EFFECTS OF DIETARY VITAMIN A RESTRICTION ON COLOR SHELF-LIFE, LIPID OXIDATION, AND SENSORY TRAITS OF LONGISSIMUS LUMBORUM AND TRICEPS BRACHII STEAKS FROM EARLY AND TRADITIONALLY WEANED CALVES

by

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Abstract

Vitamin A (VA) restriction during finishing has been shown to increase marbling in cattle. However, little work has been done to look at the effects that VA restriction might have on color shelf-life and sensory traits of beef. This study involved 48 calves either early-weaned at 137 $\pm$ 26 d or traditionally-weaned at 199 $\pm$ 26 d and supplemented with either 15,400 IU/kg dry matter of VA or restricted to no supplemental VA during the finishing phase. Cattle were harvested in two groups, and carcass data were obtained after chilling. Strip loins and shoulder clods were retrieved, vacuum packaged, and cut into steaks after 14 d of aging. Visual and instrumental color scores for 7 d of retail display, thiobarbituric acid reactive substances (TBARS) values, trained sensory panel scores, and Warner-Bratzler shear force (WBSF) values were obtained. The only differences associated with weaning group were that L* values were lower ($P < 0.05$) on d 4 to 6 for *Triceps brachii (TB)* steaks from traditionally-weaned calves restricted in VA than early-weaned calves supplemented with high VA. Both *Longissimus lumborum (LL)* and *TB* steaks from calves supplemented with high VA had darker, more tan ($P < 0.05$) color scores after 4 d of display in PVC packaging than steaks from calves restricted in VA. Also, a*, b* and saturation index values were lower ($P < 0.05$) in *LL* steaks for the high VA treatment than those from the no supplemental VA treatment. There was less lipid oxidation ($P < 0.05$), as reported by TBARS, in both muscles from calves restricted in VA than muscles from calves supplemented with high VA. No treatment effects were found for WBSF values for either muscle, and no differences existed in sensory panel traits of the *TB* steaks. Sensory panel scores were less desirable ($P < 0.05$) for myofibrillar tenderness and connective tissue amount in *LL* steaks from calves fed high VA than steaks from calves restricted in VA. Dietary VA restriction during finishing has potential to increase color shelf-life and reduce lipid oxidation, with no negative effects on cooked meat sensory attributes.

Key Words: Early-weaning, Vitamin A, Retail Display, Beef Sensory, TBARS

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Dedication

My master's dissertation is dedicated to my parents, Gary and Shirley Daniel, who have always supported me in my endeavors and have not only been my parents, but also my best friends.

CHAPTER 1 - Literature Review

Consumer perceptions of meat are determined primarily by the evaluation of sensory traits. The most common sensory characteristics associated with fresh beef include color, tenderness, and flavor. Live animal management can have a strong impact on these sensory components. Therefore, it is important for the livestock industry to produce high quality beef with the most economical approach. Much research has been conducted to look at how livestock management can be manipulated to optimize quality aspects of meat.

Effect of Marbling Scores on Beef Sensory Attributes

The impact of vitamin A restriction on increasing marbling can have effects on sensory properties of fresh meat. Consumers often use marbling as an indicator of leanness and as a selection tool in determining the palatability of meat at purchase. The industry also uses marbling as an indicator of palatability in the beef quality grading system (USDA, 1997). Yet, there is conflicting data about the true impact marbling has on the palatability of meat.

Much data indicate that the amount of marbling can impact sensory palatability scores. Savell et al. (1987) concluded that increasing marbling in top loin steaks had a positive impact on overall eating quality. Experienced sensory panelists evaluated 36.5% of steaks that graded USDA Choice "very desirable" in overall palatability and only 8.7% of USDA Select steaks as "very desirable" in overall palatability (Dolezal, Smith, Savell, Carpenter, 1982). However, contrasting data shows that even though some consumers may favor the overall eating quality of higher marbled steaks, there may be little variation in sensory traits that can be accounted for by marbling. Campion, Crouse, and Dikeman (1975) concluded that only 6% of the variation in taste panel acceptability could be attributed to marbling and that a 30-fold increase in marbling would be required to yield one unit of change in taste panel responses. Even though overall palatability scores for steaks may not be significantly affected by marbling, individual sensory components may be influenced.

Historic studies suggested that only a small amount of the variation in tenderness can be accounted for by marbling. Clover, King, and Butler (1958) and Palmer, Carpenter, Alsmeyer, Chapman, and Kirk. (1958) found that 11% of the variation in tenderness was accounted for by marbling. Later research reported a correlation of marbling score and Warner-Bratzler shear force values (r = -0.20) and with trained panel tenderness scores (r = 0.28) (Campion, et al., 1975). In contrast to these studies, Dolezal et al., (1982) reported that *Longissimus lumborum* steaks from USDA Choice carcasses received the highest percentage of "very desirable" ratings and the lowest percentage of "undesirable ratings" for overall tenderness when compared with steaks from USDA Good and Standard carcasses. In addition, their research found that steaks from USDA Standard carcass had the highest percentage of "undesirable" tenderness scores.

It is more commonly accepted that marbling has a more profound effect on juiciness and flavor than it does on tenderness. Early studies indicated that marbling may affect juiciness because fat flavor stimulates the flow of salvia and fat that melts at or below the eating temperature of meat becomes a liquid and contributes to juiciness (Blumer, 1963). According to Barbella, Tanner, and Johnson (1939), 16% of the variation in juiciness may be attributed to fat. Campion et al. (1975) found a correlation (r = 0.32) between marbling and taste panel juiciness. Dolezal et al. (1982) found that steaks grading Choice had significantly higher juiciness scores than poorer marbled steaks. This study also found flavor scores increased as the ether extract values increased. Kropf and Graf (1959) found that as fat levels increased, flavor desirability also increased. Most high-end restaurants serve USDA Choice and Prime steaks. Smith, Savell, Cross, and Carpenter, (1983), found that *Longissimus* steaks had a linear decrease in flavor desirability as quality grade decreased from USDA Prime through USDA Cutter. Yet, it must be considered that not all consumers prefer higher fat content in meat. Dunsing (1959) found, during a consumer household study, that marbling scores were inadequate for indicating desirable eating quality. Romans, Tuma, and Tucker (1965) determined a bell-shaped curve for the effect of marbling on flavor. Killinger, Calkins, Umberger, Feuz, and Eskridge (2004) found that consumers in Chicago and San Francisco preferred ($P < 0.01$) low-marbled steaks over high-marbled steaks. In addition, it has been found that women are less likely ($P < 0.05$) to prefer high-marbled steaks (Umberger, 2001). Miller, Moeller, Goodwin, Lorenzen & Savell (2000) found that the increase in fat flavor attributed to intramuscular fat content is preferred by most U.S. consumers, yet an increase in fat can be both positive and negative, depending on the person. Marbling plays an important role in fat flavor, and also lipids contribute to meat flavor when they act as a solvent for the volatile compounds that develop during production, handling, and thermal processing (Moody, 1983). Increased lipid content can also make muscle more prone to lipid oxidation leading to off-flavor development in meat.

Meat color is also another selection tool utilized by consumers. Increased marblingi in some instances my dilute meat pigments though causing more light to be reflected. Howver, research by Wulf, O'Connor, Tatum, and Smith (1997) found that marbling and instrumental color values are only slightly correlated. They reported that as marbling scores increase L* (r = 0.09), a* (r = 0.03) and b* (r = 0.02) value also increase. Therefore, marbling may be utilized as a tool in enhance perceived meat color to the consumer.

Many consumers prefer the eating quality of steaks classified as either Prime or Choice to steaks classified as Select and Standard. In a study by Killinger et al. (2004), consumers rated high-marbled steaks better in flavor, juiciness, and overall acceptability than low-marbled steaks but did not note differences in tenderness. Therefore, even though tenderness is a major component of overall palatability, consumers often value steaks that are juicy and flavorful, and marbling partially contributes to that.

Early vs. Traditional Weaning

In traditional production systems, calves are weaned at around 200 days. However, milk quality after a few months of lactation can be reduced, especially during adverse environmental conditions such as drought. In addition, the longer calves nurse their dams, the more the cows' body condition scores will decrease. Therefore, over the past several decades, research has been conducted to determine the impact that weaning age has on cow and calf performance. Green and Buric (1953) determined that weaning calves at 90 versus 180 days of age had no adverse affects on rate of gain and that early weaning could allow earlier evaluation of rate of gain. Further research has solidified that early weaning increases rate of gain in feedlot calves and can have an impact on fat deposition (Fluharty, Loerch, Turner, Moeller, and Lowe, 2000; Myers, Faulkner, Ireland and Parrett, 1999). Myers et al. (1999) found that early weaning improved overall average daily gain by 0.07 kg/d over normally-weaned steers and that early weaning could offer a 40% increase in the number of Angus x Hereford steers that grade Choice or higher. Similar results were seen in Simmental and Wagyu crossbred steers. Wertz, Berger, Walker, Faulkner, McKeith, & Rodriguez-Zas (2002) determined that early-weaned calves had greater marbling scores at harvest than normally-weaned calves at any given backfat measurement. Meyer et al. (2005) found that early weaned calves had higher ($P < 0.05$) marbling scores but no differences in loin muscle area or backfat measurements. It is hypothesized that traditionally weaned calves might be lacking total energy requirements at the end of nursing to provide both muscle growth and fat deposition.

Meyers et al. (1999) found that the number of days required to finish steers decreased as weaning age increased. In their study, steers weaned at 152 and 215 days of age were 55 and 38 days quicker to a constant fat end point than the steers weaned at 90 days. Although early weaned calves may require more days on feed to meet adequate carcass endpoints, early weaned calves are still often harvested at a younger age than traditionally weaned calves.

Animal age can also play an important role in meat quantity and quality. Lunt and Orme (1987) found that calves have greater fat thickness and numerically greater yield grades and quality grades when compared with yearlings. Dikeman, Nagele, Meyers, Schalles, Kropf, and Kastner (1985) and Johnson, Huffman, Williams, and Hargrove (1990) found that meat from calves tend to be more tender than meat from yearlings. Brewer, James, Calkins, Rasby, Klopfensteine, and Anderson (2007) also concluded that yearling finished steers tend to produce less tender meat. Animal age may not only have an impact on tenderness but also on meat color. Color research (Muramoto, Shibata, Nakanishi, 2003) in Japanese Black cattle determined that metmyoglobin formation did not differ in the *m. serratus ventralis* during 12 days of display between 24 month, 28 month, and 38 month old steers. Yet, metmyoglobin formation was lower ($P < 0.05$) in the 24 month old steers than the 38 month old steers on day 3 of display for the *m. psoas major*, and the 38 month old steers had higher (<0.05) metmyoglobin formation in the *m. semitendinosus* than the 24 and 28 month old steers on day 6 of display.

In summary, early weaning tends to positively affect average daily gain, marbling, tenderness, and meat color. Weaning calves early may allow producers to decrease stress on cow herds and also increase the value of feedlot calves.

Vitamin A

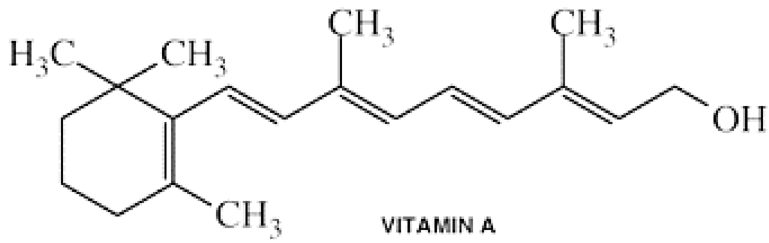
Vitamins are a group of complex organic compounds that are present in minute amounts in natural foodstuffs and are required for normal metabolism (McDowell, 2006). Vitamin A is classified, along with vitamins D, E and K, as a fat-soluble vitamin. Vitamin A is important as a dietary supplement in non-grazing livestock because it is not synthesized in the body and without grazing, livestock do not have access to vitamin A pre-cursors such as β-carotene. In animals, vitamin A plays a vital role in vision, growth and reproduction, maintenance of epithelial tissues, and bone development (NRC, 2000).

Vitamin A is unique because both deficiencies and excess amounts can cause problems in humans and animals. Deficiencies in vitamin A occur most often when animals are fed high concentrate rations, consume bleached pasture during drought periods, consume feeds that have been highly processed or stored for long periods, or have been exposed to abnormal amounts of sunlight, air and high temperatures (NRC, 2000). Livestock that are deficient in vitamin A can show symptoms such as reduced feed consumption, rough hair coat, edema of joints and brisket, lacrimation, xerophthalmia, night blindness, slow growth, diarrhea, convulsions, seizures, improper bone growth, low conception rates, abortion, stillbirths, abnormal semen, and weakened immune systems (NRC, 1984). The greatest need for vitamin A is during calving and breeding time. If young animals are inadequate in vitamin A, they may have a higher occurrence of pinkeye, pneumonia, and other illnesses associated with mucous membranes. Cows deficient in vitamin A may abort or produce blind, dead, or weak offspring (McDowell, 1989). Toxicity from vitamin A can occur with extremely high concentrations but is rare, especially in cattle, due to the microbial degradation of vitamin A in the rumen (NRC, 2000). The NRC guidelines indicate levels up to 30 times the suggested requirement (66,000 IU/kg dry matter) are safe and should not cause toxicity problems for ruminants. However, toxic levels can cause skeletal malformations, spontaneous fractures, and internal hemorrhage (NRC, 1987). In addition, excess vitamin A affects the metabolism of other fat-soluble vitamin with competition for absorption and transportation.

Characteristics and Functions

The chemical structure of vitamin A is characterized as a long-chain, unsaturated alcohol with five double bonds (Figure 1.1, McDowell, 1989). The double bonds in the structural design allow vitamin A to exist in different isomeric forms. The most common isomer form of vitamin A found in mammalian tissue is the all-*trans* structure, but *cis* forms can also be present.

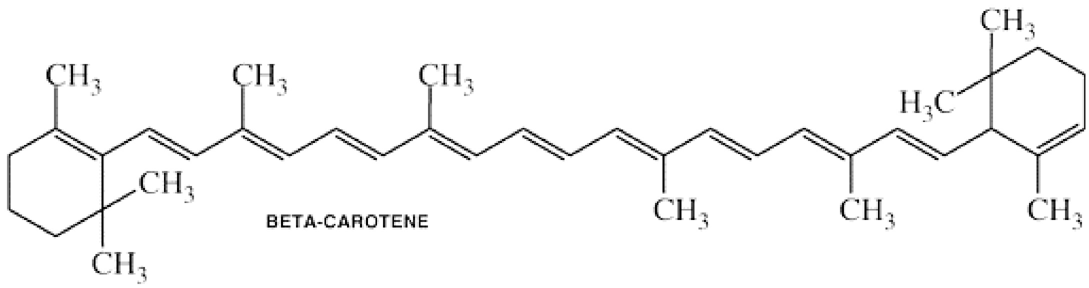
Figure 1.1 Structure of vitamin A



Vitamin A cannot be synthesized *de novo* by animals and must be taken up from food sources. Vitamin A must be obtained from the diet, either as preformed vitamin A such as retinol and retinyl ester or as provitamin A carotenoids (Litwack, 2007). Vitamin A can be found in the body in three forms: retinol, retinal, and retinoic acid. In most cases, retinol is hydrolyzed in the small intestine by the enzyme retinyl-ester hydrolase that is secreted by the pancreas. Vitamin A is absorbed as retinol and is re-esterified to palmitate, incorporated into the chylomicra of the mucosa, and secreted into the lymph system where it is transported with a low-density lipoprotein to the liver where it is deposited in hepatocytes, stellate, and parenchymal cells (McDowell, 1989). The liver is the primary storage site for vitamin A, although some retinol may be oxidized first to retinal and then to retinoic acid and pass into the portal blood. The liver can store up to 90% of the body's vitamin A. The retinol stored in the liver is transported by retinol-binding proteins to tissues where they are needed for metabolic functions (McDowell, 1989).

The vitamin A precursor, β-carotene (Figure 2), is abundant in green leaves and forages (McDowell, 1989). β-carotene is taken up during livestock grazing and converted to retinol by central cleavage of the molecule in the intestine (Litwack, 2007). In some species (pigs, sheep, and goats), most of the carotene is cleaved and vitamin A is absorbed by the intestine. However, in other livestock species (cattle and horses), carotene is absorbed by the intestine and stored in the liver and fatty tissues (McDowell, 1989). Breed differences in vitamin A absorption exist in cattle. For instance, Holsteins are efficient converters while Guernsey and Jersey breeds are inefficient converters, which lead to large amounts of carotene absorption and yellow fat color in Guernseys and Jerseys. Absorption may also be affected by the isometric form of β-carotene. *Cis-trans* isomers are absorbed less efficiently than the all-*trans* forms (McDowell, 1989).

Figure 1.2 Structure of β-carotene



Supplementation

Several methods are used to supplement livestock with vitamin A. It may be added as a concentrate or liquid supplement, included with free-choice mineral mixtures, injected, or added to drinking water (McDowell, 1989). The NRC recommended level of vitamin A for feedlot cattle is 2,200 IU/kg dry matter intake (NRC, 1996) and is slightly higher for pregnant beef heifers and cows, and for lactating cows and breeding bulls. Higher doses of vitamin A may be important under stress conditions. Feedlot cattle with unknown histories are sometimes given an injection of vitamin A (1,000,000 IU) as part of the adaptation or preconditioning process (McDowell, 1989). Also, because vitamin A is relatively cheap, feedlots often supplement vitamin A in feedlot rations at higher amounts than the NRC recommended values. A survey of feedlot nutritionists found that more than a dozen consultants recommended vitamin A to exceed the NRC requirements. The surveyed nutritionists suggested levels that ranged from 3,000 to 7,260 IU/kg of dry matter intake for finishing rations (Gaylean and Gleghorn, 2002). These elevated levels of vitamin A supplementation are not high enough to cause toxicity problems in cattle, but may have detrimental effects on meat quality aspects such as marbling. Some fat-soluble vitamins, including vitamin A, have been found to decrease adipose tissue formation in beef cattle.

Antioxidant Properties

Free radicals can lead to cell damage and increase the rate of lipid oxidation. Antioxidants function to stabilize these highly reactive free radicals (Chew and Johnston, 1995). From a health standpoint, antioxidants play a vital role in maintaining the structural components of a cell and, in return, aiding in immune defense (McDowell, 2000). From a food standpoint, antioxidants can influence color stability and the extent and rate of lipid oxidation.

Vitamins E and C have gained particular attention for their roles as antioxidants. Descalzo et al. (2007) reported that pasture diets high in vitamin E and β-carotene had an improved overall antioxidant and redox status in fresh meat. Some scientists believe that vitamin A may also pose antioxidant properties that would enhance meat quality. Li, Huang, and Zhou (2001) reported that deficiencies in vitamin A resulted in a decrease in antioxidant capacity and an increase of lipid peroxidation in rats. However, other studies suggest that vitamin A is only a moderate antioxidant because retinol and retinal cannot quench or remove free radicals. The vitamin A precursor, β-carotene, serves more of an antioxidant role because it has the ability to effectively quench singlet oxygen free radicals (Mascio, Murphy and Sies, 1991; Zamora, Hidalgo and Tappel, 1991).

Some research indicates that vitamin A may play a negative role in vitamin E utilization, which would decrease oxidation prevention in live animals and meat products. There is evidence that high levels of vitamin A decrease vitamin E absorption and blood α-tocopherol concentrations by competition for absorption sites in the small intestine. High dietary levels of vitamin A reduced the absorption of α-tocopherol in chicks (Sklan and Donoghue, 1982; Abawi and Sullivan, 1989; Blakely, Mitchell, Jerkins, Grundel and Whittaker, 1991). In pigs, Anderson, Myer, Brendemuhl, and McDowell (1995) found that supplementing pigs with 20,000 IU/kg of dry matter of vitamin A had minimal effects on blood vitamin E concentrations. However, pigs fed these high levels of vitamin A did have lower serum α-tocopherol concentrations, but this was only significant on day 3 of sampling. Similar results have been found in cattle. Dicks, Rousseau Jr., Eaton, Teichman, Grifo Jr., and Kemmerer (1959) showed that a 10-fold increase in dietary vitamin A above NRC requirements decreased the plasma α-tocopherol of young calves by 55%. Yet, similar to results found in swine, it would take extreme supplementation of vitamin A to see a significant decrease in α-tocopherol levels.

Effects on Meat Quality

Past research primarily focused on the beneficial role of vitamin A in livestock health. More recent research has focused on the possibility that excess supplementation of vitamin A can cause negative effects on meat quality. According to McDowell (2006), “Vitamin nutrition should no longer be considered important solely for preventing deficiency signs, as vitamins can play a role in optimizing animal health, productivity and product quality”. Kawada, Aoki, Kamei, Maeshige, Nishiu, and Sugimoto (1990) demonstrated that fat-soluble vitamins (A, D, E, and K) can affect terminal differentiation of adipocytes. High levels of vitamins A and D_3 inhibit the development of adipose tissue; specifically bovine marbling, while lesser levels actively stimulate deposition (Sato, Hiragun and Mitsui, 1980; Sato and Hiragun, 1988; Kawanda et al, 1990). Marbling is of highest concern to the Japanese market; therefore, much work has focused on the interaction of vitamin A levels and marbling in Japanese breeds of cattle. Oka, Maruo, Miki, Yamasaki, and Saito (1998) found that high vitamin A concentrations at the early fattening stage may influence marbling. In their research, serum vitamin A concentration and marbling scores were inversely correlated in 15-mo old steers but not 23 and 25-mo old steers. Australian research has demonstrated similar results indicating that vitamin A supplementation was associated with a 26% reduction in intramuscular fat concentration in Angus steers (Siebert, Kruk, Davis, Pitchford, Harper, and Bottema, 2006). This research further reported that cattle supplemented with low levels of vitamin A had a significantly greater reduction of saturated fatty acids, a significant increase in *cis*-monounsaturated fatty acids, and a higher conjugated linoleic acid content when compared to cattle supplemented with high levels of vitamin A (Siebert et al, 2006).

Research in the United States also supports the vitamin A and marbling interaction. Gorocica-Buenfil, Fluharty, and Loerch (2006) found that no supplemental vitamin A or only 2,700 IU/kg dry matter increased the percentage of USDA Choice carcasses by 10% in Angus-based steers. Gorocia-Buenfil, Fluharty, Reynolds, Loerch (2007) also reported that carcass weight, loin muscle area, backfat, % KPH, or yield grades were not affected by vitamin A restriction in Holstein steers. However, vitamin A restriction for long periods did increase intramuscular fat content.

Whereas much research has been conducted to look at the role of vitamin A in adipocyte function, little attention has been paid to the impact that vitamin A restriction may have on other meat quality aspects, such as, sensory traits and lipid oxidation. In Japan, it has been noticed that since levels of vitamin A have been restricted in beef rations, there has been some beef that quickly became discolored. Research by Irie, Inno, Ishizuka, Nishioka, and Morita (2006) suggested that because vitamin A and E are both fat-soluble vitamins and antioxidants, and because levels of carotene and vitamin E in roughage are related, that perhaps feeds low in vitamin A are also low in vitamin E. It is somewhat expected for meat color and lipid oxidation to be effected by vitamin A supplementation either due to increased antioxidant activity of vitamin A or because vitamin A causes restriction of the antioxidant capabilities of vitamin E.

Research by Bramblett, Martin, Harrington, and Evans (1971) showed that vitamin A supplementation may influence other components of meat. In their study, increasing vitamin A supplementation from 0 to 13,200 IU/kg dry matter caused increased evaporation losses, total cooking losses, Warner-Bratzler shear values, and visual appearance scores, whereas adhesion scores decreased ($P < 0.05$). Wang, Wang, Gong, Wang, and Tan (2007) found that steaks from Limousin x Luxi crossbred steers supplemented for three months with 1,100 IU/kg dry matter vitamin A had lower ($P < 0.05$) TBARS values than steaks from calves supplemented with 4,400 IU/kg dry matter of vitamin A. In addition, steaks from steers supplemented with 1,100 IU/kg dry matter and 2,200 IU/kg dry matter of vitamin A had lower ($P < 0.05$) shear forces values than steaks from steers supplemented with 4,400 IU/kg dry matter vitamin A. Research by Pommier (1992) found that vitamin A supplementation at a near toxic chronic dosage can lead to carcasses that have a slower rate of pH decline and increased lysosomal enzyme levels in the liver, but no effect on shear force values, myofibrillar fragmentation index or color measurements. Vitamin A restriction poses potential to increase marbling. However, limited knowledge is available on the importance of vitamin A on other meat quality components.

Longissimus and *Triceps brachii* Muscle Properties

The *Longissimus* muscle is one of the most popular muscles utilized as fresh beef steaks. The *Longissimus* muscle is commonly called the ribeye or strip loin steak and can be found in the wholesale chuck, rib, and loin. The normal sensory properties of the *Longissimus* muscle are found in Table 1.1 (http://bovine.unl.edu/bovine3D/eng/muscleIndex.jsp).

Table 1.1 Sensory properties of the *Longissimus* muscle

L*	a*	b*	Dry Heat Shear Force	Moist Heat Shear Force
40.55	31.13	23.98	5.05 kg	4.23 kg

In 2001, The National Cattleman's Association, focused on identifying muscles that have potential for added value from the chuck and round. The *Triceps brachii* from the shoulder clod was one of the identified muscles. The *Triceps brachii* can be divided into three portions, the lateral head, the long head, and the medial head. The *Triceps brachii* muscle is considered moderately juicy and tender when cooked under moist heat and slightly juicy and tender under dry heat. The sensory properties of the *Triceps brachii* muscle can be found in Table 1.2 (http://bovine.unl.edu/bovine3D/eng/muscleIndex.jsp).

Table 1.2 Sensory properties of the *Triceps brachii* muscle

L*	A*	b*	Dry Shear Force	Moist Shear Force
39.47	**31.50**	**24.78**	**4.27 kg**	**4.5 kg**

Carmack, Kastner, Dikeman, Schwenke, and Zepeda (1995) found that the *Triceps brachii, biceps femoris, psoas major, gluteus medius,* and *semimembranosus* muscles were all similar in beef flavor intensity and were all ranked highly favorable in beef flavor, whereas the *longissimus lumborum* muscle was classified as generally less favorable in beef flavor. The *psoas major, infraspinatus, longissimus lumborum, and rectus femoris* were determined to be the most tender muscles.

Summary

Live animal management such as weaning strategy, age at slaughter, vitamin supplementation, and marbling scores can all impact the eating quality of meat. Animals weaned at a younger age (~90 days) rather than the traditional weaning age (~200 days) can have higher amounts of marbling with no adverse affects on loin muscle area. Furthermore, early weaning allows animals to be harvested at a younger age, which can promote more tender meat. High levels of vitamin A supplementation can play an adverse role in marbling and vitamin E absorption. Valid research to determine what effects vitamin A restriction may have on meat quality components such as retail color stability, lipid oxidation and sensory traits need to be further research before the industry accepts vitamin A restriction in feedlot management as a tool to increase marbling. Therefore, in order to optimize marbling and meat quality components, the proper combination of weaning system, animal age at harvest, and vitamin supplementation in feedlot rations must all be given consideration.

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CHAPTER 2 - Effects of Dietary Vitamin A Restriction on Color Shelf-Life, Lipid Oxidation, and Sensory Traits of Longissimus Lumborum and Triceps brachii steaks from Early and Traditionally Weaned Calves

Abstract

Vitamin A (VA) restriction during finishing has been shown to increase marbling in cattle. However, little work has been done to look at the effects that VA restriction might have on color shelf-life and sensory traits of beef. This study involved 48 calves either early-weaned at 137 ± 26 d or traditionally-weaned at 199 ± 26 d and supplemented with either 15,400 IU/kg dry matter of VA or restricted to no supplemental VA during the finishing phase. Cattle were harvested in two groups, and carcass data were obtained after chilling. Strip loins and shoulder clods were retrieved, vacuum packaged, and cut into steaks after 14 d of aging. Visual and instrumental color scores for 7 d of retail display, thiobarbituric acid reactive substances (TBARS) values, trained sensory panel scores, and Warner-Bratzler shear force (WBSF) values were obtained. The only differences associated with weaning group were that L* values were lower ($P < 0.05$) on d 4 to 6 for *Triceps brachii (TB)* steaks from traditionally-weaned calves restricted in VA than early-weaned calves supplemented with high VA. Both *Longissimus lumborum (LL)* and *TB* steaks from calves supplemented with high VA had darker, more tan ($P < 0.05$) color scores after 4 d of display in PVC packaging than steaks from calves restricted in VA. Also, a*, b* and saturation index values were lower ($P < 0.05$) in *LL* steaks for the high VA treatment than those from the no supplemental VA treatment. There was less lipid oxidation ($P < 0.05$), as reported by TBARS, in both muscles from calves restricted in VA than muscles from calves supplemented with high VA. No treatment effects were found for WBSF values for either muscle, and no differences existed in sensory panel traits of the *TB* steaks. Sensory panel scores were less desirable ($P < 0.05$) for myofibrillar tenderness and connective tissue amount in *LL* steaks from calves fed high VA than steaks from calves restricted in VA. Dietary VA restriction during finishing has potential to increase color shelf-life and reduce lipid oxidation, with no negative effects on cooked meat sensory attributes.

Key Words: Early-weaning, Vitamin A, Retail Display, Beef Sensory, TBARS

1. Introduction

Consumers consider many factors when selecting meat products. The most important meat quality component at the time of purchase is meat color. Yet, other factors such as tenderness and flavor are associated with overall consumer satisfaction. The beef industry uses marbling as an indicator of meat palatability in the beef quality grading system (USDA, 1997). Therefore, much attention has focused on live animal management practices that optimize marbling deposition in beef cattle. Meyers, Faulkner, Ireland, and Parrett (1999) found that early weaning could offer a 40% increase in the number of Angus x Hereford steers that graded Choice or higher. In addition, over the past decade, increased attention has been paid to the role of vitamin A (VA) in adipose tissue development. Fat-soluble vitamins have been shown to affect terminal differentiation of adipocytes (Kawada, Aoki, Kamei, Maeshige, Nishiu, and Sugimoto 1990). Gorocia-Buenfil, Fluharty, and Loerch (2006) found that no supplemental VA or only 2,700 IU/kg dry matter increased the percentage of USDA Choice carcasses by 10% in Angus crossbred steers. Other studies have shown that VA may have some affects on fresh and cooked meat properties. Bramblett, Martin, Harrington, and Evans (1971) showed that VA supplementation could increase evaporation losses, total cooking losses, Warner-Bratzler shear force values, and decrease visual appearance. Pommier (1992) indicated that VA supplementation at a near toxic dose can cause more rapid pH decline and increased lysosomal enzyme levels, but no effects on shear force values. Because there is limited research on the impact of VA restriction in combination with early-weaning on beef color and sensory traits, the objective of mystudy was to evaluate the effects of VA restriction on color shelf-life, lipid oxidation, and sensory traits of *Longissimus lumborum (LL)* and *Triceps brachii (TB)* steaks from early and traditionally-weaned calves.

2. Materials and Methods

2.1. Live Animal Treatments and Steak Packaging

Angus crossbred steers (n = 48) from the Kansas State University commercial cowherd were either early-weaned at 137 ± 26 d of age or traditionally-weaned at 199 ± 26 d. Early weaned calves were transported to the Kansas Agricultural Research Center in Hays, Kansas where they were weighed and randomly allotted to one of two pens (12 animals per pen) so that the mean initial pen weights were similar. Traditionally-weaned claves were allotted to feedlot pens 60 d later than the early-weaned calves. The feeding period consisted of a preconditioning, growing and a finishing phase for the early-weaned calves and a preconditioning and finishing phase for the traditionally-weaned calves. These diets and the supplement (Table 2.1 and 2.2) were formulated by a collaborating ruminant nutritionist at Kansas State University. One pair of pens was supplemented with seven times the NRC recommended level of VA (15,400 IU/kg dry matter) and the other pair of pens was restricted to no supplemental VA.

Table 2.1 Composition (DM basis) of the preconditioning diet

Ingredient	Percent (DM basis)
Ground Sorghum Grain	48.2
Corn Gluten Feed	24.2
Tallgrass Prairie Hay (chopped)	14.8
Whole Soybeans (raw)	9.6
Supplement[a]	3.2
Total	100.0

[a]Provided NRC (1996) recommended levels of salt, trace minerals, and vitamin A.
Bovatec 91 (Alpharma, Fort Lee, NJ) was included at 1.2% (DM) of the diet.

Table 2.2 Composition (DM basis) of the supplement for the finishing diet

Ingredient	Percent (DM basis)	
	Low vitamin A	High Vitamin A
Soybean Meal	53.6	53.2
Trace Mineral	0.645	0.645
Rumensin 80	0.074	0.074
Tylan 40	0.022	0.022
Calcium	24.7	24.7
Urea	14.8	14.8
Salt	6.2	6.2
Vitamin A (60,000 IU/g)	0.000	0.346
Total	100.0	100.0

This created four treatment groups; early-weaned, high VA; early-weaned, low VA; traditionally-weaned, high VA; and traditionally-weaned, low VA. Animals were continually managed under the care of trained university personnel according to the guidelines recommended in the *Guide for the Care and Use of Agriculture Animals in Agriculture Research and Teaching* (FASS, 1998), and all experimental procedures were approved by the Institutional Animal Care and Use Committee at Kansas State University.

Blood was collected via jugular venipuncture at 60 d intervals. Samples were returned to the laboratory at the Manhattan campus and stored in dark refrigeration at 4°C for 24 hr. Tubes were then centrifuged for 25 min. at 2,600 rpm and 4°C using a JA-10 rotor (Beckman Coulter, Fullerton, CA). Serum was pipetted into two 5ml plastic tubes under dim lighting and stored at -80° C for no longer than 60 d before fatty acid analyses were conducted. In addition, liver from the caudate lobe, and a section of the LM obtained at the 12th/13th rib juncture, were analyzed for lipid content and FA profiles using a Shimadzu GC-17A (Kyoto, Japan) gas chromatograph (GC). Retinol content was determined by HPLC using the methods described by Barua and Olson (1998), with slight modifications.

Ultrasound 12th rib fat thickness was obtained to predict days to a desired fat thickness (Cattle Performance Enhancement Company, Oakley, KS). To minimize variation in fat thickness and body composition, the steers were harvested in 2 groups, 35 d apart. The fattest six steers from each of the 4 treatment combinations were harvested on each day. Approximately 15 h prior to slaughter, steers were loaded and transported approximately 350 km to Tyson Fresh Meats®, Emporia, Kansas where they were held off feed and provided access to water until humane slaughter. During the finishing phase, three calves were lost due to sickness, one each from the early-weaned high VA, traditionally-weaned low VA, and traditionally-weaned high VA treatments. Calves (n = 22) harvested in the first harvest group were fed an average of 185 d and harvested at an average age of 375 d. Calves (n = 23) harvested in the second harvest group were fed an average of 228 d and were harvested at an average age of 402 d.

Carcasses were chilled for 24 hr at 1 to 3°C before being ribbed between the 12th and 13th ribs for USDA quality and yield grade determinations. All carcass measurements and estimates were performed by experienced university faculty and graduate students. Yield grade was calculated according to USDA standards. Marbling scores were evaluated by 3 experienced university employees. The mean of the 3 scores was used for the statistical analysis. Carcass data were reported by Arnett, 2007.

Shoulder clods and strip lions were retrieved, vacuum packaged, and transported to the Kansas State University Meat Laboratory. At the plant, one carcass was eliminated from the study because it appeared to be PSE, and one strip loin was lost in the fabrication process, leaving 44 strip loins and 45 shoulder clods for my study. After 14 d of aging in dark storage at 2˚C, the *LL* and the lateral head of the *TB* were each cut into three 2.54-cm steaks and randomly assigned to either retail display, Warner-Bratzler shear force (WBSF), or sensory panel evaluation. Steaks for retail display were placed immediately in 20.32 cm x 14.61 cm x 1.74 cm foam trays, overwrapped with an oxygen permeable PVC film (MAPAC M film, 23, 250 cc/m2/24h, 72 gauge, Resinite Packaging Films Border Inc., North Andover, MA), and placed in retail-display cases. Steaks assigned to WBSF and sensory panel evaluations were frozen at -20˚C for later analysis. Also, at the time of fabrication, pH of the muscles was documented and the face of the muscle was cut and frozen at -40˚C to be used for initial thiobarbituric acid reactive substances (TBARS) measurements.

2.2. pH Measurement

Muscle pH was measured at 14 d postmortem by inserting the tip of the pH probe (MPI pH, glass electrode, Meat Probes, Inc., Topeka, KS) into the anterior end of the *LL* and *TB* muscles. Muscle pH values were measured in triplicate and averaged for statistical analysis.

2.3 Display Case

Steaks were displayed for 7 d at 2˚C in open-top display cases (Unit model DMF8, Tyler Refrigeration Corp, Niles, MI) under continuous fluorescent lighting (2153 lux, 3000 K and CRI=85, Bulb model F32T8/ADV830/Alto, Philips, Bloomfield, NJ) to simulate retail display. Display case temperatures were monitored using temperature loggers (RD-TEMP-XT; Omega Engineering, Inc., Stamford, CT). The packages were rotated twice a day within the case to minimize effects of case location.

2.4 Color Measurements

Trained color panelists (n = 8) who had passed the Farnsworth-Munsell® 100 Hue Test (MacBeth; Newburgh, NY) evaluated initial color on d 0 of display and evaluated display color and surface discoloration once daily for d 0 through 6 of display. The initial color scale used on d 0 only was: 1 = purplish pink or red or reddish tan of vacuum packages, 2 = bleached, pale red, 3 = slight cherry red, 4 = moderately cherry red, 5 = cherry red, 6 = slight dark red, 7 = moderately cherry red, 8 = dark red, and 9 = very dark red. The display color scale used daily was: 1 = very bright red, 2 = bright red, 3 = dull red, 4 = slightly dark red, 5 = slightly dark red or reddish tan, 5.5 = borderline acceptable to panelists, 6 = moderately dark red to tannish red, and 7 = tan to brown. The scales for initial color and display color were reported as half-point increments. Steak surface discoloration was evaluated as a percentage of metmyoglobin formation using the following scale: 1 = none (0%), 2 = slight discoloration (1-19%), 3 = small discoloration (20-39%), 4 = modest discoloration (40-59%), 5 = moderate discoloration (60-79%), 6 = extensive discoloration (80-99%), and 7 = total discoloration (100%). Discoloration scores were reported to the whole point. All panelists' scores were averaged for statistical analysis.

Instrumental color values including CIE L*, a*, and b* values were measured with the HunterLab MiniScan™ XE Plus Spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant A; Hunter Associates Laboratory, Inc., Reston, VA) on all days of display. Each package was scanned in triplicate and values were averaged. Hue angle was calculated using $(b^*/a^*)^{\tan^{-1}}$ and saturation index was calculated using $(a^2 + b^2)^{1/2}$ (Hunt et al., 1991).

2.5. Lipid Oxidation

Lipid oxidization was determined by analyzing for TBARS. At the time of fabrication, the face portion of the muscle was cut and frozen at -40° to be used for initial TBARS values. On the last day of retail display, steaks were removed from packages, and the top ½ of each steak (where oxidation should be the greatest) was cut into cubes and frozen at -40°C to determine post display TBARS values. The initial and post display samples were frozen in liquid nitrogen and then pulverized using a tabletop blender (model 33BL79; Waring Products, New Hartford, CT)). Ten grams of sample were blended for 30 sec with 10 ml of water and 15 ml of perchloric acid. After blending, samples were filtered through filter paper (Cat. No. 1002, 125mm dia; Whatman International Ltd, Maidstone, England), 5ml of thiobarbituric acid solution was added to the 5 ml of filtrate, and samples were allowed to react for 18 h. Absorbance was measured on a Spectrophic 21 spectrophotometer (Bausch & Lomb, Rochester, NY). Control solutions of known concentrations of malonaldehyde were plotted to calculate TBARS concentrations. Results were reported as mg malonaldehyde per 1000 g of fresh muscle tissue.

2.6. Cooking

Steaks for WBSF and sensory panel analysis were thawed at 2˚C and cooked to 40˚C , turned, and cooked to a final internal temperature of 70˚C in a dual-air-flow, convection gas oven (Blodgett, model DFG-102 CH3, G.S. Blodgett Co., Burlington, VT) preheated to 163˚C. Steak temperatures were monitored with copper-constantan thermocouples placed in the approximate geometric center of each steak and attached to a Doric temperature recorder (model 205; Vas Engineering, San Francisco, CA).

2.7. Warner-Bratzler Shear Force

Steaks frozen for WBSF evaluation were thawed at 2˚C, cooked as described above, and chilled overnight at 0˚C. Eight 1.27-cm cores from the *LL* steaks and six 1.27-cm cores from the *TB* steaks were removed parallel to the muscle fibers using a 1.27-cm corer (G-R Manufacturing Co., Manhattan, KS) attached to an electric drill (Craftsman 3/8" Electric Drill, Sears, Hoffman Estates, IL). Each core was sheared perpendicular to the direction of the muscle fibers using a Warner-Bratzler V-shaped blunt blade (G-R Manufacturing Co., Manhattan, KS) attached to a 50-kg load cell of an Instron Universal Testing Machine (model 4201, Instron Corp., Canton, MA) with a crosshead speed of 250 mm/min. Peak shear force values were recorded in kg and the values from the cores were averaged for statistical analysis.

2.8. Sensory Evaluation

Panelists (n = 6) were trained according to AMSA guidelines (1995) for steak evaluation. Cooked steaks were cut into 2.54-cm x 1.27-cm x 1.27-cm samples. Samples were kept warm in blue enamel double broiler pans with warm water in the bottom portion. Each panelist received two cubes from each sample in random order. Each session included a warm-up sample and samples from all treatments of either *LL* or *TB* steaks. Panelists were provided with unsalted crackers, and filtered water (The Brita Products Company, Oakland, CA) to cleanse their pallets between samples. Panelists evaluated samples for myofibrillar tenderness, juiciness, beef flavor intensity, connective tissue amount, overall tenderness, and off-flavor intensity using 8-point scales. The scale used for myofibrillar and overall tenderness was 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender. For juiciness, the scale was 1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, and 8 = extremely juicy. The scale used for beef flavor was 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense. The scale used or connective tissue and off flavor intensity was 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, and 8 = none. Panelists reported scores to the nearest half-point increment. Panelists' scores were averaged for statistical analysis.

2.9 Statistical Analysis

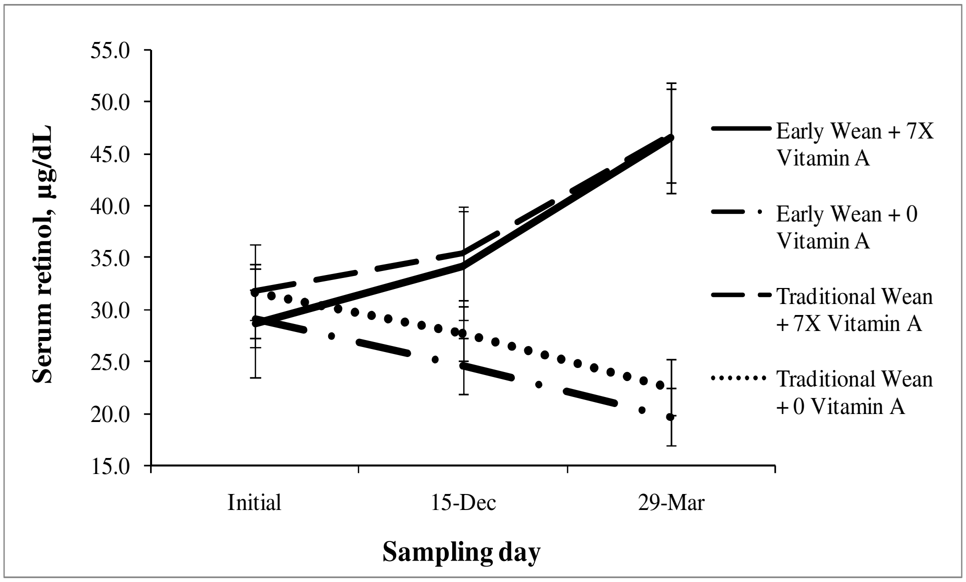
The experimental design was a 2 x 2 factorial blocked by kill group; marbling score was used as covariate. The mixed-model procedure (PROC MIXED) of SAS (SAS Institute, Inc., Cary, NC) was used for statistical analysis. Steak was the experimental unit. Fixed effects were vitamin treatment, weaning treatment, and vitamin by weaning treatment. Day was a repeated measure in display color, discoloration, and instrumental color analysis. Muscle differences were analyzed separately to determine differences in means for muscles. Least squares means for each of the measurements of interest were obtained. Pairwise comparisons of treatment least squares means were made with significant differences ($P < 0.05$).

3. Results and Discussions

3.1 Retinol Levels and Carcass Data

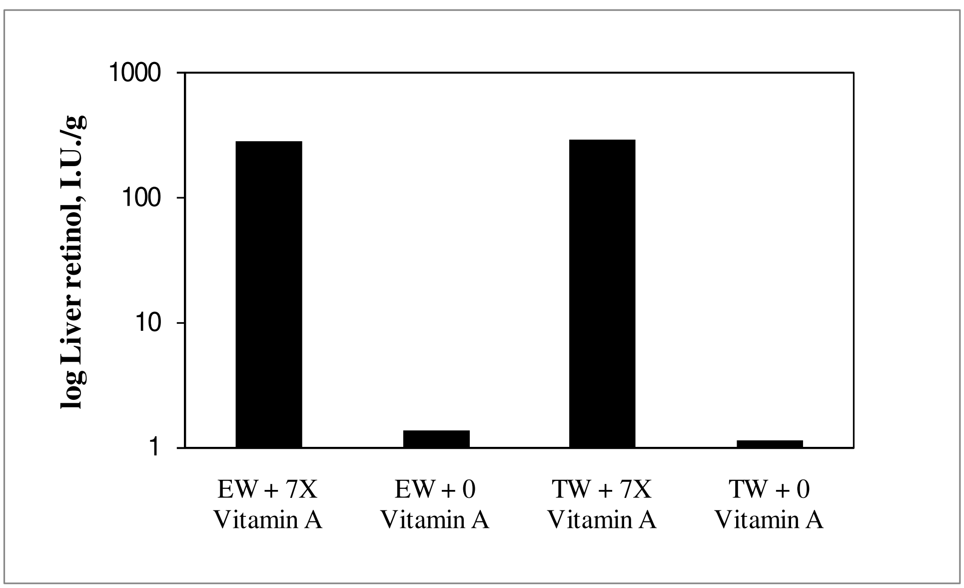
Retinol levels (Figure 2.1) reported by Arnett (2007) showed that serum retinol levels in initial serum samples were similar among the four treatment groups. However, when early-weaned steers had been fed designated VA treatments for 107 d and traditionally-weaned calves had been fed designated VA treatments for 46 d, there was a divergence in serum retinol levels by treatment. The high VA treatment steers had higher serum retinol levels than serum retinol levels from steers restricted in VA.

Figure 2.1 Serum retinol concentrations on 3 sampling days



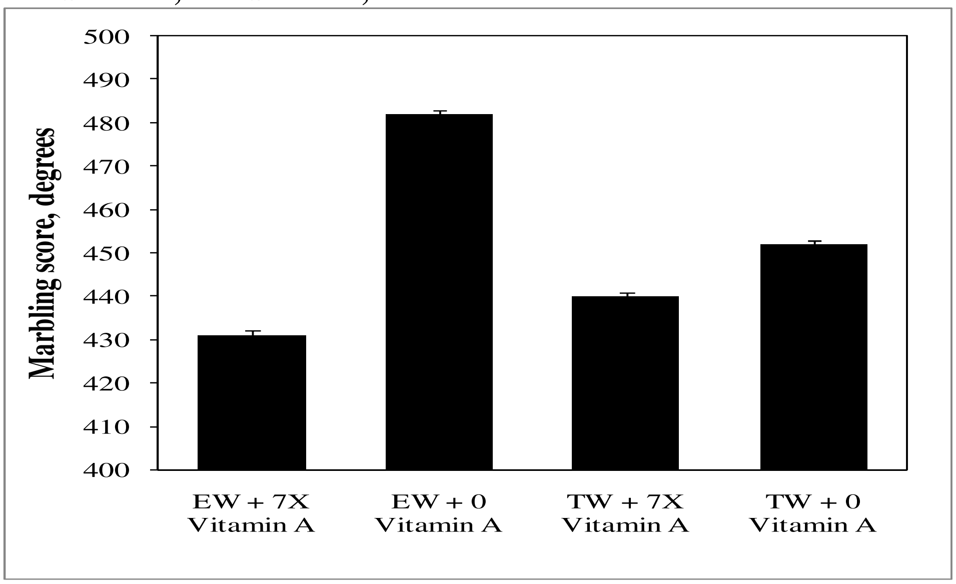
Liver retinol content (Figure 2.2), reported by Arnett (2007), was vastly different between vitamin A treatments. Livers from high VA treatment steers had higher liver retinol levels than livers from steers restricted in VA.

Figure 2.2 Liver retinol concentrations (log scale)



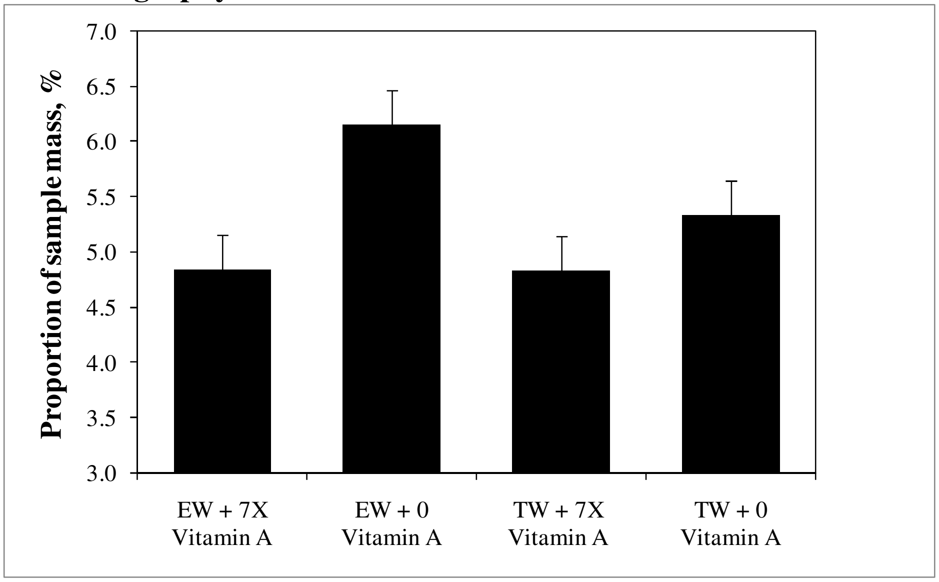
Marbling scores (Figure 2.3), reported by Arnett (2007), tended to be lower in calves that were supplemented with high levels of VA and higher marbling scores were reported for calves restricted in VA, suggesting that feeding no supplemental VA for at least 150 d increases marbling scores by 0.30 degree, regardless of weaning age. However, the response was more pronounced in the early weaned, no VA treatment steers. Compared to high VAtreatment steers at both weaning ages, early-weaned calves restricted in VA produced carcasses that averaged 0.45 degree higher marbling scores.

Figure 2.3 Marbling scores for carcasses from the four treatment combinations: 40˚=Small00, 41˚=Small10, ... 50˚= Modest00



Intramuscular fat percentages (%IMF, Figure 2.4), reported by Arnett (2007), supported the marbling scores for the four treatment combinations. Steers fed no supplemental VA produced carcasses with more IMF% than steers fed high VA at both weaning ages. This effect was most pronounced in muscles from early-weaned steers that were restricted in VA, in which contained 30% more lipid than the steers fed high VA from both weaning groups.

Figure 2.4 Percentages of intramuscular fat in the LM of carcasses as determined by gas chromatography



3.2 pH Values

No treatment differences were found for pH in the *LL* or *TB* muscle and, in both muscles, pH values were within an acceptable pH range with no values indicating a PSE or DFD problem (Table 2.1).

Table 2.3 pH values for *Longissimus Lumborum* and *Triceps brachii* muscles by treatment

	Vitamin		Weaning		
	Low	High	Early	Traditional	SE
LL	5.6	5.6	5.6	5.6	0.01
TB	5.7	5.7	5.7	5.7	0.02

3.3 Retail Display

No differences were found for initial color score for either the *LL* (Table 2.4) or the *TB* (Table 2.5) display steaks. In *LL* steaks, display color scores showed a vitamin x d interaction ($P < 0.05$), but no weaning differences.

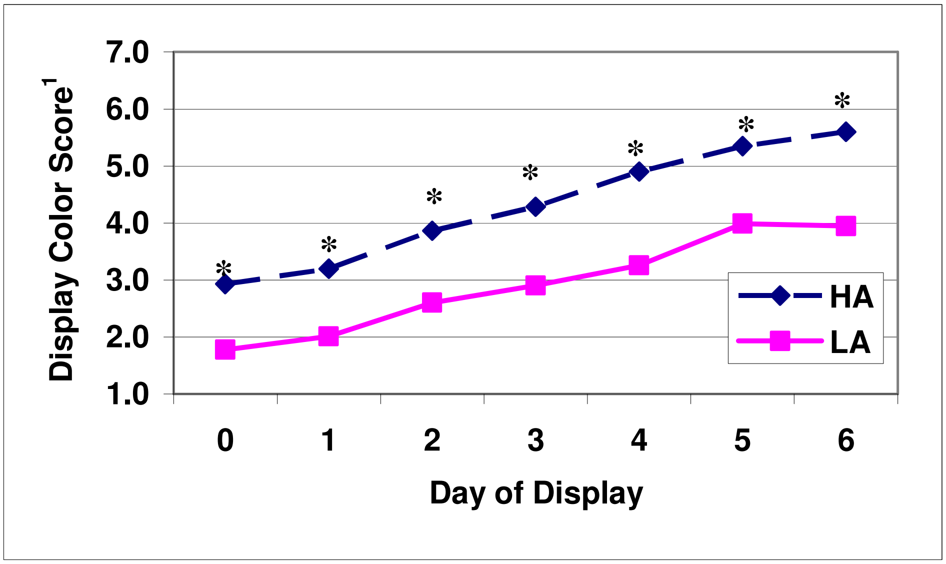
Table 2.4 ***Longissimus lumborum*** **visual color scores by day and treatment**

	Display, d							
	0	1	2	3	4	5	6	SE
Initial Color[1]								
Low VA	4.6	-	-	-	-	-	-	0.12
High VA	4.5	-	-	-	-	-	-	
Early Wean	4.5	-	-	-	-	-	-	
Traditional Wean	4.5	-	-	-	-	-	-	
Display Color[2]								
Low VA	1.8[a]	2.0[a]	2.6[b]	2.9[c]	3.3[d]	4.0[ef]	4.0[ef]	0.14
High VA	2.9[cd]	3.2[cd]	3.9[e]	4.3[f]	4.9[g]	5.4[h]	5.6[h]	
Early Wean	2.2	2.5	3.1	3.5	4.0	4.5	4.7	
Traditional Wean	2.5	2.7	3.3	3.7	4.2	4.8	4.8	
Discoloration[3]								
Low VA	0.8[a]	0.8[a]	1.0[ab]	1.1[ab]	1.4[cd]	1.6[de]	2.1[f]	0.14
High VA	1.1[abc]	1.2[abc]	1.3[bcd]	1.5[d]	2.1[ef]	2.6[g]	3.1[h]	
Early Wean	1.1	1.1	1.3	1.4	1.8	2.4	2.9	
Traditional Wean	1.1	1.1	1.2	1.4	1.9	2.4	3.0	

[1]Initial Color Scale: 3 = slight cherry red, 4 = moderately cherry red, 5 = cherry red, 6 = slight dark red
[2]Diplay color scale: 1= very bright red, 2 = bright red, 3 = dull red, 4 = slightly dark red, 5 = slightly dark red or reddish tan, 5.5 = borderline acceptable to panelist, 6 = moderately dark red to tannish red
[3]Discoloration Scale: 1 = (0%), 2 = (1-19%), 3 = (20-39%), 4 = (40-59%)
[abcdefgh] within a trait, means without a common superscript letter differ ($P < 0.05$)

Longissimus lumborum steaks in all treatment groups remained lower than 5.5 through d 5 of retail display. On d 6, steaks from the high VA treatment group exceeded 5.5 and became "unacceptable" to panelists. *Longissimus lumborum* steaks from the low VA treatment remained below 5.5 for the entire display period and had lower ($P < 0.05$) display color scores (more desirable) than the high VA treatment group on all d of retail display (Figure 2.5). There is no literature similar to the results found in this study.

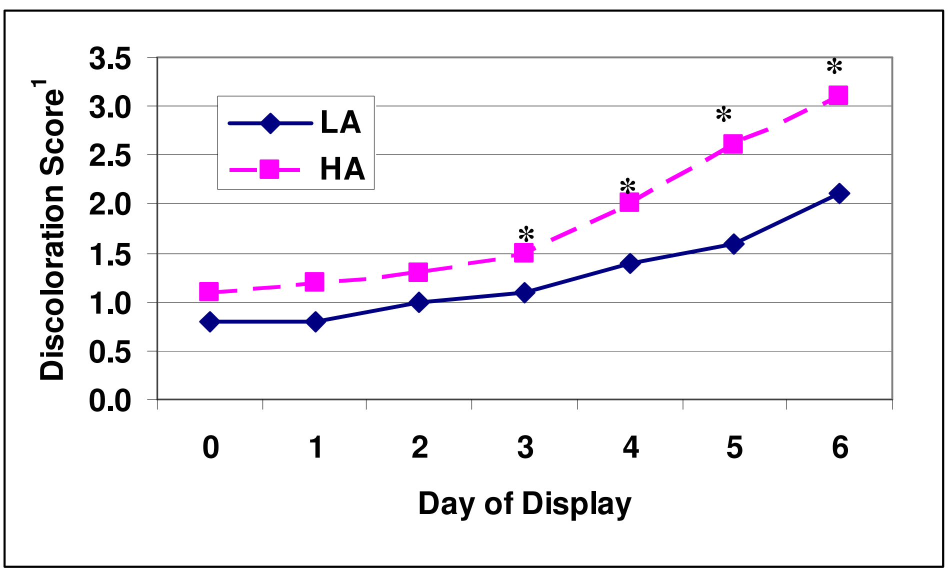
Figure 2.5 ***Longissimus lumborum*** **display color scores by vitamin and d**



[1]Diplay color scale: 1= very bright red, 2 = bright red, 3 = dull red, 4 = slightly dark red, 5 = slightly dark red or reddish tan, 5.5 = borderline acceptable to panelist, 6 = moderately dark red to tannish red
*P < 0.05

None of the *LL* steaks exceeded 40% discoloration during the 6 d of display. There was a vitamin x d interaction for discoloration scores (Table 2.4), but no weaning interaction. Discoloration scores for the high VA treatment were numerically higher on all days of display and statistically higher (P < 0.05) on d 3 to 6 (Figure 2.6).

Figure 2.6 ***Longissimus lumborum*** **discoloration scores by vitamin and d**



[1]Discoloration scale: 1 = (0%), 2 = (1-19%), 3 = (20-39%), 4 = (40-59%)
*P < 0.05

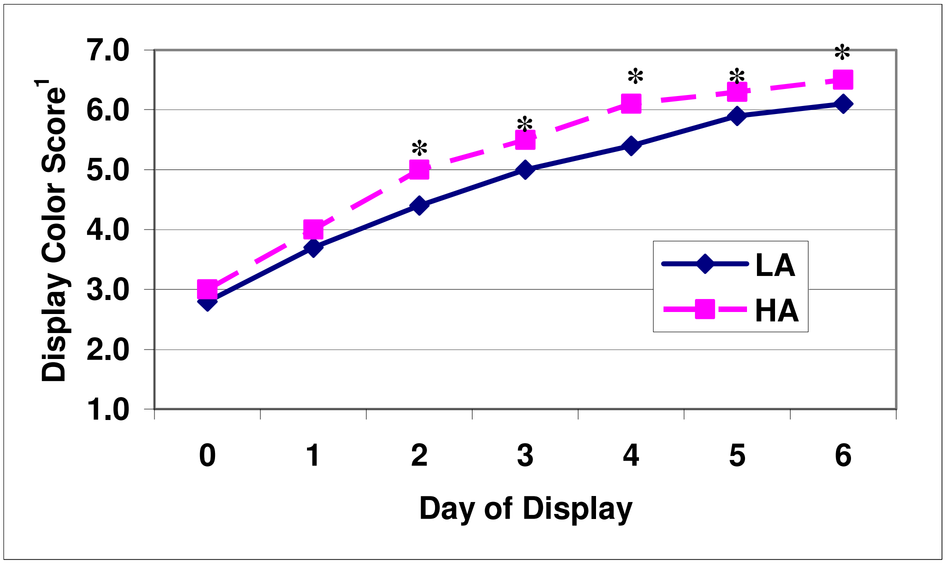
Triceps brachii steaks had a vitamin x d interaction for both display color and discoloration scores, but no weaning interaction (Table 2.5). Steaks from both vitamin treatment groups remained below 5.5 through d 4 of retail display. However, display color scores exceeded 5.5 on d 4 for the high VA steaks and on d 5 for the low VA steaks. Display color scores tended ($P > 0.05$) to be numerically lower for the low VA treatment group on all d of display and statistically lower ($P < 0.05$) on d 2 to 6 (Figure 2.7).

Table 2.5 *Triceps brachii* visual color scores by day and treatment

	Display, d							
	0	1	2	3	4	5	6	SE
Initial Color[1]								
Low VA	5.2	-	-	-	-	-	-	0.13
High VA	5.1	-	-	-	-	-	-	
Early Wean	5.2	-	-	-	-	-	-	
Traditional Wean	5.2	-	-	-	-	-	-	
Visual Color[2]								
Low VA	2.8^{a}	3.7^{b}	4.4^{c}	4.9^{d}	5.4^{e}	5.9^{f}	6.1^{f}	0.10
High VA	3.0^{a}	4.0^{b}	5.0^{d}	5.5^{e}	6.1^{f}	6.3^{g}	6.5^{g}	
Early Wean	3.0	4.0	4.8	5.3	5.9	6.3	6.5	
Traditional Wean	2.8	3.7	4.6	5.0	5.5	5.9	6.1	
Discoloration[3]								
Low VA	1.0^{a}	1.1^{a}	2.3^{b}	2.7^{cd}	3.4^{e}	4.5^{f}	4.9^{g}	0.10
High VA	0.8^{a}	1.1^{a}	2.6^{bc}	3.2^{cde}	4.2^{f}	5.1^{gh}	5.4^{h}	
Early Wean	1.1	1.4	2.7	3.3	4.2	5.2	5.5	
Traditional Wean	0.7	0.9	2.2	2.7	3.3	4.4	4.8	

[1]Initial color scale: 3 = slight cherry red, 4 = moderately cherry red, 5 = cherry red, 6 = slight dark red
[2]Visual color scale: 1 = very bright red, 2 = bright red, 3 = dull red, 4 = slightly dark red, 5 = slightly dark red or reddish tan, 5.5 = borderline acceptable to panelist, 6 = moderately dark red to tannish red
[3]Discoloration scale: 1 = (0%), 2 = (1-19%), 3 = (20-39%), 4 = (40-59%)
[abcdefgh] within a trait, means without a common superscript letter differ ($P < 0.05$)

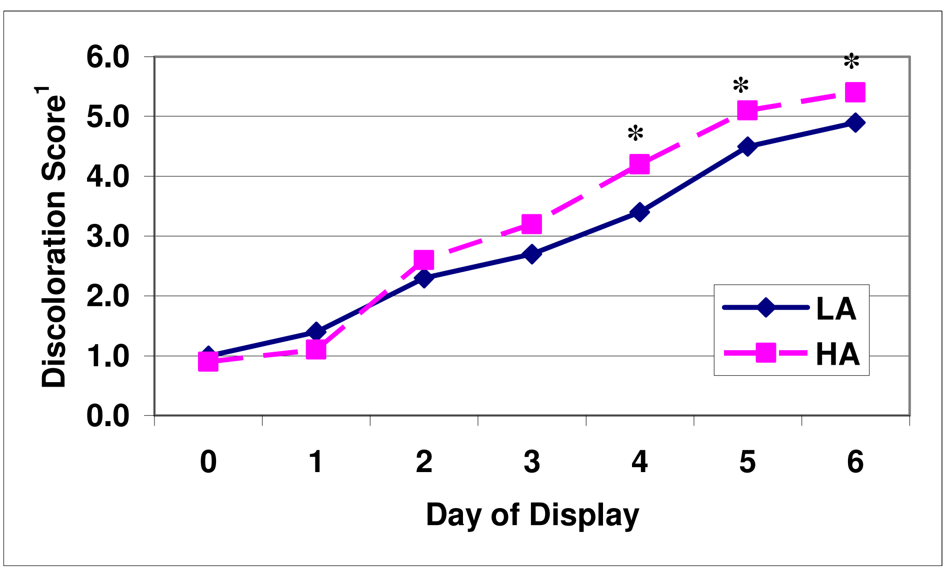
Figure 2.7 *Triceps brachii* display color scores by vitamin and d



[1]Diplay color scale: 1= very bright red, 2 = bright red, 3 = dull red, 4 = slightly dark red, 5 = slightly dark red or reddish tan, 5.5 = borderline acceptable to panelist, 6 = moderately dark red to tannish red
*P < 0.05

Discoloration scores in the *TB* steaks showed that the low VA treatment resulted in better color stability than the high VA treatment steaks (Figure 2.8). Discoloration scores were numerically higher for the high VA group on all d of display, and statistically higher (P < 0.05) during the later part of display on d 4 to 6. There is no literature similar to our results.

Figure 2.8 *Triceps brachii* discoloration scores by vitamin and d



[1]Discoloration scale: 1 = (0%), 2 = (1-19%), 3 = (20-39%), 4 = (40-59%)
*P < 0.05

No research has been conducted to look at visual color scores and visual discolorations scores of steaks from calves supplemented with high and low levels of vitamin A. However, some research in Japanese Black cattle suggests that VA and vitamin E in the diet may be related and, therefore, low levels of VA may have negative impacts on color stability. In our study, we found the opposite. Visual color scores and visual discoloration scores showed that restricted levels of VA may be beneficial in maintaining color during retail display for *LL* and *TB* steaks.

Instrumental Color

Instrumental color readings were measured to compliment visual color panel evaluations. There were no vitamin interactions in *LL* steaks for L* values, a/b ratios, or hue angles. However, a*, b* and saturation indexes had a vitamin x d interaction ($P < 0.05$) (Table 2.6). On all d of display, low VA treatments had numerically higher a* and b* values than the high VA treatments and these values were statistically higher ($P < 0.05$) on d 3 to 6 and d 2 to 6, respectfully. Higher a* values indicated more redness and higher b* values indicated more yellowness. As saturation index values increase, the vividness of red color also increases. The saturation index values in my study for *LL* steaks were higher in the low VA (more vivid color) on all d of display, and a statistical advantage ($P < 0.05$) was seen on d 3 to 6 of display. There was no weaning interaction for any of the instrumental color readings in the *LL* steaks.

Triceps brachii steaks had no vitamin or weaning interactions for a*, b*, a/b ratios, hue angles, or saturation index values. However, there was a wean x vitamin x d interaction ($P < 0.05$) for L* values (Table 2.7). High VA treatments had lower ($P < 0.05$) L* values, indicating darker color, than low VA steaks on all d of display. The early-weaned, high VA treatment steaks had the darkest ($P < 0.05$) color (lowest L* values) on all d of display, whereas the early-weaned, low VA treatment steaks had the lightest (highest L* value) on all d of display. These data indicate that VA restriction may be desirable for an extended period of time (as in the early-weaning group) to see differences in instrumental color readings in the *TB* muscle, or that VA should not be fed at levels as high as 7 times NRC recommended levels.

Table 2.6 *Longissimus lumborum* instrumental color values by day and treatment

	Display, d							
	0	1	2	3	4	5	6	SE
L*								
Low VA	49.5	47.2	47.1	46.7	46.1	46.1	46.4	0.66
High VA	48.5	45.6	44.8	45.3	45.1	44.1	44.3	
a*								
Low VA	32.5^{j}	31.6^{hi}	31.9^{hij}	31.3^{hi}	30.2^{fg}	29.2^{de}	28.0^{c}	0.40
High VA	32.2^{ij}	31.2^{gh}	31.1^{gh}	29.7^{ef}	28.2^{cd}	26.1^{b}	24.9^{a}	
b*								
Low VA	24.1^{fgh}	24.6^{h}	25.2^{i}	25.2^{i}	24.2^{gh}	23.9^{efg}	23.2^{cd}	0.25
High VA	23.6^{def}	24.0^{fgh}	24.2^{gh}	23.5^{de}	22.5^{c}	21.5^{b}	20.8^{a}	
a/b Ratio								
Low VA	1.3	1.3	1.3	1.2	1.2	1.2	1.2	0.01
High VA	1.4	1.3	1.3	1.3	1.3	1.2	1.2	
Hue Angle[1]								
Low VA	36.6	38.0	38.3	38.8	38.7	39.3	39.7	0.24
High VA	36.2	37.6	37.8	38.30	36.6	39.5	40.0	
Saturation Index[2]								
Low VA	40.5^{g}	40.0^{g}	40.7^{g}	40.2^{g}	38.7^{ef}	37.7^{d}	36.4^{c}	0.45
High VA	39.9^{fg}	39.4^{fg}	39.4^{fg}	37.8^{de}	36.0^{c}	33.8^{b}	32.5^{a}	

[1]calculated using $(b^*/a^*)^{tan-1}$
[2]calculated using $(a^2 + b^2)^{1/2}$
[abcdefghij] within a trait, means without a common superscript letter differ ($P < 0.05$)

Table 2.7 *Triceps brachii* instrumental color values by day and treatment

	Display, d							
	0	1	2	3	4	5	6	SE
L*								
EW, HA[1]	45.4^{hijk}	41.1^{cd}	40.8^{bc}	38.3^{a}	39.6^{b}	39.1^{ab}	39.5^{b}	0.56
EW, LA[1]	49.5^{l}	46.7^{k}	45.9^{jk}	45.6^{ijk}	45.7^{ijk}	45.0^{hi}	46.1^{jk}	
TW, HA[1]	45.6^{ijk}	42.1^{def}	41.0^{bcd}	41.5^{cde}	41.0^{bcd}	40.8^{bc}	40.7^{bc}	
TW, LA[1]	48.6^{l}	45.3^{hijk}	45.3^{hij}	44.3^{ghi}	44.1^{fgh}	43.6^{efg}	43.5^{efg}	
a*								
Low VA	32.0	30.0	29.0	26.5	24.5	22.1	20.0	0.68
High VA	31.7	29.5	27.4	24.7	22.0	19.4	17.9	
b*								
Low VA	23.6	23.5	13.3	21.8	21.2	20.6	19.8	0.38
High VA	23.2	23.0	22.1	21.1	19.5	19.1	18.7	
a/b Ratio								
Low VA	1.4	1.3	1.2	1.2	1.2	1.1	1.0	0.27
High VA	1.4	1.3	1.2	1.2	1.1	1.0	0.9	
Hue Angle[2]								
Low VA	36.2	37.9	38.6	39.3	40.9	43.3	45.2	0.72
High VA	36.1	37.8	38.9	40.7	41.8	45.3	47.0	
Saturation Index[3]								
Low VA	39.6	37.9	37.1	34.2	32.3	30.1	28.0	0.70
High VA	39.4	37.4	35.4	32.6	29.6	27.5	26.1	

[1]EW = early-weaned, TW = traditionally-weaned, HA = high VA, LA = low VA
[2]calculated using $(b^*/a^*)^{\tan-1}$
[3]calculated using $(a^2 + b^2)^{1/2}$
[abcdefghijkl] within a trait, means without a common superscript letter differ ($P < 0.05$)

Retail color display results of my study indicate that steaks from calves supplemented with high levels of VA tend to have poorer color stability than steaks from calves restricted in VA. This contrasts data from Irie, Inno, Ishizuka, Nishioka, and Morita (2006) on Japanese Black cattle in which VA restriction caused some beef to become partially discolored from bright red to brown red. They contributed this discoloration to the fact that feeding diets that are low in VA, such as rice straw rather than pasture, also resulted in suppressed levels of vitamin E due to diet.

Lipid Oxidation

Lipid oxidation was measured at packaging time to determine the initial amount of lipid oxidation. There were no differences between treatments for initial TBARS values in either *LL* or *TB* steaks (Tables 2.8 and 2.9). During retail display, it is expected that lipid oxidation will increase and that antioxidant status in the muscle can influence the rate of oxidation. For both muscles, there was a vitamin effect on post display TBARS values. Post display TBARS values were higher ($P < 0.05$) in the high VA treatment steaks, indicating that more lipid was oxidized in steaks from animals supplemented with high levels of VA.

Table 2.8 TBARS values for *Longissimus lumborum* steaks

	Vitamin A		Weaning		
	Low	High	Early	Traditional	SE
Initial TBARS[1]	0.2	0.2	0.2	0.2	0.1
Post TBARS[1]	0.9[a]	1.5[b]	1.3	1.1	

[1]reported as mg malonaldehyde per 1000 g fresh muscle
[ab]within a row, means without a common superscript letter differ ($P < 0.05$)

Table 2.9 TBARS values for *Triceps brachii* steaks

	Vitamin A		Weaning		
	Low	High	Early	Traditional	SE
Initial TBARS[1]	0.2	0.2	0.2	0.2	0.1
Post TBARS[1]	1.8[a]	2.3[b]	2.3	1.9	

[1]reported as mg malonaldehyde per 1000 g fresh muscle
[ab]within a row, means without a common superscript letter differ ($P < 0.05$)

The advantage in retail shelf-life, both in color stability and lipid oxidation, of the low VA treatment groups in my study could be related to high levels of VA causing a decrease in vitamin E absorption in the intestine. Dicks, Rousseau Jr., Eaton, Teichman, Grifo, and Kemmerer Jr. (1959) found that high amounts of VA can depress vitamin E utilization.

Schelling, Roeder, Garber and Pumfrey (1995) found that impractical high dietary levels (75,000 IU) of VA can depress the utilization of vitamin E in lactating dairy cows. Therefore, it might be possible that high levels of VA could be interfering with vitamin E levels in meat causing a decrease in the antioxidant status of the muscles.

3.3 Sensory Evaluation

Trained Sensory Panel

No sensory differences were found due to weaning treatment in either muscle. However, in the *LL* muscle, steaks from calves restricted in VA had higher ($P < 0.05$) myofibrillar tenderness and connective tissue scores than steaks from calves supplemented with high VA (Table 2.9). However, differences in overall tenderness were not significant.

Table 2.9 Trained sensory panel scores for Longissimus lumborum steaks

	Vitamin		Wean		SE
	Low	High	Early	Traditional	
Myofibrillar Tenderness[1]	6.6[a]	6.1[b]	6.3	6.4	0.10
Juiciness[2]	5.7	5.6	5.8	5.6	
Beef Flavor[3]	5.7	5.7	5.7	5.7	
Connective Tissue Amount[4]	7.3[a]	7.0[b]	7.1	7.2	
Overall Tenderness[1]	6.6	6.3	6.5	6.4	
Off Flavor Intensity[4]	7.4	7.5	7.4	7.5	

[1]myofibrillar and overall tenderness scale: 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender
[2]juiciness scale: 1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, and 8 = extremely juicy.
[3]beef flavor scale: 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense
[4]connective tissue and off flavor intensity scale: 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, and 8 = none
[ab]within rows, means without a common superscript differ ($P < 0.05$)

There were no weaning or vitamin treatments effects on sensory panel scores in *TB* steaks (Table 2.8).

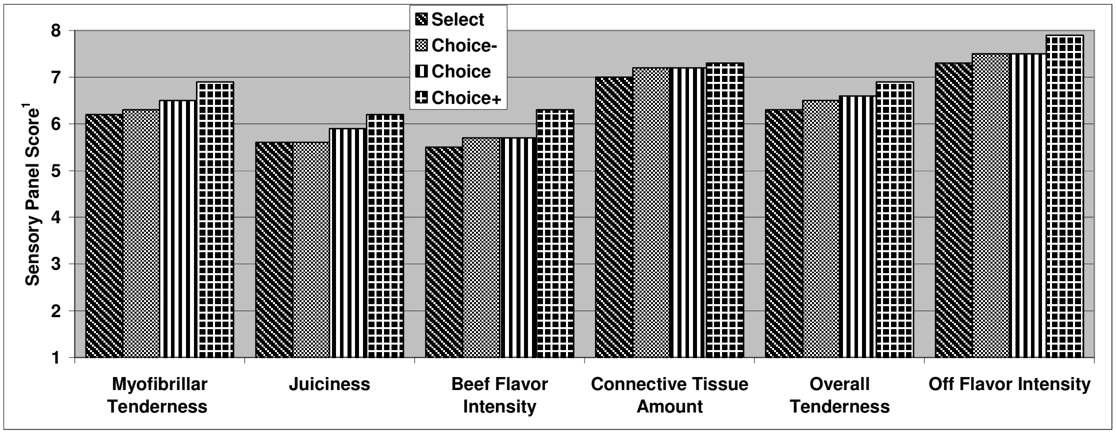
Table 2.10 Trained sensory panel scores for *Triceps brachii* steaks

	Vitamin		Wean		SE
	Low	High	Early	Traditional	
Myofibrillar Tenderness[1]	5.4	5.2	5.2	5.3	0.10
Juiciness[2]	5.4	5.5	5.4	5.6	
Beef Flavor[3]	5.5	5.5	5.4	5.5	
Connective Tissue Amount[4]	6.2	6.1	6.2	6.2	
Overall Tenderness[1]	5.5	5.3	5.4	5.5	
Off Flavor Intensity[4]	7.2	7.3	7.4	7.2	

[1]myofibrillar and overall tenderness scale: 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender
[2]juiciness scale: 1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, and 8 = extremely juicy.
[3]beef flavor scale: 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense
[4]connective tissue and off flavor intensity scale: 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, and 8 = none

Marbling could have had some impact on sensory panel scores. Figure 2.9 shows that steaks grading high Choice tended to have higher scores for myofibrillar tenderness, juiciness, beef flavor intensity, and overall tenderness, and off-flavor intensity (less off-flavors) while having less connective tissue than steaks from lower quality grade carcasses. Even though early reports by Clover, King, and Butler (1958) and Palmer, Carpenter, Alsmeyer, Chapman, and Kirk, (1958) found that only 11% of the variation in tenderness was accounted for by marbling, other research indicates that sensory panel evaluations can be effected by degree of marbling. Dolezal, Smith, Savell, and Carpenter (1982) reported that *LL* steaks from USDA Choice carcasses received the highest percentage of "very desirable" ratings and the lowest percentage of "undesirable ratings" for overall tenderness when compared with steaks from USDA Good and Standard carcasses. Campion et al. (1975) found a moderately low (r = 0.32) correlation between marbling and taste panel juiciness.

Figure 2.9 Trained sensory panel scores by quality grades



[1]myofibrillar and overall tenderness scale: 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender; juiciness scale: 1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, and 8 = extremely juicy; beef flavor scale: 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense; connective tissue and off flavor intensity scale: 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, and 8 = none

Warner-Bratzler Shear Force

In both muscles, the low VA treatment steaks had numerically lower ($P > 0.05$) WBSF values (Table 2.9). There was no effect due to weaning age.

Table 2.11 WBSF values for *Longissimus* and *Triceps brachii* steaks in kg

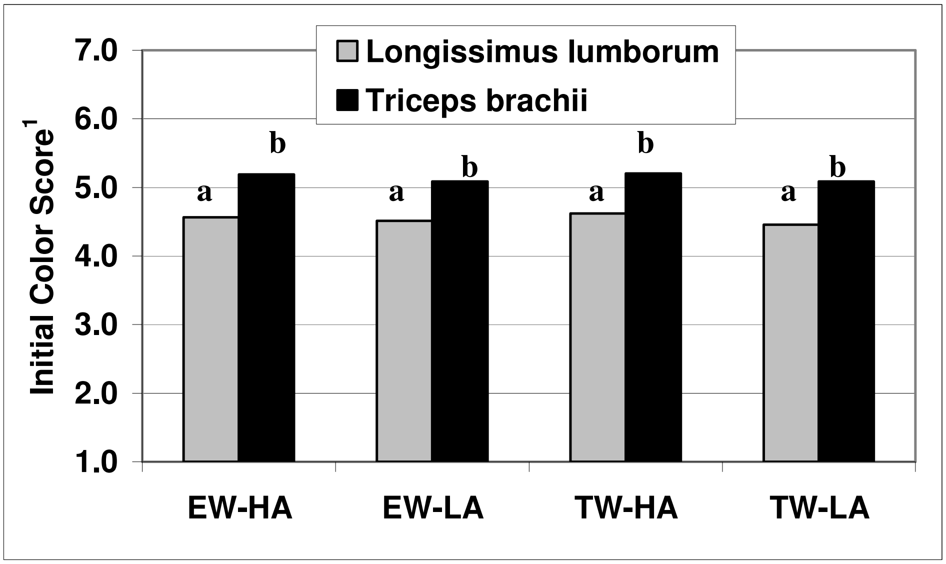
	Vitamin		Wean		SE
	Low	High	Early	Traditional	
LL WBSF	2.2	2.7	2.5	2.5	0.10
TB WBSF	3.2	3.4	3.3	3.3	

The lack of differences in WBSF values suggests that instrumental determinations are less subjective than sensory panel evaluations. The result of the effect that VA restriction might have on sensory aspects of meat is supported by past research. Bramblett, Martin, Harrington, and Evans (1971) showed that increasing vitamin A supplementation from 0 to 13,200 IU/kg caused increased evaporation losses, total cooking losses, Warner-Bratzler shear values, and visual appearance scores, whereas adhesion scores decreased ($P < 0.05$).

3.5 Muscle Differences

Initial color scores for the *TB* steaks were higher (darker, $P < 0.05$) than *LL* steaks for all treatment groups (Figure 2.10). According to muscle characteristics outlined on the bovine myology website, it is typical for the *TB* muscle to have a darker color (indicated by lower L* values) than the *LL* muscle (http://bovine.unl.edu/bovine3D/eng/muscleIndex.jsp).

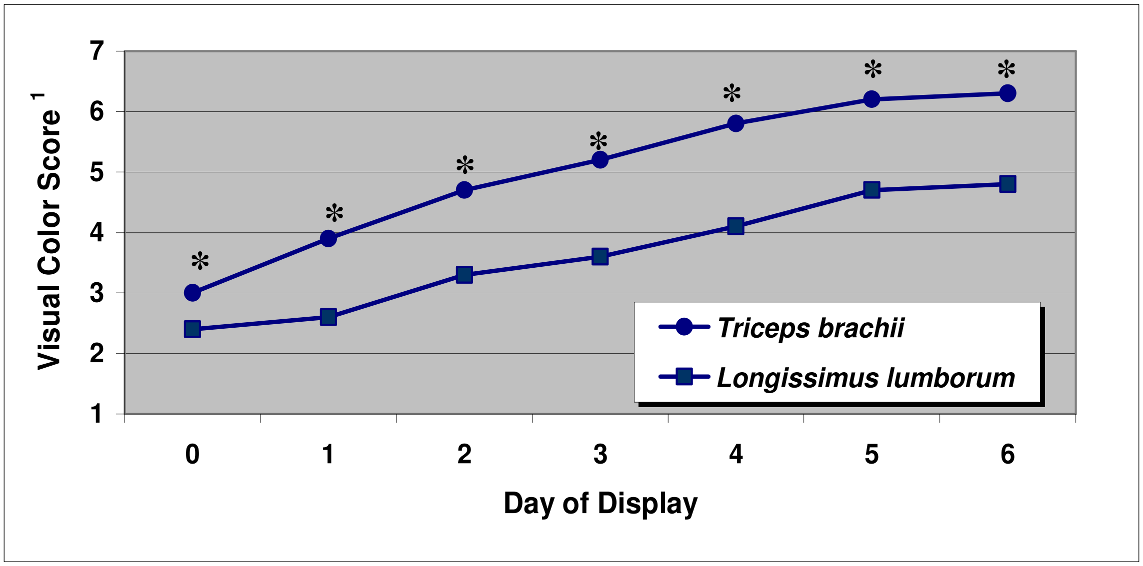
Figure 2.10 Longissimus lumborum and Triceps brachii initial color scores by treatment



[1]initial Color Scale: 3=slight cherry red, 4=moderately cherry red, 5=cherry red, 6=slight dark red
[ab]means without a common superscript letter differ ($P < 0.05$)

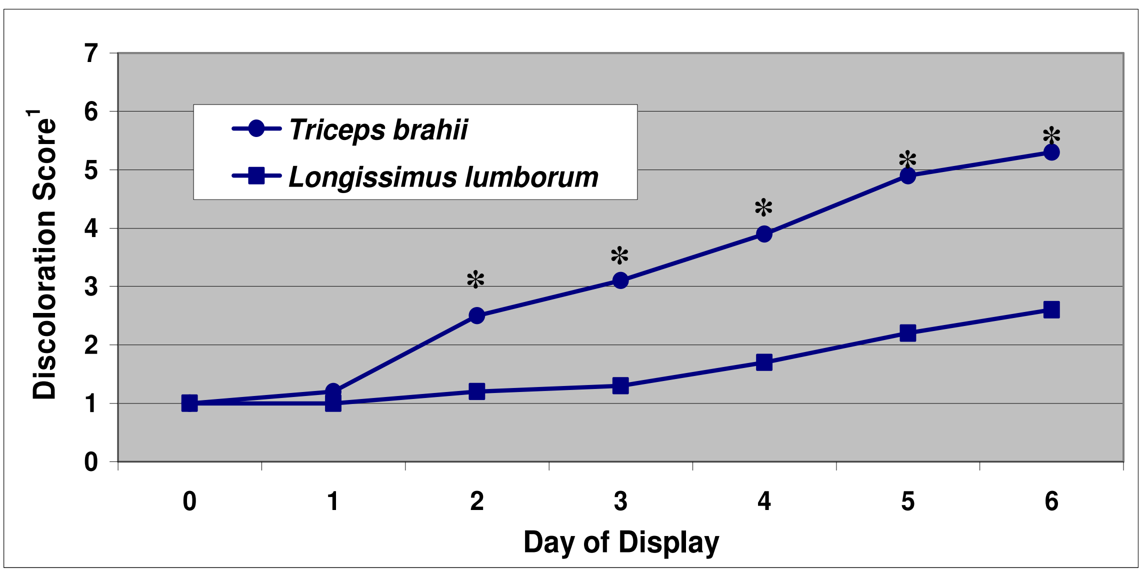
Triceps brachii steaks had higher (darker, $P < 0.05$) display color scores on all d of display (Figure 2.11) and higher ($P < 0.05$) discoloration scores on d 2 to 6 (Figure 2.12) than *LL* steaks. In research by McKenna, Mies, Baird, Pfeiffer, Ellebracht, and Savell (2005), the *LL* muscles can be classified as having "high" color stability, whereas, the *TB* tends to be less color stable showing more severe metmyoglobin formation on steak surfaces during retail display. As expected, for all treatments in both muscles, visual color scores and discoloration scores were higher on d 6 of display than d 1 of display. Color deterioration over retail display can be associated with lipid and pigment oxidation and possibly due to decreased enzyme activity with increased postmortem age.

Figure 2.11 *Longissimus lumborum* and *Triceps brachii* display color scores by day



[1]Visual color scale: 1 = very bright red, 2 = bright red, 3 = dull red, 4 = slightly dark red, 5 = slightly dark red or reddish tan, 5.5 = borderline acceptable to panelist, 6 = moderately dark red to tannish red
*Difference (P < 0.05)

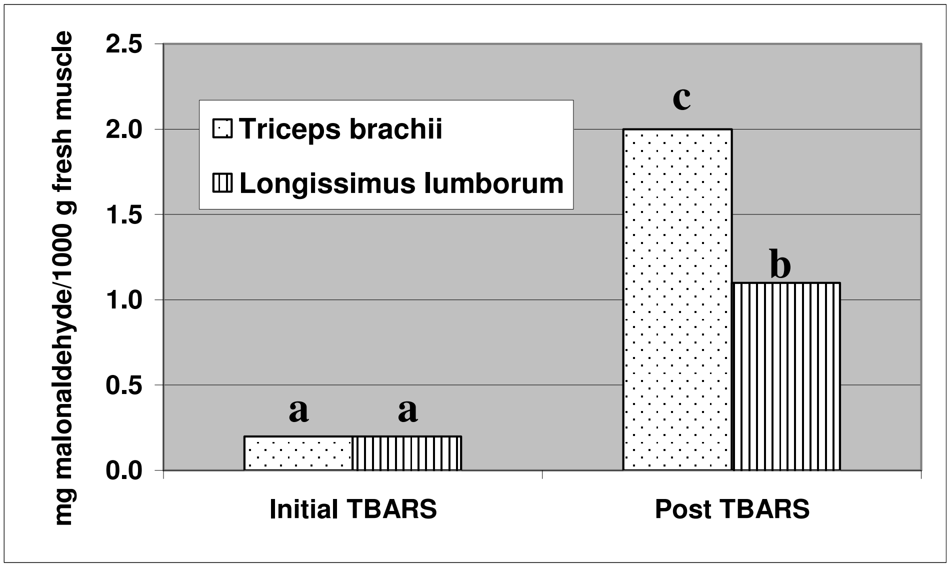
Figure 2.12 *Longissimus lumborum* and *Triceps brachii* discoloration scores by day



[1]Discoloration Scale: 1 = (0%), 2= (1-19%), 3 = (20-39%), 4 = (40-59%), 5 = (60-79%), 6 = (80-89%)
*Difference (P < 0.05)

There was no difference between muscles in initial TBARS values. However, *TB* steaks showed more lipid oxidation after 7 d of retail display than *LL* steaks (Figure 2.3). McKenna et al. (2005) found that, generally, the more color-stable muscles, such as the *LL* muscle, tend to have lower TBARS values than less color-stable muscles as in the case of the *TB*.

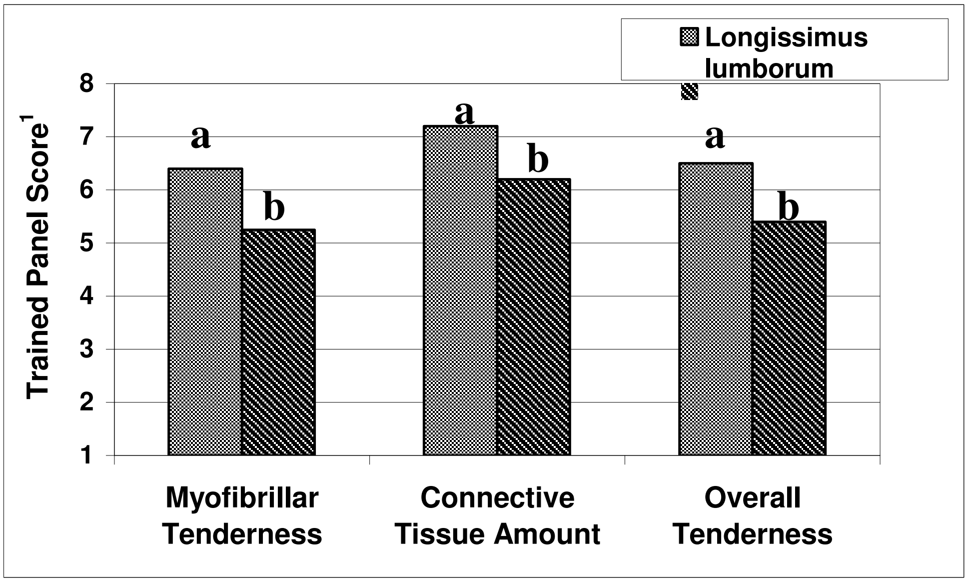
Figure 2.13 TBARS values for *Longissimus lumborum* and *Triceps brachii*



[abc] bars without a common superscript letter differ (P < 0.05).

Trained sensory panel evaluations found that *LL* muscles tended to have higher myofibrillar tenderness, less connective tissue, and higher overall tenderness scores than the *TB* muscles (Figure 2.14). According to Meisinger, James, and Calkins (2006), the *TB* tends to be only moderately tender and contain a small amount of connective tissue. Furthermore, since the *TB* is used more in animal locomotion than the *LL* muscle, it is expected that the *LL* steaks would be more tender than the *TB* steaks.

Figure 2.14 Trained sensory scores of *Longissimus lumborum* and *Triceps brachii steaks*



[1]myofibrillar and overall tenderness scale: 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender
connective tissue amount scale: 1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, and 8 = none
[ab]columns within category without common superscripts differ (P < 0.05)

WBSF differences between muscles support the sensory panel tenderness differences. *Longissimus lumborum* steaks tended to have lower WBSF values than the *TB* steaks. This coincides with the muscle characteristics outlined on the bovine myology website. The *TB* muscle tends to have higher WBSF values than the *LL* muscle (http://bovine.unl.edu/bovine3D/eng/muscleIndex.jsp) which can be attributed partly to connective tissue amount.

4. Summary

Early-weaning versus traditional-weaning had no effect on retail display life, lipid oxidation, or sensory attributes of *LL* or *TB* steaks, except that *TB* steaks from calves that were early-weaned and fed high levels of VA had higher ($P < 0.05$) L* values (darker color) than *TB* steaks from calves traditionally-weaned and fed restricted levels of VA. Both the *LL* and *TB* steaks from calves restricted in VA had more desirable visual and instrumental color scores and less lipid oxidation than calves fed high levels of VA. Trained sensory panel scores were not negatively affected by feeding restricted levels of vitamin A in the *TB* muscles. However, myofibrillar tenderness and connective tissue amount was negatively affected in *LL* steaks from calves fed high levels of VA. Instrumental tenderness values were not affected by vitamin or weaning treatment. Muscle differences indicated that *LL* steaks had better color stability, less lipid oxidation, and were more tender than *TB* steaks.

5. Implications

Vitamin A restriction during the finishing phase of cattle would be expected to have positive effects on retail color shelf-life and lipid oxidation while not having an impact on cooked meat sensory attributes. Vitamin A restriction may be a practice that can be utilized to enhance beef quality.

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