The effects of ozone, chlorine dioxide, cetylpyridinium chloride and trisodium phosphate as multiple antimicrobial interventions on microbiological, instrumental color, and sensory color and odor characteristics of ground beef

F.W. Pohlmana,*, M.R. Stivariusb, K.S. McElyea, Z.B. Johnsona, M.G. Johnsonc

*Department of Animal Science, University of Arkansas, Fayetteville, AR 72701, USA
bGriffith Laboratories, Griffith Center, Alsip, IL 60658, USA
cDepartment of Food Science, University of Arkansas, Fayetteville, AR 72701, USA

Received 26 March 2001; received in revised form 20 September 2001; accepted 20 September 2001

Abstract

The impact of multiple antimicrobial interventions on ground beef microbial, color and sensory characteristics was studied. For this, beef trimmings were inoculated with Escherichia coli (EC) and Salmonella typhimurium (ST) then treated with either (1) 1% ozonated water followed by 5% acetic acid (OA), (2) 1% ozonated water followed by 0.5% cetylpyridinium chloride (OC), (3) 200 ppm chlorine dioxide followed by 10% trisodium phosphate (CT) or (4) 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 count (APC), instrumental color and sensory color and odor characteristics. The OA and OC treatments reduced \((P < 0.05)\) all bacterial types evaluated, while CT reduced \((P < 0.05)\) EC, CO and APC. The CT treatment was redder \((P < 0.05)\) in overall color than C, and there was no difference \((P > 0.05)\) in beef odor or off odor between OC, CT or C treatments. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Ground beef; Chlorine dioxide; Acetic acid; Ozone; Cetylpyridinium chloride; Meat color

1. Introduction

Antimicrobial intervention treatment of carcasses and meat tissues have been investigated and have ranged from water washing and steam pasteurization (Phebus et al., 1997; Reagan et al., 1996) to organic acids, alkaline phosphates and other novel compounds (Kim & Slavik, 1994; Kochevar, Sofos, LeValley, & Smith, 1997). Recently, research has been conducted using the concept of hurdle technology (Ellebracht, Castillo, Lucia, Miller, & Acuff, 1999; Phebus et al., 1997). Hurdle technology utilizes multiple intervention treatments to provide different barriers for microorganisms to overcome for survival and proliferation. An important factor when using multiple intervention technology is the order of application of antimicrobial treatments.

Dorsa, Cutter, and Siragusa (1997) reported that hydration of a carcass before and during antimicrobial interventions provide protection to bacteria. Gorman, Sofos, Morgan, Schmidt, and Smith (1995) reported the loss of activity of antimicrobial agents when followed by plain water spray washing, possibly due to physical removal or dilution of the sanitizing agents.

Ellebracht et al. (1999) used hot water and lactic acid on beef trimmings destined for ground beef to achieved a reduction of 1.1, 1.8 and 1.5 log colony forming units (CFU)/g of Escherichia coli, Salmonella typhimurium and aerobic plate counts, respectively. Unfortunately, it remains unknown what effect other antimicrobials such as ozonated water, cetylpyridinium chloride, acetic acid, chlorine dioxide or trisodium phosphate, when used as combination treatments, might have on microbial reductions, color and sensory characteristics of ground beef. Therefore, the objective of this research was to determine the effectiveness of multiple intervention technologies during the manufacture of ground beef on
the reduction of microorganisms and on instrumental color and sensory 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; EC) and a nalidixic acid resistant strain of *Salmonella typhimurium* (ATCC 1769NR; ST). *E. coli* was maintained by brain heart infusion (BHI; Difco Laboratories, Detroit, Michigan, USA) broth with glycerol (20%) and *Salmonella Typhimurium* was maintained by BHI broth containing nalidixic acid (86 millimolar; Fisher Scientific, Fairlawn, New Jersey, 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 millimolar). After 18 h of incubation at 37 °C, bacteria were harvested by centrifugation (3649 xg for 20 min at 37 °C; Beckman GS-6 series, Fullerton, California, USA), re-suspended in the same volume of 0.1% buffered peptone water (BPW; Difco Laboratories, Detroit, Michigan, 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 colony forming units (CFU)/ml *E. coli* and log 10 CFU/ml *Salmonella typhimurium*) was cooled to 4 °C and combined with boneless 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

Treatments combinations for this study included (1) 1% ozonated water bath (7.2 °C; 15 min) followed by a 0.5% (wt:vol) cetlypyridinium chloride solution (Zeland Inc., Zeeland, Michigan, USA; OC); 2) 1% ozonated water bath (7.2 °C; 15 min.) followed by a 5% (vol:vol) acetic acid solution (Shurfine Inc., Northlake, Illinois, USA; OA), (3) 200 ppm (vol:vol) chlorine dioxide solution (Midland Chemical Company, Lenexa, Kansas, USA), followed by a 10% (wt:vol) trisodium phosphate solution (Rhone Poulenc, Cranbury, New Jersey, USA; CT) and (4) an untreated control (C). All antimicrobial treatments were prepared in deionized water with the exceptions of ozone and acetic acid. Ozone was generated into tap water, while acetic acid was commercially prepared. For ozone treatment combinations, 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, New Jersey, USA) for 15 min, removed, and allowed to drip dry for 1 min. The ozonated trimmings were then placed into a clean Lyco meat tumbler (Model 4Q, Lyco Inc., Janesville, Wisconsin, USA) with 400 ml of a selected antimicrobial treatment (either cetlypyridinium chloride or acetic acid) and tumbled for 3 min (16 rpm) aerobically. For the CT treatment, beef trimmings were placed into a meat tumbler with 400 ml of chlorine dioxide, aerobically tumbled for 3 min (16 rpm), removed from the tumbler and placed into another clean tumbler with 400 ml of trisodium phosphate then tumbled again for 3 min (16 rpm), aerobically.

Upon completion of the antimicrobial treatment phase, beef trimmings were removed from the tumbler and ground twice using a Hobart grinder (Model 310, Hobart Inc., Troy, Ohio, USA) with a 3.2-mm plate. The ground beef was divided into 454-g samples and packaged on styrofoam trays with absorbent diapers. The trays were overwrapped with polyvinyl chloride film with an oxygen transmission rate of 1400 cc/m²/24 h/l atm (Borden Inc., Dallas, Texas, USA) and stored under simulated retail conditions (4 °C; deluxe warm white fluorescent lighting, 1630 lx, Phillips Inc., Somerset, New Jersey, 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 was standardized to 10% and validated using a Hobart Fat Analyzer (Model F101, Hobart Inc. Troy, Ohio, USA). Treated ground beef pH was also determined 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, Massachusetts, USA).

2.3. Microbial sampling

On days 0, 1, 2, 3, and 7 of simulated retail display, 25 g of ground beef was aseptically removed from the packages and placed into whirlpack bags (Nasco, Ft. Atkinson, Wisconsin, USA) with 225 ml of 0.1% buffered peptone water and buffered to a pH of 7 with either sodium hydroxide or hydrochloric acid. Samples were then stomached in a Model 400 Lab Stomacher (Seward, London, United Kingdom) for 2 min and serial dilutions were made. Subsequent duplicate platings were made on *Salmonella shigella* agar (Difco Laboratories, Detroit, Michigan, USA) containing nalidixic acid, Petrifilm® (3M Corp., St. Paul, Minnesota, USA) aerobic plate count (APC) plates and Petrifilm®
E. coli/coli form 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, Pennsylvania, USA) and APC, Salmonella 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.

2.4. Instrumental color

On days 0, 1, 2, 3 and 7 of simulated retail display, instrumental color was evaluated using a HunterLab MiniScan XE Spectrocolorimeter, Model 4500L (Hunter Associates Laboratory Inc., Reston, West Virginia, USA). Samples were read using illuminant A/10° observer and evaluated for CIE \((L^* a^* b^*)\) 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., 1991). Before use, the Spectrocolorimeter was standardized using white tile, black tile, and working standards. 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%). 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., 1991). 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 experiment was replicated three times. The randomized complete block factorial experiment was 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 combination, day of display and appropriate interactions. For variables confounded by interactions, interaction means were generated, separated using the PDIFF option of SAS (1988), and plotted. Least square means for all other variables were generated and separated using the PDIFF option of SAS (1988).

3. Results and discussion

3.1. Effect of antimicrobial treatment combinations on microbial populations, instrumental color and sensory odor characteristics

The principle of multiple intervention technology is to capitalize on different weaknesses of various bacterial strains. Placing hurdles such as pH, chlorinated compounds or oxidizing environments in front of microorganisms may cause compromises in microbial cell wall integrity, metabolism or both, resulting in a lethal or inhibitory environment for microbial survival and proliferation. The impact of multiple interventions on the reduction of microbial populations in ground beef is presented in Table 1. Using ozone followed by cetylpyridinium chloride (OC) interventions on beef trimmings before grinding reduced \((P<0.05)\) EC, ST, coliforms (CO) and aerobic bacteria (APC) by 1.68, 1.77, 1.88 and 1.50 log CFU/g, respectively in ground beef compared with C. Likewise, treatment of beef trimmings with ozonated water followed by acetic acid (OA) reduced \((P<0.05)\) EC, ST, CO and APC by 1.42, 1.66, 1.84 and 1.27 log CFU/g, respectively in ground beef compared with C. Therefore, it appears that treatment of beef trimmings before grinding with a combination of a strong oxidant (ozone) and either a surfactant (cetylpyridinium chloride) or an organic acid (acetic acid) were very effective against both gram-negative and gram-positive bacterium. These results are consistent with those reported by Gorman et al. (1995) and Graves-Delmore, Sofos, Schmidt, and Smith (1998).
Treatment of beef trimmings before grinding with chlorine dioxide followed by trisodium phosphate (CT) did not reduce microorganisms in ground beef to the same extent as the other combination treatments (Table 1).

Table 1
Effect of multiple antimicrobial treatments applied to beef trimmings on least square mean (±S.E.) log CFU/g Escherichia coli, coliform, Salmonella typhimurium, aerobic plate count (APC) and CIE L* value, beef odor and off odor intensities of ground beef through simulated retail display

<table>
<thead>
<tr>
<th>Treatment</th>
<th>C</th>
<th>OC</th>
<th>OA</th>
<th>CT</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microorganism</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. coli</td>
<td>6.77f</td>
<td>5.09w</td>
<td>5.35x</td>
<td>6.16y</td>
<td>0.09</td>
</tr>
<tr>
<td>Coliform</td>
<td>6.02z</td>
<td>4.14y</td>
<td>4.18y</td>
<td>5.65y</td>
<td>0.10</td>
</tr>
<tr>
<td>Salmonella typhimurium</td>
<td>5.81z</td>
<td>4.04y</td>
<td>4.15y</td>
<td>5.32z</td>
<td>0.11</td>
</tr>
<tr>
<td>APC</td>
<td>7.06z</td>
<td>5.56x</td>
<td>5.79x</td>
<td>6.76y</td>
<td>0.09</td>
</tr>
<tr>
<td>Instrumental color</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIE L*</td>
<td>48.35x</td>
<td>52.30z</td>
<td>49.87y</td>
<td>43.80w</td>
<td>0.31</td>
</tr>
<tr>
<td>Sensory odor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beef odor</td>
<td>6.44z</td>
<td>6.37z</td>
<td>3.98y</td>
<td>6.51z</td>
<td>0.14</td>
</tr>
<tr>
<td>Off odor</td>
<td>4.55z</td>
<td>4.36z</td>
<td>2.54y</td>
<td>4.60z</td>
<td>0.09</td>
</tr>
</tbody>
</table>

a C, Control; OC, 15 min ozonated water bath (1%; 7.2 °C) and 0.5% cetylpyridinium chloride; OA, 15 min ozonated water bath (1%; 7.2 °C) and 5% acetic acid; CT, 200 ppm chlorine dioxide and 10% trisodium phosphate.

b Colony forming units.
c 0 = black and 100 = white.
d Beef odor score: 1 = extremely non-beef like and 8 = extremely beef like.
e Off odor score: 1 = extreme off odor and 5 = no off odor.
f Least square means within a row bearing different letters are different (P < 0.05).

The CT treatment reduced (P < 0.05) EC, CO and APC in ground beef by 0.61, 0.37 and 0.30 log CFU/g, respectively, while ST was not affected (P > 0.05) by the CT treatment. The lower bacterial reductions realized by the CT treatment could possibly be explained by the differences in pH between the CT, OC, OA and C treatments. Chlorine dioxide’s low pH was counteracted by trisodium phosphate’s high pH, thus resulting in an overall neutral treatment pH (7.02) for the CT treatment compared with a pH of 5.72 for C. Therefore, any inhibitory effect due to individual chlorine dioxide or trisodium phosphate treatments was probably negated by the elevated overall pH for this treatment.

The impact of multiple antimicrobial treatments of beef trimmings before grinding on instrumental color and sensory characteristics are shown in Table 1. Ground beef from the OC and OA treatments were lighter (L*) in color (P < 0.05), whereas ground beef from the CT treatment was darker (P < 0.05) in color compared with C. Color differences between treatments may be related to ground beef pH where both OA and OC treatments had a lower pH (4.63 and 5.42, respectively) than C (5.72) and the CT treatment had a higher pH (7.02) than C. Kaess and Weidemann (1968) found beef color was unaffected by low levels of an atmospheric ozone treatment. On the other hand, Fournaud and Lauret (1972) reported that atmospheric ozone treatment of beef caused undesirable color changes to occur. Using acetic acid as a single intervention treatment, Bell, Marshall, and Anderson (1986) found that beef cubes discolored immediately upon contact with this antimicrobial.

The OC and CT treatments were not different (P > 0.05) from C for both beef odor and off odor.

Table 2
Effect of duration of display, pooled across antimicrobial treatments, on least square mean (±SE) log CFU/g Escherichia coli, coliform, Salmonella Typhimurium, aerobic plate count (APC), CIE L* value, beef odor and off odor characteristics of ground beef

<table>
<thead>
<tr>
<th>Days of display</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microorganism</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. coli</td>
<td>5.94±0.11yz</td>
<td>6.08±0.11z</td>
<td>5.71±0.10y</td>
<td>5.80±0.10yz</td>
<td>5.67±0.10y</td>
</tr>
<tr>
<td>Coliform</td>
<td>5.22±0.12z</td>
<td>5.28±0.11z</td>
<td>4.87±0.11y</td>
<td>4.82±0.11y</td>
<td>4.80±0.11y</td>
</tr>
<tr>
<td>Salmonella typhimurium</td>
<td>5.36±0.13z</td>
<td>5.29±0.13z</td>
<td>4.65±0.13y</td>
<td>4.66±0.13y</td>
<td>4.44±0.13y</td>
</tr>
<tr>
<td>APC</td>
<td>6.20±0.10</td>
<td>6.29±0.10</td>
<td>6.24±0.10</td>
<td>4.44±0.13</td>
<td>6.51±0.10</td>
</tr>
<tr>
<td>Instrumental color</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIE L*</td>
<td>47.24±0.35x</td>
<td>47.93±0.35xy</td>
<td>48.23±0.35y</td>
<td>49.98±0.35z</td>
<td>49.50±0.35z</td>
</tr>
<tr>
<td>Sensory odor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beef odor</td>
<td>6.13±0.16yz</td>
<td>6.08±0.16yz</td>
<td>6.21±0.16z</td>
<td>5.78±0.16y</td>
<td>4.93±0.16z</td>
</tr>
<tr>
<td>Off odor</td>
<td>4.21±0.10</td>
<td>4.34±0.10</td>
<td>4.09±0.10yz</td>
<td>3.87±0.10y</td>
<td>3.54±0.10x</td>
</tr>
</tbody>
</table>

a Colony forming units.
b 0 = black and 100 = white.
c Beef odor score: 1 = extremely non-beef like and 8 = extremely beef like.
d Off odor score: 1 = extreme off odor and 5 = no off odor.
e Least square means within a row bearing different letters are different (P < 0.05).
characteristics, however, ground beef from the OA treatment had less ($P<0.05$) beef like odor and more ($P<0.05$) off odor than all other treatments (Table 1).

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

The effect of duration of display, pooled across antimicrobial treatments, on microbial populations, instrumental color and sensory odor characteristics are summarized in Table 2. By day 7 of display, EC and APC counts were similar ($P>0.05$) to counts observed on day 1 of display. However, CO and ST were reduced ($P<0.05$) by 0.42 and 0.92 log CFU/g, respectively through 7 days of display. Ground beef became ($P<0.05$) lighter ($L^*$) in color, and had less ($P<0.05$) beef odor and more off odor from day 1 to day 7 of display. Because EC and APC remained constant, and CO and ST declined through display, changes in ground beef color and odor characteristics may not be explained by microbial growth patterns. Instead, pH and oxidative environmental changes caused by antimicrobial treatments may have resulted in myoglobin and lipid oxidation, resulting in color and odor changes of ground beef through display.

### 3.3. Effects of antimicrobial treatments and duration of display on instrumental and sensory color characteristics

Fig. 1 shows the day of display by antimicrobial treatment interaction effect on ground beef redness

![](image1.png)

Fig. 1. Day of display by antimicrobial treatment interaction effect on the least square mean (±SE) (a) CIE $a^*$ value, (b) 630 nm reflectance/580 nm reflectance ratio, (c) CIE $b^*$ value, (d) hue angle and (e) saturation index of ground beef through simulated retail display. abcd Least square means within a day bearing different superscripts are different ($P<0.05$). cC, control; 1OC, 15 min ozonated water bath (1%; 7.2 °C) and 0.5% cetylpyridinium chloride; OA, 15 min ozonated water bath (1%; 7.2 °C) and 5% acetic acid; and 3CT, 200 ppm chlorine dioxide and 10% trisodium phosphate. $a^*$: -60 = green and +60 = red. Calculated as $630 \text{ nm reflectance}/580 \text{ nm reflectance}$. $b^*$: -60 = blue and +60 = yellow. Calculated as $\tan^{-1}(b^*/a^*)$. Calculated as $(a^* + b^*)^{1/2}$.

---


311
(a*; panel a) and oxymyoglobin content (630 nm/580 nm; panel b). The OC treatment was less (P<0.05) red (a*) on days 0 and 7 of display and contained less (P<0.05) oxymyoglobin (630 nm/580 nm) on day 0 of display, however, was not different (P>0.05) on days 1 through 3 for either a* or 630 nm/580 nm values when compared with C. The OA treatment was initially less (P<0.05) red (a*) than C and lost redness faster than any other treatment through display. Lower redness (a*) values for the OA treatment was caused by a reduced (P<0.05) oxymyoglobin (630 nm/580 nm) content by day 1 of display for this treatment compared with all other treatments. The lower oxymyoglobin content for the OA treatment was possibly due to heme iron oxidation in the porphyrin ring of myoglobin or to globin denaturation caused by the low pH of the acetic acid portion of this treatment. Bell et al. (1986) also observed discoloration of beef cubes when exposed to acetic acid treatment.

On day 0 of display, ground beef from the CT treatment was less (P<0.05) red (a*; Fig. 1, panel a), however not different (P>0.05) in oxymyoglobin content (630 nm/580 nm; Fig. 1, panel b) than C. Ground beef from the CT treatment was similar (P>0.05) in redness (a*) and oxymyoglobin content (630 nm/580 nm) on days 1–3 of display to C, however, by day 7, the CT treatment remained (P<0.05) redder (a*) in color and contained more (P<0.05) oxymyoglobin than all other treatments. Therefore, in addition to reducing EC, CO and APC in ground beef, CT tended to promote extended redness and oxymyoglobin stability through display compared to ground beef made from untreated trimmings (C).

The day of display by antimicrobial treatment interaction effect on the CIE b* value is shown in Fig. 1, panel c. Ground beef from the OC treatment was similar (P>0.05) in yellowness (b*) to C through display. Likewise, OA was not different (P>0.05) in yellowness (b*) on day 0 of display, however became less (P<0.05) yellow by day 1 and through the remainder of display compared with C. Ground beef from the CT treatment had lower (P<0.05) b* values on days 0 and 7 of display, however, was not different (P>0.05) on days 1–3 of display compared with C.

The hue angle, which is a calculated value using a* and b* values to determine the hue or color of a sample, is shown in Fig. 1, panel d. On day 0 of display, all treatments were similar (P>0.05) in hue angle to C. The OC and CT treatments were also similar (P>0.05) in hue angle to C on days 1–3 of display, however, by day 7, OC had a larger (P<0.05) hue angle and CT had a smaller (P<0.05) hue angle than C. The OA treated samples maintained a larger (P<0.05) hue angle from day 1–day 7 of display than all other treatments.

The saturation index, which is another mathematical calculation using a* and b* values to calculate vividness of color, is shown in Fig. 1, panel e. Because of lower a* and b* values, ground beef from the OA treatment was less (P<0.05) vivid in color (saturation index) by day 1, and through the remainder of display compared to all other treatments. Although ground beef from the CT treatment was less (P<0.05) vivid in color (saturation index) by day 1, and through the remainder of display compared to all other treatments. Although ground beef from the CT treatment was less (P<0.05) vivid in color (saturation index) by day 1, and through the remainder of display compared to all other treatments.

Fig. 2. Day of display by antimicrobial treatment interaction effect on the least square mean (±S.E.) sensory evaluated (a) overall color, (b) worst point color and (c) percentage discoloration of ground beef through simulated retail display. *a,bLeast square means within a day bearing different superscripts are different (P<0.05). cC, control; Oc, 15 min ozonated water bath (1%; 7.2 °C) and 5% cetypyridinium chloride; OA, 15 min ozonated water bath (1%; 7.2 °C) and 5% acetic acid; and CT, 200 ppm chlorine dioxide and 10% trisodium phosphate. Color score: 1 = brown and 5 = bright purple red. Percentage discoloration: 1 = total discoloration (96–100%) and 7 = no discoloration (0%).
index) initially (day 0), no difference (P > 0.05) in saturation index occurred between C, OC and CT treatments by day 1 and through the duration of display.

Fig. 2, panels a, b and c show the day of display by antimicrobial treatment interaction effect for overall color, worst point color and percentage discoloration, respectively. Sensory panelists found that ground beef from the OC treatment was less (P < 0.05) bright purple red in overall color on days 0, 1 and 7 of display, however found no difference (P > 0.05) in overall color on days 2 and 3 of display compared with C (panel a). By day 1, and through the duration of display, sensory panelists found worst point color to be similar (P > 0.05) between OC and C treatments (panel b). Likewise, by day 1 of display, no difference (P > 0.05) in percentage discoloration was evident between OC and C treatments until day 7 of display (panel c). In contrast, sensory panelists indicated that ground beef from the OA treatment was less (P < 0.05) bright purple red in overall (panel a) and worst point (panel b) color, and had a larger (P < 0.05) percentage surface discoloration (panel c) than C throughout display.

Beef treated with CT was not different (P > 0.05) from C on days 0–2 of display for overall color (Fig. 2, panel a) and percentage discoloration (Fig. 2, panel c). However, the CT treatment was brighter purple red (P < 0.05) in overall color (Fig. 2, panel a) and had less (P < 0.05) percentage discoloration (Fig. 2, panel c) than C on days 3 and 7 of display. In addition, the CT samples maintained a brighter (P < 0.05) purple red worst point color than all other treatments throughout display (Fig. 2, panel b). Therefore, treatment of beef trimmings before grinding with chlorine dioxide and CT not only reduced microorganisms in ground beef, but also improved color stability and shelf life extension.

4. Conclusion

Multiple antimicrobial intervention treatment combinations utilizing ozone, chlorine dioxide, cetylpyridinium chloride and trisodium phosphate on beef trimmings before grinding can be used to effectively reduce bacterial numbers with little effect on fresh ground beef color and odor characteristics. Therefore, the inclusion of multiple antimicrobial intervention technologies into ground beef processing systems could, if approved, provide an added measure of safety to ground beef without negatively impacting fresh product sensory characteristics.

Acknowledgements

Appreciation is expressed to the Arkansas Beef Council for funding this research. The authors would like to thank J. Davis, L. Rakes, A. Ivey, L. McBeth, R. Story and E. Kroger for their assistance in conducting these trials.

References


