Effect of Antioxidant Application Methods on the Color, Lipid Oxidation and Volatiles of Irradiated Ground Beef

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Summary and Implications

Four antioxidant treatments (none, 0.05% ascorbic acid, 0.01% α-tocopherol+0.01% sesamol, and 0.05% ascorbic acid+0.01% α-tocopherol+0.01% sesamol) were applied to ground beef using either mixing or spraying method. The meat samples were placed on Styrofoam trays, irradiated at 0 or 2.5 kGy, and then stored for 7 d at 4° C. Color, lipid oxidation, and volatiles were determined at 0, 3, and 7 d of storage. Irradiation increased lipid oxidation of ground beef with control and ascorbic acid treatments after 3 days of storage. α-Tocopherol+sesamol and ascorbic acid+α-tocopherol+sesamol treatments were effective in slowing down lipid oxidation in ground beef during storage regardless of application methods, but mixing was better than spraying method. Ascorbic acid was the most effective in maintaining redness of ground beef followed by ascorbic acid+α-tocopherol+sesamol. Beef sprayed with antioxidants produced more hydrocarbons and alcohols than mixing application, but ascorbic acid+α-tocopherol+sesamol treatment was effective in reducing the amount of volatiles produced by irradiation. Therefore, mixing was better than spraying method in preventing lipid oxidation and maintaining color of irradiated ground beef.

Introduction

Ground beef products represent about 44% of total fresh beef available for consumption in the U.S. Meat color is one of the most important parameters that determine and affect consumer purchasing decisions. In retail cases, displaying meat under high-intensity lights accelerates the formation of metmyoglobin, which produces unattractive brown color. Because of meat discoloration retailers lose more than a billion dollars every year. Irradiation negatively impacts ground beef color by developing undesirable greenish or brownish gray color.

Unlike popular belief, ground beef oxidizes faster than ground pork or poultry. Under aerobic conditions, irradiation accelerates lipid oxidation in fresh raw pork and beef patties despite their intrinsic antioxidant activities. Oxidative rancidity in food products are commonly measured by the 2-thiobarbituric acid (TBA) test, and sensory analysis of rancid odor shows strong correlations with TBA values in fresh and cooked ground beef. Food antioxidants are used in fresh and further processed meat to prevent oxidative rancidity and improve color stability. Some phenolic antioxidants such as vitamin E have free-radical-scavenging properties and stop free-radical reactions in meat during storage. Therefore, the combinations of phenolic antioxidants such as gallate, sesamol, and tocopherol were effective in reducing the oxidative reactions in irradiated pork by scavenging free radicals produced by irradiation. Ascorbic acid is a reducing agent, which prevents color changes in irradiated and nonirradiated ground beef during storage.

In addition to color changes and accelerated lipid oxidation, irradiation produces off-odor volatiles in meat. Sulfur compounds are the major volatile compounds responsible for irradiation off-odor, and are produced mainly by radiolysis of sulfur-containing amino acids and are different from those of lipid oxidation. Under aerobic conditions, the sulfur compounds were highly volatile and evaporated easily. However, under vacuum conditions, these compounds remained in meat. Although aerobic packaging was very effective in eliminating the sulfur volatiles produced by irradiation, the amounts of volatile aldehydes in irradiated ground beef significantly increased during storage unless antioxidant additives were added. Therefore, when irradiated beef is aerobically stored, the generation of lipid oxidation products is more concern than the S-volatiles. The objective of this study was to determine the effect of antioxidant application methods on the color, lipid oxidation and off-odor volatiles of ground beef.

Materials and Methods

Beef chuck were trimmed off any visible fat, ground separately through a 6-mm plate and a 3-mm plate, and used. The antioxidant treatments were: (1) control, (2) 0.05% L-ascorbic acid, (3) 0.01% dl-α-tocopherol +0.01% sesamol, (4) 0.05% L-ascorbic acid+0.01% dl-α-tocopherol+0.01% sesamol. For the mixing application, each additive was added to the ground meat, mixed for 2 min, and then patties were prepared. For spraying method, ground beef patties were placed on large metal trays, and sprayed with antioxidant treatments on both sides using an electrostatic spraying device. After spraying, beef patties were wrapped as in mixing application. Prepared patties were stored overnight at 4° C, and irradiated the next day morning. For both application methods, three sets of samples were prepared and each set was used for color and chemical analyses at each storage time. For both mixing and spray applications, half of the patties from each antioxidant treatment was used for nonirradiated and the other half for irradiated meat. For irradiation treatment, patties were irradiated at 2.5 kGy using a linear accelerator facility with 10 MeV of energy and 5.6 KW of power level. After

irradiation, the irradiated and non irradiated meat samples were immediately returned to a 4° C cold room where they were displayed in a single layer on illuminated racks under standard fluorescent light for 7 days. Color, lipid oxidation, volatile analysis, ORP and CO production were determined at 0, 3, and 7 days of storage.

Lipid oxidation was determined using a TBARS method. The amounts of TBARS were expressed as mg of malondialdehyde (MDA) per kg of meat. The color of meat was measured on the surface of meat samples using a Labscan spectrophotometer that had been calibrated against white and black reference tiles covered with the same film as those used for meat samples. A purge-and-trap apparatus connected to a gas chromatograph/mass spectrometer was used to analyze volatiles produced. The experiment was an incomplete randomized design with four replications. Data were analyzed by the procedures of generalized linear model of SAS.

Results and Discussion

Antioxidant combinations E+S and A+E+S were highly effective in preventing oxidative changes in irradiated and non-irradiated ground beef. However, ascorbate alone was effective only in non-irradiated ground beef. Adding antioxidants in beef patties by spraying produced more volatiles, hydrocarbons and alcohols than those with mixing. This indicated that patties with tested antioxidants applied on the surfaces would be more susceptible to oxidative changes than those spread antioxidants throughout by mixing. Therefore, mixing method is recommended for applying ascorbic acid and antioxidants to avoid any quality changes in irradiated ground beef.

Table 1. TBARS values of beef mixed or sprayed with different additives during storage at 4° C.

	Mixing			Spraying		
	Non-IR	IR	SEM	Non-IR	IR	SEM
	---------- (mg MDA/kg meat) ----------					
Day 0						
Control	0.87	0.91^{a}	0.26	0.97^{a}	0.75^{a}	0.16
A	0.33^{y}	0.50^{bx}	0.03	0.53^{by}	0.83^{ax}	0.06
E+S	0.29	0.34^{b}	0.03	0.42^{b}	0.47^{b}	0.05
A+E+S	0.30	0.35^{b}	0.03	0.47^{b}	0.55^{b}	0.04
SEM	0.14	0.12		0.12	0.05	
Day 3						
Control	1.27^{a}	2.00^{a}	0.38	0.89^{ay}	1.94^{ax}	0.25
A	0.45^{by}	1.06^{bx}	0.11	0.76^{aby}	2.29^{ax}	0.17
E+S	0.26^{b}	0.30^{c}	0.03	0.37^{b}	0.45^{b}	0.04
A+E+S	0.31^{b}	0.33^{c}	0.03	0.37^{b}	0.46^{b}	0.03
SEM	0.20	0.20		0.11	0.19	
Day 7						
Control	1.55	3.06^{a}	0.66	1.06^{ay}	3.01^{ax}	0.31
A	0.51^{y}	1.68^{bx}	0.15	0.85^{aby}	3.85^{ax}	0.43
E+S	0.31	0.36^{b}	0.03	0.42^{b}	0.45^{b}	0.05
A+E+S	0.30^{z}	0.36^{b}	0.03	0.46^{b}	0.51^{b}	0.04
SEM	0.30	0.37		0.14	0.35	

$^{a-c}$Values with different letters within a column of each storage period are significantly different (P<0.05).
$^{x-y}$Values with different letters within a row of each application are significantly different (P<0.05).
Abbreviation: Non-IR; non-irradiated samples (0 kGy), IR; irradiated samples (2.5 kGy), Cont.; control, A; ascorbic acid, E; vitamin E, and S; sesamol, SEM; standard error of the means (n=4).

Table 2. Volatile compounds of beef mixed with different additives during storage at 4° C.

Compound	Cont		A		E+S		A+E+S		SEM
	Non-IR	IR	Non-IR	IR	Non-IR	IR	Non-IR	IR	
	(Total ion counts x 10^4)								
Day 0									
Hydrocarbons	9847^{bc}	13059^{b}	1047^{d}	8661^{c}	24038^{a}	25045^{a}	4642^{cd}	$9592b^{c}$	1681
Ketones	9027	12870	10199	14712	10102	11558	9380	14137	1597
Alcohols	6589	8601 5859	7852	4990	7283	4969	8352	1010	
Aldehydes	2092^{a}	2480^{a}	706^{b}	1246^{b}	952^{b}	1118^{b}	969^{b}	1044^{b}	206
Aromatics	0^{c}	383^{b} 0^{c}	666^{a}	0^{c}	608^{a}	0^{c}	626^{a}	23	
Total volatiles	27556^{c}	37392^{ab}	17811^{d}	33136^{c}	40082^{ab}	45612^{a}	19960^{d}	33750^{bc}	2485
Day 3									
Hydrocarbons	6615^{cd}	13914^{b}	1823^{d}	10441^{bc}	20160^{a}	19542^{a}	4415^{d}	7213^{cd}	1435
Ketones	5359^{b}	7407^{ab}	6384^{ab}	8807^{ab}	9342^{a}	9603^{a}	6965^{ab}	8490^{ab}	835
Alcohols	7601^{abc}	8965^{a}	5289^{abc}	8123^{ab}	4037^{bc}	6578^{abc}	3752^{c}	5381^{abc}	941
Aldehydes	3325^{ab}	4646^{a}	653^{b}	1360^{b}	537^{b}	746^{b}	579^{b}	599^{b}	668
Aromatics	0^{c}	508^{b} 0^{c}	586^{a}	0^{c}	501^{b}	0^{c}	477^{b}	20	
Total volatiles	22900^{bc}	35440^{a}	14149^{c}	29316^{ab}	34076^{a}	36970^{a}	15710^{c}	$22161b^{c}$	2763
Day 7									
Hydrocarbons	7736^{cd}	17160^{b}	3717^{d}	10430^{c}	20390^{b}	27688^{a}	8318^{cd}	8922^{c}	1329
Ketones	18085	12378	13056	11727	13262	12769	12634	11763	1878
Alcohols	40494^{a}	10511^{b}	52917^{a}	7536^{b}	12671^{b}	4434^{b}	17452^{b}	3706^{b}	6854
Aldehydes	3420^{b}	9138^{a}	3156^{b}	1970^{b}	1301^{b}	833^{b}	1632^{b}	559^{b}	1240
Aromatics	0^{c}	553^{a} 0^{c}	506^{a}	146^{b}	564^{a}	189^{b}	488^{a}	21	
Total volatiles	69735^{a}	49740^{ab}	72846^{a}	32169^{b}	47770^{ab}	46288^{ab}	40225^{ab}	25439^{b}	8582

[a-c]Values with different superscripts within a row are significantly different ($P<0.05$). n=4.

Abbreviation: Non-IR: non-irradiated (0 kGy), IR: irradiated (2.5 kGy), A: ascorbic acid, E: vitamin E, S: sesamol, SEM: standard error of the means.

Hydrocarbons: 2-Methyl butane, propane, 1-pentene, pentane, 1-hexene, hexane, 1-heptene, heptane, octane, nonane; ***Ketones:*** 2-Propanone , 2,3-butanedione, 2-butanone, 2-pentanone, 2-heptanone; ***Alcohols:*** Ethanol, 1-propanol, 2-butanol, 1-pentanol, 2-methyl-1-propanol, 3-methyl-1-butanol, hexanol; ***Aldehydes:*** Acetaldehyde, propanal, 3-methyl butanal, hexanal, heptanal; ***Aromatics***: Toluene.

Table 3. Volatile compounds of irradiated and nonirradiated ground beef with antioxidants added by spraying during storage at 4° C.

	Cont		A		E+S		A+E+S		
Compound	Non-IR	IR	Non-IR	IR	Non-IR	IR	Non-IR	IR	SEM
	----------		--------- (Total ion counts x 10^4) ----------						
Day 0									
Hydrocarbons	12499^{bc}	17180^{a}	3617^{e}	8066de	7248de	14884^{ab}	6416d^{e}	8933^{cd}	1235
Ketones	10603	11553	9389	13762	10518	11681	10044	12564	1737
Alcohols	12843^{ab}	13912^{a}	11521^{ab}	14107^{a}	10919^{ab}	11703^{ab}	9572^{b}	10740^{ab}	815
Aldehydes	1474^{ab}	1927^{a}	705^{c}	1454^{ab}	1257^{abc}	1822^{ab}	1108^{bc}	1688^{ab}	172
Aromatics	0^{c}	594^{ab}	0^{c}	591^{ab}	0^{c}	715^{a}	0^{c}	553^{b}	38
Total volatiles	37419^{abc}	45166^{a}	25231^{d}	37980^{abc}	29942^{cd}	40805^{ab}	27140^{cd}	34479^{bcd}	2398
Day 3									
Hydrocarbons	7721^{b}	14966^{a}	3544^{b}	9315^{ab}	6139^{b}	15827^{a}	3372^{b}	7211^{b}	1921
Ketones	5218	7080	5517	8057	5340	6393	5312	7235	773
Alcohols	10123^{bc}	13135^{ab}	10263^{bc}	14101^{a}	8252c	10264^{bc}	7064c	9803^{bc}	829
Aldehydes	1645^{b}	5575^{a}	1311^{b}	4824^{a}	553^{b}	1483^{b}	407^{b}	1493^{b}	621
Aromatics	0^{b}	500^{a}	0^{b}	495^{a}	0^{b}	445^{a}	0^{b}	502a	27
Total volatiles	24707^{bc}	40256^{a}	20634^{c}	35802^{a}	20284^{c}	33523^{ab}	16156^{c}	25240^{bc}	2615
Day 7									
Hydrocarbons	10212^{ab}	16112^{a}	5046^{c}	13245^{a}	11310^{a}	9537^{bc}	3790^{c}	7311^{c}	1461
Ketones	13542^{a}	11063^{abc}	10193^{bc}	9800^{bc}	12689^{ab}	9073^{c}	11973^{abc}	9643^{bc}	710
Alcohols	30612^{a}	11136^{b}	23866^{ab}	9858^{b}	30657^{a}	7179^{b}	29487^{a}	6172^{b}	4357
Aldehydes	2409^{b}	7085^{a}	1396^{b}	9343^{a}	2231^{b}	896^{b}	1558^{b}	640^{b}	945
Aromatics	0^{c}	512^{ab}	0^{c}	558^{a}	0^{c}	479^{b}	0^{c}	472^{b}	17
Total volatiles	56776^{a}	45909^{ab}	40501^{abc}	42804^{abc}	56887^{a}	27163^{c}	46809^{ab}	24238^{c}	4981

$^{a-d}$Values with different superscripts within a row are significantly different ($P<0.05$). n=4.

Abbreviation: Non-IR: non-irradiated (0 kGy), IR: irradiated (2.5 kGy), A: ascorbic acid, E: vitamin E, and S: sesamol, SEM: standard error of the means. ***Hydrocarbons:*** 2-Methyl butane, 1-pentene, pentane, 1-hexene, hexane, 1-heptene, heptane, octane, nonane; ***Ketones:*** 2-Propanone , 2,3-butanedione, 2-butanone, 2-pentanone, 3-hexanone, 2-heptanone; ***Alcohols:*** Ethanol, 1-propanol, 1-butanol, 2-butanol, 1-pentanol, 1-hexanol, 2-methyl-1-propanol, 3-methyl-1-butanol; ***Aldehydes:*** Acetaldehyde, propanal, 3-methyl butanal, hexanal, heptanal; ***Aromatics***: Toluene.