Supplemental Vitamin E in Beef Cattle Diets to Improve Shelf-life of Beef

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Abstract

Quality deterioration in meat occurs because of oxidation of lipids and muscle pigments. Lipid oxidation causes development of off-odors and off-flavors; muscle-pigment oxidation negatively affects color, appearance and acceptability. Lipid and muscle-pigment oxidation are closely associated such that delaying lipid breakdown will delay meat discoloration. Supplementation of cattle diets and enough vitamin E to achieve about 4 μg g $^{-1}$ alpha-tocopherol in muscle extended the time beef was acceptable quality. Feeding supplemental vitamin E to feedlot steers and heifers produced beef with higher tissue alpha-tocopherol, slower metmyoglobin formation, fewer oxidation products and 24-48 h longer acceptable appearance during display. Growth of spoilage and pathogenic (*Escherichia coli* 0157:H7; *Listeria monocytogenes*) bacteria did not differ on beef cuts from cattle fed vs. not-fed supplemental vitamin E. Field studies documented that supplementing diets of feedlot cattle with 500-1000 IU per head per day of vitamin E for 90-100 days prior to harvest was efficacious for beef marketed in both domestic and export trades.

Keywords: Vitamin E; Lipid oxidation; Pathogenic bacteria

1. Meat quality deterioration due to lipid oxidation

Quality deterioration in meat occurs because of lipid oxidation and muscle-pigment oxidation. Of factors affecting rate and extent of lipid oxidation in muscle, the primary one is the level of polyunsaturated fatty acids present in tissue (Williams *et al.*, 1992). Lundberg (1962) described the process by which unsaturated fatty acids undergo auto-oxidation by a free-radical mechanism that involves abstraction of a labile hydrogen from the lipid molecule followed by addition of a molecule of oxygen to the lipid radical. Lipid peroxy radicals undergo reactions leading to formation of oxidation products that can adversely affect meat color, texture, nutritive value and safety (Williams *et al.*, 1992). Breakdown of lipid hydroperoxides produces aldehydes, ketones and carboxylic acids that negatively affect odor and flavor of meat (Mottram, 1987). Antioxidants can extend the shelf-life of meat by reducing or preventing lipid peroxidation (Williams *et al.*, 1992).

2. Meat quality deterioration due too muscle-pigment oxidation

Muscle-pigment oxidation negatively affects meat color; color of meat influences purchase decisions. Consumers have learned, through experience, that the desirable color of fresh meat is bright-pink to bright-red and that any deviation from this creates a degree of unacceptability (Kropf, 1980). Consumers judge meat quality via visual appearance, and surface discoloration may be interpreted as a condition of unwholesomeness (Faustman *et al.*, 1989a). Color changes from purplish-red to bright-red when the myoglobin in meat surfaces is exposed to oxygen (Cross *et al.*, 1986). 'Oxygenation' occurs about 30 min after initial exposure to air

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and is termed 'blooming'. The brown color created by changes due to oxidation of the iron in the heme moiety of myoglobin and conversion of oxymyoglobin to metmyoglobin is considered undesirable by most consumers. Signs o brownish discoloration occur when 60% of the pigment in a muscle surface area is oxidized to metmyoglobin (Lawrie, 1966). Some muscles discolor less rapidly thn others because increases in metmyoglobin-reducing activity (MRA) and reducing equivalents (e.g. NADH[2]) allow the iron in myoglobin to remain in the reduced state longer, resulting in brighter muscle color because most of the pigment exists in either reduced-myoglobin or oxymyoglobin states. Some meat cuts last 4-5 days whereas other meat cuts discolor after 1-2 days of retail display (Cross *et al.*, 1986). 'Case-life' of fresh beef is the amount of time a retail cut can maintain a bright-pink to bright-red appearance before discoloration. If the muscle color is brown, the cut of meat is not considered acceptable in freshness and usually will not be purchased at full price by US consumers (Smith *et al.*, 1993).

3. Consequences when visual quality standards for meat color are not met in the retail case

Retail packages of meat are given a 'pull date' or a 'sell-by date' on the day of preparation. Retail case-life, for a specific cut, is determined by microbial contamination, microbial activity and the MRA of muscles in the cut (Smith et el., 1993). Retail 'case-life' is 1 day for tenderloin and ground beef, 2 days for 'wet cuts' (e.g. chuck or shoulder and round) and 3 days for 'dry cuts' (e.g. loin and rib); if muscles are discolored at the 'sell-by date' or earlier, retail cuts must by marked down in price, faced and repackaged, or ground (Smith *et al.*, 1993). William *et al.* (1992) estimated that average value deterioration is 3.7% for entire meat department and 5.4% for fresh meat. Preventing this loss by increasing case-life by 1-2 days would save the US industry $175 million to $1 billion (US) annually (Williams *et al.*, 1992). Maintaining or extending case-life of retail cuts by assuring that they have bright-pink to bright-red color can be accomplished by delaying the breakdown of lipid and thus delaying meat discoloration. Procedures which enhance lipid stability stabilize the color of beef prolong its shelf-life and favorably impact its economic value and image in marketplace (Williams *et al.*, (1992).

4. Dietary supplementation of vitamin E to improve cattle performance and health

Sub-clinical deficiencies of vitamin E are usually unrecognizable, but do influence production costs of feedlot cattle (Nockels *et al.*, 1993). The antioxidant activity of vitamin E contributes to immune enhancement by stabilizing highly reactive, potentially harmful molecules called 'free radicals.' When free radicals are generated, damage occurs to membranes, enzymes and nuclear material of the cell (Nockels *et al.*, 1993). The ability of antioxidants to destroy the highly reactive free radicals protects the structural integrity of the cells (Halliwell and Gutteridge, 1985).

Hicks (1985) supplemented the diets of newly received feeder cattle with 800 IU per head per day of vitamin E and observed higher gains, decreased percent morbidity and reduced 'average days morbid'. Gill *et al.* (1986) fed vitamin E at 1600 IU per head per day to incoming stressed feeder calves and reported improved average daily gains, reduced morbidity and fewer 'sick days'. Nockels *et al.* (1993) reported that injecting 1500 IU of alpha-tocopherol in vitamin E-deficient heifers before shipping was not beneficial, but that injecting alpha-tocopherol upon arrival improved gain and tended to improve feed efficiency. Hutcheson and Cole (1985) improved growth rate and feed efficiency when vitamin E was added to the diet of yearling cattle. In the Strategic Alliance Field Study (Lambert, 1993), monetary losses due to death loss, processing cost, treatment cost, sick pulls and sick re-pulls were lower for Strategic Alliance (SA) calves than for 'highly managed' (HM) calves, 'just weaned/bawling'(JWB) calves or 'miscellaneous, put-together' (MPT)calves. Gatz (1993) attributed "all of the advantages in overall animal health for SA calves to following good management practices and keeping open communication between rancher and feedlot;" but Smith *et al.* (1993) suggested that dietary vitamin E supplementation could have enhanced the immune response and improved the health of SA cattle.

5. Dietary supplementation of vitamin E to lessen lipid oxidation in red meat

Discoloration of muscle is a combined function of (a) lipid oxidation in intramuscular fat and (b) oxidation of oxymyoglobin to metmyoglobin. Vitamin E functions as a lipid-soluble antioxidant in cell membranes and, in its most potent form (alpha-tocopherol), satiates free radicals and protects muscle-color pigments from oxidation (Faustman *et al.*, 1989b). Because lipid oxidation and muscle-pigment oxidation are caused by similar processes, delaying the breakdown of lipid should similarly delay muscle-pigment oxidation and meat discoloration (Faustman *et al.*, 1989b). Cattle cannot synthesize vitamin E and normally obtain it by consuming pasture. Grains are relatively low in vitamin E and an extended grain-feeding period may deplete tissue alpha-tocopherol levels in cattle (Faustman *et al.*, 1989a; Williams *et al.* 1992).

6. Dietary supplementation of vitamin E to enhance retail case-life in beef

One approach for maintaining oxymyoglobin in fresh meat involves enhancement of the reductant pool within muscle by feeding vitamin E, which minimizes oxidation and maximizes reduction of metmyoglobin (Williams *et al.*, 1992). Increased alpha-tocopherol in the membranes of beef muscle may delay the processes of lipid oxidation and metmyoglobin formation and lengthen case-life. Nine feeding tests at the University of Wisconsin indicated tht feeding 500 IU of vitamin E to cattle each day for the last 100 days before slaughter improved color stability in ground beef and in loin, top-round and sirloin steaks (Pinkerton, 1993). Williams *et al.* (1992) concluded that: (a) vitamin E when fed to beef cattle increased muscle tissue concentrations of alpha-tocopherol, and (b) increased muscle tissue alpha-tocopherol content allowed this natural antioxidant to perform its physiological role of protecting membranal lipids, thus delaying the onset of meat discoloration.

7. Research on the dietary supplementation of vitamin E to cattle

Elevated levels of vitamin E in cattle diets result in higher tissue alpha-tocopherol concentrations and greater stability of these tissues toward lipid oxidation (Faustman *et al.*, 1989a; Arnold *et al.*, 1993). Some studies have used high levels of vitamin E supplementation (2000-3000 IU per day) with conventional feeding-time strategies (for 30-100 days), while other studies have used lower levels of vitamin E supplementation (300-500 IU per day) with extended time-on-feed (for 7-10 months) (Arnold et al, 1992) Arnold *et al.*, 1993; Faustman *et al.*, 1989a, Faustman *et al.*, 1989b; Garber *et al.*, 1992). A critical factor to extend beef shelf-life is implementing a vitamin E-supplementation scheme which will facilitate attainment of a critical alpha-tocopherol level, in the tissue, of 3.0-3.7 μg g $^{-1}$ (Faustman *et al.*, 1989a). Meat which contains alpha-tocopherol concentrations of less that 3.0 μg g $^{-1}$ has shorter case-life in terms of reduced metmyoglobin accumulation of lipid oxidation (Faustman *et al.*, 1989b). Vitamin E supplementation of 500 IU per day for 84-126 days accomplishes the desired effect on beef case-life (Morgan *et al.*, 1993; Sanders *et al.*, 1993). Feeding supplemental vitamin E does not appear to affect average daily gain or feed efficiency (Arnold *et al.*, 1993), nor does it affect carcass weight, marbling score, USDA Quality Grade or ribeye area in beef (Arnold *et al.*, 1992).

Pinkerton (1993) described a University of Wisconsin study that involved feeding 370 IU of vitamin E per day to Holstein steers beginning 309 days before slaughter. During display, steaks from control animals were distinctly discolored within 7 days, while steaks from animals supplemented with vitamin E retained their color. In subsequent test, University of Wisconsin researchers fed daily dosages of 0, 500 or 2000 IU of vitamin E for 211 days prior to slaughter. There were no Day-1 color differences among steaks, but by Day 8, treatment effects were visible in loin and sirloin steaks (Pinkerton, 1993). Williams *et al.* (1992) reported results of a University of Wisconsin study in which Holstein steers were supplemented with 500 IU vitamin E per head per day for 100-120 days prior to slaughter. Loin, t-bone, tenderloin, sirloin and top-round steaks plus chuck or shoulder roasts from control and treated cattle were sold by retail stores in three States. Devaluation due to discoloration, as percentages of initial value, for control vs. vitamin E-supplemented beef averaged 5.62% vs. 1.98%, respectively (Williams *et al.* 1992).

Morgan *et al.* (1993) supplemented the diets of 80 steers with 500 IU of alpha-tocophenyl acetate per day for 123 days and followed beef from those steers and control steers (not fed supplemental vitamin E) to retail supermarkets. During the normal display period at the supermarket, 3.1%, 5.2% and 2.2%, respectively, of t-bone steaks, round-tip steaks and ground chuck (shoulder) from cattle fed supplemental vitamin E were marked down in price. Comparable values for t-bone steaks, round-tip steaks and ground chuck, respectively, from cattle not fed supplemental vitamin E were 18.1%, 14.6% and 17.9% (Morgan *et al.*, 1993). Garber *et al.* (1992) supplemented finishing diets of 75 steers with 0, 250, 500, 1000 or 2000 IU per head per day of alpha-tocophenyl acetate. Muscle-surface metmyoglobin formation was lowed, lipid oxidation was suppressed and case-life of fresh beef steaks was extended by vitamin E-supplementation.

Scientists at Colorado State University, to investigate the shelf-life of beef destined for the Japanese market, supplemented the diets of 84 steers with 0, 1000 or 2000 IU per head per day of alpha-tocophenyl acetate for 100 days and stored primal cuts from the steers for 40, 60, 80 or 100 days prior to arrival of the product in Japan (Smith *et al.*, 1993). At the Food-Ex 1993, beef from the three vitamin E supplementation treatments was evaluated by 10138 Japanese purveyors, restaurateurs and retailers, and 91% of those who viewed the beef on retail display at Food-Ex 1993 preferred the color of beef from cattle fed supplemental vitamin E over that of conventionally fed US beef, while 81% expressed interest in purchasing such beef for re-sale in Japan (Smith *et al.*, 1993).

As a part of the Strategic Alliance Field Study the diets of steers where supplemented with 500 IU of vitamin E for the last 60-100 days of the finishing period. Sanders *et al.* (1993) reported that, compared with cuts from control steers (not supplemented with vitamin E), cuts from steers supplemented with vitamin E (a) had 38% to 250% higher tissue alpha-tocopherol concentrations, (b) had lower metmyoglobin concentrations at all intervals and in all cuts during 96 h of display, (c) maintained 'acceptable' overall appearance longer (48 h and 24 h longer, respectively, for top-loin and tenderloin steaks), and (d) sustained less lipid oxidation (on Day 7 of display, control steaks contained 2.1-2.5 times more thiobarbituric acid reactive substances than did steaks from vitamin E-supplemented steers). Percentages of top-loin, tenderloin and cross-rib clod (shoulder) steaks that were discounted in price when displayed up to 96 h in supermarkets were 0.0%, 0.0% and 3.5%, respectively, for cuts from cattle fed supplemental vitamin E vs. 7.15, 12.5% and 39.1%, respectively, for cuts from control cattle displayed in the same store 1 week later (Sanders *et al.*, 1993).

8. Safety of red meat from animals fed supplemental vitamin E

The most potent form of vitamin E is alpha-tocopherol. This vitamin has its status conferred as GRAS (Generally Recognized As Safe) by the Food and Drug Administration (Smith, 1993). Smith (1993) quotes Dr. Adrianne Bendich (Roche Company) as stating that "Beef enriched in vitamin E would also benefit consumer health and, therefore, enhance beef's nutritional profile. Both adults and children are not receiving recommended daily allowances (RDAs) of vitamin E and research has shown that increasing one's intake of vitamin E reduces the risk of cardiovascular disease" (Smith, 1993, quoting Dr. Bendich).

Feeding supplemental vitamin E did not affect microbial growth on displayed beef in the Arnold *et al.* (1993) study. Garber *et al.* (1992) reported that microbial populations on beef gluteus medius steaks during retail display were not affected by vitamin E supplementation. Cabedo *et al.* (1994) concluded that the growth of total aerobic mesophilic bacteria, coliform bacteria and the pathogens *Escherichia coli* 0157:H7 and *Listeria momocytogenes* did not differ on beef patties (minces) and steaks from cattle fed diets supplemented with 0, 1000 or 2000 IU of vitamin E.

9. Approach to marketing beef from cattle fed supplemental vitamin E

The economics of vitamin E supplementation to feedlot cattle in the US are highly favorable. Using University of Wisconsin estimates (Hermel, 1993) and presuming that 26.5 million cattle are fed in the USA each year, the benefit-cost ratio for supplementing vitamin E to all fed steers/heifers would be 8.5:1 (based upon: benefit, $672.7 million; cost, $79.5 million). The American Meat Institute (1993) reported that the University of Wisconsin studies revealed that "the extended color shelf-life for beef (from cattle fed increased levels of vitamin E during the finishing period) indicated savings to the retailer of $156 per 454 kg of meat". Presuming that a 522 kg live steer would yield 175 kg of retail cuts, the beef from each vitamin E-supplemented steer would be worth $60.07 more to the retailer, because fewer mark-downs would be necessary (Smith *et al.*, 1993).

In a study by Colorado State University, with a cattle feeder in Ainsworth, Nebraska, supplementation to steers and heifers for 100 days at 500 IU per day cost $1.43 per head per day but the cattle feeder claimed that half the expense ($0.70-0.75 per head per day) was recovered via enhanced immune response and better health of the cattle (Morgan *et al.*, 1993). In the Strategic Alliance Field Study, conducted by Colorado State University for the National Cattlemen's Association, the beef from each vitamin E supplemented steer with worth $20.29 more to the retailer (Safeway Stores) because fewer mark-downs were necessitated at standard 'sell-by' times (Lambert, 1993; Sanders *et al.*, 1993). At a cost of $1.50 per steer to add supplemental vitamin E to the diet, the benefit-cost ratio in the Strategic Alliance Field Study was 13.5:1.

The primary obstacle to getting the vitamin E-supplementation technology into cattle feedyards is that the retailer is the primary benefactor while the cattle feeder bears the cost of adding the vitamin E to the feed. In response to a query regarding which sector of the beef production system should 'pay for' the cost of feeding vitamin E to feedlot cattle, the three Strategic Alliance Field Study economists (from Cattle Fax, Kansas State University and National Cattlemen's Association) said "Let the marketplace sort out the pass-through of such savings" (Smith *et al.* 1993).

10. Conclusion

Research studies and field trials have demonstrated that feeding of supplemental vitamin E has positive and desirable effects on beef quality and shelf-life. The feeding of supplemental vitamin E to steers and heifers while they are being 'finished' in the feedyard and the effect of such practice on retail case-life of beef is the most exciting application of science and technology in the US red-meat industry in the past 20 years (Smith *et al.*, 1993). The US beef industry simply cannot ignore the $20.29-60.07 improvement in value of the retail cuts from a single steer/heifer carcass that results from a expenditure of $1.43-3.00 per animal to add vitamin E to the diet (Smith *et al.*, 1993).

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