Effect of Vitamin C Concentration and Co-Injection with Calcium Chloride on Beef Retail Display Color[1,2]

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ABSTRACT: The objectives of these experiments were to determine 1) the most effective vitamin C concentration to stabilize color of beef cuts during retail display and 2) the effect on color of incorporating vitamin C into a calcium chloride ($CaCl_2$) injection solution. Top round cuts (semimembranosus and adductor) were injected with 5% by weight of a 0, .25, .5, 1, 2, or 4% sodium ascorbate solution (Exp. 1) or a 0, .5, 1, or 1.5% sodium ascorbate solution (Exp. 2). In Exp. 1, vitamin C resulted in more ($P < .05$) stable lean color during 9°C display, and .5, 1, and 2% vitamin C were most ($P < .05$) effective. In Exp. 2, all concentrations of vitamin C maintained redder ($P < .05$) steaks after 3, 5, and 7 d of display than control steaks and had a lower ($P < .05$) percentage of surface discoloration after 5 and 7 d of display at 1°C. Experiment 3 used beef bottom round cuts (biceps femoris) to compare control, vitamin C- (1%), $CaCl_2$- (200 m*M*) and vitamin C + $CaCl_2$-treated steaks displayed at 1°C. Calcium chloride-treated steaks were more ($P < .05$) brown and had a higher ($P < .05$) percentage of surface discoloration on d 5 and 7 than control steaks, whereas steaks treated with vitamin C or vitamin C + $CaCl_2$ were more ($P < .05$) red and had lower ($P < .05$) discoloration on d 5 and 7 than control steaks. Vitamin C can be injected into beef subprimals to enhance lean color stability and extend retail display life. Vitamin C also can be used in combination with $CaCl_2$ to offset potential color deterioration, after 5 d of display, due to salt-induced oxidation.

Key Words: Beef, Calcium Chloride, Color, Injection, Vitamin C

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Introduction

Few would argue with the critical importance of lean color in consumer purchase decisions for fresh meat. It has been estimated that the U.S. beef industry could prevent $520 million in lost revenue annually from retail sales by improving lean color stability during retail display (NCA, 1993). Vitamin C has been used in various ways to enhance the lean color stability of meat during display (Hood, 1975; Okayama et al., 1987; Mitsumoto et al., 1991a,b).

Calcium chloride has been shown to effectively improve meat tenderness when infused prerigor or injected prerigor or postrigor (for review see Wheeler et al., 1994). The addition of calcium chloride has not affected lean color through 3 d of retail display (Wheeler et al., 1993; Diles et al., 1994) but has resulted in a tendency for greater discoloration after 5 d of retail display (Lansdell et al., 1995; Kerth et al., 1995). St. Angelo et al. (1991) combined calcium chloride and vitamin C to reduce oxidation induced by the calcium chloride. Therefore, a combination of vitamin C and calcium chloride might simultaneously enhance tenderness and color stability during retail display. Thus, the objectives of this work were to determine the appropriate concentration of vitamin C to inject for maximizing lean color stability and to determine the effect of vitamin C and calcium chloride injected separately and in combination on lean color stability during retail display.

Materials and Methods

Experiment 1

The Roman L. Hruska U.S. Meat Animal Research Center Animal Care and Use Committee approved the use and treatment of animals in these studies according to guidelines established by the USDA. Ten

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[2]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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19-mo-old crossbred heifers (culled for reproductive failure) out of either Hereford, Angus, or MARC III (1/4 Angus, 1/4 Hereford, 1/4 Red Poll, 1/4 Pinzgauer) dams and Brahman (3), Hereford (3), Boran (2), Angus (1), or Tuli (1) sires were fed a diet consisting of 70% corn, 25% corn silage, and 5% supplement (dry matter basis) for 2 wk. The heifers were slaughtered humanely and the carcasses were chilled at 0°C for 24 h.

The IMPS #169 top round (semimembranosus and adductor) from each side was removed at 24 h postmortem and divided into three equal sections to yield six sections per animal. The experiment was conducted as a split-plot design with vitamin C concentration as the whole-plot treatment and display time as the split-plot treatment (repeated measures). Six treatments were blocked by muscle section so that all treatments were represented in all sections. Treatments consisted of injecting (Koch model 12354, Kansas City, MO) a muscle section at 24 h postmortem with 5% by weight of .25, .5, 1, 2, or 4% sodium ascorbate solutions (Sigma, St. Louis, MO) and a non-injected control (0%). Sections were allowed to equilibrate for 5 min then were weighed, vacuum-packaged, and stored at 1°C until 15 d postmortem. Actual injection percentage was not measured but was assumed to be similar to that in Exp. 2 and 3 (6.8 to 7.9%) because the injector was set the same.

At 15 d postmortem, sections were unpackaged and cut into three 2-cm-thick steaks. The second steak was placed in a styrofoam tray, overwrapped with polyvinyl chloride film (O_2 transmission of 1,000 mL/645 cm^2), and displayed in simulated retail conditions at 9°C under 2,152 lx of ultralume fluorescent light (F40/30U, 30,000K; Philips Lighting, Roselle, IL) continuously for 5 d. The steaks were evaluated for percentage surface discoloration (1 = 0%, 2 = 1 to 19%, 3 = 20 to 39%, 4 = 40 to 59%, 5 = 60 to 79%, 6 = 80 to 99%, 7 = 100%) according to AMSA (1991) on d 0, 1, 3, and 5 of display by a five-member trained panel. Discoloration was defined as a predominantly brown color. Hunter a* and b* values were obtained on d 3 and 5 of display with a Minolta colorimeter (model CR-200b, Minolta, Ramsey, NJ). Values were obtained by averaging four readings at different locations on the steak surface. Hunter color readings were confined to the non-discolored area of the steak surface unless 100% discolored. Hue angle was calculated as $\tan^{-1}b^*/a^*$ (Little, 1975).

Experiment 2

Ten 22-mo-old crossbred heifers (culled for reproductive failure) out of either Hereford, Angus, or MARC III (1/4 Angus, 1/4 Hereford, 1/4 Red Poll, 1/4 Pinzgauer) dams and Brahman sires were fed a diet consisting of 70% corn, 25% corn silage, and 5% supplement (dry matter basis) for 12 wk. The heifers were slaughtered humanely and the carcasses were chilled at 0°C for 24 h.

The IMPS #169 top round (semimembranosus and adductor) from each side was removed at 24 h postmortem and divided into two equal sections to yield four sections per animal. The experiment was conducted as a split, split-plot design with vitamin C concentration as the whole-plot treatment, display temperature the first split-plot treatment, and display time the second split-plot treatment (repeated measures). Four treatments were blocked by muscle section so that all treatments were represented in all sections. Treatments consisted of injecting (as in Exp. 1) a muscle section with 5% by weight of a .5, 1, or 1.5% sodium ascorbate solution and a non-injected control (0%). Sections were allowed to equilibrate for 5 min then weighed, vacuum-packaged, and stored at 1°C until 17 d postmortem. Actual injection percentages for .5, 1, and 1.5% sodium ascorbate were 7.3, 7.2, and 6.8%, respectively.

At 17 d postmortem, sections were unpackaged and cut into three 2-cm-thick steaks. The second and third steaks were displayed continuously for 7 d as described for Exp. 1, except one steak was displayed at 1°C and the other steak was displayed at 9°C. The steaks were evaluated for percentage surface discoloration on 1, 3, 5, and 7 d of display as described in Exp. 1. The steaks were also evaluated for color score on a 5-point scale (1 = extremely bright red, 2 = bright red, 3 = slightly dark red or brown, 4 = moderately dark red or brown, 5 = dark red or brown) according to AMSA (1991) on 1, 3, 5, and 7 d of display by a five-member trained panel. Hunter color data were obtained on 1, 3, 5, and 7 d of display as described for Exp. 1.

Experiment 3

The IMPS #171B bottom round (biceps femoris) from each side of the carcasses from Exp. 2 was removed at 24 h postmortem and divided into two equal sections to yield four sections per animal. Four treatments were blocked by muscle section so that all treatments were represented in all sections. The experiment was conducted as a split-plot design with injection solution the whole-plot treatment and display time the split-plot treatment (repeated measures). Treatments consisted of control, 1% vitamin C, 200 m*M* calcium chloride (FCC dry food-grade, anhydrous; Tetra Chemicals, Houston, TX), and 1% vitamin C + 200 m*M* calcium chloride obtained by injecting a muscle section with 5% by weight of 1% sodium ascorbate, 200 m*M* calcium chloride, or 1% sodium ascorbate + 200 m*M* calcium chloride solutions, respectively, and a non-injected control. Sections were allowed to equilibrate for 5 min then weighed, vacuum-packaged, and stored at 1°C until 10 d postmortem. Actual injection percentages for sodium ascorbate, calcium chloride, and sodium ascorbate + calcium chloride were 7.5, 7.8, and 7.9%, respectively.

At 10 d postmortem, sections were unpackaged and cut into three 2-cm-thick steaks. The second steak was

placed in a styrofoam tray and displayed for 7 d at 1°C as described above. Data for percentage surface discoloration, color stability, and Hunter colorimeter were obtained as described for Exp. 2.

Statistical Analyses

Data from Exp. 1 and 3 were analyzed by ANOVA for a split-plot design with vitamin C concentration (Exp. 1) or injection solution (Exp. 3) the whole-plot treatment and display time (repeated measures) the split-plot treatment (Steel and Torrie, 1980). Data from Exp. 2 were analyzed by ANOVA for a split, split-plot design with vitamin C concentration the whole-plot treatment, display temperature the first split-plot treatment, and display time the second split-plot treatment (repeated measures). Mean separation for a significant main effect was accomplished with the PDIFF option (a pair-wise *t*-test) of the least squares procedures (SAS, 1988).

Results

Experiment 1

The main effects of vitamin C concentration and display time and their interaction were significant ($P < .01$) for surface discoloration score of top round steaks displayed at 9°C (Figure 1A). Surface discoloration score increased slightly ($P < .05$) from 1 to 3 d of display time but was greatly increased ($P < .05$) at 5 d of display. These scores reflect an increase in percentage surface discoloration of less than 1% on d 3 to about 50% on d 5 of display. Low (0 or .25 %) or high (4%) concentrations of vitamin C resulted in higher ($P < .05$) discoloration scores than .5, 1, or 2% vitamin C. However, the interaction of display time and vitamin C concentration resulted in equal enhancement of color stability in steaks containing .5, 1, or 2% vitamin C through 3 d of display, but after 5 d of display 2% had the lowest ($P < .05$) discoloration scores.

Hunter color data were obtained on the nondiscolored portion of the steak surface. Hunter a* values were lower ($P < .05$) after 5 d of display than after 3 d (Figure 1B). Vitamin C concentration affected Hunter a* values such that 1% was the most red ($P < .05$), 2% had intermediate redness values, followed by .5, 4, and .25%, and the untreated steaks had the least ($P < .05$) red lean color. Hue angle was not affected ($P = .09$) by vitamin C concentration at d 3 or 5 of display and was not different ($P = .07$) between d 3 and 5 of display (Figure 1C).

Data from Exp. 1 indicate that vitamin C obtained by injecting a sodium ascorbate solution into top round cuts prior to aging stabilized lean color during steak display at 9°C (worst-case scenario for temperature) and that injecting a 1 to 2% solution of vitamin C maximized stabilization.

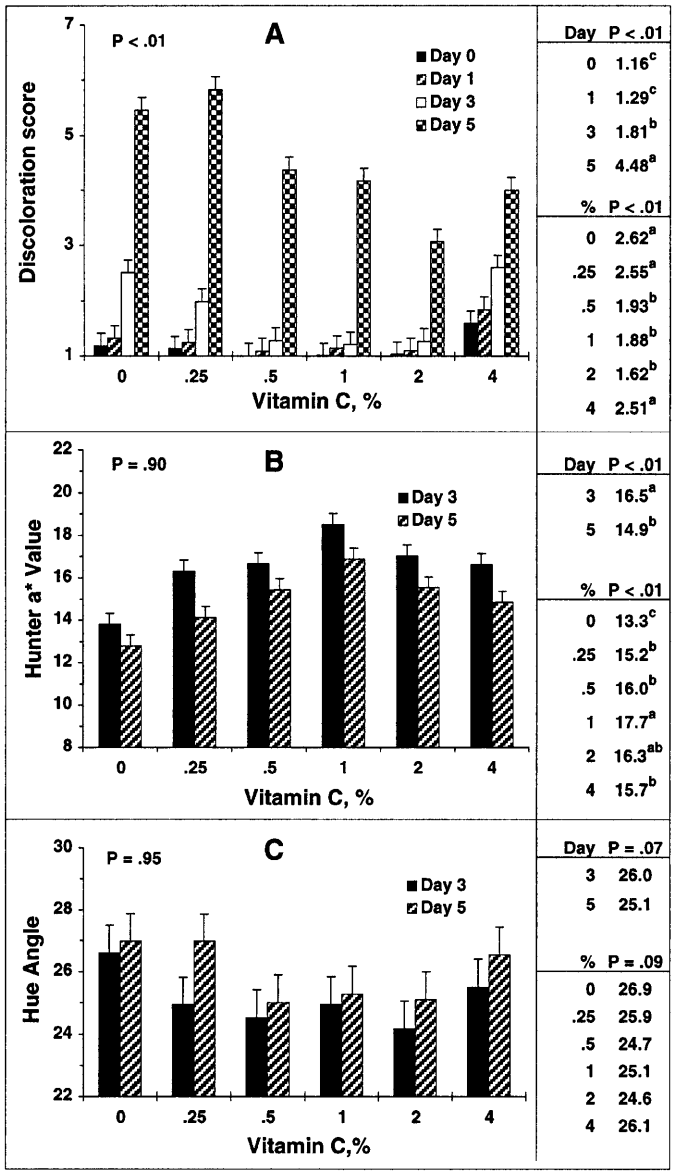

Figure 1. The effects of vitamin C concentration on various measures of lean color of top round steaks during retail display at 9°C (Exp. 1). (A) The main effects of display time, vitamin C concentration, and their interaction for surface discoloration score. 1 = 0%, 2 = 1 to 19%, 3 = 20 to 39%, 4 = 40 to 59%, 5 = 60 to 79%, 6 = 80 to 99%, 7 = 100%. LSD = .53 for interaction means. (B) The main effects of display time, vitamin C concentration, and their interaction for Hunter a* values (redness). LSD = 1.5 for interaction means. (C) The main effects of display time, vitamin C concentration, and their interaction for hue angle. LSD = 2.5 for interaction means. ^{abc}Means within a main effect that lack a common superscript are different ($P < .05$).

Experiment 2

In Exp. 1, 9°C was used to test the worst-case scenario for display temperature. Realizing that 9°C is somewhat higher than typical display temperatures,

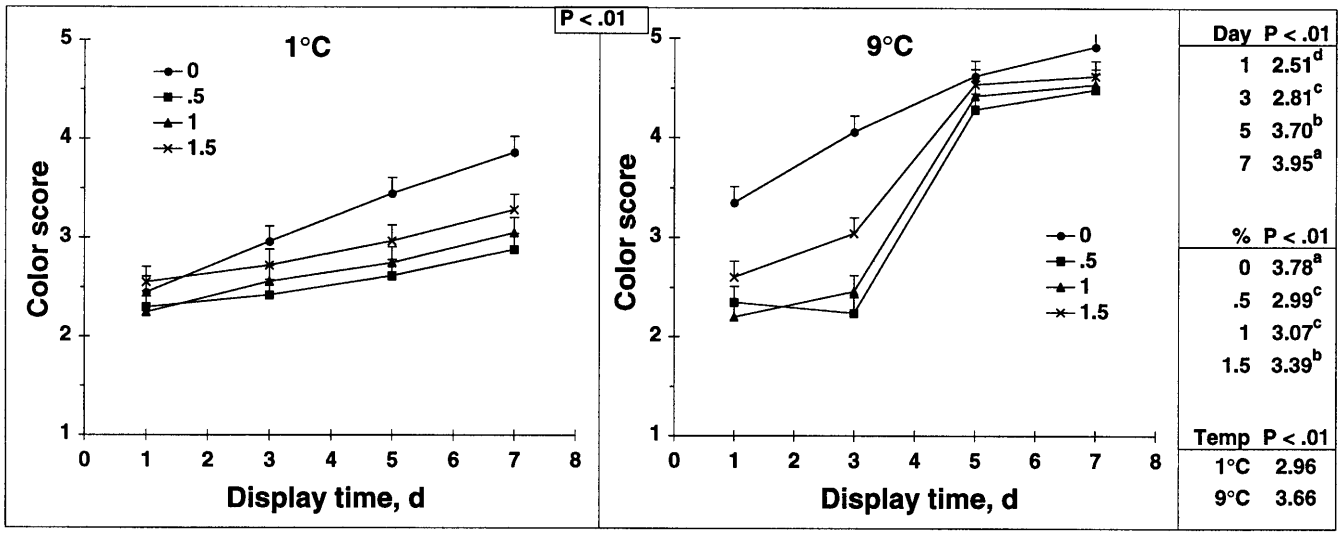

Figure 2. The main effects of display time, vitamin C concentration, display temperature, and their interaction on color score of top round steaks (Exp. 2). 1 = extremely bright red, 2 = bright red, 3 = slightly dark red or brown, 4 = moderately dark red or brown, 5 = dark red or brown. LSD = .45 for interaction means. [abcd]Means within a main effect that lack a common superscript are different ($P < .05$).

and that perhaps vitamin C would not benefit color stability of steaks stored at more typical temperature conditions, a second experiment was conducted at both 1 and 9°C. Color score, discoloration score, Hunter a* value, and hue angle were affected ($P < .01$) by display time, vitamin C concentration, display temperature, and the three-way interaction. Color score increased ($P < .05$) as display time and display temperature increased (Figure 2). In addition, greater ($P < .05$) color stability resulted from .5 and 1% vitamin C than from 1.5%, all of which gave greater ($P < .05$) color scores than the untreated control. The three-way interaction ($P < .01$) resulted in a linear increase ($P < .05$) in color stability from vitamin C treatment (regardless of concentration) at 1°C relative to the untreated control as display time increased. However, at 9°C, steaks treated with .5 or 1% vitamin C were more color-stable ($P < .05$) through 3 d of display than those treated with 1.5% vitamin C. After 5 and 7 d of display at 9°C, all samples were moderately dark red or brown.

Discoloration score increased ($P < .01$) as display time and display temperature increased (Figure 3). All vitamin C concentrations reduced discoloration scores compared to the untreated control, but .5% had slightly lower ($P < .05$) discoloration scores than the two higher concentrations. The three-way interaction ($P < .01$) indicated very little discoloration at 1°C in all vitamin C-treated steaks. At 9°C, .5% vitamin C had less discoloration after 3 d of display than the higher vitamin C concentrations. However, by 5 d of display there was little difference in discoloration among all treatments, but at 7 d of display, .5% had less ($P < .05$) discoloration than 0 or 1% and was similar ($P = .08$) to 1.5% vitamin C.

Hunter a* values (redness) declined ($P < .01$) as display time and display temperature increased (Figure 4). Untreated controls had the lowest ($P < .05$) a* values, 1.5% vitamin C had intermediate a* values, and .5 and 1% vitamin C had the highest ($P < .05$) a* values. Due to the three-way interaction ($P < .01$) a* values declined ($P < .05$) in untreated control samples as display time increased at 1°C; however, they were more ($P < .05$) red at d 1 and the same ($P > .05$) at d 3 as the vitamin C-treated samples (Figure 4). Vitamin C-treated samples were similar ($P > .05$) in redness through 5 d of display time, but after 7 d of display time, 1% resulted in greater ($P < .05$) redness than .5 or 1.5%. At 9°C, all samples were less ($P < .05$) red than samples displayed at 1°C, regardless of display time or treatment. Treated samples displayed at 9°C were more ($P < .05$) red than untreated samples at all display times, except 1.5% at 1 d was not different ($P > .05$) from 0%. At 1 and 3 d of display, .5% was redder ($P < .05$) than 1.5%; however, all treated samples had similar ($P > .05$) Hunter a* values at 5 and 7 d of display time.

Hue angle was highest ($P < .05$) at 5 d and lowest ($P < .05$) at 1 d of display (Figure 5). All vitamin C treatments resulted in lower ($P < .05$) hue angle than the untreated control. The higher display temperature resulted in higher ($P < .01$) hue angle. At 1°C, treatment and display time had little effect on hue angle. Vitamin C-treated steaks were not different in hue angle as display time increased; however, control samples had higher hue angle at 7 d than at 1 or 3 d of display time. At 9°C, hue angle of the untreated control increased ($P < .05$) greatly as display time increased. Hue angle increased slightly ($P < .05$) for 1 and 1.5% vitamin C through 5 d of display and .5%

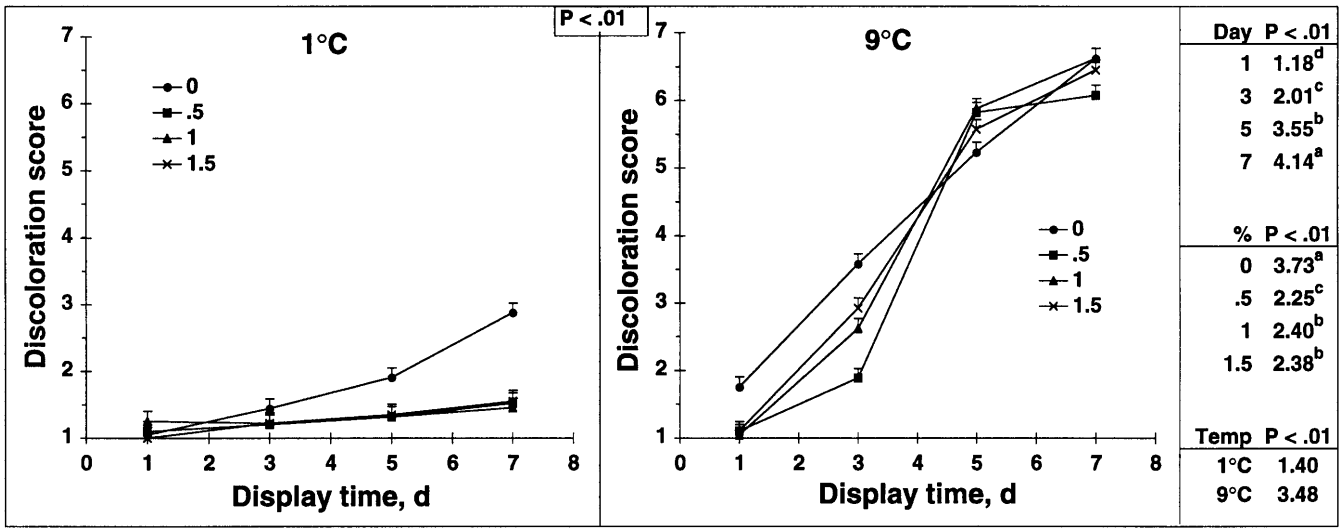

Figure 3. The main effects of display time, vitamin C concentration, display temperature, and their interaction on surface discoloration score of top round steaks (Exp. 2). 1 = 0%, 2 = 1 to 19%, 3 = 20 to 39%, 4 = 40 to 59%, 5 = 60 to 79%, 6 = 80 to 99%, 7 = 100%. LSD = .41 for interaction means. [abcd]Means within a main effect that lack a common superscript are different ($P < .05$).

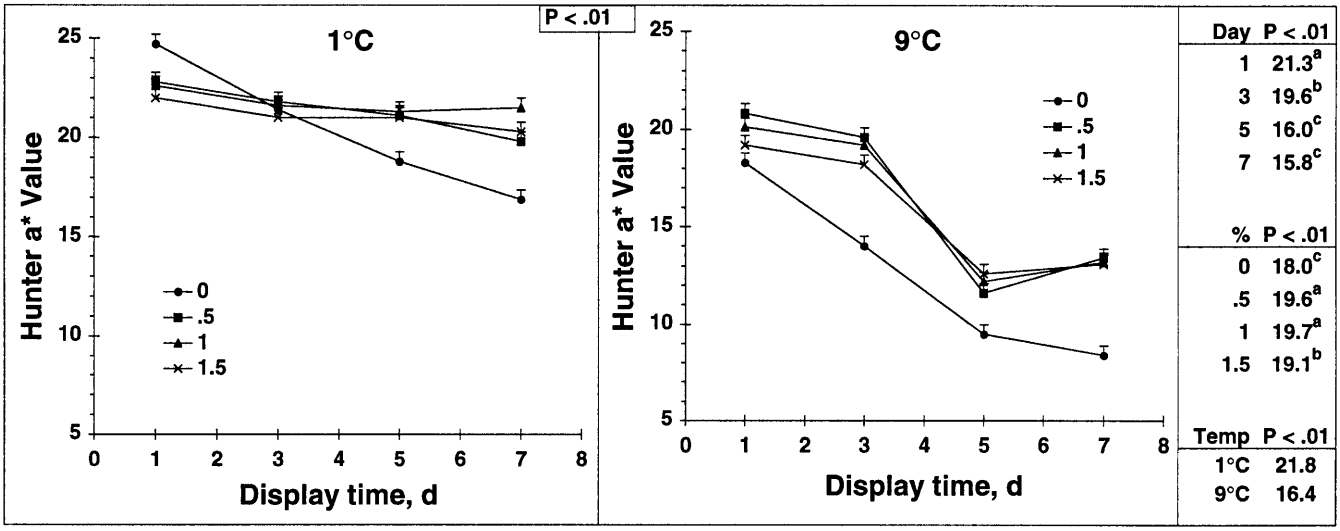

Figure 4. The main effects of display time, vitamin C concentration, display temperature, and their interaction on Hunter a* values (redness) of top round steaks (Exp. 2). LSD = 1.38 for interaction means. [abc]Means within a main effect that lack a common superscript are different ($P < .05$).

increased ($P < .05$) greatly at 5 d of display time. However, hue angle decreased ($P < .05$) for all vitamin C treatments after 7 d of display time. This decline in hue angle resulted from greatly increased b* (yellowness) values (data not shown).

Experiment 3

The objective of Exp. 3 was to determine the effect of injecting a solution containing 1% vitamin C and 200 m*M* calcium chloride on lean color when displayed at 1°C. Color stability scores indicated steaks turned ($P < .05$) from extremely bright red to slightly dark red during 7 d of display (Figure 6). Vitamin C alone had the most ($P < .05$) stable and calcium chloride the least ($P < .05$) stable lean color. The interaction ($P < .01$) of treatment and display time for color stability scores indicated that calcium chloride-treated steaks had the greatest ($P < .05$) conversion of red to brown, followed by control steaks, and vitamin C alone had the least ($P < .05$) conversion from red to brown. A similar response was detected in discoloration scores. Calcium chloride-treated steaks had significant ($P < .05$) surface discoloration by 5 d of display, control

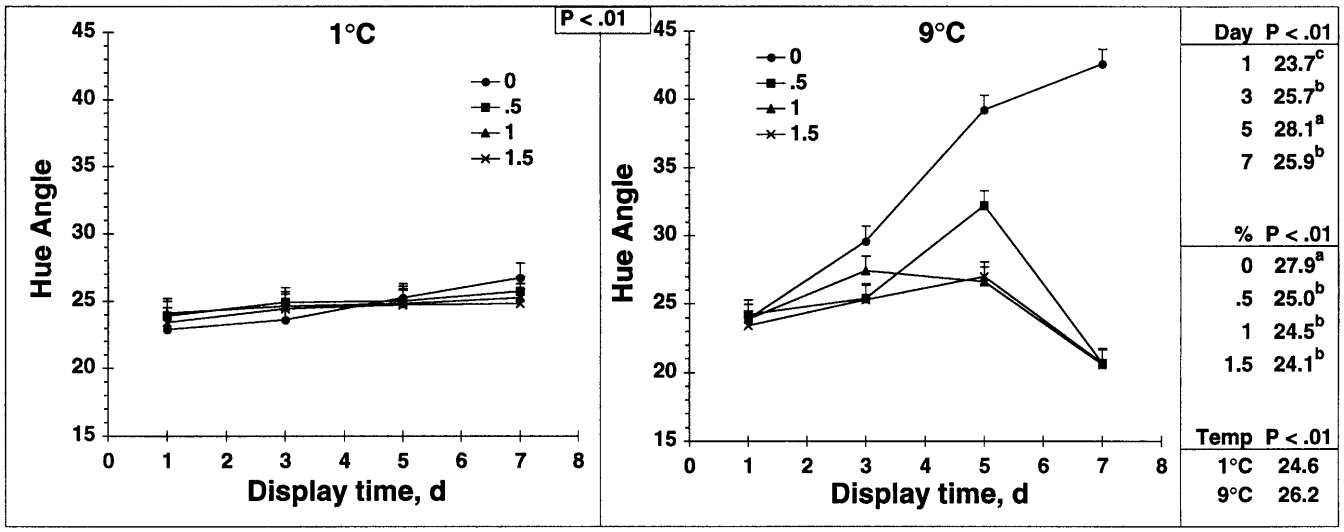

Figure 5. The main effects of display time, vitamin C concentration, display temperature, and their interaction on hue angle of top round steaks (Exp. 2). LSD = 3.0 for interaction means. [abc]Means within a main effect that lack a common superscript are different ($P < .05$).

steaks had intermediate discoloration, and steaks treated with vitamin C alone or in combination with calcium chloride developed little ($P > .05$) discoloration during 7 d of display time.

Hunter color evaluation of lean color during display resulted in similar treatment effects (Figure 7). Hunter a* values declined ($P < .05$) in control steaks from 3 to 7 d of display, but values declined to a greater extent in calcium chloride-treated steaks. Steaks with vitamin C alone or combined with calcium chloride did not vary ($P > .05$) in redness values over display time. Hue angle responded similarly to a*.

Discussion

Numerous studies have established the importance of lean color in consumer purchase decisions for fresh meat (reviewed by Kropf, 1980). Deterioration of lean color costs the retailer due to discounted prices and product further processed into a less valuable product. Dietary supplementation of cattle with an antioxidant (vitamin E) greatly reduced the percentage of retail beef items discounted in price due to unacceptable color (Sherbeck et al., 1995).

Mitsumoto et al. (1993) reported that endogenous vitamin E from dietary supplementation was much more effective at stabilizing meat color than exogenous addition of vitamin E to ground meat. They concluded that incorporation of vitamin E into cellular membranes resulting in stabilization of membranal lipids must be a critical step for improving postmortem stability of pigment. However, adoption of this technology for improving lean color stability during retail display has been hampered by the fact that one segment of the industry (feeders) must implement the technology and incur associated costs, while another segment (retailers) reaps the benefit. Vitamin C has been used in antemortem intravenous injection (Hood, 1975) and as a steak surface treatment alone or in combination with vitamin E supplementation (Okayama et al., 1987; Mitsumoto et al., 1991a,b) to enhance the lean color stability of meat during display. In addition, our results indicate that vitamin C could be added to fresh meat by postmortem injection of an aqueous solution to enhance lean color stability during retail display. Thus, although a fat-soluble antioxidant, such as vitamin E, may not enhance lean color stability when added to meat during postmortem processing to the same extent as when delivered in the diet, a water-soluble antioxidant, such as vitamin C, can be very effective at stabilizing color when added to steak surfaces or injected into subprimal cuts. Thus, vitamin C could be introduced into products by processors and priced so as to recoup those costs from retailers. This would increase the incentive to implement color-enhancing technology.

It has been reported that ascorbic acid in low concentrations can act as a prooxidant and at high concentrations as an antioxidant when added to meat (Sato and Hegarty, 1971). In model systems, ascorbic acid in low and high concentrations can act as a prooxidant (Watts and Lehmann, 1952; Kanner and Mendel, 1977). Therefore, a titration of vitamin C was necessary to determine what concentration would most effectively stabilize lean color. In Exp. 1 using display at 9°C to test the worst-case scenario for display conditions, .5, 1, and 2% were all equally effective at stabilizing lean color; however, 2% tended to have the least discoloration and 1% tended to have the highest redness values. The lower (0 and .25%)

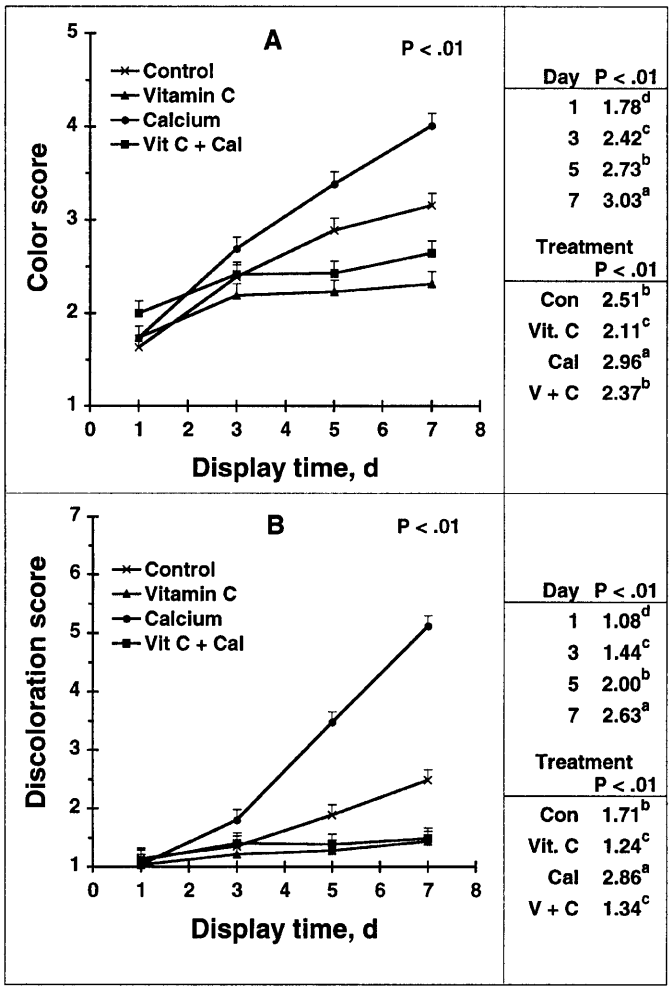

Figure 6. The effects of injecting a solution containing 1% vitamin C and 200 m*M* calcium chloride on lean color stability of bottom round steaks during retail display at 1°C (Exp. 3). (A) The main effects of display time, treatment, and their interaction for color score. 1 = extremely bright red, 2 = bright red, 3 = slightly dark red or brown, 4 = moderately dark red or brown, 5 = dark red or brown. LSD = .35 for interaction means. (B) The main effects of display time, treatment, and their interaction for surface discoloration score. 1 = 0%, 2 = 1 to 19%, 3 = 20 to 39%, 4 = 40 to 59%, 5 = 60 to 79%, 6 = 80 to 99%, 7 = 100%. LSD = .50 for interaction means. [abcd]Means within a main effect that lack a common superscript are different ($P < .05$).

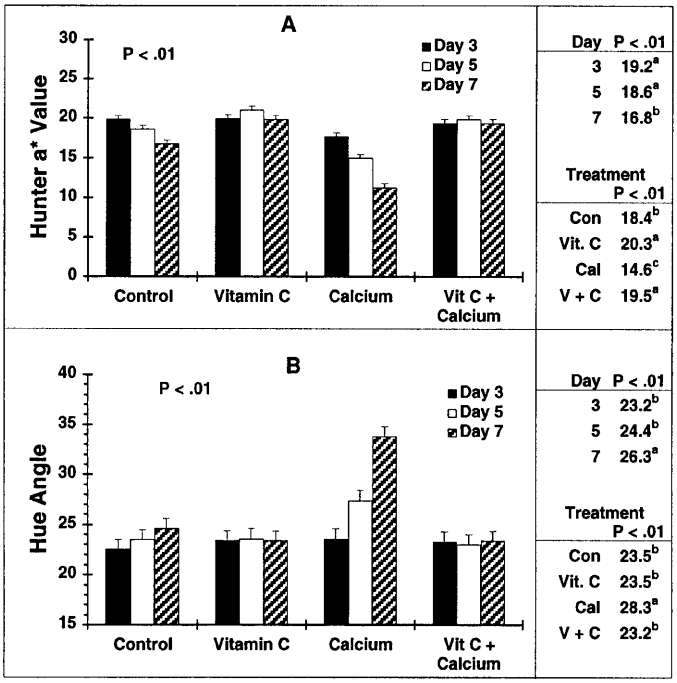

Figure 7. The effects of injecting a solution containing 1% vitamin C and 200 m*M* calcium chloride on lean color stability of bottom round steaks during retail display at 1°C (Exp. 3). (A) The main effects of display time, treatment, and their interaction for Hunter a* values. LSD = 1.1 for interaction means. (B) The main effects of display time, treatment, and their interaction for hue angle. LSD = 2.7 for interaction means. [abc]Means within a main effect that lack a common superscript are different ($P < .05$).

and higher (4%) concentrations of vitamin C resulted in less redness and more discoloration. In Exp. 2 all three concentrations of vitamin C were effective at 1°C display, but .5% had slightly more stable lean color. At 9°C, .5 and 1% were slightly better at stabilizing lean color than 1.5%. Thus, we concluded that when injecting an aqueous solution into whole subprimal meat cuts, .5 to 1% vitamin C were most effective at stabilizing lean color during retail display. Others also have demonstrated the color stabilizing effects of vitamin C on fresh steaks using antemortem infusion (Hood, 1975), a 3% dip solution (Okayama et al., 1987), a 1% dip solution (Mitsumoto et al., 1991a), and a 10% solution spread on the steak surface (Mitsumoto et al., 1991b).

The increased lean color stability at lower refrigerated temperatures has been well established (reviewed by Kropf, 1980 and Faustman and Cassens, 1990). It is important to study higher than normal display temperatures because retail display cases may not always maintain all meat packages at the desired temperatures (Kropf, 1980). Thus, the response of a treatment to temperature abuse may be important. Vitamin C was capable of extending display life even at the higher (9°C) temperature, but higher concentrations of vitamin C did not completely compensate for elevated temperature effects.

Muscles vary greatly in their color stability (reviewed by Faustman and Cassens, 1990). Vitamin C has been shown to be more effective at stabilizing color in muscles that are more color-labile (Hood, 1975). They showed that psoas major and gluteus medius benefited the most from vitamin C, longissimus was not improved, and semimembranosus was improved at

5°C but not at 0°C. Thus, our results in top and bottom round muscles would be expected to be even greater in psoas major and gluteus medius, and somewhat reduced in longissimus.

Chang and Watts (1950) reported that sodium chloride is a prooxidant. However, Miller et al. (1986) reported that restructured steaks containing calcium chloride had brighter red color than control or sodium chloride-treated steaks. Wheeler et al. (1993) reported that calcium chloride did not affect percentage surface discoloration through 3 d of retail display in longissimus, semimembranosus, or triceps brachii. Lansdell et al. (1995) reported calcium chloride injection increased percentage surface discoloration in longissimus steaks after 4 d of display and in semimembranosus steaks after 5 d of display. However, they also found that calcium chloride-treated semimembranosus steaks were more red than control steaks after all display times. Calcium chloride-treated biceps femoris steaks in Exp. 3 had lower color stability scores and greater discoloration after 3, 5, and 7 d of display than control steaks. Previous work from our laboratory indicated little effect of calcium chloride on color during display. However, the greater display time evaluated in the present work revealed that detrimental effects of calcium chloride on display color were accelerated after 3 d of display. Kerth et al. (1995) and Lansdell et al. (1995) reported that calcium chloride injection increased discoloration in longissimus after 5 d of retail display. In addition, the present work was conducted on the biceps femoris, which had not previously been studied in calcium chloride injection studies. However, the addition of vitamin C to the calcium chloride injection solution resulted in color stability superior to that of control steaks and similar to that of vitamin C-treated steaks. These results are consistent with the reduced oxidative rancidity, warmed-over flavor development, and off-flavor notes reported by St. Angelo et al. (1991) from adding 1% vitamin C to the 300 m*M* solution of calcium chloride infused into lamb carcasses.

Implications

Retail color display life can be extended by injecting whole beef subprimals with 5% by weight of a .5 or 1% vitamin C solution. Vitamin C added to the calcium chloride injection solution more than offsets any detrimental effects of the salt on color during retail display.

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