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Electrostatic spraying of antioxidants on the oxidative quality of ground beef[1]

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ABSTRACT: To prevent oxidative quality changes, a few selected antioxidants, ascorbic acid, or an ascorbic acid plus α-tocopherol combination were electrostatically sprayed on the surface of ground beef patties. Color, metmyoglobin, oxidation-reduction potential, lipid oxidation, and volatiles of the samples were determined during the 8 d of aerobic storage. Spraying of ascorbic acid at 500 mg/kg was the most effective in controlling discoloration of ground beef. Spraying of ascorbic acid at 500 mg/kg was also effective in reducing 2-thiobarbituric acid-reactive substances and volatile aldehydes such as hexanal and heptanal related to lipid oxidation. Spraying of phenolic antioxidants such as tocopherol, sesamol, or rosemary oleoresin showed significant ($P < 0.05$) antioxidant effects, but had no effects ($P < 0.05$) in stabilizing the color of ground beef. Sesamol at 100 mg/kg showed the most potent antioxidant activities among the antioxidants, and its antioxidant effect was as strong as that of 500 mg/kg of ascorbic acid. It was concluded that electrostatic spray of ascorbic acid on the surface of ground beef at 500 mg/kg was an efficient and economical way to prevent both lipid oxidation and color changes in ground beef.

Key words: antioxidant, color, electrostatic spray, ground beef, lipid oxidation, reducing agent

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INTRODUCTION

Ground beef is a popular meat product in commercial markets and makes up more than 40% of beef consumption in the United States (AMI, 1998). However, ground beef is the most susceptible form of beef to lipid oxidation, color changes, and microbial contamination due to increased surface area, mixing, and air incorporation during preparation (Ahn and Nam, 2004). Ground beef is more susceptible to oxidative changes than ground pork or poultry, and lipid oxidation deteriorates odor and color of ground beef (Min et al., 2008). Color is a prime quality variable that determines consumer acceptance of meat (Seideman et al., 1984). Liu et al. (1995) reported that the loss of value due to discoloration in beef at the retail level in the United States could be more than $700 million per year. Therefore, minimizing lipid oxidation and color change is critical to improve consumer acceptance of ground beef.

To prevent oxidative quality changes in meat and meat products, food additives such as antioxidants and reducing agents can be added (Xiong et al., 1993; Morrissey et al., 1998). Antioxidants are used in fresh and further processed meats to prevent oxidative rancidity and improve color stability. Some phenolic antioxidants such as vitamin E have free radical-scavenging properties and terminate free-radical reactions in meat during storage (Gray et al., 1996; Morrissey et al., 1998; Nam and Ahn, 2003). Ascorbic acid is a reducing agent that inhibits myoglobin oxidation and brown color development in beef (Wheeler et al., 1996; Lee et al., 1999; Sanchez-Escalante et al., 2001). The combinations of phenolic antioxidants such as gallate, sesamol, and tocopherol were effective in reducing oxidative reactions in irradiated pork by scavenging free radicals produced by irradiation (Nam and Ahn, 2003).

The antioxidant and reducing agent are mixed into meat during processing and are evenly distributed to all parts of the meat. Oxidative deterioration of meat is more serious at outer surfaces of meat product than inside because the outer part is in direct contact with oxidative initiators such as oxygen and light (O'Grady

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et al., 2000). Therefore, spraying antioxidants or reducing agents on the surface of meat products can be an effective way of preventing quality changes.

Electrostatic spraying has been used to spray disinfectants on the surface of food processing equipments and animal carcasses, or to spray pesticides and agrichemicals on the surface of fruits and vegetables (Adams and Palmer, 1989; Russell, 2003). Electrostatic spraying utilizes electrically charged spray droplets that can be easily attached to the nonuniform or hidden surfaces of foods or equipment (ESS MaxCharge Inc., 2010). The objective of this study was to determine the effect of selected food antioxidants and ascorbic acid electrostatically sprayed onto the surface of ground beef on lipid oxidation, color, and oxidative volatiles during storage.

MATERIALS AND METHODS

Animal Care and Use Committee approval was not obtained for this study because the samples were obtained from a federally inspected slaughter facility.

Sample Preparation

Beef loins (LM) were obtained from 4 different carcasses 14 d after slaughter in the Meat Laboratory at Iowa State University (Ames, IA) were used in this study. Four muscles taken from 4 carcasses were treated as 4 replications. Each muscle was trimmed and ground separately through a 3-mm plate and beef patties (approximately 50 g each) were prepared. Approximate amount of each patty was measured (50 g) using a balance, and then patty was made by hand to ensure that each patty is uniform in thickness and surface area so that treatments can be uniformly applied. Seven different treatments were prepared: 1) control, no additive; 2) ascorbic acid (EC No. 200-066-2), 500 mg/kg; 3) α-tocopherol (EC No. 200-412-2), 100 mg/kg; 4) γ-tocopherol (EC No. 200-201-5), 100 mg/kg; 5) sesamol (EC No. 208-561-5), 100 mg/kg; 6) rosemary oleoresin, 100 mg/kg; and 7) ascorbic acid, 500 mg/kg + α-tocopherol, 100 mg/kg. Ascorbic acid (EC No. 200-066-2), tocopherols, and sesamol were purchased from Sigma Chemical Co. (St. Louis, MO), and rosemary oleoresin from Ecom Manufacturing Corp. (Scarborough, Ontario, Canada), and the concentrations of all the antioxidants used were final (wt/wt). The additive treatments were applied in solution form: ascorbic acid and sesamol were dissolved in distilled water, whereas water-insoluble antioxidants (α-tocopherol and γ-tocopherol) were dissolved first in corn oil and then oil emulsion was prepared using the aqueous solutions of ascorbic acid or water (0.8 g of tocopherol, 4 g of corn oil, 35.2 g of water, and 20 mg of lecithin). A Waring blender (Dynamics Corp. America Co., New Hartford, CT) at 22,000 rpm for 2 min was used to prepare oil emulsion. The solutions were sprayed on both sides of beef patties using an electrostatic sprayer (model ESS XT-3, ESS MaxCharge Inc., Watkinsville, GA). Each patty was sprayed with 0.25 mL of 10% ascorbic acid, 2% α-tocopherol, 2% γ-tocopherol, 2% sesamol, 2% rosemary oleoresin, or 10% ascorbic acid + 2% α-tocopherol solution. To apply the target amount, we prepared the same number of patties on trays and then sprayed each of the treatments at 206,842 Pa of air pressure and 40-micron drop size for 2 min using an electrostatic spraying device and then measured the amount of treatments deposited on each patty per minute. The exact spray time needed for the electrostatic spray was calculated. Beef patties were individually packaged in oxygen-permeable bags (polyethylene, 2,300 mL/m^2 per 24 h, 10.16 × 15.24 cm, 2 mm thickness, Associated Bag Company, Milwaukee, WI) and stored at 4°C for 8 d. After storage of 1, 5, and 8 d, color, metmyoglobin, oxidation-reduction potential, lipid oxidation, and volatiles of the samples were determined at 3 or 4 repetitions using separately prepared samples.

Color Measurement

The CIE color values were measured on the surface of meat samples using a LabScan colorimeter (Hunter Associated Labs Inc., Reston, VA) using an illuminant A with a 1.225-cm aperture. The colorimeter was calibrated against a black and a white reference tile covered with the same packaging bags used for samples. The color lightness (**L***), redness (**a***), and yellowness (**b***) values were obtained. An average value from 2 random locations on each sample surface and bottom was used for statistical analysis.

Metmyoglobin Contents

Meat sample (1 g) was homogenized with 9 mL of 0.04 *M* phosphate buffer (pH 6.8, 4°C) using a Brinkman Polytron (type PT 10/35, Brinkman Instrument Inc., Westbury, NY) for 10 s at high speed. Meat homogenate (1 mL) was centrifuged at 8,000 × *g* at 4°C for 1 min, and the absorbances of the supernatant were immediately measured at 525, 572, and 700 nm using a spectrophotometer (Beckman DU 640, Beckman Instruments Inc., Fullerton, CA). Total metmyoglobin percentage was calculated using the following formula (Trout, 1989):

$$\text{metmyoglobin (\%)} = \{1.395 - [(A_{572} - A_{700})/(A_{525} - A_{700})]\} \times 100,$$

where A is absorbance at the wavelength indicated (nm).

Oxidation-Reduction Potential

To reduce the deviation of oxidation-reduction potential (**ORP**) values depending on the location of a meat patty, a modified method using meat homogenate was

used. Meat sample (5 g), 15 mL of deionized distilled water, and 50 μL of butylated hydroxytoluene (7.2% in ethanol) were placed in a 50-mL test tube and were homogenized using a Brinkman Polytron (type PT 10/35) for 15 s at high speed. The ORP values of homogenates were determined using a pH/ion meter (Accumet 25, Fisher Scientific, Fair Lawn, NJ) equipped with a platinum electrode filled with an electrolyte solution (4 *M* KCl saturated with AgCl).

2-Thiobarbituric Acid-Reactive Substances

Lipid oxidation was determined using a 2-thiobarbituric acid (**TBA**)-reactive substances (**TBARS**) method (Ahn et al., 1999). Minced sample (5 g) was placed in a 50-mL test tube and homogenized with 15 mL of deionized distilled water using a Brinkman Polytron (type PT 10/35) for 15 s at high speed. The meat homogenate (1 mL) was transferred to a disposable test tube (13 × 100 mm), and butylated hydroxytoluene (7.2%, 50 μL) and a TBA/trichloroacetic acid (**TCA**) [20 m*M* TBA and 15% (wt/vol) TCA] solution (2 mL) were added. The sample was mixed using a vortex mixer and then incubated in a 90°C water bath for 15 min to develop color. After cooling for 10 min in cold water, the samples were vortex-mixed and centrifuged at 3,000 × *g* for 15 min at 5°C. The absorbance of the resulting upper layer was read at 531 nm against a blank prepared with 1 mL of deionized distilled water and 2 mL of TBA/TCA solution. The amounts of TBARS were expressed as milligrams of malondialdehyde per kilogram of meat.

Volatile Compounds

A purge-and-trap apparatus (Solatek 72 and Concentrator 3100, Tekmar-Dohrmann, Cincinnati, OH) connected to a gas chromatograph/mass spectrometer (HP 6890/HP 5973, Hewlett-Packard Co., Wilmington, DE) was used to analyze volatiles produced (Ahn et al., 1999). The meat sample (3 g) was placed in a 40-mL sample vial, and the vial was flushed with helium gas (275,789 Pa) for 5 s to minimize oxygen content in the vial. The sample was purged with helium gas (40 mL/min) for 14 min at 40°C. Volatiles were trapped using a Tenax-charcoal-silica column (Tekmar-Dohrmann) and desorbed for 2 min at 225°C, focused in a cryofocusing module (−80°C), and then thermally desorbed into a capillary column for 60 s at 225°C.

An HP-624 column (15 m × 0.25 mm i.d., 1.4 μm nominal), an HP-1 column (60 m × 0.25 mm i.d., 0.25 μm nominal; Hewlett-Packard), and an HP-Wax column (15 m × 0.25 mm i.d., 0.25 μm nominal) were connected using zero dead-volume column connectors (J&W Scientific, Folsom, CA). Ramped oven temperature was used to improve volatile separation. The initial oven temperature of 30°C was held for 6 min. After that, the oven temperature was increased to 60°C at 5°C/min, increased to 180°C at 20°C/min, increased to 210°C at 15°C/min, and then was held for 5 min at the temperature. Constant column pressure at 155,131 Pa was maintained. The ionization potential of the mass-selective detector (model 5973, Hewlett-Packard) was 70 eV, and scan range was 19.1 to 400 *m/z*. Identification of volatiles was achieved by comparing mass spectral data of samples with those of the Wiley Library (Hewlett-Packard). Standards were used to confirm the identification by the mass-selective detector. The area of each peak was integrated using the ChemStation (Hewlett-Packard), and the total peak area (pA × s) was reported as an indicator of volatiles generated from the sample.

Statistical Analysis

A completely randomized design with 7 treatments and 4 replications (4 loins) was used. Data were analyzed using the generalized linear model procedure (SAS Inst. Inc., Cary, NC). Student-Newman-Keul's multiple-range test was used to determine significant differences between the mean values of treatments. Mean values and SEM were reported. Significance was defined at $P < 0.05$.

RESULTS AND DISCUSSION

Color

The bright red color of ground beef on d 1 faded gradually during 8 d of storage. The CIE color L*, a*, and b* values of ground beef significantly decreased ($P < 0.05$) during the aerobic storage (Table 1). The color a* values of control ground beef after 5 and 8 d of storage under aerobic conditions were 53 and 34% of the d 1 values, respectively, indicating that the heme pigments of ground beef can be easily oxidized.

Among the treatments, ascorbic acid was the most effective in preventing the discoloration of ground beef during storage. The a* values of ground beef sprayed with ascorbic acid were not changed for 5 d and were significantly greater ($P < 0.05$) than that of the control after 8 d of storage. Ascorbic acid was also effective in maintaining the b* values of ground beef at d 5, even though the same effect was not found at d 8. Spraying of ascorbic acid maintained the a* value of ground beef to about 68 to 71% of the d-1 value, whereas control beef had only 34% after 8 d of storage. Addition of ascorbic acid, however, had no effect on the L* values of ground beef.

Other antioxidants including α-tocopherol, γ-tocopherol, sesamol, and rosemary oleoresin were not effective in preventing discoloration of ground beef during storage. Although α-tocopherol and rosemary oleoresin were somewhat effective in maintaining a* values of ground beef for 5 d, they were not effective after 8 d. Addition of both ascorbic acid and α-tocopherol were effective in maintaining a* values of ground beef, but did not show synergistic effects.

Table 1. Color values[1] of ground beef electrostatically sprayed with different additives during 1, 5, or 8 d of aerobic storage at 4°C

Treatment	1 d	5 d	8 d	SEM
	L* value			
Control	54.2^{a,x}	49.6^{y}	51.0^{y}	1.0
Ascorbic acid	54.0^{a,x}	50.1^{y}	48.6^{y}	0.5
α-Tocopherol	52.8^{ab,x}	50.7^{xy}	51.9^{y}	0.6
γ-Tocopherol	55.1^{a,x}	49.9^{y}	51.9^{y}	0.9
Sesamol	53.2^{ab,x}	50.2^{y}	50.1^{y}	0.5
Rosemary oleoresin	53.2^{ab,x}	49.3^{y}	50.1^{y}	0.5
Ascorbic acid + α-tocopherol	51.1^{b,x}	50.7^{x}	48.6^{y}	0.4
SEM	0.6	0.6	0.8	
	a* value			
Control	27.6^{a,x}	14.7^{d,y}	9.3^{c,z}	0.9
Ascorbic acid	27.5^{a,x}	27.0^{a,x}	18.7^{b,y}	0.5
α-Tocopherol	29.2^{a,x}	17.9^{bc,y}	9.0^{c,z}	0.5
γ-Tocopherol	28.2^{a,x}	15.3^{cd,y}	8.6^{c,z}	0.6
Sesamol	24.6^{b,x}	15.6^{cd,y}	9.5^{c,z}	0.7
Rosemary oleoresin	29.9^{a,x}	18.8^{b,y}	8.5^{c,z}	0.5
Ascorbic acid + α-tocopherol	27.8^{a,x}	26.3^{a,x}	19.9^{a,y}	0.5
SEM	0.6	0.8	0.4	
	b* value			
Control	26.2^{a,x}	20.6^{b,y}	21.2^{y}	0.7
Ascorbic acid	26.4^{a,x}	25.8^{a,x}	22.5^{y}	0.6
α-Tocopherol	26.5^{a,x}	21.2^{b,y}	20.6^{y}	0.5
γ-Tocopherol	26.4^{a,x}	21.0^{b,y}	20.8^{y}	0.4
Sesamol	24.3^{b,x}	21.0^{b,y}	20.8^{y}	0.6
Rosemary oleoresin	27.3^{a,x}	21.0^{b,y}	20.4^{y}	0.7
Ascorbic acid + α-tocopherol	25.8^{a,x}	24.6^{a,x}	21.6^{y}	0.5
SEM	0.5	0.6	0.6	

[a–d]Within a column, values with different superscripts within a column are significantly different ($P < 0.05$).

[x–z]Values with different superscripts within a row are significantly different ($P < 0.05$).

[1]L* = lightness; a* = redness; b* = yellowness.

As shown in Table 2, the discoloration of ground beef during storage could be attributed to the generation of metmyoglobin. After 5 d of storage, more than 80% of heme pigments present in ground beef were changed to oxidized form, which was responsible for the unacceptable brownish gray color. Ascorbic acid-sprayed ground beef had decreased metmyoglobin percentage compared with the control after 5 d of storage. Thus, it was concluded that spraying of ascorbic acid on the surface of ground beef retarded the formation of metmyoglobin.

Because the red color intensity of ferrous heme pigment is stronger than that of ferric heme pigment (Ahn and Maurer, 1990), oxidation-reduction potential of meat is a very important factor for color expression. Spraying of ascorbic acid with or without α-tocopherol significantly reduced ($P < 0.05$) the ORP values of ground beef at d 1 (Table 3). The ORP values of ground beef with ascorbic acid plus tocopherol were not significantly different from those with ascorbic acid alone, indicating that the decrease of ORP in ascorbic acid

Table 2. Metmyoglobin percentage of ground beef electrostatically sprayed with different additives during 1, 5, or 8 d of aerobic storage at 4°C

Treatment	1 d	5 d	8 d	SEM
	%			
Control	45.2^{a,y}	82.0^{a,x}	85.2^{a,x}	2.3
Ascorbic acid	28.7^{b,z}	52.8^{d,y}	62.8^{b,x}	2.4
α-Tocopherol	41.7^{a,y}	80.2^{ab,x}	84.4^{a,x}	2.6
γ-Tocopherol	37.6^{ab,y}	82.8^{a,x}	85.0^{a,x}	2.3
Sesamol	40.5^{ab,z}	69.5^{c,y}	86.7^{a,x}	1.8
Rosemary oleoresin	35.6^{ab,z}	74.5^{bc,y}	86.1^{a,x}	1.7
Ascorbic acid + α-tocopherol	35.4^{ab,z}	49.8^{d,y}	59.0^{b,x}	2.5
SEM	2.8	2	2	

[a–d]Values with different superscripts within a column are significantly different ($P < 0.05$).

[x–z]Values with different superscripts within a row are significantly different ($P < 0.05$).

Table 3. Oxidation-reduction potential (ORP) values (mV) of ground beef electrostatically sprayed with different additives during 1, 5, or 8 d of aerobic storage at 4°C

Treatment	1 d	5 d	8 d	SEM
	ORP, mV			
Control	$144.8^{ab,z}$	$219.7^{a,y}$	$235.5^{a,x}$	2.4
Ascorbic acid	$107.3^{c,z}$	$140.0^{c,y}$	$163.9^{b,x}$	3.5
α-Tocopherol	$139.7^{b,z}$	$198.8^{b,y}$	$213.2^{b,x}$	1.9
γ-Tocopherol	$153.6^{a,y}$	$205.8^{b,x}$	$214.2^{b,x}$	2.8
Sesamol	$146.8^{ab,z}$	$202.9^{b,y}$	$211.8^{b,x}$	2.7
Rosemary oleoresin	$145.3^{ab,y}$	$210.5^{b,x}$	$211.4^{b,x}$	2.7
Ascorbic acid + α-tocopherol	$106.2^{c,y}$	$141.5^{c,x}$	$154.6^{c,x}$	4.7
SEM	2.3	3.1	3.8	

[a–c]Values with different superscripts within a column are significantly different ($P < 0.05$).
[x–z]Values with different superscripts within a row are significantly different ($P < 0.05$).

+ tocopherol-treated ground beef was caused mainly by ascorbic acid. The reduced ORP values by ascorbic acid kept the heme pigments in reduced (ferrous) form and stabilized the color of ground beef. Ascorbic acid reduces metmyoglobin by donating electrons to the ferric state of heme (Judge et al., 1989) and facilitates the conversion of ferric iron to ferrous form (Andersen and Skibsted, 1992). The ORP values of ground beef containing ascorbic acid gradually increased with increasing storage time, but they were always significantly less than those of the control or other antioxidant-sprayed ones.

Lipid Oxidation

Ground beef was highly susceptible to lipid oxidation during storage under aerobic conditions. The TBARS value of control ground beef after 8 d of storage was about 2 times greater ($P < 0.05$) than that at d 1 (Table 4). Ascorbic acid, tocopherol, sesamol, and rosemary oleoresin sprayed on the surface of ground beef showed significant ($P < 0.05$) antioxidant activities during storage; especially ascorbic acid and sesamol showed very strong antioxidant activities in ground beef. The TBARS of ground beef sprayed with ascorbic acid was about 76 to 80% less ($P < 0.05$) than that of the control at d 8. The results are consistent with the previous reports showing the antioxidant effects of ascorbic acid on beef products (Shivas et al., 1984; Craig et al., 1996). In the previous studies, however, ascorbic acid was mixed in to the meat samples.

Although ascorbic acid was sprayed on the surface of ground beef at greater concentration (500 mg/kg) than other antioxidants (100 mg/kg), the ascorbic acid-treated beef had significantly smaller TBARS values than control and α-tocopherol-, γ-tocopherol-, and rosemary oleoresin-treated ones. Spraying of ascorbic acid at 500 mg/kg was also effective in preventing discoloration of ground beef during the aerobic storage. If the ascorbic acid was mixed in meat samples, a greater amount of ascorbic acid should have been needed to show similar activities because relatively small amounts of ascorbic acid are presented in the outer part of patties. Therefore, electrostatic spraying of ascorbic acid can be an efficient and economical way to control quality changes in ground beef.

Among other antioxidants, sesamol at 100 mg/kg showed as strong of antioxidant activities as ascorbic acid at 500 mg/kg. Tocopherols (α and γ) and rosemary oleoresin also showed some antioxidant effects,

Table 4. 2-Thiobarbituric acid-reactive substances [mg of malondialdehyde (MDA)/kg of meat] values of ground beef electrostatically sprayed with different additives during 1, 5, or 8 d of aerobic storage at 4°C

Treatment	1 d	5 d	8 d	SEM
	mg of MDA/kg of meat			
Control	$1.57^{a,y}$	$2.69^{a,x}$	$3.20^{a,x}$	0.19
Ascorbic acid	$0.72^{c,y}$	$0.99^{b,x}$	$0.75^{c,y}$	0.05
α-Tocopherol	$1.50^{a,y}$	$2.57^{a,x}$	$2.65^{b,x}$	0.22
γ-Tocopherol	$1.22^{b,y}$	$2.67^{a,x}$	$2.73^{b,x}$	0.13
Sesamol	$0.35^{d,y}$	$0.26^{c,y}$	$0.56^{c,x}$	0.04
Rosemary oleoresin	$1.13^{b,z}$	$2.23^{a,y}$	$2.68^{b,x}$	0.11
Ascorbic acid + α-tocopherol	0.55^{c}	0.55^{bc}	0.65^{c}	0.08
SEM	0.06	0.18	0.12	

[a–d]Values with different superscripts within a column are significantly different ($P < 0.05$).
[x–z]Values with different superscripts within a row are significantly different ($P < 0.05$).

Table 5. Volatiles of ground beef electrostatically sprayed with different additives during 1, 5, or 8 d of aerobic storage at 4°C

Treatment	1 d	5 d	8 d	SEM
		Hexanal		
Control	2,291^{a,y}	3,363^{a,y}	16,442^{a,x}	1,122
Ascorbic acid	278^{b,z}	692^{c,x}	454^{b,y}	26
α-Tocopherol	1,906^{a,y}	3,055^{a,y}	16,316^{a,x}	378
γ-Tocopherol	2,222^{a,y}	2,754^{ab,y}	17,969^{a,x}	1,834
Sesamol	187^{b,y}	217^{c,y}	562^{b,x}	70
Rosemary oleoresin	1,647^{a,y}	2,025^{b,y}	12,956^{a,x}	612
Ascorbic acid + α-tocopherol	344^{b}	385^{c}	362^{b}	46
SEM	282	269		1,433
		1-Pentanol		
Control	4,609^{a,z}	7,605^{ab,y}	12,323^{a,x}	372
Ascorbic acid	1,644^{b,y}	2,912^{c,x}	3,121^{b,x}	290
α-Tocopherol	4,400^{a,z}	8,063^{ab,y}	12,739^{a,x}	880
γ-Tocopherol	4,295^{a,z}	9,256^{a,y}	13,889^{a,x}	979
Sesamol	634^{b,y}	458^{d,y}	1,503^{b,x}	210
Rosemary oleoresin	2,234^{b,z}	6,511^{b,y}	13,793^{a,x}	790
Ascorbic acid + α-tocopherol	1,023^{b,y}	1,530^{cd,y}	2,220^{b,x}	196
SEM	576	489		755
		Heptanal		
Control	223^{a,y}	171^{a,y}	713^{a,x}	48
Ascorbic acid	26^{c}	64^{bc}	135^{c}	27
α-Tocopherol	184^{ab,y}	171^{a,y}	759^{a,x}	38
γ-Tocopherol	135^{b,y}	147^{a,y}	831^{a,x}	87
Sesamol	0^{c,y}	0^{c,y}	117^{c,x}	10
Rosemary oleoresin	0^{c,z}	120^{ab,y}	481^{b,x}	24
Ascorbic acid + α-tocopherol	0^{c,y}	0^{c,y}	162^{c,x}	12
SEM	22	21		68

$^{a-d}$Values with different superscripts within a column are significantly different ($P < 0.05$).
$^{x-z}$Values with different superscripts within a row are significantly different ($P < 0.05$).

but their effects were not as strong as sesamol. When ascorbic acid and α-tocopherol were used together, the antioxidant activity was stronger than using them alone.

Thus, the spray of ascorbic acid was more effective in stabilizing beef color than any other antioxidants, but the combined spray of ascorbic acid with antioxidant would be more beneficial in controlling lipid oxidation as well as color oxidation of ground beef during storage.

Volatiles

As storage time increased, increasing amounts of volatiles were found in ground beef (Table 5). Ketones (2-propanone, 2-butanone, and 2,3-butadione) were the predominant compounds in ground beef (data not shown), but the production of hexanal, heptanal, and 1-pentanol was closely related to the oxidation status of ground beef. Hexanal was the major aldehyde detected in ground beef and drastically increased during storage. Shahidi et al. (1987) reported that hexanal was a good indicator of lipid oxidation. Spraying of ascorbic acid and sesamol was very effective in reducing the production of hexanal as shown in lipid oxidation of ground beef. Ascorbic acid and sesamol were also effective in reducing the production of heptanal and 1-pentanol.

Conclusions

Ground beef has a disintegrated muscle structure and is more susceptible to oxidative quality changes, such as lipid oxidation, formation of brown color, and production of volatile aldehydes than the whole muscle. The discoloration of ground beef was related to the loss of reducing power of the meat and could be prevented by a reducing agent, ascorbic acid. Electrostatic spraying of ascorbic acid at 500 mg/kg on the surface of ground beef was effective in reducing lipid oxidation and preventing discoloration. Ascorbic acid not only reduced TBARS values and volatile aldehydes (hexanal, heptanal), but also reduced the formation of metmyoglobin by maintaining oxidation-reduction potential. As electrostatic spraying of ascorbic acid on the surface of ground beef can effectively prevent color changes and lipid oxidation, it would be more economical than mixing in the additive to ground beef and is easily adoptable in the patty-making process by the beef industry.

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