Effect of Long- or Short-Term Feeding of α-Tocopheryl Acetate to Holstein and Crossbred Beef Steers on Performance, Carcass Characteristics, and Beef Color Stability[1]

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ABSTRACT: Three experiments were conducted to examine the effects of vitamin E supplementation on feedlot cattle. Vitamin E supplementation did not affect feedlot performance or carcass characteristics of cattle fed a high-concentrate diet ($P > .1$). The major finding was the effectiveness of vitamin E in extending the color stability of displayed beef ($P < .01$). Color stability during display of longissimus lumborum steaks from cattle supplemented with 300 IU/d for 266 d, 1,140 IU/d for 67 d, or 1,200 IU/d for 38 d was extended by 2.5 to 4.8 d. Gluteus medius steaks had an extended color display life of 1.6 to 3.8 d. The accumulation of lipid oxidation products, but not aerobic microbes, associated with displayed longissimus lumborum was suppressed for muscle from vitamin E-supplemented steers. Taste panelists detected no difference among longissimus lumborum steaks from control and vitamin E-supplemented steers but found ($P < .01$) steaks aged for 21 d to be more tender than steaks aged for 7 d. Supplementing cattle with vitamin E should reduce economic losses associated with discolored beef during retail display.

Key Words: Vitamin E, Cattle, Beef, Meat Color, Optical Properties

J. Anim. Sci. 1992. 70:3055–3065

Introduction

The initial hypothesis of this research was that dietary supplementation of vitamin E would protect ruminal epithelium against the ulcerative action of ruminal contents in cattle fed high-concentrate diets. One of the primary functions of vitamin E is to maintain and protect biological membranes from oxidative damage (Rice and Kennedy, 1988).

Faustman and Cassens (1991) reported that longissimus lumborum (LL) and gluteus medius (GM) muscles from Holstein steers had less color stability than the same muscles from yearling crossbred beef steers. A bright cherry red color is important in retail sales of fresh beef (Hood and Riordan, 1973). The undesirable brown color that develops during retail display is due to the oxidation of deoxymyoglobin to metmyoglobin (Faustman and Cassens, 1990). We hypothesized that supplemental dietary vitamin E would cause accumulation of α-tocopherol in muscle and that this antioxidant would delay the oxidation of deoxymyoglobin to metmyoglobin. Oral supplementation of vitamin E has been effective in reducing lipid oxidation in meat from poultry (Marusich et al., 1975; Bartov et al., 1983) and swine (Tsai et al., 1978; Buckley et al., 1989).

The purposes of three experiments reported here were to determine whether vitamin E supplementation is effective in Holstein steers for improving feedlot performance, carcass characteristics, and meat color stability during display.

[1]This research was generously supported by Hoffmann-La Roche Inc., Nutley, NJ; The Wisconsin Beef Council, Madison, WI; Oscar Mayer Foods Inc., Madison, WI; Packerland Packing Co., Green Bay, WI; IMC-Pitman-Moore, Terre Haute, IN, and the Univ. of Wisconsin, College of Agric. and Life Sci. The conscientious technical assistance of Max Lainberger and Jo Marriner Hermberg is deeply appreciated.

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Received December 12, 1991.

Accepted May 22, 1992.

Although the primary focus was on Holstein steers, one experiment was conducted with crossbred beef steers.

Materials and Methods

Experiment 1

Holstein steer calves were purchased from a commercial source and were received 2 wk before the initiation of this experiment. The factorial arrangement of treatments consisted of two levels of vitamin E supplementation and three designated slaughter weights. A total of 108 steers were stratified into three initial weight blocks with light weight, medium weight, and heavy weight steers averaging 99, 110, and 122 kg, respectively. Groups of six steers from each weight block were assigned randomly to each level of vitamin E supplementation by slaughter weight treatment combination. The groups of six steers were then assigned randomly to bedded pens inside a confinement barn. Vitamin E treatments consisted of either 0 (E0) or 500 (E500) IU/d of supplemental vitamin E provided as a liquid containing DL-α-tocopheryl acetate (Rovimix E-40% Dispersible Liquid Concentrate, Hoffmann-La Roche, Nutley, NJ) blended with ground corn and fed at approximately 1.4% of the diet. The vitamin E premix was formulated to provide a diet concentration of 110 IU/kg of DM for pens of steers that averaged < 227 kg of body weight and 70 IU/kg for pens of steers averaging ≥ 227 kg. Steers were fed to appetite once daily (DM basis) 10% corn silage, 67% (up to 227 kg) or 77% high-moisture corn, 17.3% (up to 227 kg) or 8.8% soybean meal, and the remainder as vitamin, mineral, and lasalocid premixes. Diet samples were collected weekly and composited every 2 wk for analysis of protein, mineral, and vitamin E concentrations. At the initiation of the experiment all steers were implanted with 36 mg of zeranol (Ralgro, IMC-Pitman-Moore, Terre Haute, IN). All cattle were weighed at 28-d intervals. One steer in each pen was selected randomly and a blood plasma sample was obtained via venipuncture on d 221 of the experiment. Designated slaughter weights were 454, 499, and 544 kg. A pen of cattle was slaughtered at a commercial packing plant when the average weight was within 5 kg of the target slaughter weight. Steers were approximately 12 to 14 mo of age at slaughter. After slaughter, livers were scored for abscesses, the ruminal wall was scored by a single evaluator for ulcerated papillae, and carcass measurements were obtained.

A portion of left strip loin was obtained from each steer on the day after slaughter and used for meat quality evaluation. Each strip loin was vacuum-packaged and aged at 4°C for 6 d (all steers) or 20 d (499 and 544 kg slaughter weight steers). After 7 d of postmortem aging, a sample of LL was saved for vitamin E analysis from the one steer per pen from which a blood plasma sample was obtained. After aging, 2.6-cm-thick LL steaks were over-wrapped with oxygen-permeable fresh meat film and displayed under simulated retail conditions (2.5 to 5°C with 1,900 to 2,600 lx of continuous, cool-white fluorescent illumination). Steaks were placed randomly under this range of illumination intensities. Beef color characteristics were evaluated by a single person for all animals and a panel of 2 to 10 persons for steers in the 544-kg slaughter weight group. For panel evaluations, coded identity of the steaks was changed daily. Visual evaluations included estimating the percentage of LL surface area that was discolored, scoring the steaks on an 8-point scale (Ray et al., 1977) for pigment intensity, determining the day that a steak started to discolor, and assessing the day on which discoloration made the steak unacceptable for consumption.

Longissimus lumborum steaks (2.6 cm thick) from 25 Choice carcasses from each vitamin E treatment group were used for taste panel and Warner-Bratzler shear force evaluations. Steaks were vacuum-packaged and frozen immediately after being aged at 4°C. Just before the taste panel evaluation, steaks were thawed for 12 to 24 h at 4°C and oven-broiled under thermocouple control to an internal temperature of 72°C. A taste panel sitting consisted of five people, each of whom evaluated four 1.27-cm-diameter cores obtained from E0 or E500 steaks aged 7 or 21 d. One additional steak from each steer × aging treatment was also cooked in a similar manner and used in the Warner-Bratzler shear force evaluation. Steaks were cored parallel to muscle fiber orientation. Eight 1.27-cm-diameter core samples were obtained from each steak and cooled for 2 h at 22°C before shearing. The highest and lowest values were discarded to reduce skewness contributed by atypical samples (e.g., connective tissue) before calculating the average shear force value for each steer (n = 6).

Results were analyzed by analysis of variance using the GLM procedure of SAS (1985). Class variables were levels of vitamin E treatment and slaughter weight. For those variables that were measured over time, a split-plot analysis was performed to account for repeated measurements. The Scheffe multiple-range test (Snedecor and Cochran, 1980) was used to determine differences between slaughter weight means.

Experiment 2

Eight crossbred beef steers (n = 4 animals per treatment) of Angus, Hereford, and Simmental breeding were fed either no supplemental (B0)

vitamin E or approximately 2,000 IU per steer daily (**B2000**) for 67 d. Steers were from the university herd and averaged 386 kg at the start of the experiment. As in Exp. 1, the vitamin E source was Rovimix E-40% Dispersible Liquid Concentrate and was incorporated into ground corn that composed 1.45% of the diet. Control steers received the same amount of liquid carrier that contained no vitamin E. Steers were fed a diet containing (DM basis) 10% corn silage, 77% high-moisture corn grain, 7.7% soybean meal; the remaining 3.85% consisted of vitamin, mineral, and lasalocid premixes. The diet was formulated to contain .1 ppm of selenium. Steers were slaughtered at 12 to 13 mo of age.

Blood plasma samples were collected 1 d before slaughter. Samples of liver, kidney, and perirenal fat were collected at slaughter for analysis of α-tocopherol. Loin and sirloin cuts were vacuum-packaged and stored at 4°C for 7 d postmortem. Samples of LL, GM, and subcutaneous fat were obtained for determination of α-tocopherol concentration.

Cores of meat (12 cm^2 × .8 cm thick, 10 g) from LL and lateral GM muscles were displayed under simulated retail conditions as in Exp. 1 for 21 d. The percentage of metmyoglobin on the surface of LL and GM cores was determined by reflectance spectrophotometry (Stewart et al., 1965; Arnold et al., 1992). A thiobarbituric acid procedure modified from that described by Bidlack et al. (1973) was used to determine the development of lipid oxidation products in cores (12 cm^2 × .8 cm thick) of LL. Ten grams of meat was blended with 50 mL of chilled, distilled water and 50 mL of 20% trichloroacetic acid. After centrifugation (10,000 × *g*, 20 min, 4°C) and filtration, 1.5 mL of filtrate was reacted with 1.5 mL of .02 *M* thiobarbituric acid solution. The reaction mixture was heated for 20 min in 100°C bath, cooled, and assayed at 538 nm. Tetraethoxypropane was the standard. The pH of LL was determined for cores displayed for 2 d. Ten grams of meat was homogenized in a stomacher (Tekmar, Cincinnati, OH) in a 5 m*M* sodium iodoacetate: .15 *M* KCl solution before pH measurement with a glass electrode (Takahashi et al., 1984). Wholesomeness of LL samples was evaluated by enumerating total aerobic microbial population present on the meat (Messer et al., 1984). After homogenizing 10 g of meat in a stomacher, triplicate plates of appropriate dilutions were incubated for 2 to 4 d at 22°C and then counted. Ether extract content of LL was measured in triplicate by Soxhlet extraction of dried (60°C) LL with ethyl ether for 48 h.

Treatments were compared by analysis of variance using the GLM procedure of SAS (1985). For comparisons pertaining to muscle or measurements over time, a split-plot analysis was conducted to account for repeated measurements. Vitamin E treatment was the main plot, muscle the first subplot, and day of display the second subplot. Time required for discoloration to occur on steak surfaces was determined from the surface percentages of metmyoglobin using the days to threshold approach (Arnold et al., 1992). A series of four threshold levels of metmyoglobin percentages (i.e., 10, 12, 15, and 20%) were assumed to be the required levels of discoloration. The lowest threshold level that provided differences ($P < .07$) in days until discoloration both between levels of vitamin E supplementation and between muscles was accepted as the discoloration threshold.

Experiment 3

Ten Holstein steers (n = 5 animals per treatment) were fed no supplemental vitamin E (**H0**) or approximately 2,000 IU per steer daily (**H2000**) for 38 d. Average weight of steers at the start of the experiment was 620 kg. The same procedures described for Exp. 2 were followed. Steers were approximately 18 to 24 mo of age at slaughter.

Vitamin E analyses of samples from all three experiments were conducted in duplicate using an HPLC procedure described previously (Faustman et al., 1989b). The series of threshold values evaluated included 20, 22, 24, and 27% metmyoglobin.

Results and Discussion

Experiment 1

Vitamin E intake averaged 74 IU/d for E0 and 375 IU/d for E500 over the last 100 d of the experiment (Figure 1). Thus, vitamin E consumption for E500 steers was approximately 300 IU/d greater than that for E0 steers. Vitamin E consumed by E0 steers was due to naturally occurring α-tocopherol in the basal diet. The average dietary concentration of vitamin E for E0 was 9 IU/kg. Average dietary concentration of vitamin E for steers fed to 277 kg was 96 IU/kg and 54 IU/kg for steers weighing > 227 kg. Dietary crude protein averaged 14.8 and 11.4% for cattle weighing < 227 kg and > 227 kg, respectively. Average dietary concentrations were .08 ppm for selenium, .52% for calcium, .35% for phosphorus, and .66% for potassium. The achieved dietary levels of protein and minerals are considered to be adequate dietary concentrations (NRC, 1984).

Vitamin E supplementation did not affect ($P >$ .1) feedlot performance or carcass characteristics (Table 1). Two pens of steers were excluded from

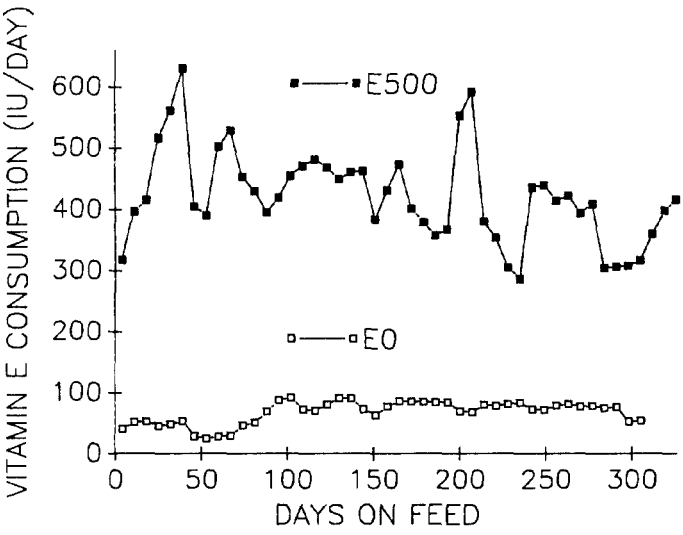

Figure 1. Average vitamin E intake per steer (Exp. 1). E0 = 0 IU/d of supplemental vitamin E; E500 = 300 IU/d of actual supplemental vitamin E.

analysis of feedlot performance data and one pen from the analysis of carcass characteristics because the vitamin E supplementation was mistakenly switched between these two pens for 25 d. The E0 pen fed the E500 diet was removed from the experiment. The E500 pen that received the E0 diet was fed the correct diet for 107 d before slaughter and the meat color response for this pen was similar to that for other pens that received supplemental vitamin E. The lack of a vitamin E response for feedlot performance implies that the nutritional requirement of Holstein steers in this trial was met by 74 IU/d of vitamin E. However, Hill (1987) and Hill et al. (1989) have suggested enhanced feedlot performance by steers fed supplemental vitamin E.

Average daily gain was not affected ($P > .1$) by slaughter weight, but feed conversion efficiency declined ($P < .05$) as slaughter weight increased (Table 1). Steers killed at heavier slaughter weights usually had greater indications of fatness than those killed at lighter slaughter weights. However, carcass characteristics were not consistently different among slaughter weights. Subcutaneous fat thickness did not differ ($P > .1$) among slaughter weights, but marbling score and kidney, pelvic, and heart fat differed ($P < .05$). Heavier steers had higher ($P < .01$) dressing percentages and produced heavier ($P < .01$) carcasses with higher ($P < .05$) quality grades and larger ($P < .01$) longissimus muscle areas. Feedlot performance results obtained here would be useful in an economic model to determine optimum slaughter weight. The highly favorable rate and

Table 1. Effect of vitamin E supplementation and slaughter weight on feedlot performance and carcass characteristics of Holstein steers (Exp. 1)

Item	Vitamin E treatment[a]		Slaughter wt, kg			SE
	E0	E500	454	499	544	
	Feedlot performance[e]					
Days on feed	265.0	266.0	231.0[f]	266.0[g]	309.0[h]	11.0
DMI, kg/d	6.6	6.6	6.4[f]	6.6[g]	6.8[h]	.1
ADG, kg	1.4	1.4	1.5	1.5	1.4	.1
ADG/DMI	.22	.22	.23[i]	.22[j]	.21[k]	.01
Final wt, kg	497.0	497.0	451.0[f]	498.0[g]	542.0[h]	2.0
	Carcass characteristics[1]					
Hot carcass wt, kg	290.0	289.0	258.0[f]	291.0[g]	319.0[h]	3.0
Dressing percentage	58.2	58.1	57.2[f]	58.5[g]	58.8[g]	.5
Marbling score[b]	11.8	11.8	10.5[i]	12.0[ij]	13.0[j]	1.2
Quality grade[c]	13.3	13.2	12.8[i]	13.3[ij]	13.7[j]	.4
Fat, cm	.52	.54	.45	.54	.59	.1
KPH[d], %	3.2	3.2	3.0[f]	3.1[f]	3.5[g]	.1
Longissimus muscle area, cm^2	70.5	70.3	67.5[f]	69.6[f]	74.1[g]	1.9
Yield grade	2.6	2.6	2.4[f]	2.6[g]	2.8[h]	.2

[a]E0 = 0 IU/d of supplemental vitamin E; E500 = 300 IU/d of actual supplemental vitamin E.
[b]10 = Small minus, 11 = Small average, 12 = Small plus, and 13 = Modest minus.
[c]12 = Select plus, 13 = Choice minus, and 14 = Choice average.
[d]KPH = kidney, pelvic, and heart fat.
[e]Total of 16 pens because two pens were incorrectly fed vitamin E treatments for 25 d.
[f,g,h]Means within a row, for a factor, lacking a common superscript letter differ ($P < .01$).
[i,j,k]Means within a row, for a factor, lacking a common superscript letter differ ($P < .05$).
[1]Total of 17 pens used because E500 diet was misfed to an E0 pen from d 69 to d 44 before slaughter.

Table 2. Ruminal papillae characteristics of Holstein steers fed two levels of vitamin E (Exp. 1)

	Vitamin E treatment[a]		
Location[b]	E0	E500	SE
Anterior sac	2.4	2.6	.1
Ventral sac	2.3[c]	1.9[d]	.1
Ventral-left side	1.6	1.6	.1
Ventral-right side	1.9	1.9	.1

[a]E0 = 0 IU/d of supplemental vitamin E; E500 = 300 IU/d of actual supplemental vitamin E.
[b]1 = flat, non-clumping papillae of uniform length and spacing, 2 = one ulcerated papillae per 100 cm^2, 3 = two or three ulcerated papillae per 100 cm^2.
[c,d]Means within a row lacking a common superscript letter differ ($P < .05$).

efficiency of weight gain for steers slaughtered at 544 kg suggest that this end point may be economically advantageous under current industry conditions (Schaefer et al., 1989).

Liver abscesses were not prevalent. Only two livers from the 105 steers that completed the study were condemned due to an abscess, and two livers were condemned due to unacceptable appearance to federal inspectors. Although antibiotics associated with liver abscess control were not used in this study, liver abscesses were not a problem. Ulcerated ruminal papillae (Table 2) occurred infrequently in the steers. Vitamin E supplementation decreased ($P < .05$) the number of ulcers in the ventral sac of the rumen but had no effect ($P > .1$) in the anterior sac, ventral-left side, and ventral-right side locations of the rumen.

Vitamin E supplementation delayed ($P < .01$) the discoloration of displayed LL steaks (Figure 2a) as determined by a panel of evaluators for the 34 steers slaughtered at 544 kg. Color score (Figure 2b) was not affected ($P > .1$) by vitamin E supplementation. Panelists indicated that steaks from the E500 steers were acceptable for a longer ($P < .01$) period of time (7.4 d) than were steaks from the E0 steers (4.9 d). As determined by a single evaluator, all steers fed supplemental vitamin E regardless of slaughter weight also discolored more slowly ($P < .01$). For steaks aged 7 d, time to first discoloration averaged 4.5 d (n = 46) for E0 steers and 8.6 d (n = 52) for E500 steers. For steaks aged 21 d, time to first discoloration averaged 2.8 d (n = 28) for E0 steers and 4.4 d (n = 28) for E500 steers. Results for color stability of sirloin steaks and pigment and lipid stability in ground sirloin from steers in this experiment were reported previously (Faustman et al., 1989a,b). Hunter "a" values were maintained and extractable metmyoglobin was suppressed for a longer period of time for steers supplemented with vitamin E than for control steers. Vitamin E supplementation also delayed lipid oxidation.

Vitamin E supplementation did not alter ($P > .1$) LL steak tenderness, juiciness, meat-flavor intensity, or off-flavor intensity as determined by taste panel evaluation or shear force measurement (Table 3). Tenderness and shear force were the only factors affected ($P < .01$) by aging.

Average α-tocopherol concentration in LL from one steer per pen was .9 μg/g of fresh weight for E0 but increased ($P < .01$) to 3.8 μg/g of fresh weight for steers on the E500 treatment. However, plasma α-tocopherol concentrations did not differ ($P > .1$) due to vitamin E supplementation (E0, 2.2

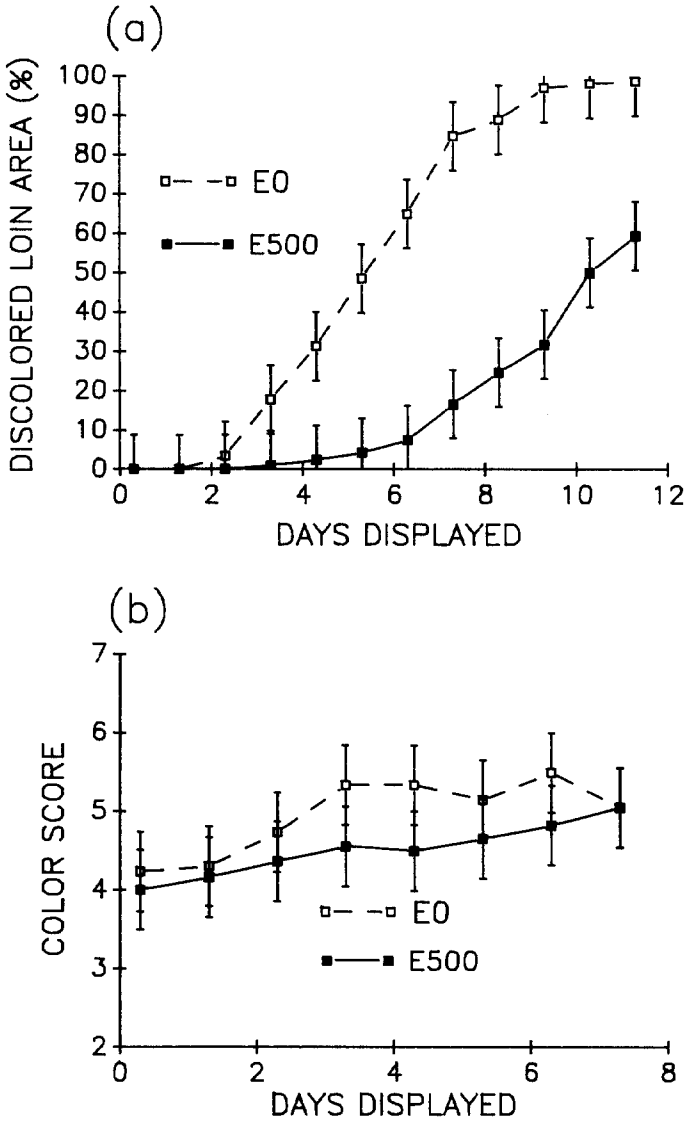

Figure 2. Effect of level of vitamin E supplementation on area of discoloration (a) and color score (b) of longissimus lumborum (loin) steaks (n = 34 steers from Exp. 1). Color scores were associated with the following descriptive terms: 3 = moderately light cherry red, 4 = cherry red, 5 = slightly dark red, and 6 = moderately dark red. E0 = 0 IU/d of supplemental vitamin E; E500 = 300 IU/d of actual supplemental vitamin E.

Table 3. Taste panel evaluation of longissimus lumborum steaks aged for 7 or 21 days from Holstein steers fed two levels of vitamin E (Exp. 1)[a]

	Vitamin E treatment			Aging period, d		
Characteristic	E0	E500	SE	7	21	SE
Tenderness[b]	5.8	5.7	.2	5.6[d]	5.9[e]	.07
Juiciness[b]	5.4	5.4	.1	5.4	5.4	.06
Meat flavor[b]	5.6	5.6	.07	5.6	5.7	.03
Off-flavor[c]	7.6	7.6	.05	7.7	7.5	.02
Shear force, kg	2.8	2.6	.1	2.9[d]	2.5[e]	.05

[a]25 steers per vitamin E per aging period mean. E0 = 0 IU/d of supplemental vitamin E; E500 = 300 IU/d of actual supplemental vitamin E.
[b]Eight-point hedonic scale: 5 = slight, 6 = moderate.
[c]Eight-point hedonic scale: 7 = weak, 8 = absent.
[d,e]Means within a row, for a factor, lacking a common superscript letter differ ($P < .01$).

μg/mL; E500, 2.9 μg/mL). This result seems to be spurious in view of other research results (Hidiroglou et al., 1988). The number of days required before LL steaks started to discolor was positively correlated with α-tocopherol concentration in the LL (Figure 3). With a quadratic fit, LL α-tocopherol content accounted for 76% of the variation in days to first evidence of discoloration. Average days to first discoloration was less ($P < .01$) for E0 (4.2 d; n = 8) than for E500 (9.5 d; n = 9). In ground sirloin (Faustman et al., 1989b), muscle α-tocopherol content greater than approximately 3 μg/g (fresh weight basis) was sufficient to retard myoglobin and lipid oxidation.

Table 4. Effects of vitamin E supplementation on feedlot performance and carcass characteristics of crossbred beef steers (Exp. 2)

	Vitamin E treatment[a]		
Characteristic	B0	B2000	SE
DMI, kg/d	8.1	8.0	.3
ADG, kg	1.4	1.4	.1
ADG/DMI	.17	.18	.01
Final wt, kg	486	487	18
Hot carcass wt, kg	288	278	11
Dressing percentage	59.1[e]	57.1[f]	.4
Marbling score[b]	8.5	8.2	2.0
Quality grade[c]	11.5	10.8	1.4
Fat, cm	1.08	.73	.19
KPH[d], %	2.6	2.8	.2
Longissimus muscle area, cm^2	86.5	80.0	2.4
Yield grade	2.2	2.1	.3

[a]B0 = 0 IU/d of supplemental vitamin E; B2000 = 1,140 IU/d of actual supplemental vitamin E.
[b]8 = Slight average and 9 = Slight plus.
[c]10 = Select minus, 11 = Select average, and 12 = Select plus.
[d]KPH = kidney, pelvic, and heart fat.
[e,f]Means within a row lacking a common superscript letter differ ($P < .05$).

Experiment 2

Vitamin E intake averaged 126 IU/d for B0 and 1,266 IU/d for B2000 (Figure 4) over the 67 d of this experiment. Feedlot performance and most carcass characteristics were not affected ($P > .1$) by vitamin E treatments (Table 4). The short length of this experiment and the small number of animals limited the ability to detect treatment effects on these traits. Dressing percentage was the only measured trait that differed ($P < .05$) between vitamin E treatment groups and was lower for B2000 than for B0.

Metmyoglobin formation on the surface of LL from beef steers (Figure 5a) fed no supplemental vitamin E rapidly increased after approximately 8 d of retail display, whereas a delayed and slower increase occurred for B2000 steers ($P < .05$).

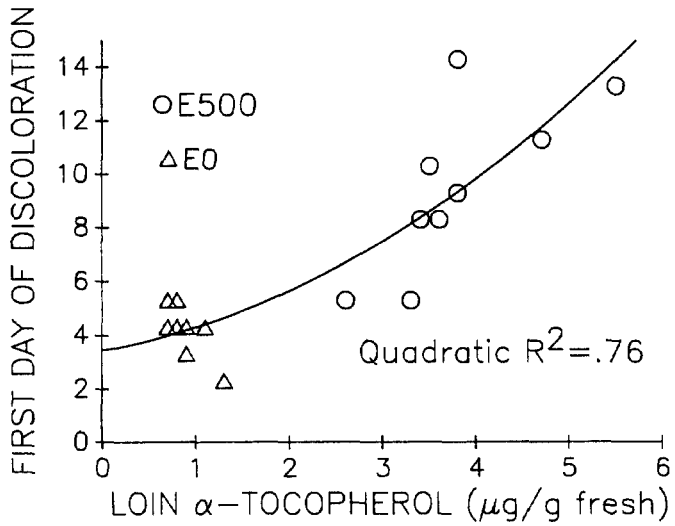

Figure 3. Relationship between longissimus lumborum (loin) α-tocopherol content and 1st d of discoloration for longissimus lumborum steaks (n = 17 steers from Exp. 1). E0 = 0 IU/d of supplemental vitamin E; E500 = 300 IU/d of actual supplemental vitamin E.

Metmyoglobin formation on GM from supplemented steers also occurred more slowly and was delayed ($P < .05$) relative to control beef steers. Metmyoglobin formation occurred more rapidly ($P < .01$) on GM than on LL. At a threshold of 15% metmyoglobin, B0 LL discolored in 10.5 d, whereas B2000 LL discolored in 13 d; thus, B2000 caused a color display stability extension of 2.5 d. Gluteus medius from B0 steers discolored in 4.2 d and B2000 GM discolored within 8.0 d; thus, the display stability extension was 3.8 d for GM.

A marked increase in lipid oxidation occurred after 6 d of simulated retail display in LL of beef steers (Figure 5b) that were not fed supplemental vitamin E, whereas LL from B2000 steers exhibited only a small increase in the amount of lipid oxidation during 18 d of display ($P < .05$).

Longissimus lumborum pH averaged 5.4 and was not affected ($P > .1$) by vitamin E supplementation. Ether extract (EE) and moisture contents of LL were similar ($P > .1$) between B0 (EE 4.3%, water 72.4%) and B2000 (EE 3.5%, water 72.5%).

Feeding supplemental vitamin E did not affect ($P > .1$) microbial growth on the displayed LL (Figure 6). Microbial populations were lowest on d 1 and 5 of retail display. By d 9 the population reached 5.2 to 6.2 log (colony-forming units per gram of fresh LL). A microbial population > 8 log (colony-forming units per gram of tissue) would probably produce off-flavors in meat (Walker, 1980). Flavor would be of more concern than pathogenicity at this microbial population density because cooking kills most microorganisms.

Steers supplemented with vitamin E had greater ($P < .01$) α-tocopherol concentrations in liver, kidney, perirenal fat, subcutaneous fat, plasma, GM, and LL than did unsupplemented steers (Table 5). When all tissues were combined in a single statistical analysis for B2000 steers, concentrations of α-tocopherol in liver were greater ($P < .05$) than those in other tissues measured, and α-tocopherol concentrations were similar among other tissues sampled.

Experiment 3

Vitamin E intake averaged 113 IU/d for H0 and 1,317 IU/d for H2000 over the 38-d experiment (Figure 7). Feedlot performance and carcass

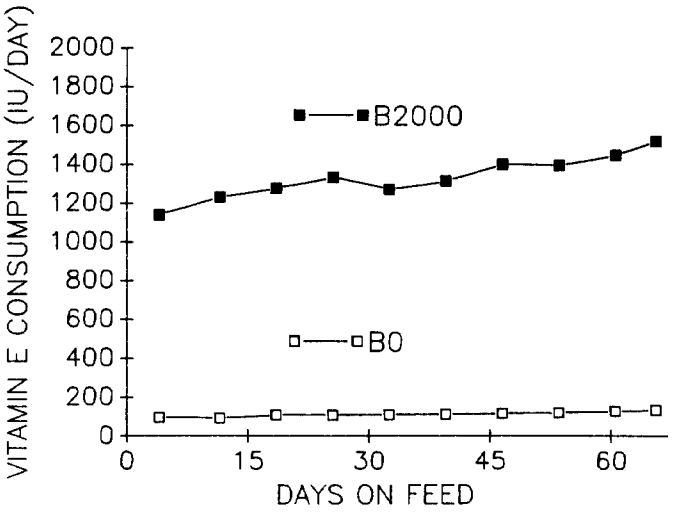

Figure 4. Average vitamin E intake per steer (Exp. 2). B0 = 0 IU/d of supplemental vitamin E; B2000 = 1,140 IU/d of actual supplemental vitamin E.

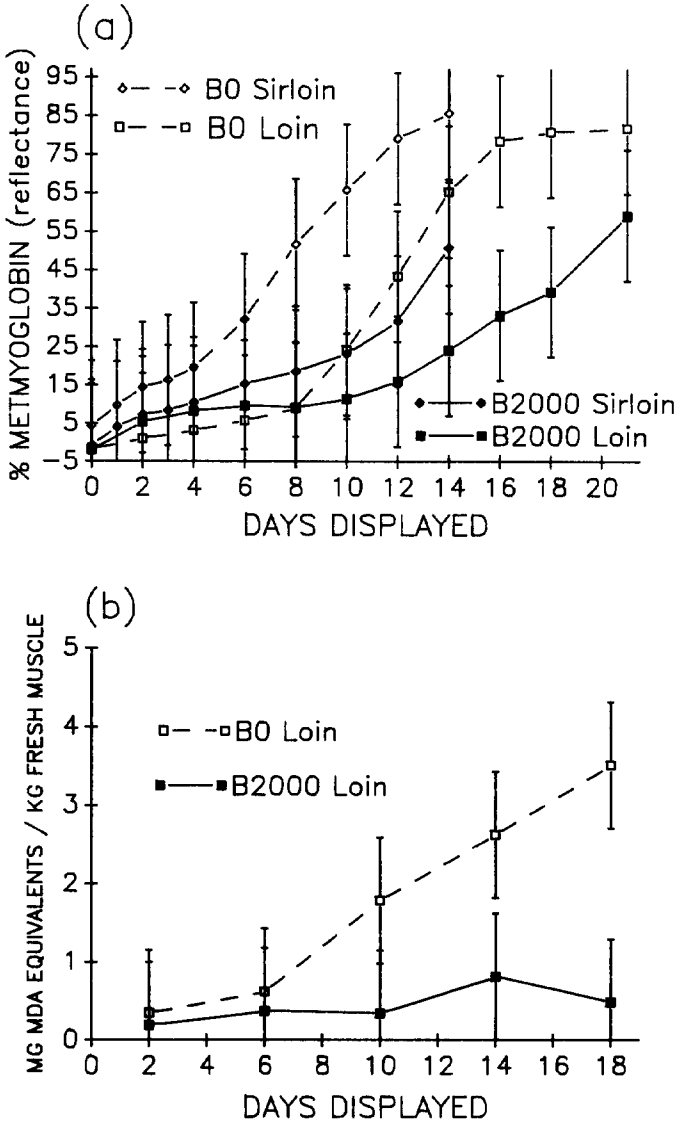

Figure 5. Effect of level of vitamin E supplementation on metmyoglobin formation (a) and lipid oxidation expressed as malonaldehyde (MDA) equivalents (b) in longissimus lumborum (loin) and gluteus medius (sirloin) muscles (Exp. 2). B0 = 0 IU/d of supplemental vitamin E; B2000 = 1,140 IU/d of actual supplemental vitamin E.

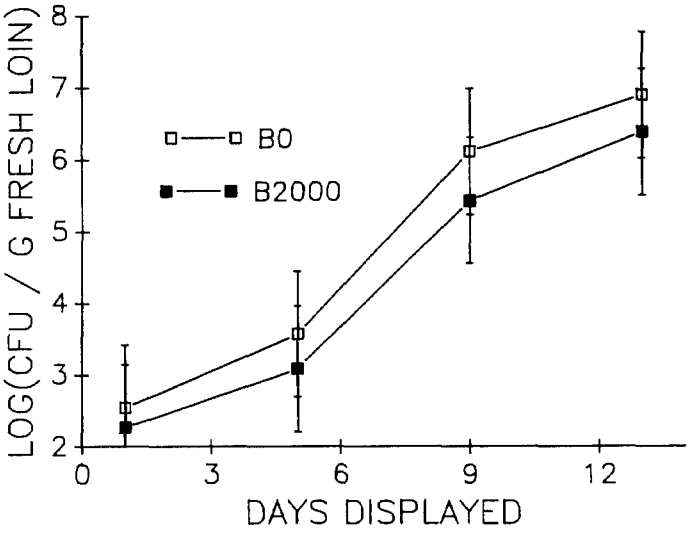

Figure 6. Effect of level of vitamin E supplementation (Exp. 2) on microbial growth on longissimus lumborum (loin). B0 = 0 IU/d of supplemental vitamin E; B2000 = 1,140 IU/d of actual supplemental vitamin E.

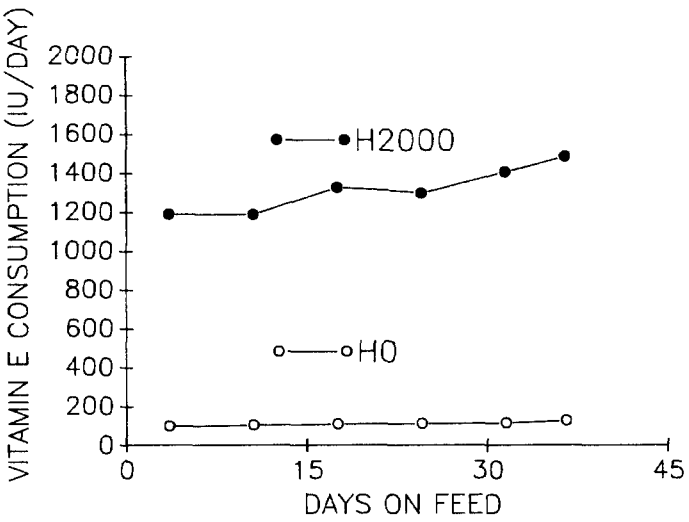

Figure 7. Average vitamin E intake per steer (Exp. 3). H0 = 0 IU/d of supplemental vitamin E; H2000 = 1,200 IU/d of actual supplemental vitamin E.

characteristics were not affected by vitamin E supplementation (Table 6). However, dressing percentage tended to be lower ($P < .1$) for the vitamin E-supplemented steers. Although dressing percentage was lower in the vitamin E-supplemented steers on Exp. 2 and 3, dressing percentage was not affected in Exp. 1. Difference in response could be due to greater dosage of vitamin E fed in Exp. 2 and 3, but these experiments were of short duration and dressing percentage could be subject to factors other than vitamin E treatment. Results from the three experiments consistently indicated that vitamin E supplementation under conditions and levels fed in these studies had no effect on feedlot performance and carcass characteristics.

Vitamin E supplementation decreased ($P < .01$) metmyoglobin formation. Metmyoglobin formation (Figure 8a) on LL occurred rapidly after 4 to 6 d of display for H0 but was slowed and delayed for H2000. Metmyoglobin formation occurred rapidly after d 4 on GM from nonsupplemented Holstein steers but was slowed and delayed for the steers fed supplemental vitamin E. Gluteus medius discolored more rapidly ($P < .01$) than did LL.

Table 5. Effect of vitamin E supplementation on α-tocopherol concentration in tissues (Exp. 2)[a]

Tissue	Vitamin E treatment B0	Vitamin E treatment B2000	SE
Plasma	3.0[b]	6.4[c]	.6
Longissimus	2.0[b]	6.2[c]	.5
Gluteus medius	2.4[b]	6.3[c]	.3
Subcutaneous fat	2.6[b]	9.0[c]	.8
Perirenal fat	3.4[b]	9.4[c]	.8
Kidney	3.4[b]	10.0[c]	.6
Liver	4.4[b]	23.8[c]	2.4

[a]Micrograms per gram of milliliter of fresh tissue. B0 = 0 IU/d of supplemental vitamin E; B2000 = 1,400 IU/d of actual supplemental vitamin E.
[b,c]Means within a row lacking a common superscript letter differ ($P < .01$).

Table 6. Effect of vitamin E supplementation on feedlot performance and carcass characteristics of Holstein steers (Exp. 3)

Characteristic	Vitamin E treatment[a] H0	Vitamin E treatment[a] H2000	SE
	— Feedlot performance —		
DMI, kg/d	8.1	7.8	.4
ADG, kg	1.2	1.4	.2
ADG/DMI	.15	.17	.02
Final wt, kg	657.0	648.0	7.0
	— Carcass characteristics —		
Hot carcass wt, kg	389.0	374.0	7.0
Dressing percentage	59.2[e]	57.7[f]	.5
Marbling score[b]	12.2	13.4	1.2
Quality grade[c]	13.6	13.6	.5
Fat, cm	.46	.58	.07
KPH[d], %	3.4	3.1	.1
Longissimus muscle area, cm^2	87.6	82.6	3.4
Yield grade	2.5	2.7	.1

[a]H0 = 0 IU/d of supplemental vitamin E; H2000 = 1,200 IU/d of actual supplemental vitamin E.
[b]12 = Small plus and 13 = Modest minus.
[c]13 = Choice minus and 14 = Choice average.
[d]KPH = kidney, pelvic, and heart fat.
[e,f]Means within a row lacking a common superscript letter differ ($P < .1$).

O'Keeffe and Hood (1982) reported that GM was more color-labile than was LL. At a threshold of 24% metmyoglobin, time required for LL discoloration was 7.2 d for H0 and 12.0 d for H2000. For GM, H0 discolored in an average of 6.0 d and averaged 7.6 d for H2000.

Vitamin E supplementation was effective in all three experiments in delaying meat discoloration. Supplementing an additional 300 IU/d for 266 d extended LL color display stability 2.5 d, 1,140 IU/d for 67 d extended LL color display stability 2.5 d, and 1,200 IU/d for 38 d extended color display stability 4.8 d. Methodology and animal differences preclude exact comparison between the three experiments. However, it seems that either long, low dosages or short, high dosages will extend color display stability of fresh beef cuts from these two muscles.

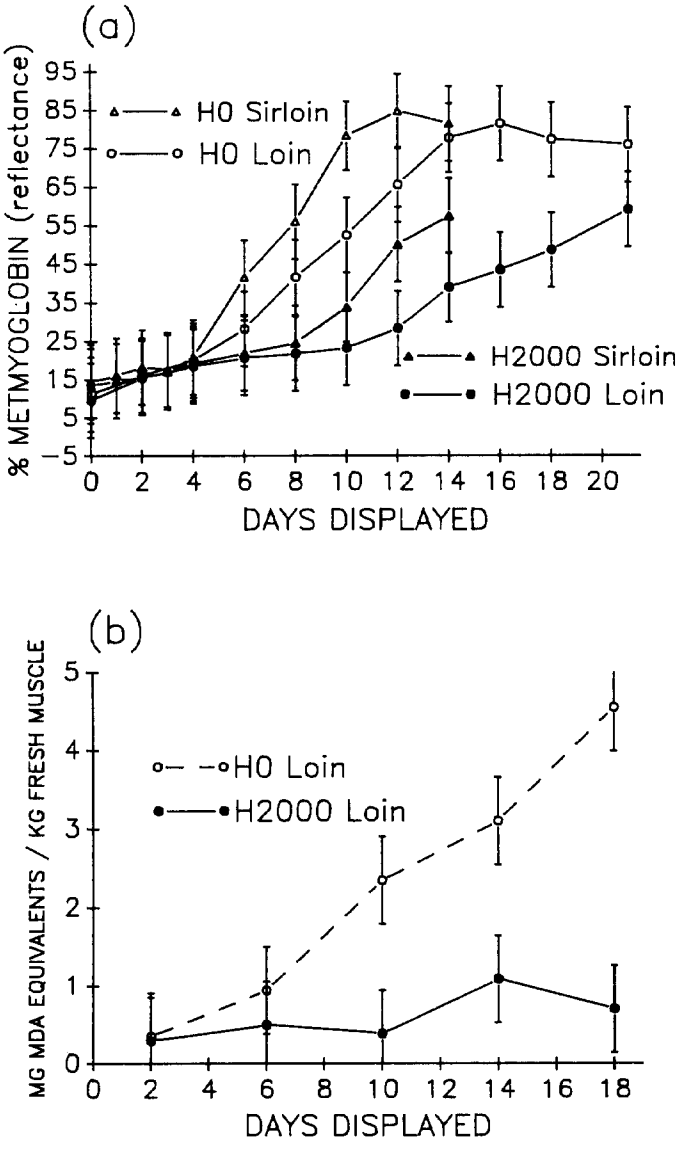

Figure 8. Effect of level of vitamin E supplementation on metmyoglobin formation (a) and lipid oxidation expressed as malonaldehyde (MDA) equivalents (b) in longissimus lumborum (loin) and gluteus medius (sirloin) muscles (Exp. 3). H0 = 0 IU/d of supplemental vitamin E; H2000 = 1,200 IU/d of actual supplemental vitamin E.

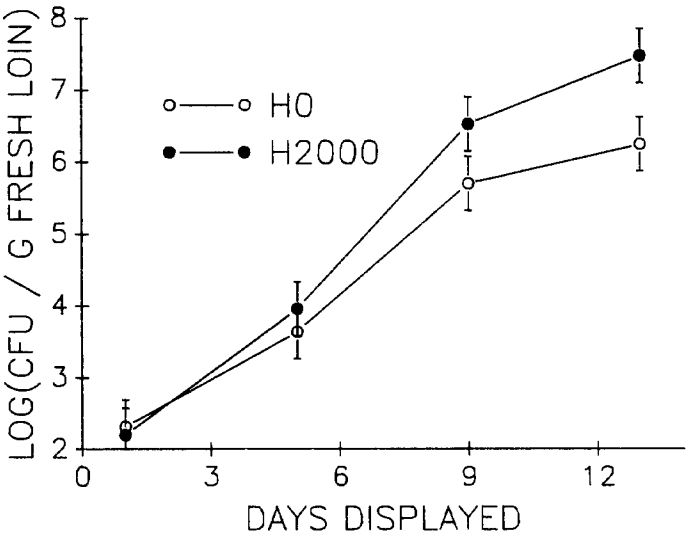

Figure 9. Effect of level of vitamin E supplementation (Exp. 3) on microbial growth on longissimus lumborum (loin). H0 = 0 IU/d of supplemental vitamin E; H2000 = 1,200 IU/d of actual supplemental vitamin E.

Similar to results in Exp. 2, vitamin E supplementation inhibited ($P < .01$) lipid oxidation in LL (Figure 8b). A marked increase in LL lipid oxidation occurred after 6 d of display for Holstein steers that were not fed supplemental vitamin E, whereas LL samples from steers fed 1,200 IU/d exhibited only a small increase in the amount of lipid oxidation during 18 d of display.

Feeding supplemental vitamin E did not affect microbial growth on displayed LL (Figure 9). The microbial population was small on d 1 and 5 of display. By d 9 the population reached 5.5 to 6.5 log (colony-forming units per gram of fresh LL). This is similar to results in Exp. 2.

Elevations in α-tocopherol concentrations for vitamin E-supplemented steers occurred in liver, kidney, plasma, LL (all $P < .01$), perirenal fat, subcutaneous fat, and GM (all $P < .05$) relative to respective tissues from nonsupplemented steers (Table 7). When all tissues were combined into a single analysis, liver had a greater ($P < .05$) α-tocopherol concentration than did other tissues, whereas the concentration in subcutaneous fat was greater than that in LL. Concentration of α-tocopherol was lower ($P < .01$) in tissues from Holstein steers in Exp. 3 than in tissues from crossbred beef steers in Exp. 2. This probably was due to a shorter supplementation period for the

Table 7. Effect of vitamin E supplementation on α-tocopherol concentration in tissues (Exp. 3)[a]

Tissue	Vitamin E treatment		SE
	H0	H2000	
Plasma	1.8[b]	4.5[c]	.4
Longissimus	2.2[b]	3.5[c]	.1
Gluteus medius	3.1[d]	4.8[e]	.3
Subcutaneous fat	3.4[d]	6.8[e]	.9
Perirenal fat	3.0[d]	5.3[e]	.7
Kidney	1.9[b]	6.9[c]	.4
Liver	3.7[b]	12.7[c]	.8

[a]Micrograms per gram or milliliter of fresh tissue. H0 = 0 IU/d of supplemental vitamin E; H2000 = 1,200 IU/d of actual supplemental vitamin E.
[b,c]Means within a row lacking a common superscript letter differ ($P < .01$).
[d,e]Means within a row lacking a common superscript letter differ ($P < .05$).

Holstein than for the beef steers, but the comparison is confounded by breed differences between studies. Plasma vitamin E concentrations from steers on both vitamin E treatments in Exp. 1 seemed to be similar to those of control steers in Exp. 2 and 3. It is not clear whether the lower dosage level in Exp. 1 is the reason for lack of treatment response. Alpha-tocopherol concentrations in LL from nonsupplemented steers in Exp. 1 were less than half the concentration in Exp. 2 and 3. Longissimus lumborum concentrations from supplemented steers in Exp. 1 and 3 seemed to be similar and lower than those in Exp. 2, which are at least consistent with dosage level and time.

The average LL pH was 5.4 and was not different ($P > .1$) between levels of vitamin E supplementation. The EE and moisture contents of LL were 4.7 and 71.8%, respectively, for H0, which were not different ($P > .1$) from 3.7 and 72.5%, respectively, for H2000. These results are consistent with those of Exp. 2. Lipid-soluble α-tocopherol was not present in higher concentrations in LL of vitamin E-supplemented steers because of greater concentrations of ether-extractable lipid in their LL muscles. Faustman et al. (1989b) drew a similar conclusion for α-tocopherol in GM. The hypothesis that α-tocopherol is assimilated into membrane lipids (Faustman et al., 1989b) is consistent with the above evidence.

These experiments provide initial evidence of the potential usefulness of providing cattle with supra-requirement levels of vitamin E to enhance the retail product. Although vitamin E supplementation did not seem to influence performance in the feedlot, it has potential to reduce the economic losses associated with discolored fresh beef in the retail counter. More detailed, larger-scale experiments need to be conducted to confirm and clarify the possible role that vitamin E supplementation may have in extending the color display stability of fresh beef.

Implications

Supplementing feedlot cattle, especially Holstein steers, with vitamin E extended the color display stability of fresh beef displayed under simulated retail conditions. This was accomplished whether an additional 300 IU/d was supplemented for 9 mo, 1,140 IU/d for 67 d, or 1,200 IU/d for 38 d. Lipid oxidation was also decreased due to vitamin E supplementation. Concentrations of α-tocopherol in tissues were lower in steers fed for 38 d than in those fed for 67 d. Microbial growth on fresh beef was not affected by vitamin E supplementation. Feedlot performance and carcass characteristics were not affected by vitamin E supplementation. The primary advantage of vitamin E supplementation to nonstressed feedlot cattle seemed to be enhancement of color stability of fresh beef.

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