Meat and Muscle Biology™

Changes in the Flavor Profile of Ground Beef Resulting from the Application of Antimicrobial Interventions

Michael J. Hernandez-Sintharakao[1,#], Joanna K. Swenson[1,#], Mahesh N. Nair[1]*, Ifigenia Geornaras[1], Terry E. Engle[1], Keith E. Belk[1], and Dale R. Woerner[2]

[1]Center for Meat Safety & Quality, Department of Animal Sciences, Colorado State University, Fort Collins, CO 80523, USA
[2]Department of Animal and Food Sciences, Texas Tech University, Lubbock, TX 79409, USA
*Corresponding author. Email: mahesh.narayanan_nair@colostate.edu (Mahesh N. Nair)
[#]These authors contributed equally and share co-first authorship in this work.

Abstract: The objective of this study was to characterize flavor, fatty acid composition, and volatile compounds of beef treated with common antimicrobial interventions in beef processing facilities. The effect of 3 prechilling antimicrobial interventions (4.5% lactic acid [LA]; 400 ppm peroxyacetic acid acidified to pH 1.2 with a sulfuric acid and sodium sulfate blend [aPAA]; or untreated control [CON]) and 4 postchilling treatments (CON; LA; aPAA; or a 2.5% solution of a commercial blend of lactic and citric acid [LAC]) were analyzed. Briskets ($n = 30$/treatment) were treated before and after chilling using a custom-built pilot-sized spray cabinet, ground twice, and formed into patties. Cooked patties were analyzed by a trained sensory panel, and a subset of raw samples ($n = 6$) were analyzed for fatty acid composition and volatile compounds. Samples treated with LA before and after chilling were more intense in sourness than the CON ($P < 0.05$). Fatty acid analysis showed no differences ($P > 0.05$) due to the use of chemical interventions. Only postchilling treatments had an effect on volatile compounds. The relative abundances of pentanal and pentanol were greater ($P < 0.05$) in LA-treated postchilling intervention samples than CON and LAC, hexanoic acid was greater ($P < 0.05$) in aPAA than CON and LAC, and acetic acid was greater ($P < 0.05$) in aPAA than LAC. Overall, these results demonstrated that LA pre- and postchilling antimicrobial interventions only impact the sourness of ground beef but did not affect the fatty acid composition, while postchilling antimicrobial treatments had a minimal impact on volatile compounds.

Key words: beef, flavor, sensory, antimicrobial interventions, fatty acids, volatile compounds
Meat and Muscle Biology 6(1): 13495, 1–12 (2022) **doi:10.22175/mmb.13495**
Submitted 2 December 2021 Accepted 5 April 2022

Introduction

Skeletal muscle from animals has historically been considered sterile prior to slaughter (Huffman, 2002). However, carcasses can become contaminated from the hide, fecal material, and abdominal contents from the animal itself as well as through cross-contamination during the slaughter process from tools, equipment, employees, and other contact surfaces (Lahr, 2001; Huffman, 2002). The United States Department of Agriculture Food Safety and Inspection Service requires that plants validate critical control points for food safety, which may include the use of chemical decontamination treatments applied to the surface of carcasses or cuts (FSIS, 1996). Multiple hurdle technology involves the application of several sequential treatments, which together are more effective at reducing microbial contamination levels than any single process (Delmore et al., 1998; Bacon et al., 2000; Kang et al., 2001). Therefore, sequential decontamination processes are commonly applied within the beef industry as a more effective method for controlling the risk of pathogens.

In the beef industry, various chemical and physical systems are used throughout the meat production chain to reduce pathogen contamination on beef hides, carcasses, and trimmings (Geornaras and Sofos, 2005). Numerous studies have reported on the decontamination efficacy of antimicrobials such

as lactic acid (LA), blends of LA with citric acid, peroxyacetic acid (PAA), acidified sodium chlorite, and hypobromous acid (Stivarius et al., 2002a; Ransom et al., 2003; Bosilevac et al., 2004; Gill and Badoni, 2004; Kalchayanand et al., 2009; Pohlman et al., 2009; Scott et al., 2015; Mohan and Pohlman, 2016). Most of these antimicrobial compounds are predominantly acidic, while others are strong oxidants, and there is concern that they may impact the taste of meat. Previous research has addressed the effects of chemical interventions on product pH, texture, color, and odor, but few studies have focused on flavor impacts (Pohlman et al., 2002; Stivarius et al., 2002b; Gill and Badoni, 2004; Quilo et al., 2009; McCarty et al., 2016). In addition, previous studies on beef consumer satisfaction have shown that flavor is the most important attribute in the overall likability of beef when tenderness is acceptable (Goodson et al., 2002; Killinger et al., 2004; Behrends et al., 2005; Hunt et al., 2014). Therefore, the objective of this study was to evaluate the effect of common antimicrobials used in combination on the flavor profile, fatty acid profile, and volatile components of ground beef.

Materials and Methods

Sample collection, fabrication, and treatment design

Ninety whole beef briskets were randomly selected and collected from separate carcasses the harvest floor of a commercial beef production facility over 2 separate production days before grading. Briskets were removed from the carcasses before grading and immediately transported (<30 min) in insulated coolers to the Colorado State University Meat Laboratory (Fort Collins, CO). For logistical and regulatory reasons, briskets were collected after antimicrobial treatments were applied on the harvest floor. Thus, the external surface of the briskets was trimmed prior to application of the treatments evaluated in our study as follows. Upon arrival, the entire external surface, sternum fat, and deckle fat of each brisket were quickly trimmed using a Whizard Quantum Trimmer (Quantum Q1400, Bettcher Industries, Birmingham, OH) to eliminate any potential antimicrobial treatment residues and ensure a minimal and uniform external fat level. The briskets remained warm (>30°C) until the prechilling treatment was applied to mimic an initial intervention on the harvest floor before carcass chilling.

This study was designed as a split-plot to evaluate the effect of 3 prechilling treatments and 4 postchilling ones. Trimmed whole briskets were randomly assigned to 1 of 3 prechilling treatments ($n = 30$ per treatment): an untreated control (CON), 400 ppm PAA (Kroff, Pittsburgh, PA) pH-adjusted (acidified) to a pH of 1.2 with a commercial blend of sulfuric acid and sodium sulfate (aPAA) (Centron; Zoetis, Parsippany, NJ), or 4.5% LA (Purac; Corbion, Lenexa, KS). The aPAA and LA treatments were applied to individual briskets using a custom-built pilot-sized spray cabinet (Birko/Chad Equipment, Olathe, KS). The spray cabinet was fitted with 18 FloodJet spray nozzles (378 cm^3 per minute; Spraying Systems Co., Glendale Heights, IL), with 10 nozzles positioned above the product belt and 8 nozzles below. The antimicrobial solutions were applied at a pressure of 1.34 kg/cm^2 with a product contact time of 15 s. Then, briskets were placed on plastic trays with stainless steel wire racks to allow for drying during the chilling period. The briskets were chilled uncovered at 2°C for approximately 24 h. After chilling, each brisket was divided into 4 equal parts, and all portions were randomly assigned to 4 postchilling intervention treatments ($n = 30$ per treatment): CON, aPAA, LA, or a 2.5% solution of a commercial blend of lactic and citric acid (LAC) (Beefxide; Birko Corporation, Henderson, CO). Postchilling treatments were sprayed following the same procedure as the prechilling treatments. Brisket portions were stored uncovered on drying racks (as previously described) at 2°C for approximately 72 h. Then, portions were individually coarse ground with a 9.5 mm plate (Model #1781, Big Bite #22 Stainless Steel Grinder; LEM, West Chester, OH), homogenized for 3 min using a hand mixer (MMX02, Uniworld Foodservice Equipment, Inc., Bell, CA), and finely ground using a 4.5 mm plate. The ground samples were formed into approximately 1 cm thick, 6 cm diameter, 28 g round patties using a manual patty forming device (Patty-O-Matic Eazy Slider; Patty-O-Matic, Farmingdale, NJ), crust frozen at −20°C for 30 min, vacuum packaged, and stored at −20°C until further analysis. A subset of samples was frozen by liquid nitrogen, homogenized using a blender (NutriBullet Lean, Pacoima, CA), packed in individual bags, and stored at −80°C for further chemical analysis (crude fat, fatty acid composition, and volatile compound analysis).

Trained sensory panel

The described protocol was evaluated by the Colorado State Research Integrity & Compliance Review Office, and it was approved as "exempt" (IRB number 355-18H) since it does not meet the requirements

of the federal definition of human subject research 45CFR46.102(f). Frozen patties were thawed for 12 h at 0°C to 2°C to attain raw internal temperatures of 0°C to 2°C at the time of cooking. Patties were cooked in an oven (Model SCC WE 61 E; Rational, Landsberg am Lech, Germany) at 204°C and 0% relative humidity to an internal temperature of 71°C to 74°C. Peak temperatures were recorded using a type-K thermocouple thermometer (AccuTuff 34032, Cooper-Atkins Corporation, Middlefield, CT). Immediately after cooking, samples were placed in a vacuum pouch bag, vacuum packaged, and held warm in a circulating water bath (Isotemp Heated Immersion Circulator: Model 6200 H24; Fisher Scientific, Waltham, MA) set at 57.5°C until served. Patties from each treatment ($n = 30$) were evaluated by a trained sensory panel consisting of 6 to 8 qualified panelists. Samples for sensory analysis were randomly assigned to 30 sessions to have a representation of each treatment group in every panel for a total of 12 samples per panel. A maximum of 2 sessions per day were performed, leaving 8 h resting time in-between. Patties were cut equally into fourths, allowing each panelist to receive 2 to 3 pieces, and served warm in individual booths equipped with a red incandescent light. Unsalted saltine crackers, apple juice, and distilled water were given to panelists for palate cleansing.

Panelists were trained to objectively quantify 11 flavor attributes from the Beef Lexicon (Adhikari et al., 2011) described in Table 1. Panelists objectively quantified attributes using an unstructured line scale anchored at both ends (0 = absence or low intensity of specified attribute, 100 = extreme intensity of specified flavor attribute). Panelist intensity scores were captured using an electronic ballot produced by an online survey software (Qualtrics, Provo, UT), and a single average for each sample was obtained.

Crude fat analysis

Lipid content was determined for all ground beef samples ($N = 360$) using a modified Folch method (Folch et al., 1957), as described by Phillips et al. (2010). Briefly, 1 g of sample was homogenized with 20 mL of chloroform-methanol solution (2:1, v/v). Samples were shaken at room temperature for 20 min and filtered using fat-free filter paper to remove the solid residues. The filtrate was mixed with 4 mL of 0.9% NaCl solution and held in refrigeration (0°C to 4°C) for 24 h to let the mixture separates into 2 phases. After refrigeration, the lower layer was pipetted and transferred to a clean glass vial. Samples were dried using a nitrogen evaporator for 2 h and then a forced air-drying oven for 12 h at 100°C. Fat percentage was calculated by dividing the fat weight by the weight of the original sample multiplied by 100.

Table 1. Definition and reference standards for beef descriptive flavor aromatics and basic taste sensory attributes and their intensities based on Adhikari et al. (2011) where 0 = none and 100 = extremely intense

Attribute	Definition	Reference
Beef Flavor	Amount of beef flavor identity in the sample	Swanson's beef broth = 35 80% lean ground beef = 4 Beef brisket (160°F) = 75
Bitter	The fundamental taste factor associated with a caffeine solution	0.01% caffeine solution = 15 0.02% caffeine solution = 25
Browned	Aromatic associated with the outside of grilled or broiled meat; seared but not blackened or burnt	Steak cooked at high temperature (internal 137°F, seared on outside)
Chemical	The aromatics associated with garden hose, hot Teflon pan, plastic packaging, and petroleum-based product such as charcoal liter fluid	Clorox in water = 45
Fat-Like	The aromatics associated with cooked animal fat	Hillshire Farm Beef Lit'l Smokies = 45 Beef suet = 80
Liver-Like	The aromatics associated with cooked organ meat/liver	Beef liver = 50
Metallic	The impression of slightly oxidized metal, such as iron, copper, and silver spoons	0.10% potassium chloride solution = 10 Select strip steak (60°C internal) = 25 Dole canned pineapple juice = 40
Rancid	The aromatics commonly associated with oxidized fat and oils. These aromatics may include cardboard, paint, varnish, and fishy.	Microwaved Wesson vegetable oil (3 min at high) = 45 Microwaved Wesson vegetable oil (5 min at high) = 60
Roasted	Aromatic associated with roasted meat	Precooked roast
Sour	The fundamental taste factor associated with citric acid	0.015% citric acid solution = 10 0.050% citric acid solution = 25
Warmed-Over Flavor	Perception of a product that has been previously cooked and reheated	80% lean ground beef (reheated) = 40

Fatty acid analysis

A subset ($n = 6$) of raw samples randomly selected from each treatment group were designated for fatty acid analysis. Lipids were extracted from allotted samples using the method described in the previous section, and saponification and methylation were performed using the protocol described by Park and Goins (1994). Briefly, 1 g of homogenized sample was mixed with chloroform:methanol (2:1 v/v) solution to extract the lipids. Extracted lipids were saponified with 0.5 N KOH in methanol solution at 70°C for 10 min. Internal standards (1 mg of C12:0 and C27:0) were incorporated to further fatty acid methyl esters (FAME) quantification. Samples were methylated with 14% BF_3 in methanol at 70°C for 30 min. Before gas chromatography (GC) analysis, samples were reconstituted with hexane.

FAME were analyzed using an Agilent Model 6890 Series II (Santa Clara, CA) gas chromatograph equipped with a 100 m by 0.25 mm fused silica capillary column (SP-2560; Supelco Inc., Bellefonte, PA). Helium was used as a carrier gas at a 1.0 mL/min flow rate. The column temperature was increased at 1°C/min from 150°C to 160°C, 0.2°C/min from 160°C to 167°C, increased at 1.5°C/min from 167°C to 225°C, and held for 16 min at the last temperature for a total running time of 100 min. Individual FAME were identified by comparing with internal standards and quantified as a percentage of total FAME.

Volatile compound analysis

A subset ($n = 6$) of raw samples randomly selected for volatile analysis corresponded with the subset of samples utilized for fatty acid analysis. Five grams of homogenized ground beef were weighed into a 20 mL headspace vial and stored at −80°C until analysis. Samples were incubated at 40°C for 30 min, and then the headspace volatiles were extracted by a Carboxen/polydimethylsiloxane fiber (85 µm, StableFlex, Sigma-Aldrich, St. Louis, MO) for 40 min following the method of Pérez et al. (2008) and injected into a DB-WAXUI column (30 m × 0.25 mm × 0.25 µm, Agilent) in a Trace 1310 GC (Thermo Scientific, Waltham, MA) coupled to an ISQ-LT mass spectrometer (Thermo Scientific). Solid-phase microextraction fiber was desorbed at the injection port (250°C) for 3 min and then at the fiber conditioning port (270°C) for 10 min. GC inlet was operated under splitless mode during fiber desorption. The oven program started at 35°C for 5 min, with the first ramp to 100°C at a rate of 8°C/min, the second ramp to 240°C at a rate of 12°C/min, and a final hold at 240°C for 5 min. Data were acquired under electron impact ionization mode, with full scan 35 to 350 amu and a scan rate of 10 scans/second. Transfer line and source temperatures were 250°C. A nontargeted processing method was used in Chromeleon software (Thermo Fisher Scientific, Waltham, MA). Twelve compounds were identified, and their retention times and peak width were built into the processing method. Chromeleon software was used to export the peak area of compounds of interest. GC-mass spectrometry spectra were annotated by matching unknown spectra to the NIST v12 EI spectral database. Additionally, an alkane mix of C:8 to C:20 was injected at the end of the sequence as a retention index standard to calculate Kovats Index and identify compounds. Spectra pattern, molecular ions, and fragments ions were used to identify compounds in addition to the indexes.

Statistical analysis

Data analyses were performed using R version 4.1.0 (R Core Team, 2018). Individual panelist flavor scores were averaged to obtain a single value for each flavor attribute of each sample. Data from the trained sensory panel were analyzed as a split-plot using the *lme4* package (Bates et al., 2015) with pre- and postchilling treatments and their interaction as fixed effects. Brisket number, panel number, feed order, and collection day were included as random effects in all models. Crude fat was used as a covariate in the model to analyze flavor attributes. To more accurately reflect production practices, only samples with crude fat levels of 5% to 20% were included in the analysis ($N = 298$). In further analysis, samples were stratified into 3 crude fat levels (LOW, 5% to 10% fat; MED, 10% to 15% fat; and HIGH, 15% to 20% fat), and flavor attributes were compared between fat levels along with pre- and postchilling treatments. Data from fatty acid and volatile compound analysis were analyzed as a split-plot, using pre- and postchilling treatments and their interactions as fixed effects and brisket number as random effect. The least-squares means of all response variables for treatments before and after chilling were analyzed using the *emmeans* package (Lenth, 2021) with $\alpha = 0.05$ and Kenward-Roger approximation for the degrees of freedom.

Results and Discussion

Trained sensory analysis

Since there was no significant ($P < 0.05$) interaction, only the main effects of pre- and postchilling

on sensory attributes were evaluated. The effects of prechilling treatments on ground beef sensory attributes assessed by trained panelists are presented in Table 2. Sourness was more intense ($P < 0.05$) in prechilling LA-treated samples than in the CON, but aPAA and control were similar ($P > 0.05$). These results were expected since LA has a sour taste and its sourness threshold (0.0027% in water) is relatively smaller than the concentration used in this study (Pangborn, 1963). Thus, the use of LA as an antimicrobial intervention likely contributes to sour flavor. Additionally, previous studies have indicated that the generation of LA by LA bacteria in vacuum-packed beef may be responsible for the development of sour taste (Pierson et al., 1970; O'Quinn et al., 2016). These results differ from Jimenez-Villarreal et al. (2003), who did not find differences in off-flavor between the control group and beef trimming treated with 2% LA before grinding. The differences may be because Jimenez-Villarreal et al. (2003) used a lower concentration of LA than the current study. Although acetic acid, which exists in equilibrium with PAA (Gehr et al., 2003), could also contribute to sourness, the concentration of aPAA used may not be enough to impact flavor.

Table 3 shows sensory attributes of the postchilling treatments. Sourness was the only attribute different ($P < 0.05$) due to the postchilling treatments. LA-treated samples were more sour than CON samples ($P < 0.05$) but did not differ from aPAA and LAC samples. Panelists may detect higher sourness in LA and not in LAC samples because the concentration of LA was 4% compared to 2.5% of LAC. In addition, the LAC solution contains a mix of LA and citric acid, which taste less sour than LA (Pangborn, 1963). These results were similar to those reported by Marcos et al. (2015), who did not find differences in beef flavor and off-flavor between untreated beef trimmings and samples treated with a single intervention of LAC (LA/citric acid 3:2, 2.5%) before processing them into ground beef.

Overall, the results of the pre- and postchilling treatments are in agreement with previous studies on the effect of antimicrobial interventions on beef odor and flavor. Several studies reported that a single LA and PAA interventions do not affect beef-odor and off-odor of raw beef (Stivarius et al., 2002b; Quilo et al., 2009; Marcos et al., 2015; Mahalitc, 2019; Han et al., 2021). Similarly, in the present study, no differences were found in other flavor attributes (e.g., beef flavor identity, browned, roasted), which result from a combination of odor and taste (Legako et al., 2015). Eastwood et al. (2018) also reported that multiple interventions (control, acidified sodium chloride, Beefxide, and LA) applied prechilling or postchilling on carcasses and on beef trimmings have minimum effect on ground beef flavor.

To determine the role of fat in flavor differences, 3 crude fat levels (LOW, MED, HIGH) were used as an interaction with pre- and postchilling treatments.

Table 2. Trained sensory attributes[1] of ground beef ($n = 30$ per treatment) representing 3 prechilling antimicrobial treatments[2]

	Prechilling Treatment[2]				
Attribute	CON	aPAA	LA	SEM[3]	*P* Value
Beef Flavor ID	44.23	45.03	44.36	0.78	0.29
Browned	35.73	36.79	36.05	0.75	0.08
Roasted	42.41	42.69	42.30	0.83	0.72
Fat-Like	15.62	15.99	16.43	0.63	0.43
Metallic	7.26	7.13	7.45	0.39	0.74
Sour	8.07[b]	8.77[ab]	10.03[a]	0.58	<0.01
Bitter	2.39	2.31	2.45	0.30	0.90
Rancid	1.68	1.48	2.04	0.33	0.24
Warmed Over	5.04	5.49	6.36	0.63	0.11
Liver-Like	1.52	1.68	1.24	0.25	0.28
Chemical	2.25	2.30	2.92	0.34	0.11

[a,b]Least-squares means in the same row without a common superscript differ ($P < 0.05$).

[1]Attributes were scored using a 100 mm unstructured line scale, anchored at both ends: 0 = absence, not present; 100 = extreme intensity of specified flavor attribute.

[2]Untreated control (CON; no interventions applied); peroxyacetic acid (400 ppm) acidified to a pH of 1.2 with a sulfuric acid and sodium sulfate blend (aPAA); lactic acid at 4.5% in solution (LA).

[3]Standard error (largest) of the least-squares mean.

Table 3. Trained sensory attributes[1] of ground beef ($n = 90$ per treatment) representing 4 postchilling antimicrobial treatments[2]

	Postchilling Treatment[2]					
Attribute	CON	aPAA	LA	LAC	SEM[3]	*P* Value
Beef Flavor	44.48	43.91	44.97	44.81	0.80	0.28
Browned	35.60	36.14	36.42	36.59	0.77	0.27
Roasted	42.16	42.07	42.73	42.91	0.83	0.26
Fat-Like	16.00	15.55	16.12	16.38	0.67	0.69
Metallic	6.98	7.24	7.55	7.34	0.40	0.64
Sour	8.14[b]	8.55[ab]	10.14[a]	8.99[ab]	0.59	<0.05
Bitter	2.44	2.78	2.20	2.12	0.31	0.16
Rancid	1.67	1.80	1.93	1.52	0.33	0.64
Warmed Over	5.09	6.44	5.54	5.45	0.65	0.25
Liver-Like	1.56	1.26	1.50	1.60	0.26	0.71
Chemical	2.10	2.55	2.96	2.35	0.34	0.11

[a,b]Least-squares means in the same row lacking a common superscript differ ($P < 0.05$).

[1]Attributes were scored using a 100 mm unstructured line scale, anchored at both ends: 0 = absence, low intensity, not present; 100 = extreme intensity of specified flavor attribute.

[2]Untreated control (CON; no interventions applied); peroxyacetic acid (400 ppm) acidified to a pH of 1.2 with a sulfuric acid and sodium sulfate blend (aPAA); lactic acid at 4.5% in solution (LA); lactic/citric acid blend at 2.5% in solution (LAC).

[3]Standard error (largest) of the least-squares mean.

Table 4. Trained sensory attributes[1] of ground beef across all treatments ($N = 298$), stratified into 3 fat levels[2]

	Fat Level[2]				
Attribute	LOW ($n = 130$)	MED ($n = 103$)	HIGH ($n = 65$)	SEM[3]	*P* Value
Beef Flavor ID	43.26[b]	44.92[a]	46.22[a]	0.80	<0.01
Browned	35.44[b]	36.45[ab]	37.29[a]	0.79	<0.01
Roasted	42.06	42.76	42.67	0.85	0.22
Metallic	8.15[a]	6.91[b]	6.04[b]	0.42	<0.01
Fat-Like	12.91[c]	16.60[b]	19.97[a]	0.62	<0.01
Sour	9.84[a]	8.57[b]	7.77[b]	0.63	<0.05
Bitter	2.55	2.57	1.84	0.33	0.06
Rancid	1.94	1.65	1.50	0.35	0.34
Warmed Over	6.87[a]	5.27[b]	3.92[b]	0.68	<0.01
Liver-Like	1.56	1.44	1.34	0.29	0.79
Chemical	2.96[a]	2.12[b]	2.39[b]	0.38	<0.05

[a–c]Least-squares means in the same row lacking a common superscript differ ($P < 0.05$).

[1]Attributes were scored using an unstructured line scale, anchored at both ends: 0 = absence, low intensity, not present; 100 = extreme intensity of specified flavor attribute.

[2]Samples were divided into 3 crude fat levels: LOW = 5% to 10%; MED = 10% to 15%; HIGH = 15% to 20%.

[3]Standard error (largest) of the least-squares mean.

The only significant ($P < 0.05$) 3-way interaction was for fat-like, which could be expected because crude fat level should be an indicator of fat-like flavors (Table 4). Therefore, the main effect of crude fat level was evaluated for each flavor attribute. No differences ($P > 0.05$) in roasted, bitter, rancid, or liver-like were found due to crude fat levels. Off-flavor attributes, including metallic, sour, warmed over, and chemical, were higher ($P < 0.05$) in the LOW-fat level group than the MED and HIGH levels. These results could be due to the HIGH samples having more fat to mask off-flavors or the fat repelling the antimicrobial solution. Potentially, there was less antimicrobial residue in higher fat samples because fat tissue tends to retain less surface moisture than lean tissues (Dickson, 1992). Browned flavor was lower ($P < 0.05$) in the LOW-fat level than the HIGH levels. As expected, fat-like perception increased ($P < 0.05$) with fat levels, with LOW levels having the lowest intensity ($P < 0.05$) and HIGH having the highest intensity ($P < 0.05$). Beef flavor

identity was more intense in MED and HIGH samples than LOW samples ($P < 0.05$). Berry (1992) and Troutt et al. (1992) reported that a higher percentage of fat in ground beef contributes to a more intense beef flavor. However, other authors did not find differences in beef flavor intensity when comparing ground beef patties with different fat percentages (Cross et al., 1980; Kregel et al., 1986; Blackmon et al., 2015). A possible explanation of these contrasts may be that the beef trimmings used to formulate the patties in the studies above were from different lean and fat sources and from combinations of different carcasses, while in the present study, individual patties came from a unique lean, fat, and carcass source. For example, in the study of Cross et al. (1980), ground beef patties were formulated combining lean from chucks trimmings with fat from flanks, plates, or kidney; and in the study of Blackmon et al. (2015), lean and fat trimmings from 4 different carcasses were combined to obtain specific fat percentages. Regardless of the flavor differences in all 3 levels of fat in the ground beef samples, they were not influenced by the antimicrobial interventions used in this study.

Fatty acid analysis

Results of the fatty acid analysis (Tables 5 and 6) were similar to those reported in other studies (Ekine-Dzivenu et al., 2014; Kerth et al., 2015) on the fatty acid composition of beef, and no differences ($P > 0.05$) were found due to the interventions in any of the fatty acids identified. Although the interventions involve the use of chemicals that could oxidize fatty acids (Smulders and Greer, 1998; Kitis, 2004), the concentrations applied in this study

Table 5. Percentages of neutral fatty acids identified for ground beef patties ($n = 24$ per treatment, $N = 72$) representing 3 prechilling treatments[1]

	Prechilling Treatment[1]				
Fatty Acid	CON	aPAA	LA	SEM[2]	*P* Value
C10:0	0.10	0.13	0.12	0.02	0.34
C12:0	0.084	0.091	0.089	0.008	0.80
C12:1	0.037	0.037	0.041	0.004	0.66
C14:0	2.04	1.91	1.98	0.04	0.12
C14:1	0.68	0.68	0.69	0.06	0.95
C16:0	22.69	22.36	22.51	0.13	0.18
C16:1	5.14	4.87	5.14	0.20	0.57
C17:0	1.28	1.30	1.27	0.03	0.81
C17:1	0.86	0.84	0.86	0.01	0.44
C18:0	13.78	14.38	13.94	0.32	0.39
C18:1 t6	0.41	0.39	0.40	0.02	0.64
C18:1 t8	0.42	0.40	0.41	0.01	0.56
C18:1 t10	3.76	3.62	3.68	0.12	0.76
C18:1 trans vaccenic	0.64	0.70	0.61	0.04	0.26
C18:1 c9	39.62	39.47	40.00	0.48	0.63
C18:1 c11	1.91	1.87	1.93	0.04	0.47
C18:2 (n-6)	4.78	5.12	4.59	0.20	0.26
C18:3	0.162	0.152	0.151	0.001	0.55
C18:2 c9 t 11	0.30	0.31	0.30	0.01	0.65
C18:2 t10 c12	0.029	0.027	0.028	0.005	0.94
C20:0	0.032	0.033	0.030	0.003	0.80
C20:1	0.09	0.07	0.08	0.02	0.96
C20:4	0.91	1.02	0.89	0.06	0.27
C20:5	0.016	0.016	0.013	0.005	0.86
C22:6	0.91	1.02	0.89	0.02	0.36
C24:0	0.16	0.18	0.16	0.01	0.24
Unknown	0.11	0.10	0.10	0.01	0.86

[1]Untreated control (CON; no interventions applied); lactic acid at 4.5% in solution (LA); peroxyacetic acid (400 ppm) acidified to a pH of 1.2 with a sulfuric acid and sodium sulfate blend (aPAA).

[2]Standard error (largest) of the least-squares mean.

Table 6. Percentages of neutral fatty acids identified for ground beef patties ($n = 18$ per treatment, $N = 72$) representing 4 postchilling treatments[1]

	Postchilling Treatment[1]					
Fatty Acid	CON	aPAA	LA	LAC	SEM[2]	*P* Value
C10:0	0.14	0.10	0.08	0.15	0.02	<0.05
C12:0	0.092	0.078	0.091	0.092	0.008	0.49
C12:1	0.036	0.042	0.036	0.040	0.004	0.61
C14:0	1.98	1.92	2.01	1.98	0.05	0.57
C14:1	0.64	0.71	0.66	0.71	0.07	0.61
C16:0	22.57	22.39	22.53	22.57	0.15	0.84
C16:1	4.84	5.26	4.94	5.15	0.24	0.61
C17:0	1.30	1.24	1.31	1.28	0.04	0.59
C17:1	0.84	0.88	0.85	0.85	0.02	0.41
C18:0	14.31	13.54	14.21	14.05	0.36	0.46
C18:1 t6	0.39	0.38	0.43	0.40	0.02	0.44
C18:1 t8	0.38	0.41	0.43	0.41	0.01	0.12
C18:1 t10	3.72	3.45	3.89	3.72	0.15	0.25
C18:1 trans vaccenic	0.63	0.61	0.67	0.70	0.04	0.24
C18:1 c9	39.33	40.70	39.26	39.51	0.51	0.25
C18:1 c11	1.85	1.94	1.91	1.90	0.05	0.54
C18:2 (n-6)	4.89	4.63	4.97	4.67	0.24	0.34
C18:3	0.162	0.167	0.152	0.152	0.007	0.87
C18:2 c9 t 11	0.31	0.29	0.30	0.31	0.01	0.35
C18:2 t10 c12	0.029	0.029	0.025	0.029	0.008	0.95
C20:0	0.038	0.029	0.028	0.030	0.004	0.27
C20:1	0.07	0.09	0.08	0.07	0.03	0.85
C20:4	0.97	0.92	0.96	0.91	0.07	0.89
C20:5	0.016	0.019	0.017	0.007	0.006	0.51
C22:6	0.95	0.94	0.98	0.89	0.07	0.67
C24:0	0.17	0.16	0.17	0.16	0.01	0.71
Unknown	0.11	0.09	0.10	0.11	0.01	0.36

[1]Untreated control (CON; no interventions applied); lactic acid at 4.5% in solution (LA); lactic/citric acid blend at 2.5% in solution (LAC); peroxyacetic acid (400 ppm) acidified to a pH of 1.2 with a sulfuric acid and sodium sulfate blend (aPAA).

[2]Standard error (largest) of the least-squares mean.

might not be enough to affect the fatty acid composition. In the current study, the most predominant fatty acids were C18:1 n-9, C16:0, and C18:0. These results are similar to the results obtained by Ekine-Dzivenu et al. (2014) and Kerth et al. (2015), who characterized the fatty acid composition of beef briskets. Previous research reported a positive correlation of C18:0, C16:0, and polyunsaturated fatty acids levels with some off-flavor attributes and a negative correlation with desirable flavor attributes of beef (Melton et al., 1982; Campo et al., 2003; O'Quinn et al., 2016). In contrast, monounsaturated fatty acids are positively correlated with desirable beef flavor attributes (Melton et al., 1982; O'Quinn et al., 2016). The lack of differences in the fatty acid profile of the different treatments before and after chilling might partly explain the minimal variation in the flavor profile observed in the current study.

Volatile compounds

The relative abundance of volatile organic compounds identified are presented in Tables 7 and 8. There were no differences ($P > 0.05$) in volatile components in prechilling treatments. As expected, hexanal was a dominant component, as it is a major contributor to volatile compounds of meat products and is a main volatile indicator of lipid oxidation (Shahidi and Pegg, 1994; Fernando et al., 2003). However, no differences were found in hexanal ($P > 0.05$) for any pre- and postchilling treatment. In postchilling treatments (Table 7), the concentration of acetic acid in aPAA was higher than in LAC samples ($P > 0.05$). These results were expected since PAA in aPAA is in equilibrium with acetic acid and hydrogen peroxide (Gehr et al., 2003). Pentanal and pentanol were greater ($P < 0.05$) in LA-treated samples than CON and LAC samples (Table 8). Hexanoic acid abundance was greater

Table 7. Relative abundance of volatile compounds as percent of compounds identified for ground beef patties ($n = 24$ per treatment, $N = 72$) representing 3 prechilling treatments[1]

	Prechilling Treatment[1]				
Compound	CON	aPAA	LA	SEM[2]	*P* Value
Pentanal	4.09	4.61	5.31	0.61	0.32
Hexanal	71.49	75.83	71.51	3.44	0.58
Propanol	0.26	0.34	0.30	0.06	0.66
Pentanol	4.95	5.11	5.22	0.65	0.95
P-xylene	0.34	0.28	0.31	0.08	0.85
Acetoin	11.15	6.31	9.39	1.60	0.10
Octanedione	0.35	0.32	0.38	0.07	0.83
Acetic acid	6.36	6.38	6.53	1.18	0.99
Butanoic acid	0.61	0.42	0.56	0.09	0.27
Benzaldehyde	0.06	0.10	0.11	0.02	0.23
Pentanoic acid	0.10	0.10	0.11	0.01	0.51
Hexanoic acid	0.21	0.22	0.27	0.02	0.07

[1]Untreated control (CON; no interventions applied); peroxyacetic acid (400 ppm) acidified to a pH of 1.2 with a sulfuric acid and sodium sulfate blend (aPAA); lactic acid at 4.5% in solution (LA).

[2]Standard error (largest) of the least-squares mean.

Table 8. Relative abundance of volatile compounds as percent of the compounds identified for ground beef patties ($n = 18$ per treatment, $N = 72$) representing 4 postchilling treatments[1]

	Postchilling Treatment[1]					
Compound	CON	aPAA	LA	LAC	SEM[2]	*P* Value
Pentanal	3.56^{b}	5.44^{ab}	6.56^{a}	3.13^{b}	0.71	<0.01
Hexanal	76.65	66.95	68.47	79.71	4.01	0.05
Propanol	0.30	0.29	0.31	0.28	0.07	0.99
Pentanol	3.86^{b}	6.16^{ab}	6.63^{a}	3.71^{b}	0.76	<0.01
P-xylene	0.28	0.42	0.36	0.29	0.10	0.34
Acetoin	8.67	10.14	9.33	7.66	1.87	0.78
Octanedione	0.21	0.40	0.51	0.26	0.08	0.05
Acetic acid	5.67^{ab}	9.02^{a}	6.74^{ab}	4.25^{b}	1.38	0.08
Butanoic acid	0.53	0.56	0.59	0.44	0.11	0.71
Benzaldehyde	0.05	0.12	0.11	0.06	0.03	0.14
Pentanoic acid	0.09	0.12	0.12	0.10	0.01	0.06
Hexanoic acid	0.16^{c}	0.32^{a}	0.27^{ab}	0.19^{bc}	0.03	<0.01

[a–c]Least-squares means in the same row lacking a common superscript differ ($P < 0.05$).

[1]Untreated control (CON; no interventions applied); peroxyacetic acid (400 ppm) acidified to a pH of 1.2 with a sulfuric acid and sodium sulfate blend (aPAA); lactic acid at 4.5% in solution (LA); lactic/citric acid blend at 2.5% in solution (LAC).

[2]Standard error (largest) of the least-squares mean.

($P < 0.05$) in aPAA samples than LAC and CON, and higher in LA than the CON ($P < 0.05$). Stetzer et al. (2008) reported that pentanal and hexanoic acid are positively correlated with livery off-flavor, while O'Quinn et al. (2016) reported that pentanal was positively correlated with buttery and sweet flavor. Hexanoic acids aroma has been described as pungent, blue cheese, and sour (Lecanu et al., 2002). However, none of these compounds seemed to affect the flavor profile of treated samples.

Aldehydes, ketones, and alcohols could result from lipid oxidation (Mezgebo et al., 2017), which might explain why aPAA and LA samples had slightly higher values for some of these compounds. The aPAA solution contains PAA and sulfuric acid, both of which are oxidant agents. Although the LA is a weak acid, it can work as an oxidant when in contact with the meat at higher pH. Moreover, McCoy et al. (2018) reported that PAA and LA interventions increase lipid oxidation. On the contrary, Quilo et al. (2009) reported that

PAA reduced lipid oxidation when used as an antimicrobial agent on ground beef, while Jimenez-Villarreal et al. (2003) did not find any differences in lipid oxidation during the initial days of display in samples treated with LA compared to untreated samples. Higher pentanal, pentanol, and hexanoic acid concentrations could suggest higher lipid oxidation. However, the reason for the lack of difference in hexanal abundance between the treatment groups is unclear.

Conclusions

With multiple interventions being currently utilized during beef processing, it is inevitable that the residues of the applied chemicals might remain on beef primals and trimmings. The results of the current study showed that spray application of antimicrobials that resemble interventions during the slaughter process, before and after chilling of carcasses, could impact beef flavor, with the LA application as a pre- or postchilling treatment resulting in higher sourness. When considering the fat level of the samples, pre- and postchilling interventions had a greater influence in leaner samples with the samples in the LOW-fat group (5% to 10% crude fat) having higher intensities of off-flavor attributes, including metallic, sour, warmed over, and chemical. Overall, the pre- and postchilling antimicrobial treatments did not influence the fatty acid composition, and only postchilling interventions impacted the volatile compounds.

Acknowledgements

The authors declare that they have no conflicts of interest. Funding for this research was provided in part by The Beef Checkoff. The use of trade names in this publication does not imply endorsement or criticism by Colorado State University of those or similar products not mentioned.

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