum packaged and frozen to -20°C then thawed for 30 minutes at 22°C. The packages were then either stored in the dark or on display at -20°C for 126 days. They also randomly selected several packages to be refrozen and thawed again to test the effects of vitamin E on extensive freezer abuse (Lanari et al., 1993a). The results suggested that treatment steaks had improved color stability over control after being frozen and then thawed. The study also revealed that vitamin E increased the caselife for LL steaks displayed in light ($P < .05$) and for product held in the dark for 30 months prior to light display ($P < .05$). The same study also revealed that the vitamin E product was also able to withstand two freeze thaw cycles while control appeared to discolor after one cycle. These findings coincide with other research by the same authors confirming vitamin E's ability to enhance oxygenation of Myoglobin while decreasing the formation of MMb (Lanari et al., 1993b). In a later study, the effect of atmosphere and bloom time on supplemented frozen product was analyzed (Lanari et al., 1994). The researchers found that with dark freezer storage, color stability was enhanced when exposed to oxygen for six hours prior to freezing. However, when the treatment product was being stored in a lighted area, one hour of blooming was a sufficient time prior to freezing to delay discoloration (Lanari et al., 1994).

In several more recent studies, Liu et al. (1994, 1995, 1996a, 1996c) looked at the effect of vitamin E supplementation in cooked beef, the color coordination or intensity of color improvement and the effects of varying concentration levels in different muscles, on MMb formation. In the 1994 study Liu et al., found that cooking beef did not affect the α-tocopherol content of the meat and it also delayed lipid oxidation ($P < .01$) during a six day display period. However, the authors noted that the ability of α-tocopheryl acetate to defer lipid oxidation was greatly decreased with cooking therefore, a warmed over flavor caused by the lipid oxidation may be improved but, only by negligible amounts. In 1996, Liu et al., researched the color coordinates for assessment of dietary vitamin E effects on beef color stability. There were several very interesting outcomes of this study, first supplementation with high levels of vitamin E (approximately 2000 IU/head/day for 126 days) resulted in the higher a* value color scores from a color measurement machine called the Chroma Meter CR-200 on a* values. Color score machines are common in meat caselife extension research, the providing color measurement through numbers, making identification of the color more consistent. The study also found that extended aging accelerated loss of redness, but as the vitamin E dose increased, the effects of discoloration were decreased (2000 > 500 = 250 > 0, respectively) which coincide with Arnold et al. (1993b). These finding suggest that unlike previous research (Arnold et al., 1992; Liu et al., 1996a) aged product (up to 56 days) was positively affected by supplementation, and that higher concentrations of α-tocopherol due to higher levels of supplementation (2000 IU) may increase caselife more effectively than lower levels. Vacuum package storage decreased display life ($P < .01$) for all products with a slight improvement seen in aged product that had higher doses for longer periods of time. In a later study, Liu et al. (1996a) found similar results as vitamin E continued to contribute to the stability of the product after chilled vacuum package storage of the LL for up to 56 days. Another interesting finding dealt with the color display life of the different muscles in the treated product, listed here in descending order: LL > SM > GM ($P < .05$). In another study, Liu et al. (1996c) looked at differences in caselife of the Longissimus lumborum, semimembranosus and gluteus medius muscles. Surprisingly, they found that the accumulation of vitamin E in each of these muscle types was exactly the opposite of the display life of each muscle.

In other words, the rate vitamin E uptake in each muscle type is: GM > SM > LL while the caselife extension is: LL > SM > GM. There is not a clear explanation behind these findings; however, Liu et al., (1995) suggested: 1) that different muscles types possess different amounts of white and red fibers, 2) that different fiber sizes may affect the membranes uptake ability, and 3) that the distribution of capillaries could also effect absorption rates (red muscle fibers are thought to have greater capillary blood supply than white). Hunt & Hedrick (1977) found through subjective and objective color score analysis that the LD, PM, GM muscle colors were similar in redness and a* values, but were not significantly correlated with myoglobin, hemoglobin and total pigment content. The IST, OST and the OSM muscles were also comparable in color while, the ISM color was significantly paler yet had more myoglobin and hemoglobin (Hunt & Hedrick, 1977). Histochemical analysis of muscle types indicated that major metabolic differences occur between muscle types with the highest metabolic rate occurring in ISM. The same study, revealed that αW fibers (α-white muscle fibers) were the largest of the fiber types in all tested muscle types except the PM. Ashmore & Doerr (1971) suggest that the primary function of βR (β-red muscle fibers) and αW fibers is oxidative and glycolytic respectively, and the αR fibers contain the anaerobic and(or) aerobic pathways. The final conclusions of Liu et al. (1996c) study reiterate the theory that MMb formation is delayed with supplementation of vitamin E and that levels above 500 IU/head/day for aged product does not differ from that of 2000 IU/head/day at 28 days of aging.

Several studies have been conducted to evaluate the effect of E supplementation on pigment and lipid stability of strictly beef breeds. Mitsumoto et al. (1991) looked at how vitamin E and C affect ground beef. Due to the physical breakdown of muscle cells during the grinding process, ground beef tends to discolor more quickly than whole muscle products. This study used product from six crossbred steers and analyzed not only the separate effects of each vitamin, but the compound affect of the two. The two vitamins were added to the ground beef, with vitamin E at 6 mg/kg tissue and 500 mg/kg tissue for sodium ascorbate. Vitamin E reduced the lipid and pigment oxidation in ground beef with slight increases in MMb and TBA scores occurring as days after treatment increased. Vitamin C showed improved stability over the control and vitamin E product with surface MMb increasing from 23.9% on day 1 to 26.7% on day 7. Studies by Hood (1975) and Liu et al. (1994) researched preslaughter infusion of sodium ascorbate and found it to extend color stability of several different muscles. The vitamin combination in this study provided the best stability of all the treatments, which would prove very useful for any retail store (Mitsumoto et al., 1991). The surface MMb percentage ranged from 22.2% at day 1 to 25.7% on day 7. It has been suggested that vitamin C and E act "synergistically", vitamin E being the primary antioxidant results in the radical form of vitamin E reacting with C to yield vitamin E (Tappel et al., 1961). A review by Schaefer et al. (1995) found limitations to this research in that the vitamin E effect was almost at the saturation level, allowing the synergism to be easily detected.

Researchers at Colorado State University (CSU) simulated retail store conditions to test the validity of vitamin E as a caselife enhancement in a "real world" scenario. Sherbeck et al. (1995) fed 80 crossbred steers a conventional feedlot diet supplementing at least 500 IU/head/day for approximately 123 days. After animal harvesting, the carcasses went through conventional fabrication, a ten to fourteen day aging process and normal transportation to a distribution warehouse. Following these procedures, vacuum packaged sub-primal boxed beef was sent to two participating grocery stores in the Fort Collins, CO area. Upon arrival, the meat was fabricated into the desired retail cuts and packaged for display. Visual assessment was done under simulated retail conditions at CSU. Treatment T-bones and ground chuck maintained a desirable cherry red color throughout the seven day display period as compared to controls ($P < .01$), and measured by visual assessment. At the grocery store, 3.1% of the VITE T-bones and 2.3% of the VITE ground chuck were discounted in price due to discoloration while 18.1% and 17.9% of the control cuts were discounted respectively. VITE round steaks appeared to have a brighter color for display days one through seven of display and a lower percentage (9.3%) of VITE product that was discounted. In turn, the researchers concluded that the advantages of vitamin E supplementation will not only extend caselife but, of greater importance, improve the profitability of retail meat counters.

Sanders et al. (1993) conducted a similar study to look at the feasibility of vitamin E beef products in the retail sector. As in the previous study, retail cuts were fabricated and displayed in two grocery stores and in the CSU meat lab under simulated retail conditions. In the stores, packages were marked prior to display for identification of treated product. Four times daily, packages were observed and counted to track the number of products sold and the number discounted in price or number discarded. The retail cuts were displayed for zero to seven days. The product at the meat lab was also displayed for seven days, and underwent visual and spectrophotometer color score evaluations. The visual scoring was performed by a trained panel using a scale with eight being superior bright cherry red and one being dark brown/green. The results of the analysis on the MMb percentages present on muscle tissue revealed an increase of both control and VITE MMb percentages during the initial 96 hours of display. However, the increase was greater for the non-supplemented product during the first 72 hours and the concentrations for the VITE were never higher than those of the control (Sanders et al. 1993). The visual scores also revealed greater stability with the VITE steaks. Interestingly, when a retail cut obtained a visual number score of 4 or 5, it frequently corresponded with the time at which a meat market manager would discount or discard a retail cut. The caselife of the tenderloin and loin steaks was longer than that of the ribeye steaks, confirming the research presented previously by Liu et al. (1996b). The TBA scores on day seven of display for control products were 2.3 times greater than those of control, which agree with other studies (Faustman et al., 1989; Morgan et al., 1993). When the discount and discard data were collected from the same store for loin, tenderloin and ribeye steaks the control product percentages were 7.1, 12.5 and 39.1%, respectively, while the VITE percentages were 0, 0, and 1%, respectively.

Sanders et al. (1994) also conducted an international project to test the viability of vitamin E and its antioxidant properties. The cattle were supplemented with 0, 1000 or 2000 IU/head/day for approximately 100 days. A portion of the supplemented and non-supplemented subprimal products were transported to CSU for analysis with the final portion sent to the University of Nippon, Food Technology facility in Japan. At each location, the product was fabricated, wrapped and displayed in conditions which simulated a retail case. The VITE (1000 and 2000 levels) product in Japan was brighter ($P < .05$) at time of fabrication, and, as time continued no difference occurred between the two treatments (Sanders et al., 1994). In fact, it was reported that on days one to three VITE 1000 product had less discoloration than VITE 2000 IU products (Sanders et al., 1993b). In this particular study, VITE strip loin steaks discolored at an accelerated rate than ribeye steaks; however, the discoloration did not occur until days six and seven of display. These findings conflict with the research by Liu et al. (1996a) which stated that the LL had a longer display life than the SM. A survey of Japanese food manufacturers, meat buyers and meat retailers, etc. was also conducted. Results from this survey reported: 85% of the participants were able to detect a difference in the supplemented and non-supplemented product with 79% explaining that the major difference was in the bright cherry red color of the product. The authors concluded this report by stating "approximately $3.5 billion worth of beef is exported annually from the US and any factor that can improve the storage-life of beef products would be very beneficial to this lucrative market."

Economic Benefits

In a recent report by National Cattleman's Beef Association (NCBA); US beef production was reported to have reached an all time high of 11.67 billion kilograms in 1996; however, they noted only 62.5 pounds. of boneless beef were consumed per person; less than 2 ounces of cooked beef per person per day. Interestingly, this is less than the USDA recommended daily allowance of 3 ounces of cooked meat per day. A short caselife is by no means the only factor affecting the decrease in beef consumption, but a strong service and a quality product can give the beef industry the ability to compete with consumers (Berry, 1991). In 1993, the NCBA also estimated that $520 million dollars are lost each year from retail sales due to the discoloration of lean muscle tissue (Wheeler et al., 1996).

Domestic and international studies conducted by Sanders et al. (1993), commonly the Strategic Alliance Field Studies documented that vitamin E supplemented beef had fewer "markdowns" or "discounts" in retail stores resulting in higher returns. Smith et al. (1993) reported that 174 kg of retail products from a vitamin E supplemented steer would be worth $60.07 more to the retailer, due to fewer discounts. The difficulty with the acceptance of vitamin E within the industry lies in the payment plan. Initially it appears that the major portion of the benefit and (or) profit will be realized by the retailers, leaving the rest of the industry asking "why do it?" John Isadore, general manager and vice president of Harris Ranch Beef, believes that the supplemented product is beneficial; however, as a feeder he has to see a cost:benefit ratio to commit the $3 to $4 cost/head for the supplementation of vitamin E (Hermal, 1997). Therefore, the debate remains as to who will pay for the cost of supplementing, and who will profit from the supplementation. In a response to this issue, Smith et al. (1993) reported that the economists involved in their study believed that the market place would sort out the payment and benefactors possibly by payment of premiums by retailers for the VITE product or in a less direct manor through product and service improvement leading to increased sales and (or) market share. The beef industry as a whole is concerned with the decreasing market share and the existing problems with customer satisfaction. The National Quality Audit (1995) reported that caselife of beef products is poor and improvement is needed, while the International Quality Audit (1995) found that most of the US beef exports had unacceptable caselife and in fact was one of the primary reasons for not purchasing more US beef. One scenario that may solve the payment question is that the retailer will pay a premium for vitamin E supplemented beef because of the increase in sales and decrease in markdowns that occur with the product. The second scenario coincides with the economists opinions in the Strategic Alliance Field Study in 1993. In a recent newspaper article, Abner Womack of the Food and Agricultural Policy Research Institute at the University of Missouri in Columbia, was quoted as saying, "despite volatile prices in grains and low prices in the beef and dairy industries, the outlook for the US agricultural economy is good" (Hendee, 1997). Backing for this statement, comes from research conducted for the US Congress on future market and policy analysis, which reported that the 10 year outlook for beef shows a 106 percent increase in beef sales. Therefore, an improvement of beef products that is beneficial for both domestic and international markets, along with the increase in exports and market share may also balance the extra cost of vitamin E supplementation to all sectors of the industry.

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CHAPTER III

EFFECTS OF VITAMIN E SUPPLEMENTATION ON THE "QUALITY & ECONOMIC" GAINS ACHIEVED THROUGH SUPPLEMENTATION OF α-TOCOPHERYL ACETATE IN FEEDLOT STEERS

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ABSTRACT

Approximately 235,000 steers were utilized in three commercial feedyards (Cactus Feedyard Inc., Amarillo, TX; Con-Agra/Monfort Feedyard Division, Greeley, CO; Harris Ranch Feedyard, Coalinga, CA), to evaluate the effects of supplementing approximately 500 IU/animal/day of dl (rac)-α-tocopheryl acetate (VITE) for the last 100 days of the finishing period on retail beef caselife. To determine the α-tocopheryl concentration of diets, feed samples were collected from five pens every other week during the feeding period. Microassay analysis of feed samples revealed a higher ($P < .01$) concentration of α-tocopheryl in VITE than control (CON) diets (11.13 vs. 2.86 mg E/kg DM). Post-harvest, samples were taken from the Rectus capiti dorsalis major muscle for determination of α-tocopherol concentration using a new rapid assay analysis. VITE carcasses had higher ($P < .01$) concentrations of α-tocopherol than CON

(3.5 vs. 1.5 μg/g). After chilling, carcasses were graded, conventionally fabricated and subprimal cuts were vacuum packaged for transport to alliance retail store locations in Reno NV, Longmont CO, Minneapolis MN and Houston TX. Sample collection of muscle tissues from specified retail cuts at participating grocers were analyzed and revealed all VITE cuts contained higher ($P < .01$) levels of α-tocopherol than CON cuts. Supplementing cattle with VITE resulted in retail cuts with a slightly more desirable lean color. The percentage of discounted items were not statistically different ($P > .05$); however, chuck, round, and ground beef products from cattle supplemented with α-tocopheryl acetate had lower percentages of discounted items than controls (7.4, 7.7 and 7.5 %, respectively). Caselife for VITE chuck cuts was prolonged ($P < .01$; 3.6 vs. 3.2 days for VITE vs. CON). Additionally, the caselife of round cuts from VITE steers (3.5 days) was extended ($P < .05$) over CON steers (2.9 days). Although not statistically significant ($P > .05$), the percentage of ribeye, strip loin, T-bone and tenderloin steaks discounted as a result of discoloration was lower for VITE compared to CON (1.9, 3.5, 1.4, 1.6 % lower for VITE vs. CON, respectively). Interestingly, VITE supplementation was not beneficial for top sirloin steaks (VITE discount was 23.9% vs. 23.7% for CON). Objective color score analysis with a PCM color tech revealed; higher initial "a" values (or the redness of the muscle) for all VITE supplemented product along with a tendency for the CON product to discolor at a faster rate. This survey indicates supplementing cattle with VITE at 500 IU/animal/day for 100 days prior to harvest will result in improved caselife and consequently, a decrease in discount percentages for most retail products.

Introduction

"From the customer's perspective, the proof of a service is its flawless performance" (Berry & Parasuraman, 1991). A service that the beef industry supplies to the customer is its product. Supplying customers with a consistent, *"high quality"* product is a basic element in the overall scheme of satisfying consumers. More than ever, today's "fast-track" consumers rely heavily on their perception of quality. Any deviation from their model of quality results in a flaw of product performance, and most importantly a poor consumer experience.

Consumers have learned through experience that the desirable color of fresh beef is bright cherry-red. Discoloration of fresh beef is a combined result of lipid oxidation and oxidation of muscle color pigments. Currently, between 2% and 20% of all beef cuts sold in US retail stores are discounted, or even discarded, due to the loss of desirable cherry-red color, which the consumer associates with freshness (Sherbeck et al., 1995). In turn, meat retailers increase their prices to account for those beef items that are discounted and (or) discarded.

Extensive research has documented that supplementing the diet of finishing steers with elevated levels of vitamin E is one method that could be utilized to stabilize the fresh cherry-red color of retail beef and, in turn, prolong caselife. Vitamin E is an antioxidant and therefore delays the oxidation of oxymyoglobin, thus prolonging the time prior to which the meat becomes discolored and unattractive to consumers. Qualities of vitamin E supplemented beef such as delayed meat surface browning, increased color stability and reduced retail losses, extend the marketing window during which beef cuts can be sold at full retail value.

To summarize, the US beef industry has been shrinking in market share since 1966. If nothing intervenes to stop this trend, the beef industry will have only 26% of the US meat production market share by the year 2005; and, more specifically, approximately one-half of beef's market share will have been lost in only three decades. In a "Profitability of Cattle" meeting held at Oklahoma State University on October 1, 1996, CEO of National Beef Packing Company, Mr. John Miller stated, "Consumers base their perceptions of quality in the market place on product appearance. If we can enhance appearance, thus increasing market share, we can begin to intervene with the current downward spiral of the beef market."

The study was conducted: 1) To determine the efficacy of supplementing cattle with vitamin E in order to extend the color display life of beef retail cuts, 2) To determine the monetary losses at a retail level for control vs. vitamin E supplemented beef and 3) To determine the economical benefits of caselife extension in "real-world" applications.

Experimental Procedures

Animal Feeding: Approximately 235,000 steer calves of numerous breeds and breedcrosses were fed finishing diets at three commercial feedyards located in three different geographical regions of United States (Table 1). Pens of cattle were assigned randomly to control (CON) or vitamin E (VITE) treatments. The CON treatment consisted of feeding the routine finishing diet used in each of the participating feedyards. No attempt was made to standardize the CON treatment among participating feedyards. For the VITE treatment groups, diets were formulated to provide at least 500 International Units of vitamin E, (as α-tocopheryl acetate; Hoffmann LaRoche, Nutley, NJ) per animal per day for the final 100 days of feeding. All diets contained 0.12 to 0.30 ppm selenium and 1500 to 3000 International Units of vitamin A per pound of feed on a dry matter basis.

Samples of the diet were collected from five randomly selected pens of cattle fed the CON treatment and five pens fed the VITE treatment at each participating feedyard. On each of three days of every second week during a period from February 13 to July 31, 1996, a one pound sample of the experimental diet was collected from each of the selected pen's feed bunk; the three samples from each pen were combined weekly for ease in shipping and handling. The samples were then cooled in a refrigerator and one-half of each composite sample was shipped via Fed Ex for analysis to the Soils and Plant Analyses Laboratory of the University of Wisconsin in Madison WI. The diet samples were dried at 110°C, ground and analyzed for α-tocopheryl acetate concentration by procedures described in Arnold et al. (1993a). The drying procedure was included in this process to attempt to determine its effect. Duplicate analyses were conducted on 30% of the samples.

Animal Harvesting: Cooperating feedyards transported two groups of CON steers and four groups of VITE steers at one-week intervals to their respective beef processing plants where they were harvested using conventional procedures (Table 1). Prior to chilling, a one-ounce samples of the neck muscle; Rectus capiti dorsalis major (RCDM) were obtained from 1-10% of the vitamin E supplemented cattle and < 1% for the control treatment cattle included in this study (Figure 1). The individual tissue samples were placed in plastic whirl-pak bags, labeled and chilled prior to shipment in an insulated box for analysis of α-tocopherol concentration. Analysis of each sample was performed within two days of collection. The analysis procedure performed by the Soils and Plant Analyses Laboratory consisted of a rapid microassay process, which is a simplified method for determining the α-tocopherol concentration developed by Liu et al. (1996). [y= -.16 + .95*x, where y and x represent the concentration from simplified and Arnold et al. (1993) methods]. Following harvest of the initial six groups, a second replication of the trial was performed following the same protocol.

Subprimal Collection: Following a 48-hour postmortem chilling period, carcasses were evaluated for USDA Quality Grade and Yield Grade factors.

When collection of grade data was completed, carcasses were fabricated using conventional methods. With the assistance of plant personnel, CON and VITE subprimal cuts were obtained, vacuum-packaged and boxed. All VITE beef utilized in this study was marked for identification with large fluorescent stickers that OSU and plant personnel adhered to each box prior. Samples were then transported via refrigerated truck to the distribution warehouses of cooperating retail stores. Following an average 10-day aging period, boxed beef products were transported to the cooperating retail stores. Upon arrival, the subprimals were stored at 34°F for approximately two additional days (to reach the 14-day postmortem endpoint) prior to retail caselife display.

Retail Data Collection: The cooperating retail chains involved in this study are listed in Table 1. Prior to the initiation of the project, in-store personnel participated in the selection of specific retail cuts to be included in the study. The retail cuts were selected based upon evaluations of poor retail caselife in comparison with other retail cuts. Meat department personnel were informed of the study and were asked to conduct business in a routine fashion throughout the duration of the project. In accordance with the animal harvesting protocol, CON product was monitored in the case for two weeks followed by four weeds of VITE this procedure was then repeated for the second of the project (Figure 2). The daily schedule for data collection involved an initial visit to each of the participating stores between 5:30 and 7:30 a.m. At that time an initial package count, for each of the retail cuts being monitored, was recorded prior to the removal of any discolored product that remained from the previous day. Following the initial package count, supermarket meat personnel would evaluate the retail meat case and identify cuts that did not have an acceptable cherry-red color. Research personnel would then determine the number of packages that had been sold, discounted in price and(or) discarded. In addition to package number, loses in monetary value and weight of retail product, due to inferior retail caselife, were recorded. Production data for each cut was recorded daily for the purpose of calculating discount and discard percentages. Additionally, box production dates and retail case temperature were checked daily. A second visit (approximately 12:00 p.m.) was made to each retail store to obtain further discount and discard information and to record the temperature. A final visit between 5:00 and 6:00 p.m. consisted of recording the case temperature and documenting the arrival of new product from the warehouse. Data collection of CON product at the Safeway grocery stores started July 15, 1996 and continued through August 25, 1996. The Vitamin E data collection began August 26, 1996 through October 6, 1996. The discount and discard data collection at the Safeway grocery stores is included in the results of this study. However, no diet, tissue or color score analysis from the Safeway stores were utilized in this report.

Retail Cut Tissue Sampling: Sampling of muscle tissue for subsequent determination of α-tocopherol concentration was conducted once per week during both the CON phase and VITE phases of the trial. Three packages of each retail cut were randomly selected and purchased from two stores at each participating retail grocery chains. A specific muscle within each cut was designated to be analyzed for α-tocopherol concentration (Table 2). Muscle selection was based on the desire to sample different muscle types and for ease in sampling procedure. A one-ounce sample from each cut was collected, chilled and shipped for analysis of α-tocopherol, by the same rapid microassay described previously.

Objective Meat Color Scoring Procedures: Visual evaluation of meat color is the primary method by which meat managers determine the length of time that a retail cut remains in the case. Included in the data collection process for this study, was the evaluation of meat color with a PCM Color Tech Analyzer (Color Tech, Lebanon NJ). The PCM Tech, classifies muscle color into three different categories within the color spectrum: "L*" represents the measurement of lightness to darkness, "a*" represents the red to green hue and "b*" represents the blue to yellow hue. The color is calculated as a number within each category, thus providing an objective interpretation of results and analysis of product appearance. The PCM Tech evaluation of color is similar to that of the Hunter color scoring process. Color evaluations of retail beef cuts were performed in two Scolari's and Holiday Plus grocery stores. Color scoring was performed through the retail wrap on cuts that remained in the case as well as on cuts that were removed as a result of discoloration. PCM Tech scoring was performed on retail cuts included in the project immediately following fabrication and packaging. Cuts were then measured twice a day, approximately ten to twelve hours apart, until they were either sold or removed from the case due to discoloration. Three color readings were obtained for each retail cut at each scheduled measurement period and then averaged for an overall color score. For all packages of product removed from the case, color scores were measured at the time of removal or within one hour of removal. The a* value (red to green) is the primary focus of analysis for this study.

Results and Discussion

Diet and Muscle Tissue Analysis: Microassay analysis of feed samples revealed an average concentration of 2.86 mg E/kg DM for CON and 11.13 mg E/kg DM for VITE for the last 100 d of the feeding period ($P < .01$). Thus, VITE diets contained approximately 8.27 mg E/kg DM more than did diets for CON steers. The least square means for the diet α-tocopheryl acetate levels are illustrated in Figure. 6. The 2.27 mg E/kg DM present in the control diet is attributed to the naturally occurring α-tocopheryl acetate in the diet and a small supplementation present in conventional feedyard diets, used for animal health purposes. According to the cooperating feedyard managers, feedlot performance and carcass characteristics were not affected by supplemental vitamin E, which is in agreement with results of previous studies (Arnold et al., 1993b; Sanders et al., 1996; Secrist et al., 1995).

Initial screening of carcasses using the rectus capiti dorsalis major muscle samples revealed that α-tocopherol concentrations were approximately doubled as a result of dietary vitamin E supplementation (3.10 μg/g) when compared to concentrations of vitamin E in neck muscle samples from steers which were fed a CON diet (1.53 μg/g) (Table 3). The concentrations of α-tocopherol varied among retail cuts within and between treatments for cattle fed either a CON or VITE diet ($P < .05$). For example, only a small difference (approximately 5.8%) in α-tocopherol concentration was detectable between ribeye steaks from animals fed different vitamin E concentrations. However, α-tocopherol concentrations for tenderloin steaks from cattle fed a VITE diet were approximately 100% higher than were those for tenderloin steaks from their CON counterparts. Least square means for the α-tocopherol tissue concentrations for retail cuts is presented in Table 3.. Several previous investigations (Arnold et. al., 1993a; Arnold et. al., 1993b; Sherbeck et al., 1995) have documented that animals supplemented with α-tocopherol, have vitamin E concentrations which differ between muscles within the same animal. Currently, differences in α-tocopherol concentrations within muscles is not fully understood. It is possible that the differences in muscle physiology, blood supply and polyunsaturated fatty acid (PUFA) concentrations may have an effect on retention of vitamin E (Liu et al., 1995; Schaefer et al., 1995). Jensen et al (1988) and Hunt and Hedrich (1977) also suggested accumulation of α-tocopherol is due to muscle fiber type with different fibers having varying aerobic potential.

Discount/Discard and Caselife Analysis: Vitamin E supplementation was numerically effective in stabilizing the cherry-red color of clod cuts (Figure 8).

Steers supplemented with vitamin E were not significantly different (P > .05) however; they yielded clod cuts with a lower incidence, 26.5% vs. 19.4%, of discoloration during retail display (CON, n = 7618; VITE, n = 5104). According to Texas A&M University (TAMU 1993), a typical beef carcass generates 74 retail chuck cuts. If 74 is the appropriate number, 5 fewer retail chuck cuts would be discounted and(or) discarded from the chuck of a steer supplemented with vitamin E. The caselife, or the number of days and hours a product remains an acceptable lean color, was extended for VITE clod cuts (P< .05). The VITE clods could be displayed an additional 9 hours (3 days, 13 hours for VITE cuts vs. 3 days, 4 hours for CON cuts) before they were discounted/discarded. Figure 9 illustrates the least square means for caselife of vitamin E and control clod cuts. Coinciding with the caselife data, is the caselife distribution information. Caselife distribution provides the percentage of product discounted or removed from the case due to discoloration from day one to the final day that the product can remain in the case for the entire project. The caselife distribution analysis was performed on a subprimal basis and divided into chuck, middle, and round meats. The clod steaks are located in the chuck subprimal region. The VITE chuck cuts had a lower percentage of discounts and(or) discards on day four; 72% than CON chuck cuts 85%, these data are illustrated in Figure 10.

Although not statistically significant (P>.05) vitamin E supplementation of cattle was effective in lowering the percentage of discounted ribeye, strip loin and tenderloin steaks by approximately 1.9, 3.5 and 1.6% as compared to their CON counterparts, respectively (Figure 11). For example, one of every ten (10.6%) CON strip loin steaks was pulled from the retail counters of cooperating retail stores and discounted or discarded. However, through VITE supplementation of cattle this number was reduced to one of every 14 strip loin steaks. Additionally, vitamin E supplementation slightly improved the amount of time -- obtainable caselife -- for which ribeye and strip loin steaks were capable of receiving full market value by 14 and 7 hours, respectively ($P > .05$; CON, n = 7901, n = 851; and VITE, n = 1414, n = 2315, for ribeye and strip loin steaks, respectively) (Figure 12). The numerical increase that is seen with the middle meats, provides reasonable confidence in the increased dollar value that can be seen through supplementation of vitamin E The discount percentage for the number one "out-of-stock" beef item, tenderloin steak, was reduced through VITE supplementation of cattle (Figure 11); one of fourteen compared to one of twenty tenderloin steaks were discounted in the CON and VITE, treatments, respectively (CON, n = 2400; VITE, n = 2079). In fact, numbers like these may encourage retailers to fabricate additional numbers of tenderloin steaks each day because they have a greater level of confidence in the color stability of VITE product. T-bone steaks from steers supplemented with vitamin E also yielded numerically lower percentages of discoloration during display than controls, 4.6 and 6.0%, respectively ($P > .05$; CON, n = 564 and VITE, n = 1251). No differences were evident between CON and VITE top sirloin steaks;

approximately 24% of the top sirloin steaks in both CON and VITE treatments were discounted or discarded prior to retail sale (CON, n = 1568, VITE, n = 3352). Caselife distribution also reveals an improved performance of vitamin E supplemented product over non-supplemented product with 99.7% of the control product being removed or discounted from the case on day 6 in comparison to 99.7% on day 7 for the treatment cuts. The distribution of caselife for vitamin E and control middle meats is presented in Figure 13.

Round cuts from vitamin E supplemented cattle had the lowest discount/discard percentage resulting in the highest treatment effect (Figure 14). Though a statistically significant improvement was not found ($P > .05$) the percentages of inside round and top round steaks which had to be reduced in price were lowered by 3.7 and 13.8 percentage points, for VITE, as compared to CON, products, respectively (CON, n = 3339, n = 1627 and VITE, n = 7054, n = 1978, for inside round and top round, respectively). No difference in discount percentage points (2.3%) between the CON vs. VITE were reported for full round steaks (CON, n = 819 and VITE, n = 1086). Additionally, retail caselife was improved with cuts from cattle given supplemental vitamin E prior to harvest ($P < .05$). The least square means for caselife of vitamin E supplemented and control cattle are presented in Figure 15. In this case, caselife for VITE supplemented inside rounds (17 additional hours) and top round steaks (11 additional hours) was improved over that for CON inside rounds and top round steaks. Throughout this study, – in 16 of 19 comparisons of combined round cuts –

those from VITE supplemented cattle had improved retail caselife. The distribution curve also shows a benefit from vitamin E supplemented beef and is illustrated in Figure 16. For example; 92.1% of the CON product round cuts were pulled by the four day of display while only 71.3% of the VITE round cuts were removed from the case on day four of display.

According to opinions of many U.S. retailers, top-of-mind concerns associated with food safety has led to a recoil response by most consumers in that the entire "freshness" of the meat case on the initial appearance of ground beef. It was mentioned by the cooperating retailers in this investigation that they are constantly grinding, discounting and in many cases, discarding ground beef items. Ground beef data was collected at one retail grocery chain. During this survey, approximately one of every five packages (20.5%) of CON ground beef was discounted/discarded (Figure 17); by way of comparison, only one of every 7.5 packages (13.5%) of VITE ground beef was discounted or discarded (CON, n = 1408 and VITE, n = 1175); this is a numerical but, not statistical improvement (P >.05). Most retailers only process as much ground beef as they can sell in a specific time frame (i.e., approximately 6 hours), therefore, it is difficult to determine if vitamin E supplementation of cattle would be useful for prolonging caselife of ground beef even though it will remain bright cherry-red in color longer and in turn, could be sold at full retail price longer. If "real world" retail supermarket situations dictate frequent grinding and display of ground beef, prolonged caselife of this product would not be advantageous. Conversely though, if the last ground beef -- for the day -- is put on display at 5 p.m. and will remain bright in color for one, two or any number of additional hours sales of ground beef would be markedly increased. There is no question that under simulated conditions, dietary supplementation of cattle with vitamin E generates product that when ground and displayed has improved retail caselife in comparison to that prepared from beef from cattle control diets (Mitsumoto et al. 1993).

Color Score Analysis: The least square means for a* values (red to green) in the color score analysis for each retail cut are presented in Table 4. Though the vitamin by cut interaction was not significant a numerical increase occurred for each vitamin E retail cut. These values are only for the retail cuts represented in the selected stores were color analysis was performed. The overall least square means revealed a significant improvement ($P < .01$) for the vitamin E product at 16.7 over that of the control product 15.9. These finding coincide with research by Hunt & Hedrick (1977) on subjective color score analysis revealed different red hues for varying muscle types resulting in the following list of muscles from the highest (reddest) to the lowest: outside semimembranosus (OSM) > gluteus medius (GM) > psoas major (PM) > longissimus dorsi (LD) > inside semitendinosus (IST) = outside semitendinosus (OST) > inside semimembranosus (ISM). In the same study myoglobin and hemeglobin levels were not consistent with the color scores for LD, PM and GM but, were for the OST and IST. The ISM which was significantly paler than any other muscle had higher levels of myoglobin and hemoglobin than the OSM.

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Economics will play an important part in the use of vitamin E, to prolong caselife of beef, to the extent in which this technology, will be implemented throughout the industry. There have been several studies documenting that beef of increased vitamin E content has the potential to positively impact the retail beef market. For example, in a study conducted for the National Cattlemen's Association entitled the Strategic Alliance Field Study, Sanders et al. (1993) demonstrated that cost to benefit ratios, associated with generating and merchandising vitamin E supplemented beef were in the range of 1:8 and 1:10. These data suggest, that vitamin E supplementation to cattle is beneficial for the retail market associated with the beef industry. However, as with many economic issues, the increased profit potential associated with vitamin E supplementation to cattle, to generate VITE beef, is still being questioned. In a recent meeting (1996), Wayne Purcell an Agricultural Economist from Virginia Tech University stated that, "Everybody wants to work together to get the opportunity to realize more money from the same amount of profit, but, we must be honest with ourselves and face the fact that we are in a business driven economy and a general greed oriented society". "The basic mentality is rather than dividing the pie for the good of the whole, get as big a piece as you can for yourself."

In an attempt to estimate the impact of vitamin E supplementation of cattle, on the industry, a computer program -- the OSU Boxed Beef Calculator (Dolezal et al., 1996) – was utilized; the program was originally developed to estimate live cattle value and carcass values for beef, based on boxed beef subprimal yields. The OSU Boxed Beef Calculator, is based on information from 453 steer carcasses, generates fabrication yields of the nine major subprimal cuts, the minor subprimal cuts (i.e., loose meats) and of both 75% and 50% lean trim. An example of the OSU pricing program for boxed beef subprimal and for a lean pricing matrix is presented in Table 5.

In the current exercise, the average steer carcass with a Yield Grade: 2.8, and a Hot Carcass Weight of 748 lbs. was identified by the National Beef Quality Audit (NBQA, 1995). The estimated carcass value for an average steer on a commodity-trimmed boxed beef basis was $699.38, using July 3, 1996 wholesale prices (Table 6). In an attempt to estimate the savings associated with vitamin E supplementation of cattle and generation and display of VITE beef, the above value estimates were utilized to calculate the dollar value associated with product loss due to discount and discard information. Estimates of product lost for CON vs. VITE commodity-trim beef products are presented in

Table 7. Value estimates for the same steer carcass using closely-trimmed boxed beef product prices is presented in Table 8.

The absolute value difference between commodity-trimmed and closely-trimmed boxed beef product prices for a average steer carcass was $54.06. The added value for closely-trimmed boxed beef is associated with the removal of excess waste fat as well as differing fabrication styles between the commodity-trimmed and closely-trimmed products. Estimates of differences in product loss for closely-trimmed beef products are presented in Table 9.

In the previous examples, carcass values were calculated using commodity-trimmed and closely-trimmed beef wholesale prices. Both of these examples allow for an estimate of the savings associated with vitamin E supplementation of cattle and generation of VITE beef as related to box beef trade. Estimations of the economic savings associated with beef sales in a retail environment were attempted and, using the most current fabrication styles and denuded trim procedures in conjunction with average retail beef prices associated with the duration period of this investigation, "retail-ready" carcass values were calculated (Table 10). This allowed for an estimation to be made of the influence of vitamin E supplementation of cattle and generation of VITE beef on the percentage of discounted or discarded beef products in a retail environment (Table 11).

As was the case in the previous examples, the estimated product discount/discard percentage as influenced by vitamin E supplementation of cattle and generation of VITE beef was utilized to calculate the savings in discolored product in a retail situation. These data are summarized in Table 10.

Implications

In a time when service and high quality products determine the success of an industry, the ability to improve is invaluable. With the market share of US beef declining in conjunction with increasing competition from other meat species, enhancing the appearance of beef products may improve customer satisfaction. In the current investigation, supplementation of cattle (i.e., 500 IU/animal/day for 100 days) with vitamin E extended the caselife of retail beef cuts under commercial conditions. Caselife enhancement was achieved in all subprimal cuts with chuck and round cuts as well as ground beef showing the most benefit. Implementation of this technology costs the feeder approximately $4.00 per animal with an ultimate savings of between $30.00 and $35.00 per carcass marketed through retail operations.

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Table 1 : Description of participants and retail cuts utilized.

Feedyard	Number of Cattle Fed	Processing Plant	Retail Grocery Chain	Retail Cuts
Cactus Feeders Inc. (Amarillo, TX)	70,000	IBP (Amarillo, TX)	Kroger (Houston, TX) 2 Stores	T-bone Steak Porterhouse Steak Full Round Steak Top Sirloin Steak
			Holiday Plus (Minneapolis, MN) 2 Stores	Clod Steak Ribeye Steak NY Strip Steak Clod Roast London Broil 80/20 Ground Beef
Harris Ranch Beef Co. (Coalinga, CA)	65,000	Harris Ranch Beef Co. (Selma, CA)	Scolari's (Reno, NV) 6 Stores	Clod Steak Fillet Mignon Steak Top Sirloin Steak Top Round Steak London Broil
Monfort/ Con-Agra Feed Yard (Gilcrest, CO)	100,000	Monfort/ Con-Agra Red Meats (Greeley, CO)	Safeway (Longmont, CO) 2 Stores	Clod Steak Ribeye Steak Fillet Mignon Steak Top Round Steak Clod Roast Ribeye Roast London Broil

Table 2 : Domestic Caselife Strategic Alliance : Tissue sampling.

Retail Cut	Muscle Sampled
Arm Roast or Clod Steak	Triceps Brachii
Inside Round or Round Steak	Semimembranosus
Top Sirloin Steak	Gluteus Medius
T-bone and New York Strip	Longissimus Dorsi
Ribeye	Multifidus Dorsi
Filet Mignon	Psoas Major

Figure 5. Neck muscle sample protocol, a 2 gram sample of the Rectus capiti dorsalis major.

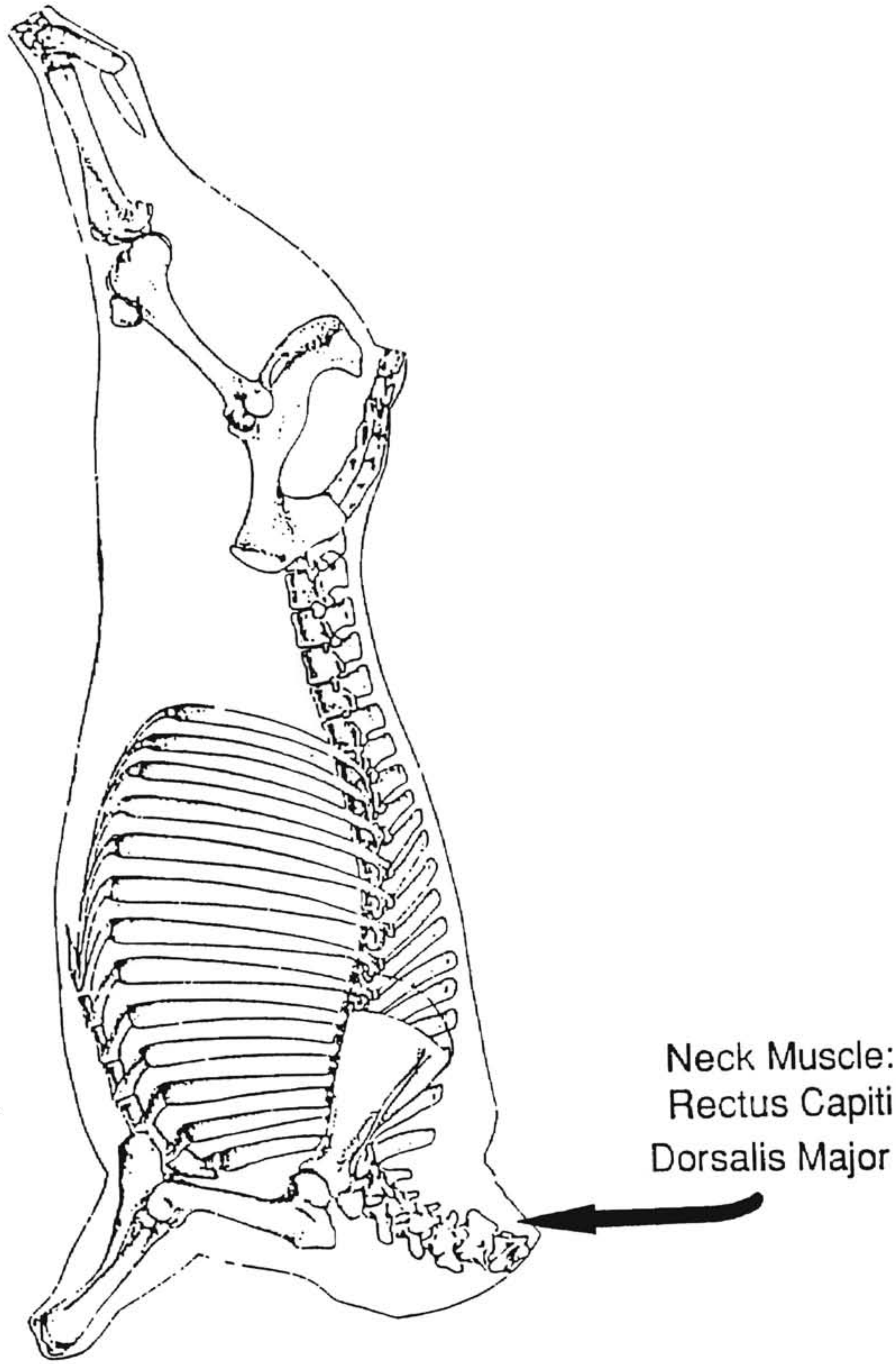

Figure 6. Experimental Protocol for Domestic Caselife Strategic Alliance: Time Line.

Cattle On Feed
March - June, 1996

⇩

Animal Harvesting
May - July, 1996

⇩

Data Collection

Control Phase

May 12 - May 25, 1996 (Rep I)
July 7 - July 20, 1996 (Rep II)

Vitamin E Phase

June 2 - June 29, 1996 (Rep 1)
July 28 - Aug 24, 1996 (Rep II)

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Data Summarization

Figure 7: Vitamin E levels in feedyard diets.

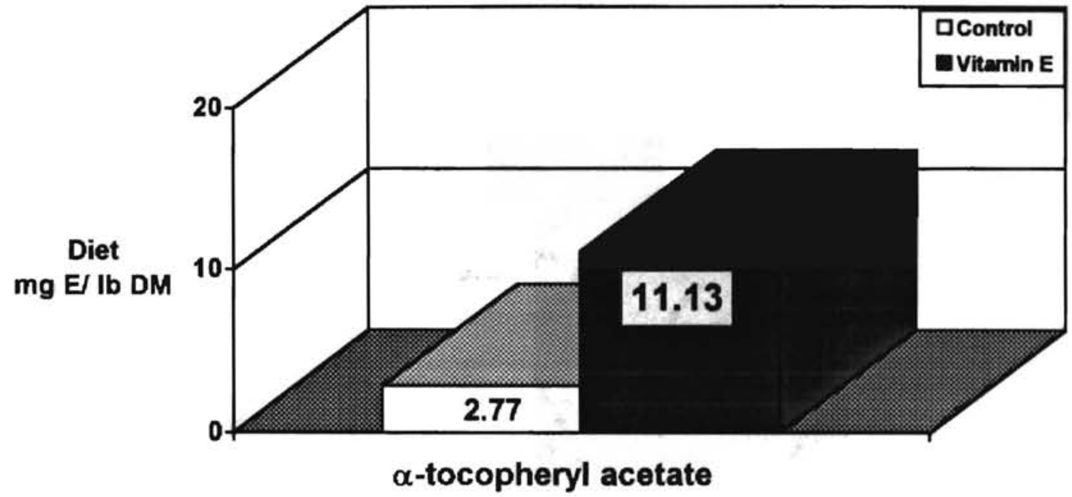

Table 3: Least square means for α-tocopherol in lean muscle (μg/g) from control and supplemented cattle.

ITEM(S)	CONTROL	VITAMIN E
NECK MUSCLE	1.53[b]	3.10[a]
CLOD STEAKS	1.98[b]	3.41[a]
RIBEYE STEAKS	1.47[b]	2.05[b]
STRIPLOIN STEAKS	1.56[b]	2.72[a]
T-BONE STEAKS	1.37[b]	2.64[a]
TENDERLOIN STEAKS	1.88[b]	4.24[a]
TOP SIRLOIN STEAKS	2.10[b]	3.17[a]
INSIDE ROUND STEAKS	1.44[b]	3.10[a]
GROUND BEEF	1.40[b]	2.72[a]

[a, b]Means within Item with different superscript are different ($P<.05$).

Figure 8: Effect of dietary Vitamin E supplementation of cattle on percentage of clod retail cuts discounted when displayed under supermarket conditions.

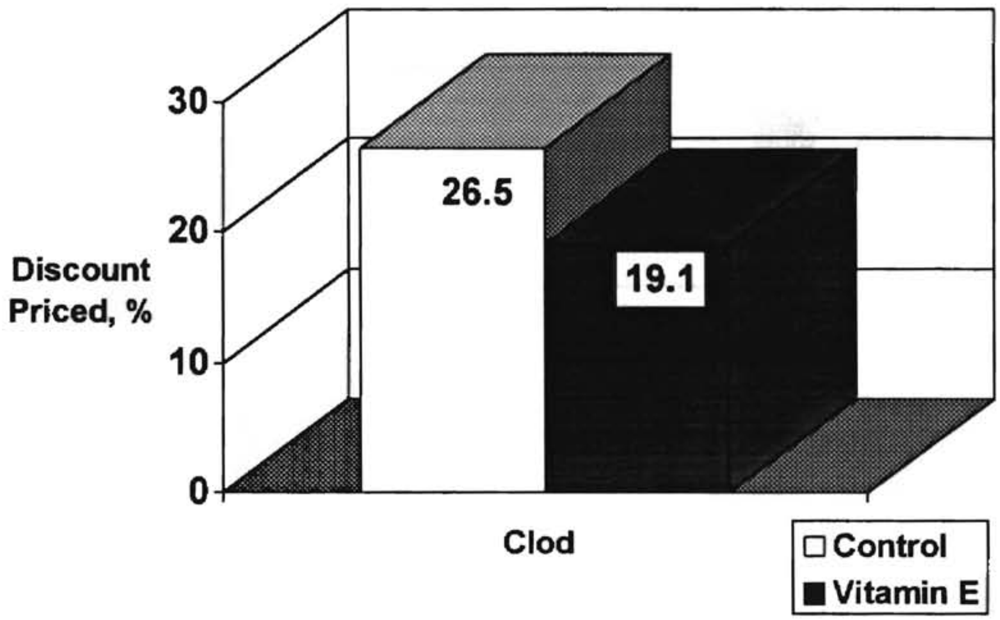

Figure 9: Effect of dietary Vitamin E supplementation of cattle on obtainable caselife of clod retail cuts when displayed under supermarket conditions.

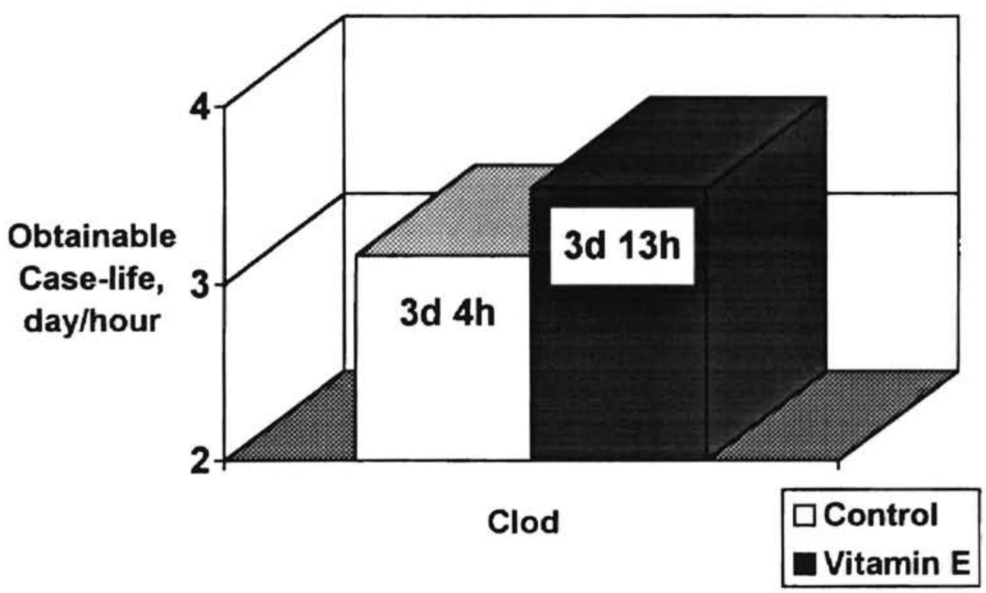

Figure 10: The Effect of dietary Vitamin E supplementation of cattle on the caselife distribution of retail cuts from the chuck subprimal section. PDAY= the day that the product was removed from the case.

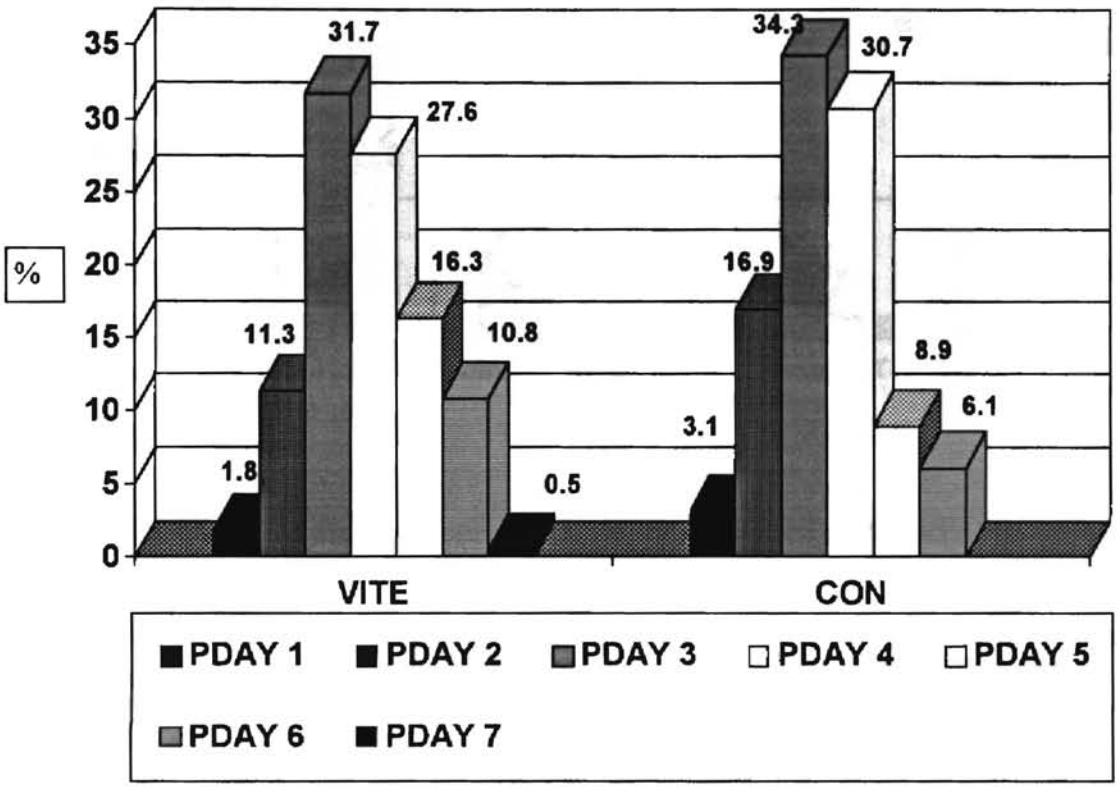

Figure 11: Effect of dietary Vitamin E supplementation of cattle on percentage of rib and loin retail cuts discounted when displayed under supermarket conditions.

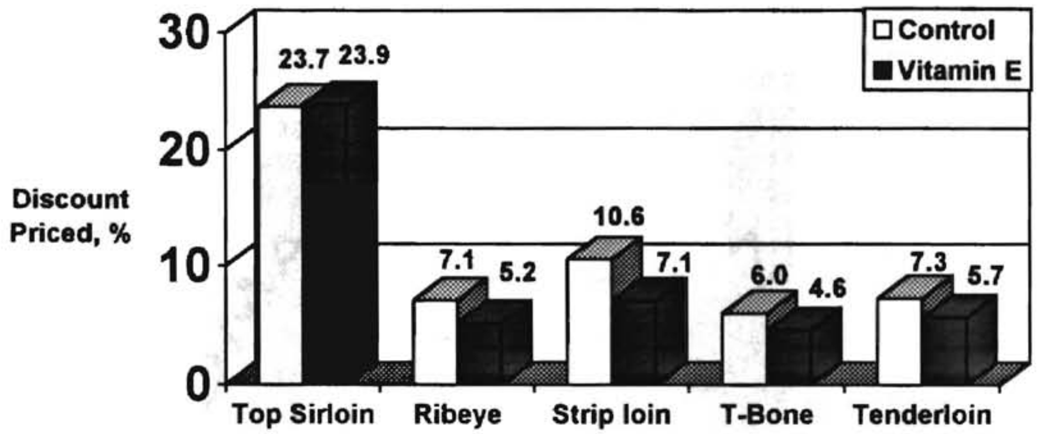

Figure 12: Effect of dietary Vitamin E supplementation of cattle on obtainable caselife of rib and loin retail cuts when displayed under supermarket conditions.

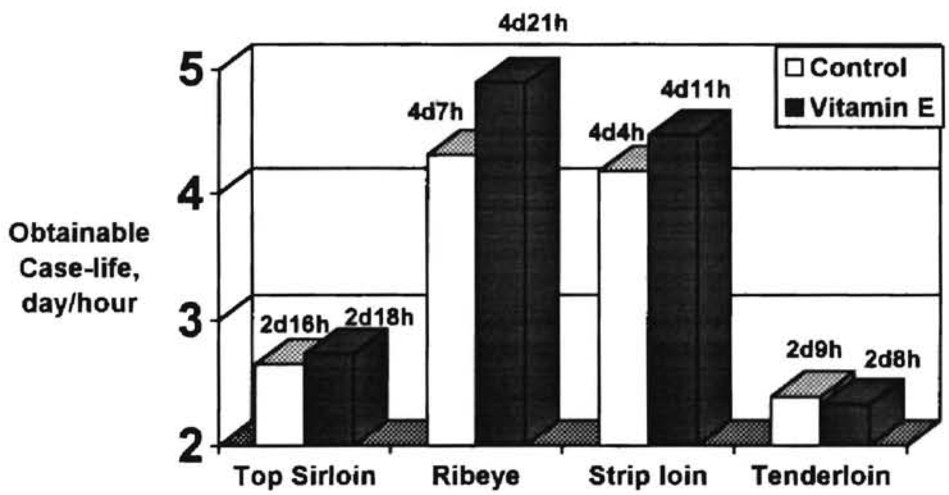

Figure 13: The Effect of dietary Vitamin E supplementation of cattle on the caselife distribution of retail cuts from the middle subprimal section. PDAY= the day that the product was removed from the case.

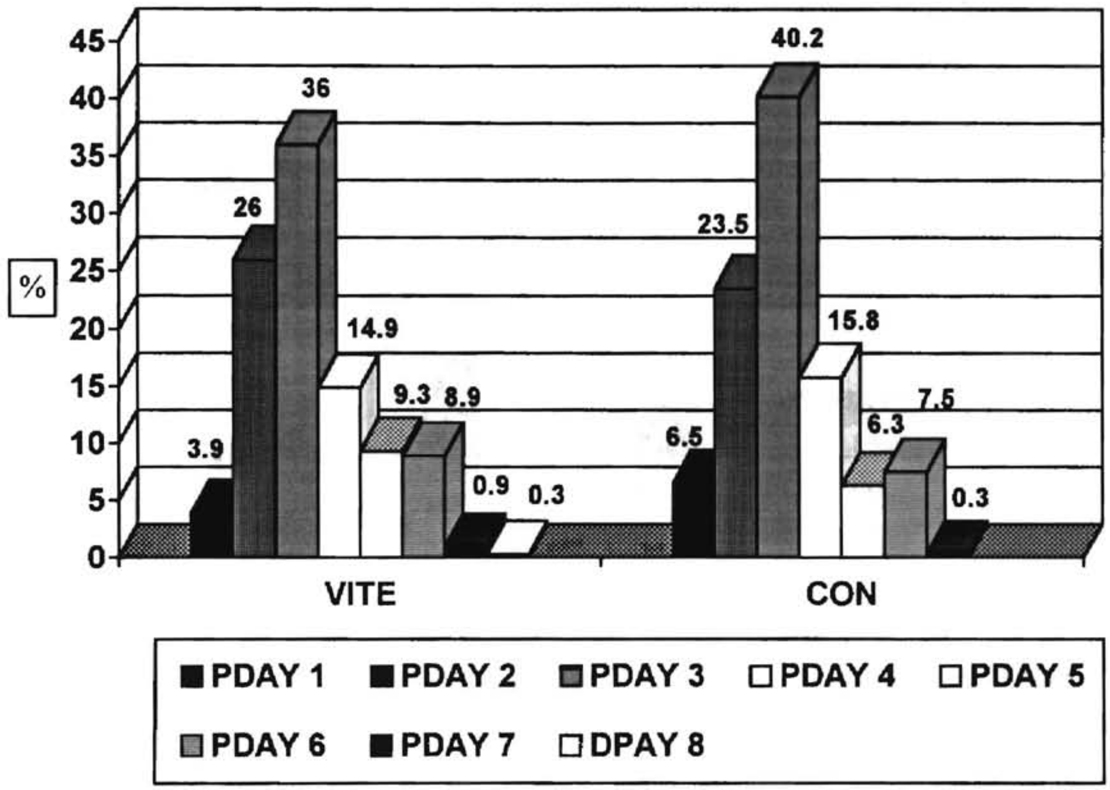

Figure 14: Effect of dietary Vitamin E supplementation of cattle on percentage of round cuts discounted when displayed under supermarket conditions.

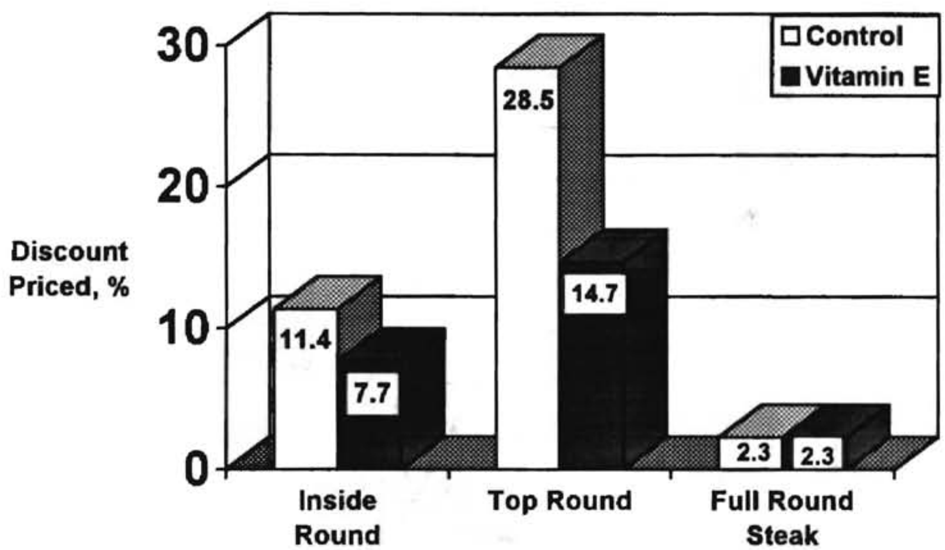

Figure 15: Effect of dietary vitamin E supplementation on of cattle on obtainable caselife of round retail cuts under supermarket conditions.

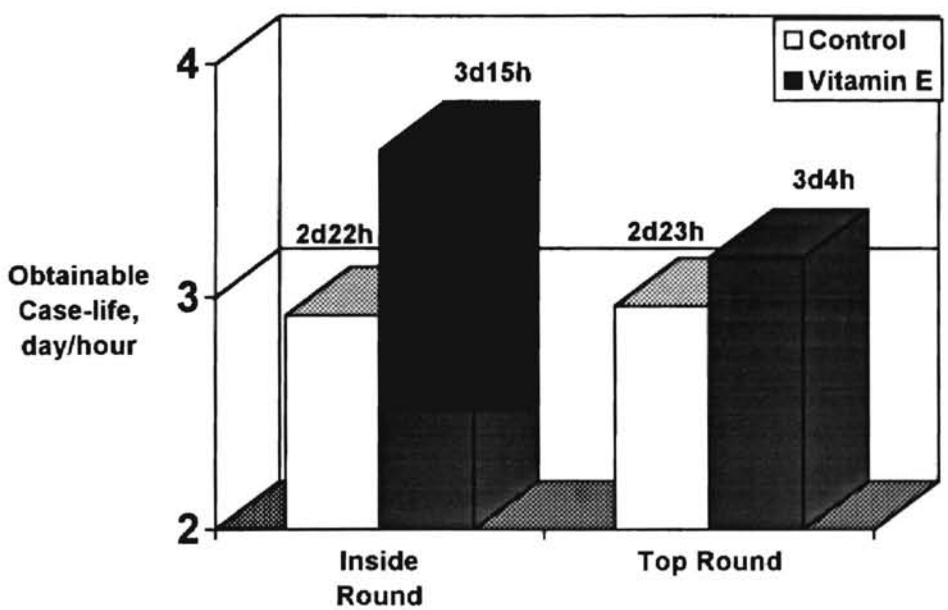

Figure 16: The effect of dietary Vitamin E supplementation of cattle on the caselife distribution of retail cuts from the round subprimal section. PDAY= the day that the product was removed from the case.

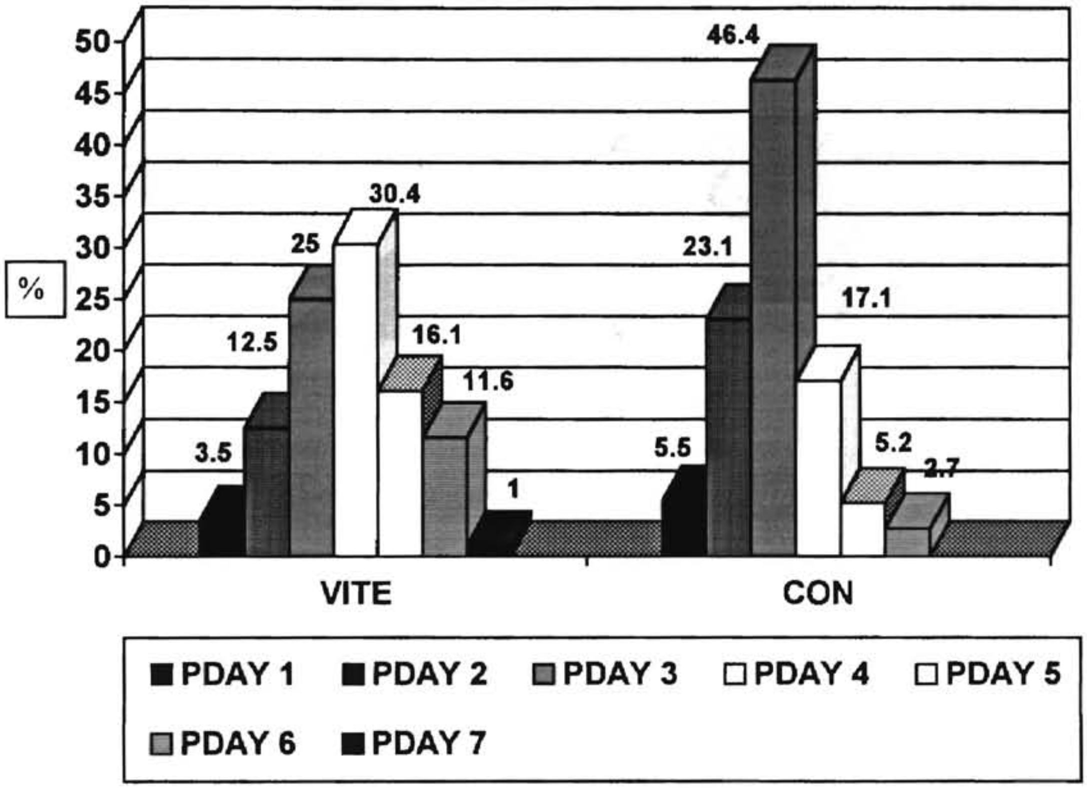

Figure 17: Effect of dietary Vitamin E supplementation of cattle on the percentage of Ground Beef discounted when displayed under supermarket conditions

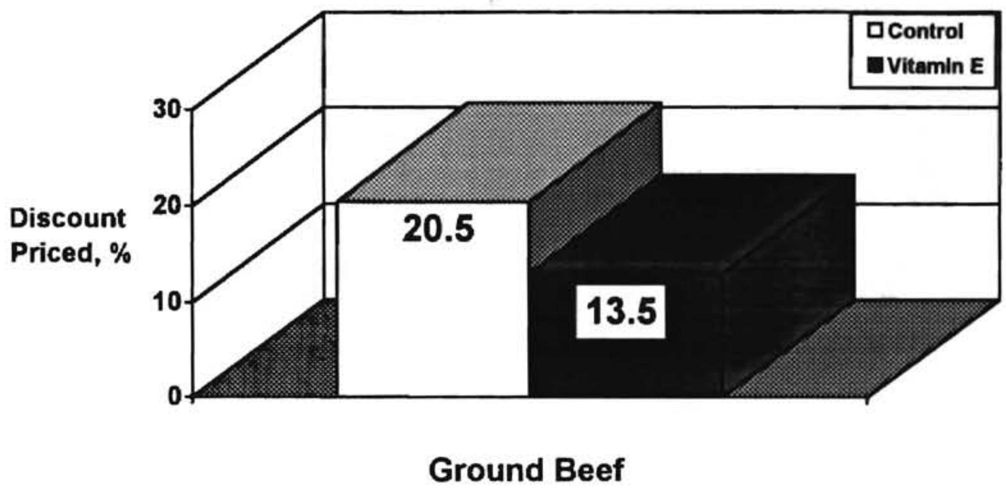

Table 4: Least squares means for a* values in color analysis for vitamin E and control product.

ITEMS	VITAMIN E	CONTROL
Clod Cuts	13.47	13.00
Tenderloin Cuts	15.07	13.93
Inside Round Cuts	19.00	18.56
Top Round Cuts	18.87	16.97
Top Sirloin Cuts	17.45	16.48

Table 5: Pricing Matrix for Boxed Beef Items[a]

OSU CALCULATOR TO ESTIMATE BEEF VALUE BASED ON OUR CUTOUT VALUES.

CLOSELY-TRIMMED (.25") PRICING

	INPUTS		
CARCASS WEIGHT LBS	748	CALC LIVE WT	1173
QUALITY GRADE(1=CH,2=SEL)	1	GROSS CARC VALUE	794.97
YIELD GRADE (1,2,3,OR 4)	2	EST DROP CREDIT	$99.85
DROP CREDIT $ / CWT	$8.51	GROSS LIVE VALUE	894.82
KILL-FAB COST EST.	$88.00	**NET CARCASS $/CWT**	**107.86**
ESTIMATED DRESS %	63.75	**NET LIVE $/CWT**	**$68.76**

US CHOICE

YIELD GRADE 2

THE USER MUST SUPPLY THE BOXED BEEF CUTOUT VALUES IN THE BOX BELOW:

THESE DATA WERE UPDATED-> 07/03/96

BOXED BEEF CUTS			PRODUCT WORTH	
(GRADE--->>)	CHOICE	SELECT	POUNDS	DOLLARS
112A RIBEYE <11 lbs	$380.00	$330.00	25.74	$96.52
112A RIBEYE 11> lbs	$375.00	$333.00		$0.00
114 SH CLOD	$105.00	$105.00	41.06	$43.11
116A CHUCK ROLL	$103.00	$103.00	60.56	$62.37
120 BRISKET	$103.00	$103.00	21.19	$21.83
167 KNUCKLE	$124.00	$124.00	21.16	$26.24
168 INSIDE RND	$143.00	$135.00	43.32	$61.94
170 GOOSENECK	$113.00	$113.00	54.96	$62.11
180 STRIP LOIN <12 lbs	$504.00	$366.00	24.65	$124.22
180 STRIP LOIN 12-13.9 #	$504.00	$366.00		$0.00
180 STRIP LOIN 14> lbs	$504.00	$366.00		$0.00
184 TOP BUTT <12 lbs	$216.00	$178.00	23.79	$51.39
184 TOP BUTT 12> lbs	$216.00	$178.00		$0.00
185A BOT SRLN FLAP	$200.00	$200.00	7.47	$14.95
185B BOT SRLN BALL TIP <2	$132.00	$132.00	4.88	$8.29
185B BOT SRLN BALL TIP 2>	$170.00	$160.00		$0.00
185C BOT SRLN TRITIP	$202.00	$202.00	5.59	$11.29
189A TENDERLOIN <5 lbs	$605.00	$535.00	12.18	$74.94
189A TENDERLOIN 5> lbs	$615.00	$540.00		$0.00
193 FLANK STEAK	$270.00	$265.00	3.85	$10.40
INSIDE SKIRT	$190.00	$190.00	9.07	$17.22
CAP & WEDGE MEAT	$102.00	$102.00	33.44	$34.10
BACK RIBS	$64.00	$64.00	12.44	$7.96
75% LEAN TRIM	$70.00	$70.00	68.11	$47.67
50% LEAN TRIM	$49.00	$49.00	37.57	$18.41
TOTAL			511.02	794.97

[a]Prices reflect those for closely-trimmed boxed beef subprimal markets on July 3, 1996.

Table 6: Value determination for commodity-trimmed carcass

Item	Product Worth	
	Weight, lb.	Value, $
Chuck cuts	108.3	99.80
Middle meat cuts	92.2	294.72
Round cuts	126.4	134.96
Ground cuts	138.6	99.80
Loose meat cuts	56.4	70.10
Total	**521.9**	**$699.38**

Table 7: Product loss determination for commodity-trimmed cuts

Item	Discount Product, %		Product Loss, $	
	CON	VITE	CON	VITE
Chuck cuts	26.5	19.1	26.45	19.06
Middle meat cuts	13.0	12.0	38.31	35.37
Round cuts	18.1	10.4	24.43	14.04
Ground cuts	20.5	13.0	14.38	9.11
Loose meat cuts	?	?	?	?
Total	**19.53%**	**13.63%**	**$103.57**	**$77.58**
Difference	**-5.90%**		**-$25.99**	

Table 8: Value determination for closely-trimmed carcass

Item	Product Worth	
	Weight, lb.	Value, $
Chuck cuts	101.6	105.49
Middle meat cuts	86.4	315.55
Round cuts	119.4	148.56
Ground cuts	139.1	100.30
Loose meat cuts	52.0	83.64
Total	**498.5**	**$753.44**

Table 9: Product loss determination for closely-trimmed cuts

Item	Discount Product, %		Product Loss, $	
	CON	VITE	CON	VITE
Chuck cuts	26.5	19.1	27.95	20.15
Middle meat cuts	13.0	12.0	41.02	37.87
Round cuts	18.1	10.4	26.89	15.45
Ground cuts	20.5	13.0	17.15	10.87
Loose meat cuts	?	?	?	?
Total	**19.53%**	**13.63%**	**$113.01**	**$84.34**
Difference	**-5.90%**		**-$28.67**	

Table 10: Value determination for denuded retail-ready cuts.

Item	Product Worth	
	Weight, lb.	Retail Value, $
Chuck cuts	95.3	120.85
Middle meat cuts	81.9	348.42
Round cuts	98.3	151.20
Ground cuts	172.9	138.11
Loose meat cuts	44.7	101.33
Total	**493.1**	**$859.91**

Table 11: Product loss determination for denuded retail-ready cuts.

Item	Discount Product, %		Product Loss, $	
	CON	VITE	CON	VITE
Chuck cuts	26.5	19.1	32.03	23.08
Middle meat cuts	13.0	12.0	45.29	41.81
Round cuts	18.1	10.4	27.37	15.72
Ground cuts	20.5	13.0	28.32	17.95
Loose meat cuts	?	?	?	?
Total	**19.53%**	**13.63%**	**$133.01**	**$98.56**
Difference	**-5.90%**		**-$34.45**	

APPENDIX

Vitamin E Project - Chuck Cuts		
	Control	Vitamin E
Avg Pkg Weight/lbs	1.78	1.78
Avg Retail Price/lbs	$2.79	$2.79
Pull number/d	24.98	23.72
Pull Percentage	26.5%	19.1%
Product Lost/d, lbs	44.46	42.22
Product Lost/d, $	$144.02	$136.77
Avg Shelf-Life (d)	3d 4hrs	3d 13hrs

Vitamin E Project - Middle Cuts		
	Control	Vitamin E
Avg Pkg Weight/lbs	1.73	1.73
Avg Retail Price/lbs	$6.10	$6.10
Pull number/d	27.0	19.9
Pull Percentage	13.0%	12.0%
Product Lost/d, lbs	46.71	34.43
Product Lost/d, $	$306.53	$225.94
Avg Shelf-Life (d)	3d 1hrs	3d 4hrs

Vitamin E Project - Fillet Mignon		
	Control	Vitamin E
Avg Pkg Weight, lbs	.91	.91
Avg Retail Price/lb, $	$8.09	$8.09
Pull Number/d	4.43	3.52
Pull Percentage	7.3%	5.7%
Product Lost/d, lbs	4.03	3.20
Product Lost/d, $	$36.14	$28.71
Avg Caselife, d	2d 9h	2d 8h

Vitamin E Project - NY Strip		
	Control	Vitamin E
Avg Pkg Weight, lbs	1.15	1.15
Avg Retail Price/lb, $	$6.99	$6.99
Pull Number/d	2.03	1.63
Pull Percentage	10.6%	7.1%
Product Lost/d, lbs	2.33	1.87
Product Lost/d, $	$17.91	$14.37
Avg Caselife, d	4d 4h	4d 13h

Vitamin E Project - Top Sirloin		
	Control	Vitamin E
Avg Pkg Weight, lbs	1.17	1.17
Avg Retail Price/lb, $	$4.34	$4.34
Pull Number/d	15.09	10.75
Pull Percentage	23.7%	23.9%
Product Lost/d, lbs	17.66	12.58
Product Lost/d, $	$88.71	$63.20
Avg Caselife, d	2d 16h	2d 18h

Vitamin E Project - T-Bone		
	Control	Vitamin E
Avg Pkg Weight, lbs	1.45	1.45
Avg Retail Price/lb, $	$5.94	$5.94
Pull Number/d	3.21	2.58
Pull Percentage	6.0%	4.6%
Product Lost/d, lbs	4.65	3.74
Product Lost/d, $	$30.91	$24.28

Vitamin E Project - Ribeye		
	Control	Vitamin E
Avg Pkg Weight, lbs	1.84	1.84
Avg Retail Price/lb, $	$5.76	$5.76
Pull Number/d	4.72	3.42
Pull Percentage	7.1%	5.2%
Product Lost/d, lbs	8.68	6.29
Product Lost/d, $	$53.78	$39.00
Avg Caselife, d	2d 9h	2d 8h

Vitamin E Project - Round Cuts		
	Control	Vitamin E
Avg Pkg Weight/lbs	1.56	1.56
Avg Retail Price/lbs	$3.37	$3.37
Pull number/d	29.9	17.2
Pull Percentage	18.1%	10.4%
Product Lost/d, lbs	46.64	26.83
Product Lost/d, $	200.23	104.18
Avg Shelf-Life (d)	2d 22hrs	3d 11hrs

Vitamin E Project - Round Steak		
	Control	Vitamin E
Avg Pkg Weight, lbs	1.77	1.77
Avg Retail Price/lb, $	$2.99	$2.99
Pull Number/d	3.92	2.35
Pull Percentage	2.34%	2.33%
Product Lost/d, lbs	6.94	4.16
Product Lost/d, $	$23.89	$14.32

Vitamin E Project - London Broil		
	Control	Vitamin E
Avg Pkg Weight, lbs	1.52	1.52
Avg Retail Price/lb, $	$3.32	$3.32
Pull Number/d	17.02	10.05
Pull Percentage	11.4%	7.7%
Product Lost/d, lbs	25.87	15.28
Product Lost/d, $	$99.51	$58.77
Avg Caselife, d	2d 22h	3d 15h

Vitamin E Project - Top Round		
	Control	Vitamin E
Avg Pkg Weight, lbs	1.03	1.03
Avg Retail Price/lb, $	$3.49	$3.49
Pull Number/d	11.31	6.37
Pull Percentage	28.5%	14.7%
Product Lost/d, lbs	11.65	6.56
Product Lost/d, $	$49.40	$27.99
Avg Caselife, d	2d 23h	3d 4h

Vitamin E Project - Ground Beef

	Control	Vitamin E
Avg Pkg Weight, lbs	1.72	1.72
Avg Retail Price/lb, $	$1.89	$1.89
Pull Number/d	13.7	12.7
Pull Percentage	20.5%	13.0%
Product Lost/d, lbs	36.12	21.84
Product Lost/d, $	$79.22	$51.44

VITA

Elizabeth A Westcott

Candidate for the Degree of

Master of Science

Thesis: VITAMIN E: AN ASSESSMENT OF THE "QUALITY & ECONOMIC" GAINS ACHIEVED THROUGH SUPPLEMENTATION OF α-TOCOPHERYL ACETATE IN FEEDLOT STEERS

Major Field: Animal Science

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Education: Graduated from Holdrege High School, Holdrege, Nebraska in May of 1989; received a Bachelor of Science degree in Agricultural Sciences with an Emphasis in Political Science from the University of Nebraska, Lincoln, Nebraska in August of 1994. Completed the requirements for the Master of Science degree with a major in Animal Science at Oklahoma State University in May 1997.

Experience: Raised in Holdrege, Nebraska and on a ranch near Nenzel, Nebraska; worked as wrangler and horse trainer in summer at Fort Robinson State Park in Crawford, Nebraska; Congressional Internship in Washington DC for the Honorable Virginia Smith; employed by the University of Nebraska, Department of Animal Science as an undergraduate assistant; employed by Oklahoma State University, Computer Information Services as a lab monitor and team leader; employed by Oklahoma State University, Department of Animal Science as a graduate assistant.

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