Fresh Beef Marketing Opportunities Due to Dietary Vitamin E

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Nature and Significance of the Challenge

Color of fresh beef during retail display is an important factor used by consumers to judge freshness of the product and make their purchase decision. A bright, cherry-red muscle tissue color is desired. Recession of the cherry-red color during product display, and the appearance of brown hues, is a natural process in beef. Consumers have a keen eye for recognizing when beef color does not meet their ideal mental image. When this happens, they either choose a different package of beef or decide not to purchase beef. Retailers and meat case managers have widely recognized this consumer behavior. Products that are in the early stages of discoloration may be discounted to encourage quick sale to more price-conscious consumers, seasoned or marinated into products for which fresh meat color is not pertinent, or converted to ground beef. Products with advanced discoloration are likely to be discarded. Any of these options compromises retail receipts or adds expense.

Another strategic approach of retailers is to match the amount of product offered for sale as closely as possible to anticipated sales. However, under-estimation of sales results in consumers finding empty or out-of-stock meat cases, and over-estimation leads to decreased revenue, due to price discounts or discarded product. Management of product color and product stocking rate has been an issue in retail fresh beef sales for decades. U.S. retailers fail to capture at least one billion dollars of revenue annually from fresh beef sales, due to product discoloration.

Consumers use color as an indicator of freshness, but it is not a good indicator of freedom from microbial spoilage. In fact, discoloration occurs prior to microbial spoilage in fresh beef products. From a product wholesomeness perspective, microbial spoilage is more important than the lack of an appealing color. A long-standing challenge in meat science has been to extend the stability of the desirable bright red color of fresh beef to more fully capture the marketing opportunity that exists prior to the time of microbial spoilage. Discoloration of fresh beef products has been very premature, relative to microbial spoilage.

Color in fresh beef is primarily due to the presence of the protein, myoglobin. The bright red color of beef is due to the oxygenated form of myoglobin, oxymyoglobin. Myoglobin contains iron. While myoglobin is in the oxy form, oxygen is bound to the iron and the iron is present in the ferrous (Fe+2) state. When brownish discoloration develops on beef, it is due to the increasing formation of metmyoglobin from oxymyoglobin. Delaying, not preventing, the conversion of oxymyoglobin to metmyoglobin is the goal of meat retailers. The two major differences between the oxy- and met- forms of myoglobin are that in metmyoglobin a molecule of water substitutes for oxygen, and the iron is present in the ferric (Fe+3) state. The conversion from ferrous to ferric states is termed oxidation because a negative charge is lost from iron. The oxidation of oxymyoglobin to metmyoglobin is the chemical process that causes discoloration and is key to understanding the mechanism of vitamin E's action.

Vitamin E Improves Beef Color Stability

The connection between general oxidative processes and the oxidation of oxymyoglobin in beef has been appreciated for a long time. Rancidity in lipids is due to the formation of fatty acid oxidation products, and the correlation between the oxidative processes involved with rancidity and discoloration is well-known. Efforts to retard lipid oxidation have historically focused on the use of antioxidants either fed to or added to poultry or pork products. Since the lipids of ruminants are less susceptible to oxidation, less attention has been focused on application of

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antioxidant strategies to beef. However, Greene et al. (1971) added several antioxidants to ground beef and found that lipid and pigment oxidation were delayed.

In March 1988, the observation was made at the University of Wisconsin-Madison that steaks from cattle that had received 375 International Units (IU) of supplemental vitamin E for 265 days (Arnold et al., 1992) yielded sirloin steaks (Faustman et al., 1989) and loin steaks (Figure 1) that had more persistent redness. Key features which are important to the effectiveness of vitamin E in enhancing the duration of color shelf-life are that it be fed to cattle in a sufficient dose and for a sufficient duration to result in increased muscle α− tocopherol concentration. Mitsumoto et al. (1993) demonstrated convincingly that an increased muscle α− tocopherol concentration resulting from dietary supplementation of vitamin E was much more effective as an antioxidant than α−tocopherol added as an ingredient postmortem.

Current Understanding of the Role of Vitamin E

Vitamin E is an essential nutrient that functions as an antioxidant in the body and is found in plants and seeds, and especially their oils. Eight molecules, four tocopherols and four tocotrienols, have vitamin E activity. One member of this molecular family, α− tocopherol, has the most vitamin E activity in biological systems. Alpha-tocopherol can be chemically synthesized. Due to the chemical structure of α− tocopherol, the synthetic version is a mixture of eight stereoisomers and is termed "all-rac" or "dl" α− tocopherol. Only one of these stereoisomers occurs in plants as a result of natural synthesis. It is termed RRR- α−tocopherol and has more vitamin E potency than the other seven stereoisomers that occur in all-rac-α− tocopherol. In addition to the inherently potent antioxidant property of α−tocopherol, the liver accounts for the selective retention and distribution of α− tocopherol, and especially the RRR stereoisomer of the alpha form, to the tissues of the body (Igarashi and Kiyose, 1999). Due to the plurality of molecules with vitamin E activity in feeds, references to the diet of cattle are done in terms of "vitamin E", while references to tissues are done in terms of "α−tocopherol". Since α− tocopherol is slowly degraded by atmospheric oxygen and rapidly degrades in the presence of trace minerals like iron and copper, it is stabilized for the purposes of commerce by esterifying it to an acetate or succinate molecule. One international unit is defined as the vitamin E activity associated with 1 mg of all-rac-α− tocopheryl acetate.

Vitamin E is commonly supplemented to the diets of finishing cattle as all-rac-α−tocopheryl acetate. This form of vitamin E is very stable during storage, feed processing and passage through the animal's forestomach (Leedle et al., 1993). The acetate ester lacks antioxidant activity. However, upon reaching the small intestine, the acetate component is cleaved by intestinal esterases, leaving α−tocopherol which is promptly absorbed across the intestinal wall into the mesenteric lymphatic system. From here, chylomicrons carry α−tocopherol into the circulatory system. Lipoproteins, synthesized by the liver, and chylomicrons transport α−tocopherol to organs and tissues of the body. Alpha−tocopherol enters the tissues and then embeds itself in cell membranes, specifically within the hydrophobic, or lipid-rich, regions at the interior of the membrane where it exerts its potent antioxidant effect. Recall that vitamin E is a "fat-soluble" vitamin, which explains why it prefers to be in cellular locations that have high fat, or lipid, content.

The lipids in muscle cell membranes are considered to be susceptible to oxidation (Gray et al., 1996). Lipid oxidation in fresh beef products is associated with the penetration of atmospheric oxygen into meat and its contact with membrane lipids. Oxidation of lipids is positively correlated with metmyoglobin formation (Faustman and Cassens, 1990). Alpha−tocopherol exerts its antioxidant effect by intercepting free radicals propagated during the early steps of lipid oxidation. Alpha−tocopherol neutralizes a free radical molecule by donating one of its electrons and becoming α−tocopheroxyl radical and associated α− tocopherolquinones (Faustman et al., 1999). These events have been modeled mathematically to suggest that α−tocopherol prevents

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oxymyoglobin from interacting with free radicals (Lanari et al., 1996). Fortunately, the α−tocopheroxyl radical and related oxidation products are stable and not damaging to surrounding lipid molecules. A very small number of α− tocopherol molecules are able to protect a very large number of nearby fatty acid molecules. A model based on current knowledge (Schaefer et al., 1995a) suggests that in the absence of a sufficient concentration of α− tocopherol, lipid radicals presumably migrate out of the lipid regions of membranes and into the sarcoplasm to make contact with oxymyoglobin. The pro-oxidative lipid oxidation products oxidize oxymyoglobin to metmyoglobin, and brown hues appear in meat.

Vitamin E consumed by cattle equilibrates into cell membranes slowly, but the rate of α−tocopherol accumulation is influenced in a dose- 2 — PRODUCT EHANCEMENT and duration-dependent manner. Approximately 100 days is required for muscle α−tocopherol concentrations to come into equilibrium with ingested vitamin E (Arnold et al., 1993a; Schaefer et al., 1995a). Table 1 displays the relationship between supplemental vitamin E dose and dose duration for longissimus muscle α−tocopherol concentration and color display life. Increasing dosages and dose durations increase muscle α−tocopherol concentration. Dosage and duration affect rate of α− tocopherol accumulation in that a concentration of 2.5 mg/g in longissimus was achieved by supplementation of 486 IU/day for 126 days, or 2109 IU/day for 42 days or less. The increases in α−tocopherol concentrations to a threshold are associated with increases in color display life of the meat cut (Faustman et al., 1989; Liu et al., 1996b). Color display life is the number of days during which the meat shows no significant change in color relative to the bright, red color that was initially present when meat was put on display. Muscles differ in the extent to which they accumulate α−tocopherol, and the order of accumulation is as follows: psoas major > gluteus medius > semimembranosus > longissimus (Chan et al., 1996). Ironically, the color display life ranking for these muscles is the inverse of the α−tocopherol accumulation ranking. This fact emphasizes that there are factors in muscle chemistry, in addition to α−tocopherol, that account for variation in color stability.

In some instances, supplemental vitamin E has not produced the expected effects on beef color. This may possibly be explained on the basis of preexperimental nutritional regimens that resulted in muscle α−tocopherol accumulation and the slow rate of α−tocopherol depletion from muscle (Arnold et al., 1993a). Hill and Williams (1993) grazed yearling steers on Bermuda grass or pearl millet prior to 130-day trials involving supplementation of 500 or 1000 IU of vitamin E, and found no effect on fresh beef color stability. Yang et al. (2002) found no effect of vitamin E when it was supplemented to pasture- or sorghum-fed cattle. The latter study raises the notion that there are other naturally-occurring antioxidants in grasses and sorghum.

Supplemental Vitamin E (IU/day)	0	486		2109	
Duration (days)	126	42	126	42	126
α–Tocopherol L (mg/g fresh)	0.5	1.3	2.5	2.9	5.5
Display life in L (days)	4.7	6.0	7.7	8.7	10.0
α–Tocopherol in RCDM (mg/g fresh)	0.38	1.48	3.12	3.67	7.23

Table 1: Relationship between daily dose and dose duration of supplemental Vitamin E pre-harvest on longissimus (L) and rectus capitis dorsalis major (RCDM) α–tocopherol concentrations and color display life of longissimus samples.
Source: Liu et al. (1996a and b) and Shaefer et al. (1995b).

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Effects of vitamin E supplementation are most easily recognized for those variables that respond to antioxidants. When ground beef has been packaged in a high-oxygen atmosphere, which is known to accelerate lipid oxidation, vitamin E supplementation has resulted in beef with an extended period of redness (O'Grady et al., 1998; Houben et al., 2000). In contrast, vitamin E supplementation appears to not influence meat tenderness (Arnold et al., 1993b), microbial growth on fresh beef products (Cabedo et al., 1998), or cooked color of ground beef (Lavelle et al., 1995). There is some evidence for improved cattle health when dietary vitamin E supplementation is initiated upon receipt of feeder cattle into feedyards (Smith et al., 1996). Secrist et al. (1997) summarized 21 studies and concluded that average daily gain was increased and feed conversion efficiency tended to improve with vitamin E supplementation.

It is fortunate that this vitamin E technology does not mask high levels of bacterial contamination (Zerby et al., 1999c) or impair the ability of observers to detect spoilage (Chan et al., 1996). Although vitamin E is an important antioxidant in human health, beef from vitamin E-supplemented cattle is not an important contributor of α−tocopherol to the human diet, accounting for only 3% of the recommended dietary allowance for adults that consume a three-ounce serving (Liu et al., 1994).

Retail Product	Non-Vitamin E	Vitamin E	Increment
Bottom Round	1.4	3.9	2.5*
Clod	3.1	4.0	0.9*
Eye-of-Round	1.4	3.7	2.3*
Inside Round	1.9	3.1	1.2*
Strip Loin	2.0	3.2	1.2*
Tenderloin	1.6	3.4	1.8
Ground Beef	1.5	4.7	3.2*

* α−tocopherol concentration was elevated due to vitamin E supplementation.

Table 2: Average muscle α−tocopherol concentrations (mg/g) for six steak cuts and ground beef from vitamin E and non-vitamin E-supplemented cattle.
Source: Zerby et al. (1996b). Data reprinted with permission.

Implementation of the Technology

The beef cattle industry has been highly segmented - cow/calf, stocker, feedyard, packer, purveyor and retailer. Implementation of the dietary vitamin E technology is difficult in a segmented production system because the cattle feeder bears the expense of the supplemental vitamin E, but the retailer realizes the increased sales revenue. Retailers ask for validation of vitamin E supplementation before being willing to compensate cattle feeders for their expense. In a segmented marketing system, compensation for expense through price rewards is awkward. However, validation can be accomplished by two methods - either by sampling diets fed to cattle destined to be marketed under a claim of vitamin E supplementation, or by sampling neck muscle from animals after harvest and prior to carcass fabrication. In the former circumstance, knowledge of the daily feed intake and dietary vitamin E concentration permits calculation of total daily vitamin E intake. In the latter circumstance, a sample of the rectus capitis dorsalis major (RCDM) is collected, held in a chilled or frozen state and then analyzed by a simplified, yet robust laboratory method involving liquid chromatography (Liu et al., 1996c). The RCDM is located on both sides of the atlas joint, at the junction between the vertebral column and the head.

Validation of implementation of the technology is done to confirm that a threshold level of supplementation has occurred. For domestic beef markets, the common goal is to provide 500 IU of supplemental vitamin E per animal daily for the last 100 days prior to harvest. For export markets, the common goal is to provide 1000 IU per head daily for the same finishing period. When RCDM muscle sampling is used, the threshold α−tocopherol concentration for domestic markets is 3.1 mg/g fresh muscle (Table 1). This concentration ensures that the α−tocopherol concentration in other skeletal muscles is elevated, relative to unsupplemented animals, and that the retailer could expect about a 60% improvement in color display life (4.7 vs 7.7 d. Table 1).

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Retail Product	Non-Vitamin E	Vitamin E	Increment
Bottom Round	35	60	25*
Clod	52	58	6
Eye-of-Round	40	70	30*
Inside Round	33	41	8*
Strip Loin	59	70	11*
Tenderloin	30	34	4
Ground Beef	28	46	18*

* Display life was extended due to vitamin E supplementation.

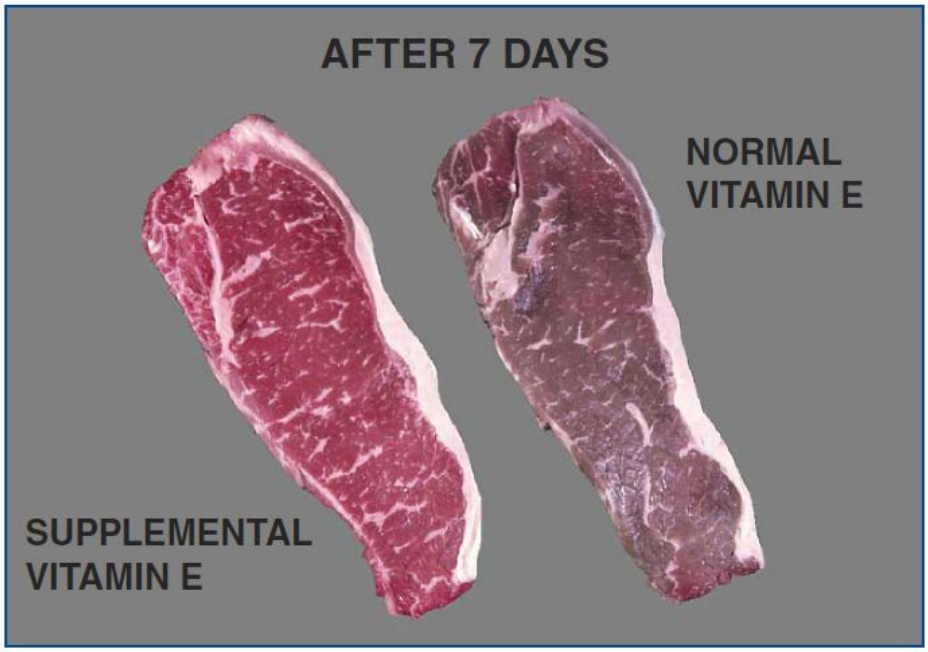
Table 3: Average daily life of six steak cuts and ground beef from vitamin E and non-vitamin E supplemented cattle. Display life is time (hours) elapsed until panelists recognized color to be unacceptable.
Source: Zerby et al. (1999b). Data reprinted with permission.

Benefits and Application of the Technology

Dietary vitamin E supplementation has resulted in elevated α−tocopherol concentrations in all muscles examined. Zerby et al. (1999b) examined six wholemuscle, retail products and ground beef from cattle that received 0 or 500 IU daily for a minimum of 100 days. Muscle α−tocopherol concentrations (Table 2) were elevated for all retail products, though the increments were not uniform.

Display life was enhanced for all seven products (Table 3) due to vitamin E supplementation, with five of the seven products having at least an eight-hour increase in display-life. Other research has shown that tenderloin (Chan et al., 1996) and clod steaks (Westcott et al., 2000) from vitamin E-supplemented cattle have possessed improved display life, though Chan et al. (1996) used a relatively high level of vitamin E supplementation (1205 IU head daily).

Figure 1: Strip loin steaks were obtained from steers that had recieved either normal (75 IU/head daily for 265 days) or supplemental vitamin E (450 IU/head daily for 265 days), aged (4°C) in vacuum packages for seven days, and then displayed under simulated retail display conditions (4°C) for seven days (Exp. 1 of Arnold et al., 1992).



Improved color display life implies that vitamin E supplementation expands the marketing window during which beef products could be sold at full price. Several studies conducted in the U.S. and also in Japan have confirmed that more value is captured from beef products when they are derived from vitamin Esupplemented cattle. A recent, extensive retail marketing study (Westcott et al., 2000) revealed that supplementation of 500 IU daily for 100 days at a cost of $4.00 per animal reduced the proportion of product discounted due to discoloration, and thus improved retail value by $30 to $35 per carcass. Zerby et al. (1999a) found that products derived from cattle that had received 1000 IU per head daily for 100 days decreased discoloration losses for Japanese retailers, saving them US $0.11 per pound. Smith et al. (2000) reviewed the economic implications of the vitamin E technology and concluded that realistic scenarios for net receipts to the beef industry per cattle-equivalent were $28.05 and $37.67 for domestic and export applications.

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The economic merit of this technology is being recognized by the beef industry. Approximately 15% of fed cattle marketed annually in the U.S. and Canada are currently receiving supplemental vitamin E to improve retail marketability of fresh beef products. This technology is typically one of the component technologies around which a beef cattle marketing alliance is formed. An alliance allows for verticallycoordinated business practices and circumvents the difficulties that a segmented industry structure has with compensating cattle feeders for added vitamin E expense. In this manner, the vitamin E technology is a factor that is stimulating structural change in the feeding, packing, processing and retailing sectors of the U.S. beef cattle industry.

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