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Impact of Multiple Antimicrobial Interventions on Ground Beef Quality

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Abstract: Multiple antimicrobial intervention strategies are employed in beef manufacturing, and some may impact quality and palatability of ground beef patties. Combinations of antimicrobial treatments – hot water (at least 82 °C), lactic acid (4.0 to 5.0%), acidified sodium chlorite (pH of 2.7 to 2.8) and Beefxide (lactic/citric acid mixture; up to 2.5%) – were applied to hot or chilled carcasses and trimmings before manufacturing ground beef patties, which were designated for color evaluation, consumer panel, or trained panel evaluation. Few significant changes were seen in color space values for each treatment combination. Consumer scores for overall liking, flavor liking, and beefy flavor liking were impacted ($P < 0.05$) by combined antimicrobial treatment effects. Trained panelists detected 18 out of 33 attributes with only scores for fat-like ($P = 0.0391$) and cardboardy ($P < 0.0001$) being impacted by treatments. No clear trends were related to any single or combined antimicrobial treatment, and findings support that these food safety interventions have minimal negative impacts on beef patty quality.

Keywords: antimicrobial, beef, intervention, trimmings
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Introduction

With the United States Department of Agriculture – Food Safety and Inspection Service (USDA-FSIS) declaration of *Escherichia coli* O157:H7 and Shiga-toxin producing *E. coli* as adulterants in non-intact raw beef products and intact raw beef products intended for non-intact use (USDA-FSIS, 2012), the addition of one or more antimicrobial interventions has become standard procedure during beef harvest and further processing. Despite best practices, microbial contamination of beef carcasses can be a direct result of harvesting cattle (Kang et al., 2001b). The implementation of multiple applications of antimicrobial interventions can mitigate possible contamination from the slaughter process and improve the microbiological quality of beef carcasses (Bacon et al., 2000).

Beef safety and quality are continuous challenges for the meat industry. A study conducted by Bacon et al. (2000) validated that sequential multiple hurdle interventions reduce bacteria on beef carcasses more effectively than any one intervention alone. In addition to the effectiveness of antimicrobial interventions, the impact of such treatments with respect to meat quality must be addressed. Consumers often associate meat quality with color and base buying decisions on such attributes (Mancini and Hunt, 2005). Therefore, considerations for the impact of implementing safety strategies are necessary to mitigate quality concerns. The goal of this study was to determine if multiple hurdle intervention combinations produced ground beef patties with quality (color) and palatability defects when compared to control patties.

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Material and Methods

Consumer panel procedures were approved by the Texas A&M Institutional Review Board (IRB2013-0060D).

Cattle harvest

Five head of cattle were purchased from a commercial feedyard. Cattle were harvested on the same day using normal slaughter procedures at the Rosenthal Meat Science and Technology Center, Texas A&M University, College Station, Texas.

Treatment design

For antimicrobial interventions, 5 treatment groups were compared for this project (Table 1). Treatments were assigned randomly to carcass sides (*n* = 10) during the slaughter process. Hot water (at least 82 °C) and lactic acid (4.0 to 5.0%) interventions were applied to hot carcass forequarters (because the application of lactic acid was a critical control point in the Rosenthal Meat Science and Technology Center's HACCP plan for beef slaughter, all hot carcasses received this intervention). In an effort to reduce variation in composition of trimmings among the carcasses, only forequarters were used. In subsequent treatments, lactic acid (4.0 to 5.0%), acidified sodium chlorite (pH of 2.7 to 2.8), and Beefxide (up to 2.5%) were applied to cold carcass forequarters and subsequent trimmings subgroups.

Hot carcass intervention application

Hot carcass interventions were applied to the carcass after a final wash step. Lactic acid was mixed in a plastic garden sprayer (Roundup Lawn & Garden Sprayer, model M2OP10, The Fountainhead Group, Inc., New York Mills, NY), heated in a hot water vat, and titrated before and after the intervention spray for the slaughter process (actual concentration: 4.9%). The lactic acid solution temperature was approximately 55 °C immediately before application and was applied to the entire side for 60 s (≈ 500 ml). The hot water intervention preparation was achieved using a metal garden sprayer (GroundWork model LFSX-CS20009, Tractor Supply, Brentwood, TN) submerged in a hot water vat at the final wash cabinet on the slaughter floor. The hot water intervention was applied to the forequarter only, at least 82 °C (85.1 °C average temperature for all sprays), for 90 s (≈ 250 ml). Temperature of each intervention was evaluated in the sprayer before application. Carcasses then were weighed, tagged, and chilled for 36 h at approximately 2 °C.

Cold forequarter intervention application and trimmings production

Before fabrication, carcass temperature and pH (Model IQ 150; Spectrum Technologies, Aurora, IL) were taken, and antimicrobial interventions were applied to the designated forequarters. Antimicrobial solutions were mixed in a plastic garden sprayer: lactic acid and Beefxide were heated in a hot water vat and applied at approximately 55 °C, and acidified sodium chlorite was applied at room temperature (≈ 25 °C). Interventions were titrated before and after fabrication to ensure proper concentration (actual concentrations: lactic acid: 4.3%; acidified sodium chlorite: pH of 2.8; Beefxide: 1.3%) and applied for 30 s (≈ 250 ml). Carcasses having received similar hot carcass and cold forequarter treatments were fabricated on the same table. The rib portion was removed and the remainder of the forequarter was separated into fat and lean trimmings and bone. All exposed exterior surfaces subject to the initial intervention sprays were included in the trimmings. Because of varying carcass compositions, excess intermuscular fat was removed from areas such as the plate to minimize variation due to fat differences among the carcasses. Trimmings were weighed, separated into 4 similar trimmings subgroups, and placed in individual plastic totes (*n* = 40). Each tote was covered

Table 1. Treatment design showing stages of antimicrobial intervention application

Application[1]	Treatment 1 - Control	Treatment 2	Treatment 3	Treatment 4	Treatment 5
Hot carcass	Lactic acid	Hot water and lactic acid	Hot water and lactic acid	Hot water and lactic acid	Hot water and lactic acid
Cold carcass	No intervention	No intervention	Lactic acid	Acidified sodium chlorite	Beefxide
Trimmings	No intervention (n = 2)	No intervention (n = 2)	No intervention (n = 2)	No intervention (n = 2)	No intervention (n = 2)
Trimmings	Lactic acid (n = 2)	Lactic acid (n = 2)	Lactic acid (n = 2)	Lactic acid (n = 2)	Lactic acid (n = 2)
Trimmings	Acidified sodium chlorite (n = 2)	Acidified sodium chlorite (n = 2)	Acidified sodium chlorite (n = 2)	Acidified sodium chlorite (n = 2)	Acidified sodium chlorite (n = 2)
Trimmings	Beefxide (n = 2)	Beefxide (n = 2)	Beefxide (n = 2)	Beefxide (n = 2)	Beefxide (n = 2)

[1]Following carcass treatments, trimmings were assigned to 1 of 4 treatment groups: control, lactic acid, acidified sodium chlorite, or Beefxide.

with plastic and placed on a rack in refrigerated storage (≈ 2 °C) until trimmings interventions were applied.

Trimmings antimicrobial application

For the application of the trimmings intervention spray, each trimmings subgroup of fresh beef trim was removed from refrigerated storage and placed on a mesh stainless steel screen to allow for even distribution. The cold forequarter and trimmings interventions were applied on the same day under the parameters described for forequarter intervention application. Temperature of antimicrobial solutions was taken before spraying each treatment subgroup. Trimmings were sprayed for either a 10 or 15 second interval (100 to 150 ml) based on the amount of trimmings. Trimmings temperature and pH were evaluated immediately before and after the intervention spray. Treated trimmings were returned to their respective plastic tote, covered, and placed in refrigerated storage (≈ 2 °C) for approximately 48 h before grinding. The antimicrobial solutions were titrated again following the trimmings intervention application to ensure consistent concentration throughout use (actual concentrations: lactic acid: 4.3%; acidified sodium chlorite: pH of 2.9; Beefxide: 1.2%).

Grinding and production of patties

Before grinding, temperature and pH were taken on all trimmings subgroups (*n* = 40). Trimmings subgroups were coarse ground through a 1.27 cm diameter plate followed by final grinding through a 0.32 cm diameter plate using a Biro meat grinder (Model 1056SS; Biro Manufacturing Company, Marblehead, OH). Temperature and pH were taken on all trimmings subgroups before and after the grinding process, and grinders underwent a thorough hot water rinse between subgroups. Ground product was placed back into a plastic tote, covered, and placed in refrigerated storage (≈ 2 °C) for approximately 12 h.

Ground beef from each trimmings subgroup (*n* = 40) were used to produce 21 patties (≈ 150 g each) using a hand press (Weston Products LLC, Strongsville, OH). Patties destined for color evaluation were assessed for color, pH, and temperature before being packaged with 57-gauge meat film (WP-MWL14, Performance Plastic Meat Film, U.S. Packaging & Wrapping, Cabot, AR) with an oxygen transmission rate (OTR) of 1,400 cc/254 cm^2 per 24 h @ 23°C, 1 atm on a plastic foam tray (Genpak 1004D [#4D] Foam Meat Tray Yellow, Genak, LLC, Charlotte, NC). All other patties were crust frozen, individually packaged in 17.8 × 30.5 cm Sealed Air Food Care 2.0 mil vacuum bags (Item No. B2870, Sealed Air, Charlotte, NC) with an OTR of 3 to 6 [1 cm^3 (STP) / (m^2-24 hr-1 atm) at 0% RH, 4.4 °C], boxed, and stored at approximately -10 °C until needed for subsequent evaluations.

Color evaluation

Patties were placed in a "retail-like" refrigerated (≈ 4 °C) setting to mimic retail display with 1,600 lx fluorescent lighting (Lithonia Lighting, Aculty Brands Lighting, Inc., Conyers, GA; 1,614 lux) using cool white bulbs to simulate a retail case. Color measurements were taken using a Hunter MiniScan EZ (HunterLab, Reston, VA) colorimeter on days 1, 2, 3, 4, and 5.

Sensory evaluation

Both consumer and trained panels were conducted for sensory evaluation. Patties were removed from frozen storage and allowed to thaw (≈ 2 °C) for approximately 18 h. Patties were cooked on Rival 11" Square Electric Skillets (Jarden Corporation, Boca Raton, FL). Internal temperatures were monitored using thermocouple readers (Omega HH506A, Stamford, CT) and 0.2 cm diameter copper-constantan Type-T thermocouple wires (Omega) inserted into the geometric center of each patty. Once the patty reached an internal temperature of 35 °C, the patty was flipped and cooked until the final internal temperature of 70 °C was reached. Each patty then was cut into 1/6 wedges and served warm in individual booths equipped with red theater gel lights. Samples were served in a random order and identified with random 3-digit codes. Unsalted saltine crackers and double distilled, deionized water, as well as ricotta cheese for the trained panel, were served to panelists to cleanse their palate between samples.

Consumer panelists (*n* = 80) were recruited from the Bryan/College Station area using an existing consumer database and informed consent was obtained for experimentation with human subjects. Panelists were asked to evaluate patty attributes based on a 9-point scale. Attributes included: overall liking (1 = dislike extremely; 9 = like extremely), flavor liking (1 = dislike extremely; 9 = like extremely), beefy flavor liking (1 = dislike extremely; 9 = like extremely), level of beefy flavor (1 = extremely bland or no flavor; 9 = extremely flavorful or intense), off-flavors (yes or no), intensity of off-flavors (1 = extremely bland or no flavor; 9 = extremely intense), tenderness liking (1 = dislike extremely; 9 = like extremely), juiciness liking (1 = dislike extremely; 9 = like extremely). Each panelist evaluated 10 samples per session. To avoid panelist fatigue, there was a 10-minute break halfway through the session.

A 6-member, trained panel (Meilgaard et al., 2007) was used to determine flavor attributes and aromatics as described by Adhikari et al. (2011) and American Meat Science Association (2016). Ballot development sessions and training, as defined by American Meat Science Association (2016), were conducted before trained panel sessions were held. Panelists were provided random treatment samples during training sessions and ballot adjustments were made. Definitions and references for attributes are outlined in Table 2. Trained panel sessions were not conducted until panelists were able to accurately describe selected sensory attributes (American Meat Science Association, 2016). The panelists evaluated samples using a 16-point universal scale where 0 = none and 15 = extremely intense for attributes defined during ballot development sessions (American Meat Science Association, 2016, Meilgaard et al., 2007). A total of 8 trained panel sessions were conducted with 10 samples evaluated per session.

Statistical analysis

All data were analyzed using JMP Pro, Version 12.0.1 (SAS Inst. Inc., Cary, NC). The Fit Model was used to determine the effects of carcass treatment group, trimmings subgroup, and their interaction. Color evaluation day was included where applicable. Least squares means were calculated; where ANOVA testing indicated significance ($\alpha < 0.05$), means were separated using the Student's t procedure.

Results and Discussion

Cold forequarter intervention spray

The pH values of surfaces were numerically lower (data not shown in tabular form) for treatments that received a cold forequarter carcass intervention spray (Treatments 3, 4, 5) compared to the surface pH before spraying. Similar results in surface pH decline were noted in studies that used lactic acid as well as multiple hurdle interventions on fresh beef trim (Ellebracht et al., 2005, Kang et al., 2001a). A study conducted by Hardin et al. (1995) also noted a pH decline when comparing the pre-treatment and post-treatment pH of the inoculated carcasses treated with either combined treatments of water and lactic acid or water and acetic acid.

Trimmings intervention spray

Least squares means for main effects (carcass treatment group and trimmings subgroup) for surface pH for the trimmings intervention sprays are shown in Table 3. There were no carcass treatment main effect differences in pH within the before ($P = 0.3743$) or after ($P = 0.5027$) treatment sprays. There were no differences ($P = 0.2824$) for surface pH before trimmings treatments. As the antimicrobial agent dissipated, the pH of meat surfaces returned to a normal level. Surface pH was lower ($P = 0.0168$) for all treatment combinations after trimmings interventions were applied. These results, showing a decrease in surface pH, were similar to those seen when interventions were applied as a cold forequarter treatment.

Production of patties

Quality parameters including pH and Commission Internationale de l'Eclairage (CIE) color space values (L^*, a^*, b^*) for beef patties following production are shown in Tables 4 and 5. Under normal conditions, the pH in beef muscle decreases from 7.0 upon slaughter to approximately 5.3 to 5.8. Although there were small, but significant differences among trimmings subgroups for pH (Table 4), there were no differences ($P = 0.7638$) for carcass treatments. There were carcass treatment group × trimmings subgroup interactions for L^* ($P = 0.0038$), a^* ($P = 0.0063$), and b^* ($P = 0.0253$) as shown in Table 5. For the first 3 carcass treatment groups, L^*, a^*, and b^* color space values differed within, whereas the color space values for the last 2 treatment groups did not differ. There was no apparent trend within the color space values for the influence of antimicrobial treatment on trimmings subgroup. Maca et al. (1997) found initial Hunter L^*, a^*, and b^* values to be lower for raw ground beef across organic acid treatments when compared to our study. This could be due to differences in antimicrobial compounds and application methods used across studies. Multiple applications of interventions in our study may be responsible for slightly higher L^*, a^*, and b^* values as compared to Maca et al. (1997).

Color evaluation

There were no differences ($P > 0.05$) in b^* CIE color space values observed for main effects or interactions over the "retail-like" storage display. Least squares means for beef patty L^* and a^* CIE color space values stratified by carcass treatment group × trimmings subgroup are shown in Table 6. There were

Table 2. Definition and reference standards for beef descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none; 15 = extremely intense adapted from Adhikari et al. (2011)

Attribute	Definition	References
Barnyard	Combination of pungent, slightly sour, hay-like aromatics. Associated with farm animals and the inside of a horn.	White pepper in water = 4.0 (F); 4.5 (A)
Beef identity	Amount of beef flavor identity in the sample.	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket = 11.0
Bleu cheese	The aromatics associated with bleu cheese.	
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% caffeine solution = 2.0 0.02% caffeine solution = 3.5
Bloody/ serumy	The aromatics associated with blood on cooked meat products. Closely related to metallic aromatic.	USDA choice strip steak = 5.5 Beef brisket = 6.0
Brown/ roasted	A round, full aromatic generally associated with beef suet that has been broiled.	Beef suet = 8.0 80% lean ground beef = 10.0
Burnt	The sharp/acrid flavor note associated with over-roasted beef muscle, something over-baked or excessively browned in oil.	Alf's red wheat puffs = 5.0
Cardboardy	Aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging.	Dry cardboard, 2.54 cm square = 5.0 (F); 3.0 (A) Wet cardboard, 2.54 cm square steeped in 236.6 mL water for 30 min = 7.0 (F); 6.0 (A)
Chemical	The aromatics associated with garden hose, hot Teflon pan, plastic packaging and petroleum based product such as charcoal liter fluid.	Zip-Loc sandwich bag = 13.0 Clorox in water = 6.5
Chocolate/ Cocoa	The aromatics associated with cocoa beans and powdered cocoa and chocolate bars. Brown, sweet, dusty, often bitter aromatics.	Hershey's cocoa powder in water = 3.0 Hersey's chocolate kiss = 8.5 (F)
Dairy	The aromatics associated with products made from cow's milk, such as cream, milk, sour cream or butter milk.	Dillon's reduced fat milk (2%) = 8.0
Fat-like	The aromatics associated with cooked animal fat.	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Fishy	The aromatics associated with fish.	Canned Starkist tuna = 12 (F); 10 (A)
Green-hay like	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley, and tea leaves.	Dry parsley in medium snifter = 5.0 (A) Dry parsley in ~30-mL cup = 6.0
Heated Oil	The aromatics associated with oil heated to a high temperature.	Wesson Oil, microwaved 3 min = 7.0 (F&A) Lay's Potato Chips = 4.0 (A)
Lactic acid	The aromatics associated with lactic acid antimicrobial.	Birko® lactic acid 88% FG, 2.5% and 5.0%
Liver-like	The aromatics associated with cooked organ meat/liver.	Beef liver = 7.5 Oscar Mayer Braunschweiger liver sausage = 10.0
Medicinal	A clean sterile aromatic characteristic of antiseptic like products such as Band-Aids, alcohol and iodine.	Band-Aid = 6.0 (A)
Metallic	The impression of slightly oxidized metal, such as iron, copper and silver spoons.	0.10% potassium chloride solution = 1.5 USDA choice strip steak = 4.0 Dole canned pineapple juice = 6.0
Musty-moldy/ hummus	Musty, sweet, decaying vegetation.	Sliced button mushrooms = 3.0 (F); 3.0 (A) 1000 ppm of 2,6-Dimethylcyclohexanol in propylene glycol = 9.0 (A)
Overall sweet	A combination of sweet taste and sweet aromatics. The aromatics associated with the impression of sweet.	Post-shredded wheat spoon size = 1.5 Hillshire farms Lit'l beef smokies = 3.0 SAFC ethyl maltol 99% = 4.5 (A)
Painty	Aromatics associated with paint container in 100 °C oven for 14 days.	Wesson oil placed in covered glass = 8 (F); 10 (A)
Rancid	The aromatics commonly associated with oxidized fat and oils. These aromatics may include cardboard, painty, varnish, and fishy.	Microwaved Wesson vegetable oil (3 min at high) = 7.0 Microwaved Wesson vegetable oil (5 min at high) = 9.0

Table 2 continued on next page

Table 2 continued from previous page

Attribute	Definition	References
Refrigerator stale	Aromatics associated with products left in refrigerator for an extended period of time and absorbing a combination of odors (lack of freshness/flat).	Ground beef cooked over medium-high heat to 165 ˚F, grease drained, store overnight in covered glass container at room temperature = 4.5 (F); 5.5 (A)
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5
Smoky wood	Dry, dusty aromatic reminiscent of burning wood.	Wright's Natural Hickory seasoning in water = 7.5 (A)
Sour aromatics	The aromatics associated with sour substances.	Dillon's buttermilk = 5.0
Sour dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.	Laughing cow light Swiss cheese = 7.0 Dillon's buttermilk = 9.0
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Spoiled	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates the product is starting to decay and putrefy.	Dimethyl disulfide in propylene glycol (10,000 ppm) = 12.0 (A)
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% accent flavor enhancer solution = 7.5
Warmed-over	Perception of a product that has been previously cooked and reheated.	80% lean ground beef (reheated) = 6.0

Table 3. Least squares means for surface pH of beef trimmings before and after antimicrobial trimmings treatments stratified by carcass treatment group and trimmings subgroup

		Surface pH	
Main effects	n[1]	Before treatment	After treatment
Carcass treatment group[2]			
Hot carcass = lactic acid	2	5.59	4.37
Hot carcass = hot water and lactic acid	2	5.71	4.05
Hot carcass = hot water and lactic acid; cold carcass = lactic acid	2	5.67	4.00
Hot carcass = hot water and lactic acid; cold carcass = acidified sodium chlorite	2	5.65	4.23
Hot carcass = hot water and lactic acid; cold carcass = Beefxide	2	5.51	4.51
$P > F$		0.3743	0.5027
Trimmings subgroup[3]			
Acidified sodium chlorite	10	5.64	4.52[a]
Beefxide	10	5.66	4.12[b]
Lactic acid	10	5.66	4.06[b]
Control	10	5.55	-
$P > F$		0.2824	0.0168
RMSE[4]		0.136	0.326

[a,b]Means within the same main effect column lacking a common letter differ ($P < 0.05$).

[1]n = number of forequarters per carcass treatment group and number of trimmings groups per trimmings subgroup treatment.

[2]Carcass treatment groups.

[3]Following carcass treatments, trimmings were assigned to one of four trimmings subgroups: acidified sodium chlorite, Beefxide, lactic acid or control. No antimicrobial intervention was applied to control trimmings, and thus was not included in the after treatment analysis.

[4]RMSE = Root mean square error from analysis of variance.

no clear trends for differences in color space values related to carcass treatment group and trimmings subgroup combinations. Least squares means for beef patty a^* CIE color space values stratified by color evaluation day × carcass treatment group are shown in Table 7. There were no differences ($P > 0.05$) among carcass treatment group in a^* values within color evaluation day over the first 3 days of the color evaluation period.

Table 4. Least squares means for beef patty pH on production day stratified by trimmings subgroup

Trimmings subgroup[1]	pH
Acidified sodium chlorite	5.74[a]
Beefxide	5.70[b]
Lactic acid	5.70[b]
Control	5.76[a]
P > F	0.0052
RMSE[2]	0.066

[a,b]Means within the same column lacking a common letter differ ($P < 0.05$).

[1]Following carcass treatments, trimmings were assigned to one of four trimmings subgroups: acidified sodium chlorite, Beefxide, lactic acid or control. No antimicrobial intervention was applied to control trimmings.

[2]RMSE = Root mean square error from analysis of variance.

However, by d 4, cold carcasses having received the lactic acid intervention, had among the lowest *a** values. Least squares means for beef patty *a** CIE color space values stratified by color evaluation day × trimmings subgroup are shown in Table 8. The *a** values for trimmings subgroups were similar within each color evaluation day for d 1, 2, and 3. However, on d 4 and 5, the patties from the lactic acid trimmings subgroup received among the lowest *a** values. After the initial drop in *a** values from d 1 to 3, patties produced from trimmings having received acidified sodium chlorite, maintained their color from d 3 to 5. The *a** values for carcasses and trimmings having received lactic acid interventions were among the lowest when compared

Table 5. Least squares means for beef patty CIE color space values (*L*, a*, b**) on production day stratified by carcass treatment group × trimmings subgroup

Carcass treatment group[1] × trimmings subgroup[2]	*L**	*a**	*b**
Hot carcass = lactic acid			
Acidified sodium chlorite	60.7[a]	17.3[cde]	20.5[abc]
Beefxide	54.4[ef]	19.0[abcd]	19.9[abcd]
Lactic acid	58.9[ab]	15.7[e]	18.1[def]
Control	56.5[bcde]	18.2[abcde]	21.2[a]
Hot carcass = hot water and lactic acid			
Acidified sodium chlorite	58.3[abcd]	15.8[e]	16.5[f]
Beefxide	54.3[ef]	19.0[abc]	19.3[abcde]
Lactic acid	52.5[f]	17.8[bcde]	18.2[cdef]
Control	55.9[bcde]	17.2[cde]	18.5[bcdef]
Hot carcass = hot water and lactic acid; cold carcass = lactic acid			
Acidified sodium chlorite	55.0[cdef]	20.6[a]	20.8[ab]
Beefxide	58.7[ab]	16.2[de]	17.0[ef]
Lactic acid	54.2[ef]	18.5[abcde]	19.2[abcde]
Control	55.1[cdef]	17.9[bcde]	18.4[cdef]
Hot carcass = hot water and lactic acid; cold carcass = acidified sodium chlorite			
Acidified sodium chlorite	56.5[bcde]	19.8[abc]	20.8[abcd]
Beefxide	55.4[bcdef]	18.3[abcde]	18.5[abcdef]
Lactic acid	56.9[bcde]	18.3[abcde]	18.9[abcdef]
Control	54.8[def]	20.6[ab]	20.6[abcd]
Hot carcass = hot water and lactic acid; cold carcass = Beefxide			
Acidified sodium chlorite	58.5[abc]	17.5[cde]	19.7[abcde]
Beefxide	57.3[abcde]	18.0[abcde]	19.2[abcdef]
Lactic acid	57.5[abcde]	19.0[abcd]	20.3[abcd]
Control	57.2[bcde]	17.9[abcde]	20.1[abcd]
P > F	0.0038	0.0063	0.0253
RMSE[3]	2.26	1.79	1.66

[a–f]Means within the same column lacking a common letter differ ($P < 0.05$).

[1]Carcass treatments were applied to hot carcasses and cold forequarters before trimmings were generated: hot carcass lactic acid application only; hot water applied to hot carcasses followed by hot carcass lactic acid application; hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter lactic acid spray; hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter acidified sodium chlorite spray; and hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter Beefxide spray.

[2]Following carcass treatments, trimmings were assigned to one of four trimmings subgroups: acidified sodium chlorite, Beefxide, lactic acid or control. No antimicrobial intervention was applied to control trimmings.

[3]RMSE = Root mean square error from analysis of variance.

Table 6. Least squares means for beef patty L^* and a^* CIE color space values over color evaluation period stratified by carcass treatment group × trimmings subgroup

Carcass treatment group[1] × trimmings subgroup[2]	CIE color space values	
	L^*	a^*
Hot carcass = lactic acid		
Acidified sodium chlorite	51.7[cdefg]	12.9[abcd]
Beefxide	50.8[fgh]	12.6[abcd]
Lactic acid	51.9[cdef]	12.1[de]
Control	53.8[a]	12.4[abcde]
Hot carcass = hot water and lactic acid		
Acidified sodium chlorite	49.9[h]	13.4[ab]
Beefxide	51.3[efg]	13.3[abc]
Lactic acid	51.7[cdefg]	11.9[de]
Control	52.3[bcde]	12.5[abcd]
Hot carcass = hot water and lactic acid; cold carcass = lactic acid		
Acidified sodium chlorite	51.6[defg]	12.8[abcd]
Beefxide	52.8[abcd]	10.6[f]
Lactic acid	53.0[abcd]	11.2[ef]
Control	53.1[abc]	12.4[abcd]
Hot carcass = hot water and lactic acid; cold carcass = acidified sodium chlorite		
Acidified sodium chlorite	52.9[abcd]	12.6[abcd]
Beefxide	50.2[gh]	13.5[a]
Lactic acid	53.6[ab]	11.7[def]
Control	52.1[cdef]	12.7[abcd]
Hot carcass = hot water and lactic acid; cold carcass = Beefxide		
Acidified sodium chlorite	54.1[a]	12.1[cde]
Beefxide	51.9[cdef]	12.8[abcd]
Lactic acid	54.2[a]	12.1[bcde]
Control	52.3[bcde]	12.4[abcde]
$P > F$	<0.0001	0.0101
RMSE[3]	2.13	1.81

[a–h]Means within the same column lacking a common letter differ ($P < 0.05$).

[1]Carcass treatments were applied to hot carcasses and cold forequarters before trimmings were generated: hot carcass lactic acid application only; hot water applied to hot carcasses followed by hot carcass lactic acid application; hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter lactic acid spray; hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter acidified sodium chlorite spray; and hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter Beefxide spray.

[2]Following carcass treatments, trimmings were assigned to one of four trimmings subgroups: acidified sodium chlorite, Beefxide, lactic acid or control. No antimicrobial intervention was applied to control trimmings.

[3]RMSE = Root mean square error from analysis of variance.

Table 7. Least squares means for beef patty a^* CIE color space values stratified by color evaluation day × carcass treatment group

Carcass treatment group[1]	Color evaluation day				
	1	2	3	4	5
Hot carcass = lactic acid	16.7[a]	14.0[b]	10.6[ef]	10.3[efg]	10.9[cdef]
Hot carcass = hot water and lactic acid	16.8[a]	13.7[b]	10.7[def]	10.4[ef]	12.2[c]
Hot carcass = hot water and lactic acid; cold carcass = lactic acid	15.7[a]	14.0[b]	11.2[cde]	8.9[g]	8.9[g]
Hot carcass = hot water and lactic acid; cold carcass = acidified sodium chlorite	16.8[a]	13.9[b]	10.7[ef]	9.8[fg]	12.1[cd]
Hot carcass = hot water and lactic acid; cold carcass = Beefxide	16.5[a]	14.2[b]	10.9[cdef]	9.8[efg]	10.3[efg]
$P > F$	0.0062				
RMSE[2]	1.81				

[a-g]Means lacking a common letter differ ($P < 0.05$).

[1]Carcass treatments were applied to hot carcasses and cold forequarters before trimmings were generated: hot carcass lactic acid application only; hot water applied to hot carcasses followed by hot carcass lactic acid application; hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter lactic acid spray; hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter acidified sodium chlorite spray; and hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter Beefxide spray.

[2]RMSE = Root mean square error from analysis of variance.

Table 8. Least squares means for beef patty *a** CIE color space values stratified by color evaluation day × trimmings subgroup

	Color evaluation day				
Trimmings subgroup[1]	1	2	3	4	5
Acidified sodium chlorite	16.5[a]	13.2[c]	11.0[def]	11.4[de]	11.7[d]
Beefxide	16.5[a]	14.1[bc]	10.8[defg]	9.9[fgh]	11.4[de]
Lactic acid	16.2[a]	14.1[bc]	10.4[efgh]	8.5[i]	9.8[gh]
Control	16.9[a]	14.4[b]	11.1[de]	9.4[hi]	10.6[defg]
$P > F$	0.0013				
RMSE[2]	1.81				

[a–i]Means lacking a common letter differ ($P < 0.05$).

[1]Following carcass treatments, trimmings were assigned to one of four trimmings subgroups: acidified sodium chlorite, Beefxide, lactic acid or control. No antimicrobial intervention was applied to control trimmings.

[2]RMSE = Root mean square error from analysis of variance.

to other treatment combinations. This may be a result of the additive effect of applying lactic acid sequentially. Stivarius et al. (2002) noted that hot water and lactic acid treatments applied to fresh beef trimmings before grinding resulted in little difference in overall color and discoloration when compared to a control treatment over their color evaluation period. The same study also found that *a** values decreased over the color evaluation period. These results are similar to those seen in this study. A decrease in *a** values denotes a decrease in oxymyoglobin content and is shown by decreased redness of the product over the display period (Stivarius et al., 2002). Quilo et al. (2010) also noted decreasing *a** values for antimicrobial treated ground beef versus the control over a 7-d color evaluation period, whereas Jimenez-Villarreal et al. (2003b) found no statistical difference in overall color among control and treated groups by the end of the 7-d display period. However, the use of varying antimicrobials as well as concentrations of those antimicrobials across studies might greatly impact the results regarding color over a color evaluation display period.

Sensory evaluation

Overall, few significant relationships were noted between the combined effects of multiple interventions and consumer perception on ground beef quality. Consumer panel scores for overall liking, flavor liking, and beefy flavor liking attributes were significantly ($P < 0.05$) impacted by combined antimicrobial treatment effects (Table 9). There were no differences ($P > 0.05$) detected by consumers for level of beefy flavor, off-flavors, intensity of off-flavors, tenderness liking, and juiciness liking. The acidified sodium chlorite treated trimmings from the hot carcass = lactic acid carcass treatment group, had among the lowest sensory attributes when compared to the other treatments within the same carcass treatment group. However, the acidified sodium chlorite trimmings for the remaining carcass treatment groups were similar for at least the overall liking ratings. Bosilevac et al. (2004) noted similar findings in a study using acidified sodium chlorite as an antimicrobial for ground beef products and stated that a lower dosage of the antimicrobial reduced the negative organoleptic effects. For the remaining treatment combinations, few differences were detectable by consumers.

Of the 33 attributes outlined in the trained panel ballot, panelists detected only 18 attributes over the course of this study (Table 10). Trained panelists were not able to detect the following attributes: barnyard, bleu cheese, chemical, chocolate/cocoa, fishy, green-hay like, liver-like, medicinal, musty-moldy/hummus, paint-like, refrigerator stale, smoky wood, sour aromatics, spoiled, and warmed-over. However, scores for fat-like were impacted by trimmings subgroup ($P = 0.0391$), with patties from the Beefxide trimmings subgroup receiving less intense ratings compared to those from lactic acid and acidified sodium chlorite, but not differing from the control. Additionally, scores for cardboardy were impacted ($P < 0.0001$) by the interaction of carcass treatment × trimmings subgroup (data not shown in tabular form). Although these patties were frozen immediately after production and thawed for approximately 18 h before each trained panel session, cardboardy attributes are typically considered indicators of oxidative rancidity. Further, on a 16-point scale (0 = attribute not detected; 15 = strong presence of attribute) panelists did not rate this attribute higher than a 3, with mean scores of 0.088 for cardboardy. Because attributes that showed significance returned low mean scores, there was no reason to believe that the antimicrobial intervention combinations impacted patty quality. Jimenez-Villarreal et al. (2003a) found that trained panelists were not able to detect any differences for beef flavor and off

Table 9. Least squares means for consumer sensory scores of beef patties stratified by carcass treatment group × trimmings subgroup

	Beef patty sensory attributes[1]		
Carcass treatment group[2] × trimmings subgroup[3]	Overall liking	Flavor liking	Beefy flavor liking
Hot carcass = lactic acid			
Acidified sodium chlorite	5.3[d]	5.4[d]	5.4[d]
Beefxide	6.8[a]	6.7[a]	6.7[ab]
Lactic acid	6.6[abc]	6.3[abc]	6.4[abc]
Control	6.2[abc]	5.9[abcd]	6.1[abcd]
Hot carcass = hot water and lactic acid			
Acidified sodium chlorite	6.2[abcd]	5.6[cd]	5.9[abcd]
Beefxide	6.4[abc]	6.4[abc]	6.4[abc]
Lactic acid	6.7[ab]	6.5[ab]	6.7[ab]
Control	6.6[abc]	6.4[abc]	6.7[ab]
Hot carcass = hot water and lactic acid; cold carcass = lactic acid			
Acidified sodium chlorite	6.8[ab]	6.7[a]	6.6[abc]
Beefxide	5.7[cd]	5.6[bcd]	5.9[bcd]
Lactic acid	6.8[ab]	6.8[a]	6.7[a]
Control	6.6[abc]	6.4[abc]	6.4[abc]
Hot carcass = hot water and lactic acid; cold carcass = acidified sodium chlorite			
Acidified sodium chlorite	6.0[abcd]	6.1[abcd]	6.1[abcd]
Beefxide	6.0[abcd]	6.2[abcd]	6.2[abcd]
Lactic acid	6.4[abc]	6.4[abc]	6.6[ab]
Control	6.5[abc]	6.2[abcd]	6.5[abc]
Hot carcass = hot water and lactic acid; cold carcass = Beefxide			
Acidified sodium chlorite	6.5[abc]	6.3[abcd]	6.4[abc]
Beefxide	6.1[abcd]	5.9[abcd]	6.4[abc]
Lactic acid	5.8[bcd]	5.6[bcd]	5.7[cd]
Control	6.2[abcd]	6.2[abcd]	6.8[ab]
$P > F$	0.0190	0.0246	0.0313
RMSE[4]	1.88	1.94	1.84

[a–d]Means within the same column lacking a common letter differ ($P < 0.05$).

[1]Overall liking (1 = dislike extremely; 9 = like extremely), flavor liking (1 = dislike extremely; 9 = like extremely), and beefy flavor liking (1 = dislike extremely; 9 = like extremely).

[2]Carcass treatments were applied to hot carcasses and cold forequarters before trimmings were generated: hot carcass lactic acid application only; hot water applied to hot carcasses followed by hot carcass lactic acid application; hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter lactic acid spray; hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter acidified sodium chlorite spray; and hot water applied to hot carcasses followed by hot carcass lactic acid application, followed by a pre-fabrication cold forequarter Beefxide spray.

[3]Following carcass treatments, trimmings were assigned to one of four trimmings subgroups: acidified sodium chlorite, Beefxide, lactic acid or control. No antimicrobial intervention was applied to control trimmings.

[4]RMSE = Root mean square error from analysis of variance.

flavor when comparing ground beef patties treated with multiple hurdle interventions and a control group, which supports current findings. The lack of differences noted by trained panelists across different studies suggests that multiple hurdle interventions can be used without negatively impacting taste attributes for ground beef.

Conclusions

Beef safety and quality are continuous challenges for the meat industry. With foodborne pathogens being of utmost concern, antimicrobial interventions are commonly used as a method to reduce the prevalence of pathogenic bacteria throughout the beef production process. Multiple hurdle antimicrobial intervention strategies are commonly employed in all facets of beef product manufacturing to ensure the highest level of food safety possible. In general, findings from this study show that food safety interventions, while effective in reducing microbiological counts on product surfaces, have minimal negative impacts on beef patty quality.

Table 10. Mean responses for sensory attributes detected by trained panelists[1]

Attributes	Overall mean	Standard deviation	Minimum	Maximum
Beef identity	6.0	0.51	4.8	7.2
Bitter	0.7	0.33	0.2	1.6
Bloody/serumy	0.9	0.49	0	2.4
Brown/roasted	2.1	0.78	0.2	3.5
Burnt	0.4	0.53	0	2.8
Cardboardy	0.1	0.16	0	0.6
Dairy	0.2	0.30	0	1.2
Fat-like	3.1	0.43	2.0	4.2
Heated oil	0.1	0.25	0	1.0
Lactic acid	0.1	0.20	0	1.0
Metallic	1.1	0.29	0.6	2.0
Overall sweet	0.6	0.30	0	1.4
Rancid	0.1	0.26	0	1.2
Salty	1.2	0.25	0.6	1.8
Sour dairy	0.1	0.22	0	0.8
Sour	0.9	0.55	0	2.2
Sweet	0.3	0.19	0	0.8
Umami	0.1	0.16	0	0.8

[1]Trained panelists evaluated samples using a 16-point universal scale with 0 = none and 15 = extremely intense for attributes. Of the 33 attributes outlined in the ballot, only 18 were detected by trained panelists.

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