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Microbial, instrumental color and sensory color and odor characteristics of ground beef produced from beef trimmings treated with ozone or chlorine dioxide

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Abstract

The effects of beef trimming decontamination with ozone and chlorine dioxide on ground beef microbial, color and odor characteristics were studied. Beef trimmings were inoculated with *Escherichia coli* (EC) and *Salmonella* Typhimurium (ST), then treated with either 1% ozonated water for 7 min (7O) or 15 min (15O), or with 200 ppm chlorine dioxide (CLO) and compared with a control (C). Trimmings were ground, packaged and sampled at 0, 1, 2, 3 and 7 days of display for EC, ST, coliforms (CO), aerobic plate counts (APC), instrumental color, as well as sensory color and odor characteristics. The 15O and CLO treatments reduced ($P<0.05$) all bacterial types evaluated, whereas the 7O treatment reduced ($P<0.05$) APC and ST. All treatments caused ground beef to become lighter (L^*) in color ($P<0.05$); however, the 15O treatment was similar ($P>0.05$) in redness (a^*), percentage discoloration, beef odor and off odor intensities when compared to C.

Keywords: Ground beef; Ozone; Chlorine dioxide; Meat color; Antimicrobial; Microorganism

1. Introduction

After chilling, fabrication of beef carcasses can result in product contamination. Carcass contamination not removed by trimming or washing at slaughter is spread to newly exposed surfaces, which in turn can potentially decrease the shelf life of retail cuts and ground beef in retail meat display cases (Emswiler, Kotula, & Rough, 1976). Johnson, Titus, McCaskill, and Acton (1979) theorized that carcass washing treatments would reduce total bacteria counts on carcasses and in ground beef prepared from such carcasses. Dickson and Anderson (1992) and Siragusa (1995) have reviewed the practice of using antimicrobial interventions to reduce the microbial load on beef carcasses. Both agree that the use of decontamination steps can play an integral part in reducing pathogens inoculated onto carcasses during slaughter. Due to the possibility of product microbial contamination through normal processing, researchers (Dorsa, Cutter, & Siragusa, 1998; Ellebracht, Castillo, Lucia, Miller, & Acuff, 1999) have begun to evaluate the effect of using antimicrobial treatments in the production of ground beef, and the effects on microbial control. If successful, an additional decontamination step before grinding would allow for an added measure of safety by reducing microbial numbers on beef trimmings, which may become contaminated through processing before the production of ground beef.

Powerful oxidants such as ozone and chlorine dioxide have been used as potential antimicrobial treatments to decontaminate beef tissues (Kochevar, Sofos, LeValley, & Smith, 1997; Reagan et al., 1996). The method of action for oxidants is to cause irreversible damage to the fatty acids in the cell membrane and to cellular proteins of the microorganisms (Luck & Jager, 1998). Emswiler et al. (1976) reduced aerobic plate counts by 1.64 log colony forming units (CFU)/cm^2 using 200 ppm chlorine on beef carcass tissues. Similarly, Unda, Molins, and Zamojcin (1989) found that 100 ppm chlorine dioxide reduced aerobic mesophilic bacteria by 1 log CFU/cm^2 on fresh beef steaks but had a negative affect on the redness of color. Kochevar et al. (1997) reported a

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reduction in aerobic plate count (APC) of 2.64 log CFU/cm^2 using 35 °C water in combination with 0.003% chlorine dioxide on lamb adipose tissues. Likewise, Gorman, Sofos, Morgan, Schmidt, and Smith (1995) used a combination of 35 °C water and 0.5% ozone to reduce *Escherichia coli* on beef brisket fat by 1.84 log CFU/cm^2. Gorman, Morgan, Sofos, and Smith (1995) achieved an APC reduction of 1.49 log CFU/cm^2 using 35 °C water and 0.5% ozone on beef adipose tissue. In addition, Reagan et al. showed that using 2.3 ppm of ozone on beef carcasses reduced APC by 1.3 log CFU/cm^2.

Although the use of oxidants has received attention for reducing microorganisms on muscle surfaces and adipose tissue, it is unclear what effect these antimicrobials might have when used in a ground beef production system. Furthermore, few researchers have evaluated the impact of oxidant antimicrobial treatments on instrumental color or sensory characteristics of beef tissues. Therefore, the objective of this study was to determine the effects of ozone or chorine dioxide treatment of beef trimmings before grinding on the reduction of pathogens and other microorganisms, as well as instrumental and sensory color and odor characteristics of ground beef.

2. Materials and methods

2.1. Bacterial preparation and inoculation

Inoculums were prepared from frozen (−80 °C) stock cultures of *E. coli* (ATCC #11775) and a nalidixic acid resistant strain of *Salmonella* Typhimurium (ATCC #1769NR). *E. coli* was maintained by brain heart infusion (BHI)(Difco Laboratories, Detroit, MI, USA) broth with glycerol (20%) and *Salmonella* Typhimurium was maintained by BHI broth containing nalidixic acid (86 mmol; Fisher Scientific, Fairlawn, NJ, USA) with glycerol (20%). Frozen cultures of *E. coli* and *Salmonella* Typhimurium were thawed, and 0.1 ml of *E. coli* suspension was inoculated into separate 40 ml aliquots of BHI, and 0.1 ml of *Salmonella* Typhimurium suspension was inoculated into separate 40 ml aliquots of BHI with nalidixic acid (86 mmol). After 18 h of incubation at 37 °C, bacteria were harvested by centrifugation (3649 ***g*** for 20 min @ 37 °C)(Beckman GS-6 series, Fullerton, CA, USA), re-suspended in the same volume of 0.1% buffered peptone water (BPW) (Difco Laboratories, Detroit, MI, USA) and then pooled together (1600 ml of *E. coli* and 1600 ml of *Salmonella* Typhimurium) to make a bacterial cocktail. The cocktail (3200 ml; log 10^7 CFU/ml *E. coli* and log 10^7 CFU/ml *Salmonella* Typhimurium) was cooled to 4°C and combined with thawed, boneless cow beef trimmings (12.8 kg) and allowed to attach for 1 h under refrigeration (4 °C). The meat was then drained and separated into 3.2 kg batches and placed in a 4 °C cooler for 12–14 h to allow further microbial attachment.

2.2. Antimicrobial treatment application and sample processing

Antimicrobial treatments for this study included (1) 1% ozonated water bath (7.2 °C; 15 min) (15O); (2) 1% ozonated water bath (7.2 °C; 7min) (7O); (3) 200 ppm (vol:vol) chlorine dioxide solution (Midland Chemical Company, Lenexa, KS, USA) (CLO) and (4) an untreated control (C). Chlorine dioxide was prepared using deionized water while ozone was generated into tap water. For the ozone treatments, batches (3.2 kg) of inoculated beef trimmings were placed into a stainless steel vessel continuously replenished with ozonated water supplied by an ozone generator (Aqua Air Technologies, Bloomfield, NJ, USA) for 7 or 15 minutes (7O or 15O), removed, and then allowed to drip dry for 1 min. For the CLO treatment, beef trimmings (3.2 kg) were placed into a Lyco meat tumbler (Model 4Q, Lyco Inc., Janesville, WI, USA) with 400 ml of CLO and aerobically tumbled for 3 min (16 rpm).

Upon completion of the antimicrobial application phase, beef trimmings were ground twice using a Hobart grinder (Model 310, Hobart Inc., Troy, OH, USA) with a 3.2 mm plate. The ground beef was divided into 454 g samples and packaged on stryrofoam trays with absorbent diapers. The trays were overwrapped with polyvinyl chloride film with an oxygen transmission rate of 1400 cc/m^2/24 h/1 atm (Borden Inc., Dallas, TX, USA) and stored under simulated retail display conditions (4 °C; deluxe warm white fluorescent lighting, 1630 lx, Phillips Inc., Somerset, NJ, USA). Multiple trays of ground beef from each treatment were packaged to allow for independent package use for microbial, instrumental color and sensory color and odor analysis on each sampling day of display (days 0, 1, 2, 3, and 7). Fat content of all ground beef treatments was standardized to 10% and validated using a Hobart Fat Analyzer (Model F101, Hobart Inc. Troy, OH, USA). Treated ground beef pH was also sampled immediately after grinding by homogenizing a 1.8 g portion of ground beef in 18 ml of distilled water and evaluated using an Orion Model 420A pH meter with a ROSS electrode (Model 8165BN, Orion Research, Inc., Beverly, MA, USA).

2.3. Microbial sampling

On days 0, 1, 2, 3, and 7 of simulated retail display, 25 g of ground beef were aseptically removed from the packages and placed into whirlpack bags (Nasco, Ft. Atkinson, WI, USA) with 225 ml of 0.1% buffered peptone water and buffered to a pH of 7 with sodium hydroxide. Samples were then stomached in a Model

400 Lab Stomacher (Seward, London, UK) for 2 minutes and serial dilutions were made. Subsequent duplicate platings were made on *Salmonella* Shigella agar (Difco Laboratories, Detroit, MI, USA) containing nalidixic acid, Petrifilm® (3M Corp., St. Paul, MN, USA) aerobic plate count (APC) plates and Petrifilm® *E. coli*/coliform plate count plates. Plates were then incubated at 37 °C in an aerobic incubation chamber (either VWR Model 5015 or Model 3015 incubators, VWR Scientific, West Chester, PA, USA) and APC, *S. Shigella* agar plates, and *E. coli* plates were read at 48 h, while coliform counts were determined at 24 h. Counts were recorded as colony forming units per gram (CFU/g).

2.4. Instrumental color

On days 0, 1, 2, 3 and 7 of simulated retail display, instrumental color was also measured using a Hunter-Lab MiniScan XE Spectrocolorimeter, Model 4500L (Hunter Associates Laboratory Inc., Reston, WV, USA). Samples were read using illuminant A/10° observer and evaluated for CIE (L^*, a^* and b^*) color values. In addition, reflectance measurements were taken in the visible spectrum from 580 to 630 nm. The reflectance ratio of 630 nm/580 nm was calculated and used to estimate the oxymyoglobin proportion of the myoglobin pigment (Hunt et al., 1991; Strange, Benedict, Gugger, Metzger, & Swift, 1974). In addition, hue angle, which describes the hue or color of ground beef was calculated ($\tan^{-1}(b^*/a^*)$, as was the saturation index ($(a^{*2}+b^{*2})^{0.5}$), which describes the brightness or vividness of color (Hunt et al.). Before use, the Spectrocolorimeter was standardized using a white tile, black tile, and a working standard. Eight measurements were taken of each sample and averaged for statistical analysis.

2.5. Sensory color and odor

A six-member trained sensory panel was used to evaluate sensory color and odor characteristics of ground beef samples through display. Panelists were selected and trained by an experienced panel leader according to the American Meat Science Association guidelines (AMSA, 1978; Hunt et al., 1991). On days 0, 1, 2, 3 and 7 of simulated retail display, sensory panelists evaluated overall color and worst point color (5 = bright purplish red, 4 = dull purple red, 3 = slightly brownish red, 2 = moderately brownish red, and 1 = brown) and percentage surface discoloration (7 = no discoloration (0%), 6 = slight discoloration (1–20%), 5 = small discoloration (20–39%), 4 = modest discoloration (40–59%), 3 = moderate discoloration (60–79%), 2 = extensive discoloration (80–95%), 1 = total discoloration (96–100%)) (Hunt et al.). In addition panelists evaluated beef odor (8 = extremely beef like, 7 = very beef like, 6 = moderately beef like, 5 = slightly beef like, 4 = slightly non-beef like, 3 = moderately non-beef like, 2 = very non-beef like, and 1 = extremely non-beef like) and off odor characteristics (5 = no off odor, 4 = slight off odor, 3 = small off odor, 2 = moderate off odor, and 1 = extreme off odor) (Hunt et al.). For evaluation, packages were first viewed under simulated retail lighting conditions (deluxe warm white fluorescent lighting, 1630 lx) for overall color, worst point color and percentage discoloration. Packages were then taken to a static pressure room, opened, and evaluated by panelists for beef odor and off odor characteristics.

2.6. Statistical analysis

The randomized complete block factorial experiment was replicated three times and analyzed using the GLM procedure of SAS (1988). For sensory panel data, a panelist term was added to the model to account for sensory panelist variation. Treatments were blocked by replicate then analyzed for the main effects of antimicrobial treatment, day of display and main effect interactions. For variables involved in interactions, interaction means were generated, separated using the PDIFF option of SAS, and plotted. Least square means for all other variables were generated and separated using the PDIFF option of SAS.

Table 1
Effect of chlorine dioxide or ozone treatments[a] applied to beef trimmings before grinding on the least square mean (±S.E.) log CFU[b]/g *E. coli*, coliform, *Salmonella* Typhimurium, and aerobic plate count (APC) of ground beef through simulated retail display

Microorganism	Treatment			
	C	CLO	7O	15O
E. coli	6.51±0.08z[c]	5.80±0.09y	6.39±0.08z	6.37±0.08z
Coliform	5.89±0.12z	5.32±0.12x	5.74±0.13yz	5.45±0.09xy
Salmonella Typhimurium	5.70±0.09z	5.09±0.09xy	5.25±0.09y	4.92±0.09x
APC	7.20±0.10z	6.48±0.10x	6.88±0.11y	6.63±0.09xy

[a] C = Control; CLO = 200 ppm chlorine dioxide; 7O = 7 minute ozonated water bath (1%; 7.2°C); 15O = 15 min ozonated water bath (1%; 7.2°C).
[b] Colony forming units.
[c] Least square means within a row bearing different letters are different ($P < 0.05$).

Table 2
Effect of chlorine dioxide or ozone treatments[a] applied to beef trimmings before grinding on the least square mean (±S.E.) CIE L^*[b], a^*[b] and b^*[b] values, 630 nm/580 nm[c] reflectance, hue angle,[d] saturation index,[e] worst point color,[f] percentage discoloration,[g] beef odor[h] and off odor intensities[i] of ground beef through simulated retail display

Attribute	Treatment			
	C	CLO	7O	15O
Instrumental color				
CIE L^*	46.24±0.25x[j]	49.59±0.25z	48.52±0.25y	49.95±0.25z
CIE a^*	20.66±0.27z	18.79±0.27y	19.33±0.27y	20.33±0.27z
CIE b^*	21.00±0.21y	20.53±0.21xy	20.23±0.21x	22.23±0.21z
630 nm/580 nm	2.52±0.27z	2.12±0.27x	2.23±0.27xy	2.28±0.27y
Hue angle	45.92±0.38y	47.83±0.38z	46.55±0.38y	47.93±0.38z
Saturation index	29.53±0.27z	27.89±0.27y	28.02±0.27y	30.25±0.27z
Sensory trait				
Worst point color	3.59±0.06z	3.26±0.06y	3.40±0.06y	3.40±0.07y
Percentage discoloration	5.50±0.10	5.21±0.10	5.45±0.10	5.42±0.10
Beef odor	6.14±0.12	5.83±0.12	6.20±0.12	5.97±0.13
Off odor	4.31±0.08	4.20±0.08	4.42±0.08	4.27±0.08

[a] C = Control; CLO = 200 ppm chlorine dioxide; 7O = 7 min ozonated water bath (1%; 7.2 °C); 15O = 15 min ozonated water bath (1%; 7.2 °C).
[b] L^*: 0 = black and 100 = white; a^*: −60 = green and +60 = red; b^*: −60 = blue and +60 = yellow.
[c] Calculated as 630 nm reflectance/580 nm reflectance.
[d] Calculated as $\tan^{-1}(b^*/a^*)$.
[e] Calculated as $(a^{*2}+b^{*2})^{0.5}$.
[f] Worst point color score: 1 = brown and 5 = bright purple red.
[g] Percentage discoloration: 1 = total discoloration (96–100%) and 7 = no discoloration (0%).
[h] Beef odor score: 1 = extremely non-beef like and 8 = extremely beef like.
[i] Off odor score: 1 = extreme off odor and 5 = no off odor.
[j] Least square means within a row bearing different letters are different ($P<0.05$).

3. Results and discussion

3.1. Antimicrobial treatment effects on microbial populations, instrumental color and sensory color and odor characteristics

Chlorine dioxide (CLO) was effective ($P<0.05$) against all bacterial types evaluated (Table 1). Chlorine dioxide reduced *E. coli* (EC), coliforms (CO), *Salmonella* Typhimirium (ST) and aerobic plate count (APC) 0.71, 0.57, 0.61 and 0.72 log CFU/g, respectively, in ground beef compared to the control (C). These results are in agreement with Emswiler et al. (1976) which concluded that 200 ppm chlorine sprayed on beef carcasses was effective for reducing APC by 1.64 log CFU/cm^2. Similarly, Unda et al. (1989) found beef ribeye steaks dipped in 100 ppm of CLO reduced aerobic mesophilic bacteria 1 log CFU/cm^2. The 15O treatment reduced ($P<0.05$) CO, ST and APC 0.44, 0.78 and 0.57 log CFU/g, respectively in ground beef. Ground beef pH was 5.55 for C, 5.34 for CLO, 5.29 for 7O and 5.77 for 15O treatments, respectively. The slightly lower antimicrobial effectiveness for the 15O treatment compared with the CLO treatment may be related to treatment differences in pH. Since a lower pH tends to inhibit microbial growth and survival, the lower pH of the CLO treatment (5.34) may have inhibited a slightly greater number of microorganisms than the 15O treatment (5.77). Treatment of beef trimmings with 7O was effective ($P<0.05$) against ST and APC in ground beef, with reductions of 0.45 and 0.32 log CFU/g, respectively. The shorter duration of treatment with 7O could possibly explain the reduced effectiveness against EC and CO.

Table 2 summarizes the impact of antimicrobial treatments applied to beef trimmings on ground beef instrumental color and sensory characteristics. Ground beef from the CLO treatment was ($P<0.05$) lighter (L^*), less red (a^*), contained less oxymyoglobin (630 nm/580 nm), and was less orange (hue angle) in color, but was not different ($P>0.05$) in yellowness (b^*) compared to C. Unda et al. (1989) found that 100 ppm of CLO caused lower a^* values when used on ribeye steaks. Also, beef trimmings treated with CLO were less ($P<0.05$) vivid in color (saturation index), when compared to C. The 7O treatment was also ($P<0.05$) lighter (L^*), less red (a^*) possessed less oxymyoglobin (630 nm/580 nm), was less yellow (b^*) and less vivid (saturation index) in color compared to C, however, hue angle did not differ ($P>0.05$) between the 7O and C treatments. Likewise, ground beef from the 15O treatment was also ($P<0.05$) lighter (L^*) and more yellow in color (b^*), and contained less oxymyoglobin (630 nm/580 nm) than C, yet was no different ($P>0.05$) in redness (a^*) when compared to C. Differences in the CIE b^* value translated into a larger ($P<0.05$) hue angle for the 15O

Table 3
Effect of duration of display, pooled across antimicrobial treatments, on the least square mean (±S.E.) log CFU[a]/g *E. coli*, colifom, *Salmonella* Typhimurium, and aerobic plate count (APC) of ground beef

Microorganism	Days of display				
	0	1	2	3	7
E. coli	6.39±0.09z[b]	6.43±0.09z	6.29±0.09z	6.28±0.09z	5.95±0.10y
Coliform	5.67±0.13xyz	5.88±0.15z	5.72±0.14yz	5.43±0.13xy	5.30±0.14x
Salmonella Typhimurium	5.54±0.10z	5.52±0.10z	5.45±0.10y	4.98±0.10y	4.72±0.10y
APC	6.77±0.10	6.90±0.11	7.01±0.11	6.62±0.12	6.11±0.11

[a] Colony forming units.
[b] Least square means within a row bearing different letters are different ($P<0.05$).

Table 4
Effect of duration of display, pooled across antimicrobial treatments, on the least square mean (±S.E.) CIE L^*[a], a^*[a] and b^*[a] values, hue angle[b], saturation index[c], 630 nm/580 nm[d] reflectance, worst point color[e], percentage discoloration[f], beef odor[g] and off odor[h] of ground beef

Attribute	Day of display				
	0	1	2	3	7
Instrumental color					
CIE L^*	47.03±0.27x[i]	48.74±0.27yz	49.22±0.27z	49.49±0.27z	48.40±0.27y
CIE a^*	23.54±0.27z	21.76±0.27y	20.23±0.27x	17.88±0.27w	15.46±0.27v
CIE b^*	22.02±0.20z	22.25±0.20z	21.04±0.20y	19.44±0.27w	20.34±0.20x
Hue angle	43.11±0.43w	45.67±0.43x	46.13±0.43x	47.73±0.43y	52.94±0.43z
Saturation index	32.24±0.30z	31.13±0.30y	29.20±0.30x	26.42±0.30w	25.64±0.30w
630 nm/580 nm	3.07±0.05z	2.57±0.05y	2.31±0.05x	1.98±0.05w	1.50±0.05v
Sensory trait					
Worst point color	4.27±0.07z	4.05±0.07y	3.77±0.08x	3.33±0.07w	1.63±0.07v
Percentage discoloration	6.43±0.12z	6.35±0.11z	6.13±0.12z	5.60±0.11y	2.47±0.11x
Beef odor	6.64±0.14yz	6.72±0.14z	6.40±0.15yz	6.27±0.14y	4.15±0.14x
Off odor	4.70±0.09z	4.72±0.09z	4.62±0.09z	4.63±0.08z	2.84±0.09y

[a] L^*: 0 = black and 100 = white; a^*: −60 = green and +60 = red; b^*: −60 = blue and +60 = yellow.
[b] Calculated as $\tan^{-1}(b^*/a^*)$.
[c] Calculated as $(a^{*2}+b^{*2})^{0.5}$.
[d] Calculated as 630 nm reflectance/580 nm reflectance.
[e] Worst point color score: 1 = brown and 5 = bright purple red.
[f] Percentage discoloration: 1 = total discoloration (96–100%) and 7 = no discoloration (0%).
[g] Beef odor score: 1 = extremely non-beef like and 8 = extremely beef like.
[h] Off odor score: 1 = extreme off odor and 5 = no off odor.
[i] Least square means within a row bearing different letters are different ($P<0.05$).

treatment compared to C, however, saturation index did not differ ($P>0.05$) between these two treatments.

Sensory panelists evaluation of color and odor characteristics of ground beef through simulated retail display is presented in Table 2. Although all treatments were slightly less ($P<0.05$) bright purplish red in worst point color when compared to C, no differences ($P>0.05$) were observed between C and any other treatment for percentage discoloration, beef odor or off-odor characteristics. Garcia-Zepeda, Kastner, Kenney, Campbell, and Schwenke (1994) found that vacuum packaged beef chucks treated with 200 ppm CLO were actually higher in odor acceptability scores when compared to a control. They hypothesized that the decrease in off-flavor aromatic notes were caused by the ability of chlorine to dissipate faster off treated meat surfaces, leaving no residual aroma. Therefore, our findings show that both ozone and chlorine dioxide can be effective against different bacterial types, with little effect on sensory color and odor characteristics.

3.2. Effect of duration of display on microbial populations, instrumental color and sensory color and odor characteristics

The effect of duration of display, pooled across antimicrobial treatments, on microbial populations, instrumental color and sensory characteristics are summarized in Tables 3 and 4. Across 7 days of display, EC and ST were reduced ($P<0.05$), however, CO and APC populations remained relatively ($P>0.05$) constant (Table 3). These results show that oxidants such as chlorine dioxide and ozone have a greater residual

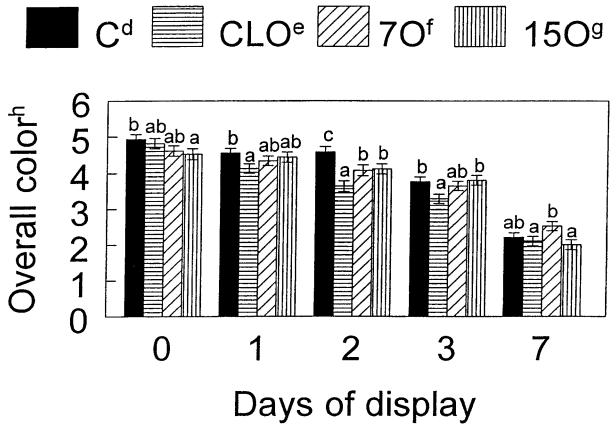

Fig. 1. Day of display by antimicrobial treatrment interaction effect on the least square mean (±S.E.) sensory evaluated overall color of ground beef through simulated retail display. abc Least square means within a day bearing different superscripts are different ($P<0.05$). [d]C = control, [e]CLO = 200 ppm chlorine dioxide, [f]70 = 7min ozonated water bath (1%; 7.2 °C) and [g]150 = 15 min ozonated water bath (1%; 7.2 °C). Overall color score: 1 = brown and 5 = bright purple red.

impact for controlling EC and ST than for controlling CO and APC through simulated display even though CO and APC outgrowth was held in check.

The effect of duration of display on instrumental color and sensory color and odor traits of ground beef is shown in Table 4. Across 7 days of display, ground beef became ($P<0.05$) lighter (L^*), less red (a^*; 630 nm/580 nm), and less yellow (b^*) in color, which subsequently caused an increase ($P<0.05$) in the hue angle, or change in ground beef hue or color. In addition to color changes, ground beef, as might be expected, became less vivid in color (saturation index) as display progressed. The loss of the oxymyoglobin pigment (630 nm/580 nm) across display may have caused the increased hue angle and decreased a^* value. This is consistent with results reported by Unda et al. (1989) who found a* values decreased for rib eye steaks with increasing storage time.

In addition to instrumental color changes through display, sensory panelists indicated that worst point color became less ($P<0.05$) bright purple red and that percentage surface discoloration increased ($P<0.05$) as display progressed (Table 4). Likewise, off odor increased ($P<0.05$) while beef odor decreased ($P<0.05$) through display.

The day of display by antimicrobial treatment interaction effect on sensory evaluated overall ground beef color is shown in Fig. 1. Initially, sensory panelists detected no difference ($P>0.05$) in overall color between C, CLO or 7O treatments. Likewise, by day 1 of display, sensory panelists found no difference ($P>0.05$) in overall color between C, 7O or 15O treatments. However by day 1 and though day 3 of display, sensory panelists indicated that the CLO treatment was less ($P<0.05$) bright purplish red in overall color than C. This decreased overall color may have been caused by the oxidation of myoglobin in the CLO treated samples, thus causing slightly lower redness values through display.

4. Conclusion

The use of chlorine dioxide or ozone in ground beef production systems can be effective for reducing microbial pathogens with minimal effects on color or odor characteristics. Additional work might focus on concentration and exposure times necessary to optimize antimicrobial properties.

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