Fat Content Influences the Color, Lipid Oxidation and Volatiles of Irradiated Ground Beef

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Summary and Implications

Ground beef with 10, 15 or 20% fat were added with none, 0.05% ascorbic acid + 0.01% α-tocopherol, or 0.05% ascorbic acid + 0.01% α-tocopherol + 0.01% sesamol, and irradiated at 0 or 2.5 kGy. The meat samples were displayed under fluorescent light for 14 days at 4° C. Irradiation increased both lipid oxidation and total volatiles, especially aldehydes, but decreased redness of ground beef over the 14 days storage period regardless fat content. The production of alcohol greatly increased in nonirradiated ground beef during storage due to microbial growth. Adding antioxidants such as ascorbic acid + α-tocopherol was effective in minimizing lipid oxidation, volatile production and color changes in irradiated ground beef, but fat content had little effect on the quality parameters of irradiated and nonirradiated ground beef. Therefore, up to 20% fat would not affect quality changes of irradiated ground beef if ascorbic acid + α- tocopherol is added.

Introduction

Color changes, accelerated lipid oxidation, and off-odor production are the main changes that occur in ground beef as a result of irradiation. Because these are the major quality parameters, consumer decisions to purchase irradiated meat will be affected by these changes. It was reported that 74% of consumers indicated that meat color was important in making their purchase decision where they associated bright red color with freshness. Over 700 million dollars per year could be lost in beef at retail level in the U.S. because of discoloration alone. Color changes, caused by irradiation, are different among different meat species. While light meat such as pork and poultry breast developed pink color when irradiated, dark meat such as beef became brown or gray color. The formation of CO-heme pigment complex is responsible for the pink color formed in irradiated precooked turkey breast. Considerable amount of carbon monoxide (CO) gas was produced as a result of radiolysis of organic component, such as alcohols, aldehydes, ketones, carboxylic acids, amindes, and esters, in irradiated frozen meat and poultry. Reactivity of myoglobin toward diatomic ligands such as oxygen, nitric oxide, and carbon monoxide is different. The affinity of CO to ferrous myglobin was 100 times greater than that of metmyoglobin. The oxidation-reduction potential (ORP) of meat determines the status of iron in heme pigments and lowering ORP favors CO-Mb complex formation, which intensifies the redness of heme pigments. The ORP of meats decreased after irradiation but increased rapidly after aerobic storage. The affinity of CO to heme pigments reduced by the rapid increases of ORP in irradiated meat under aerobic condition. Although the amount of CO produced and changes in ORP in beef are not much different from those from light meat, the color of irradiated beef after irradiation becomes brown/gray instead of pink, especially under aerobic conditions.

Lipid oxidation is a major cause of quality deterioration in meat and meat products. The 2-thiobarbituric acid reactive substances (TBARS) test is the most commonly used method to measure lipid oxidation in meat. Rancid odor was first perceived by sensory panelists when TBA number was between 0.5 and 1.0, and this level has been serving as a guide for interpreting TBA test results. Irradiation and high fat content accelerated the lipid oxidation in raw meat during storage. Oxygen availability during storage, however, was more important than irradiation on the lipid oxidation and color values of raw patties. Irradiated meat produced more volatiles than nonirradiated patties, and the proportion of volatiles varied by the packaging-irradiation conditions of patties.

Irradiation produced characteristic off-odor in all meat species, and that odor was not related to lipid oxidation. Irradiation off-odor had been described by several researchers as “bloody and sweet”, “burned oil” or “burned feather”, and “barbecued corn-like” odor. Sulfur compounds are the most important volatiles for off-odor production in irradiated meat. Sulfur amino acids are the most susceptible to changes by irradiation and sulfur compounds can be produced from the side chains of the amino acids methionine and cysteine. Sulfur compounds were not only produced by the radiolytic cleavage of side chains (primary reaction) of sulfur amino acids, but also by the secondary reactions of the primary sulfur compounds with other compounds around them. Among the sulfur amino acids, methionine was the major source for the sulfur volatiles, and more than 99% of sulfur compounds produced by irradiation were from methionine. The objective of this study was to determine the effect of ascorbic acid and selected antioxidants on the color, lipid oxidation and off-odor volatiles of ground beef with different fat content.

Materials and Methods

Meat blocks from two animals were combined, ground through a 6-mm plate, and treated as a replication. High fat beef trimmings were also bought from the same packing plant and used to adjust fat content of ground beef for the study. High fat trimmings were also ground through a 6-mm plate, the fat content determined, and appropriate amounts of ground fat trimmings were added to the ground beef in order to make ground beef containing 10%, 15%, and 20% fat. For both irradiated and nonirradiated meat, one of the following antioxidant treatments was added: (1) control, (2) meat added with 0.05% (w/w) L-ascorbic acid + 0.01% α-tocopherol, (3) meat added with 0.05% (w/w) L-ascorbic acid + 0.01% α-tocopherol + 0.01% sesamol. The ground beef were then mixed for 2 min in a bowl mixer, and beef patties were prepared. Wrapped beef patties were irradiated at 2.5 kGy using an electron beam linear accelerator facility. 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 lights for 14 days. Color, lipid oxidation, volatile analysis, oxidation-reduction potential (ORP) and carbon monoxide (CO) production were determined at 0, 3, 7, and 14 days of storage.

Lipid oxidation was determined using a TBARS method. A purge-and-trap apparatus connected to a gas chromatograph/mass spectrometer was used to analyze volatiles produced. Identification of volatiles was achieved by comparing mass spectral data of samples with those of the Wiley Library (Hewlett-Packard). The color of meat was measured on the surface of meat samples using a Labscan reflectance spectrophotometer that had been calibrated against white and black reference tiles covered with the same film as those used for meat samples. A pH/ion meter connected to a platinum electrode filled with a 4 M-KCl solution saturated with AgCl was used to determine the change of ORP in meat. Carbon monoxide (CO) gas was analyzed using a gas chromatograph with a flame ionization detector (FID). Data were analyzed by the procedures of generalized linear model of SAS (SAS Institute 1995). Student-Newman-Keuls' multiple-range test was used to compare the mean values of treatments. Mean values and standard error of the means (SEM) were reported. Significance was defined at $P < 0.05$.

Results and Discussion

TBARS values of nonirradiated beef patties were not significantly different from those of irradiated ones at Day 0. As storage time increased, however, irradiated patties showed higher TBARS values than nonirradiated ones and some of the patties treated with additives showed significant differences (Table 1). Ascorbic acid + α-tocopherol and ascorbic acid + α-tocopherol + sesamol treatments were effective in reducing lipid oxidation of beef. Adding sesamol to ascorbic acid + α-tocopherol made them more effective in preventing oxidative changes during storage under aerobic conditions. As storage time increased, overall lipid oxidation increased, and the rate of lipid oxidation was faster in irradiated than nonirradiated beef. The effect of antioxidants in ground beef was more distinct after 7 days of storage than at 0 days. The antioxidant effect of ascorbic acid + tocopherol started to decrease at 7 days of storage, but that of ascorbic acid + tocopherol + sesamol still remained strong even at 14 d of storage. This indicated that adding ascorbic acid + tocopherol was not good enough to prevent oxidative changes in irradiated ground beef stored more than 3 d under aerobic conditions. Thus, addition of another antioxidant such as sesamol and other natural ingredients such as gallate, ferulic acid, and quercetine may be necessary to prevent oxidative changes in ground beef for longer than 3 days.

Irradiation increased the amounts of hydrocarbons, ketones, toluene and total volatiles in ground beef at 0 d regardless of fat contents or additive treatments. Additives had no effect on the production of hydrocarbons, ketones, toluene and total volatiles in ground beef. Among the volatiles, alcohols and aldehydes were affected the most by irradiation, additives and storage. The amount of alcohols greatly increased at 7 days in nonirradiated beef regardless of additive treatments and increased further at 14 days. Ethanol was mainly responsible for the increase in alcohol content in nonirradiated ground beef over the storage period probably due to microbial growth in the meat during storage. The production of aldehydes increased as storage time increased, but the increase was the most significant in irradiated control meat (no additives). Addition of antioxidants, especially sesamol + ascorbic + α-tocopherol, to ground beef was effective in preventing aldehydes production during storage (Table 2). Among the aldehydes, hexanal increased the most by irradiation and storage. Hexanal is a common indicator of lipid oxidation in meat. Ground beef with low fat content (10%) produced greater amount of aldehydes than that with higher fat content (20%) at 14 days of storage (Table 2). In general, however, fat content had little effect on the production of volatiles in irradiated and nonirradiated ground beef during storage.

Fat contents influenced the lightness of both irradiated and nonirradiated beef, where L*-values increased as fat content increased throughout the storage period. Irradiation reduced the redness (a*-values) of ground beef at 0 day (Table 3). As storage period increased, however, irradiation did not show any effect on beef redness. As fat content increased a*-values of nonirradiated control patties decreased at both 0 and 3 d of storage. At 7 days, the influence of fat was not consistent, and at 14 days a*-values of nonirradiated

control increased as fat content increased. Ascorbic acid + α-tocopherol maintained the redness of irradiated patties at 0 and 3 d of storage. As storage period increased, however, the effectiveness of the additive to keep the red color decreased. Redness values of patties treated with sesamol were lower than those treated with ascorbic acid + α-tocopherol. The yellowness (b*-values) of beef were decreased by irradiation, regardless of fat content.

Irradiation increased the production of CO regardless of fat content (Table 4). The amount of CO decreased over the storage period, and no differences between irradiated and nonirradiated beef patties were found at 7 and 14 days of storage. The mechanisms of color changes in irradiated dark meat are different from those in light meat. Dark meat has about 10 times higher pigment than light meat. The amount of CO produced by irradiation, however, is similar in both meats. So the percentages of CO-heme to total meat pigment are different. CO-heme pigment represents only a small portion of pigments in irradiated dark meat such as ground beef, while it represents the majority of pigments in irradiated light meat. Thus, light meat such as poultry and pork produce pink color while dark meat produces brown or gray color after irradiation.

ORP values were influenced by irradiation and additives during the first 7 days of storage but the change became inconsistent at 14 days of storage. Ascorbic acid + α-tocopherol was effective in lowering ORP values regardless of fat contents. The reducing power of ascorbic acid maintained lower ORP values for 3 days after irradiation. Oxidation-reduction potential (ORP) played an important role in color change of meat, because low ORP value maintains heme pigments in ferrous form, which is stronger in color intensity than that of ferric form and enables CO-heme pigment complex formation, which intensifies the red color intensity further. Because of its reducing capability, ascorbic acid inhibited the oxidation of myoglobin, and thus prevented the development of brown color in nonirradiated meat.

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Table 1. TBARS values of beef added with different additives and fat contents during storage at 4° C.

	10 % fat			15 % fat			20 % fat		
	Non-IR	IR	SEM	Non-IR	IR	SEM	Non-IR	IR	SEM
	---------- mg MDA/kg meat ----------								
Day 0									
Control	2.17^{a}	2.41^{a}	0.24	1.92^{a}	2.11^{a}	0.24	1.98^{a}	2.19^{a}	0.26
A+E	0.72^{b}	0.9^{b}	0.08	0.80^{b}	0.96^{b}	0.13	0.79^{b}	0.98^{b}	0.10
A+E+S	0.64^{b}	0.71^{b}	0.07	0.64^{b}	0.73^{b}	0.09	0.77^{b}	0.81^{b}	0.10
SEM	0.16	0.15		0.15	0.18		0.17	0.17	
Day 3									
Control	3.36^{a}	4.10^{a}	0.52	3.20^{a}	4.10^{a}	0.27	3.11^{ay}	4.31^{ax}	0.25
A+E	0.87^{b}	1.12^{b}	0.14	0.76^{b}	0.90^{b}	0.20	0.93^{b}	1.33^{b}	0.32
A+E+S	0.66^{b}	0.69^{b}	0.07	0.69^{b}	0.72^{b}	0.05	0.76^{b}	0.88^{b}	0.11
SEM	0.37	0.25		0.13	0.25		0.20	0.28	
Day 7									
Control	6.53^{a}	5.82^{a}	0.38	4.30^{ay}	6.28^{ax}	0.43	5.15^{a}	5.25^{a}	0.62
A+E	1.76^{by}	2.99^{bx}	0.24	1.56^{b}	2.19^{b}	0.42	2.37^{b}	1.76^{b}	0.27
A+E+S	0.71^{c}	0.69^{c}	0.08	0.67^{by}	1.10^{cx}	0.06	0.85^{b}	0.65^{c}	0.11
SEM	0.20	0.32		0.27	0.41		0.49	0.27	
Day 14									
Control	5.62^{a}	7.52^{a}	0.60	4.55^{ay}	7.26^{ax}	0.40	4.98^{ay}	8.16^{ax}	0.62
A+E	2.9^{b}	3.79^{b}	0.45	2.35^{b}	2.60^{b}	0.40	2.48^{b}	3.15^{b}	0.21
A+E+S	0.59^{by}	1.82^{cx}	0.22	0.64^{by}	1.76^{cx}	0.19	0.72^{cy}	1.46^{cx}	0.18
SEM	0.36	0.53		0.34	0.35		0.19	0.52	

$^{a-c}$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 fat % are significantly different ($P < 0.05$)

Abbreviation: Non-IR; non-irradiated samples, IR; irradiated samples, Cont; control, A; ascorbic acid, E; vitamin E, and S; sesamol, SEM; standard error of the means (n=4).

Table 2. Production of alcohols and aldehydes of beef with different additives and fat contents during storage at 4° C.

Compound	10% fat			15% fat			20% fat		
	Non-IR	IR	SEM	Non-IR	IR	SEM	Non-IR	IR	SEM
	(Total ion counts x 10^4)								
Alcohols									
After 0-day storage									
Control	6267	6643	1476	4916^{b}	6542^{a}	427	5645	8661	1667
A+E	3327	5566	696	3541	5981	928	4279	7498	1435
A+E+S	3977	9258	1632	6786	5202	2442	8099	7377	1813
SEM	1401	1260		1955	922		1510	1770	
After 7-day storage									
Control	61331^{a}	16565^{bx}	11212	55259^{a}	13193^{bx}	6677	47611^{a}	9565^{b}	6952
A+E	58820^{a}	16460^{bxy}	6021	38862^{a}	12425^{ax}	5687	56534^{a}	15374^{b}	4484
A+E+S	31923^{a}	10439^{by}	4270	51737^{a}	17217^{ay}	3021	47604^{a}	12122^{b}	3864
SEM	20814	1729		20395	806		17769	899	
After 14-day storage									
Control	125396^{a}	33314^{b}	11959	115636^{a}	32422^{b}	17011	106083^{a}	22161^{b}	8845
A+E	117342^{a}	33811^{b}	14653	136097^{a}	38812^{b}	12242	93581^{a}	24494^{b}	21144
A+E+S	154207^{a}	39784^{b}	6431	130720^{a}	43373^{b}	22581	94059^{a}	36476^{b}	20943
SEM	50494	2745		53921	7186		28026	11505	
Aldehydes									
After 0-day storage									
Control	5568^{x}	8414^{x}	1142	3843^{x}	6258^{x}	912	6102^{bx}	9557^{ax}	815
A+E	556b^{y}	1917^{ay}	89	161b^{y}	2184^{ay}	181	597^{by}	3010^{ay}	239
A+E+S	671b^{y}	2030^{ay}	155	644b^{y}	1494^{ay}	159	624^{by}	2610^{ay}	264
SEM	547	769		487	597		481	544	
After 7-day storage									
Control	15464	32329^{x}	8719	19920^{x}	19819^{x}	5124	10358^{b}	24944^{ax}	3181
A+E	12850	6312^{y}	3011	5825^{y}	8787^{xy}	2919	13258	3474^{y}	4175
A+E+S	1582	996^{y}	256	2558^{y}	1240^{y}	514	2563	1529^{y}	490
SEM	6368	4027		2346	4226		3497	2509	
After 14-day storage									
Control	12706^{b}	48224^{ax}	6587	5842^{b}	26008^{ax}	3074	3296^{b}	29646^{ax}	1710
A+E	8366	17476^{y}	3055	6664	14900^{y}	2942	3145	4524^{y}	718
A+E+S	15695^{a}	868^{bz}	3515	6652^{a}	1500^{bz}	1341	3563	3908^{y}	1053
SEM	4539	4773		1801	3166		464	1679	

$^{a-b}$Values with different superscripts within a row with the same fat content are significantly different ($P < 0.05$).
$^{x-z}$Values with different superscripts within a column of the same storage time are significantly different ($P < 0.05$).
Abbreviation: Non-IR; non-irradiated samples, IR; irradiated samples, A; ascorbic acid, E; vitamin E, S; sesamol, SEM; standard error of the means (n = 4).
Alcohols: ethanol, 1-propanol, 1-butanol, 2-butanol, 1-pentanol, 2-pentanol, 2-methyle-1-propanol, 2-methyl-1-propanol, hexanol, 3-methyl-1-butanol
Aldehydes: acetaldehyde, propanal, 2-methyl-propanal, 3-methyl-butanal, pentanal, hexanal, heptanal

Table 3. CIE color a*-values of beef with different additives, fat contents, and storage times at 4° C.

	10 % fat			15 % fat			20 % fat		
	Non-IR	IR	SEM	Non-IR	IR	SEM	Non-IR	IR	SEM
Day 0									
Control	24.8^{cw}	14.5^{cx}	0.7	25.5^{cw}	14.9^{cy}	0.3	26.2^{w}	15.5^{cy}	0.5
A+E	28.7^{aw}	16.8^{bx}	0.4	29.9^{aw}	17.5^{bx}	0.4	27.8^{w}	16.5^{bx}	0.4
A+E+S	26.7^{bw}	18.0^{ax}	0.3	27.4^{bw}	18.9^{ax}	0.4	26.5^{w}	19.3^{ax}	0.6
Day 3									
Control	14.8^{cw}	11.3^{bx}	0.8	11.5^{cx}	11.2^{cx}	0.5	10.9^{c}	11.4^{b}	0.5
A+E	26.3^{aw}	20.2^{ax}	0.5	27.3^{aw}	21.4^{ax}	0.5	26.3^{aw}	21.4^{ax}	0.6
A+E+S	20.9^{bx}	19.9^{ax}	0.4	20.5^{bx}	18.9^{by}	0.4	19^{bx}	20.2^{awx}	0.5
Day 7									
Control	9.8^{abx}	9.7^{bx}	0.2	9.4^{bx}	9.8^{cwx}	0.2	9.7^{bx}	9.7^{cx}	0.2
A+E	9.5^{bz}	13.6^{ax}	0.5	9.9^{ay}	16.7^{ax}	0.6	9.3^{by}	17.1^{ax}	0.6
A+E+S	10.4^{ay}	14.2^{ax}	0.3	10.3^{ay}	12.6^{bx}	0.3	10.7^{ay}	14.1^{bx}	0.4
Day 14									
Control	10.8^{x}	9.5^{bx}	0.7	11.4^{bx}	9.2^{by}	0.4	13.4^{w}	9.3^{bx}	0.7
A+E	9.7^{x}	9.6^{bx}	0.6	12.6^{ay}	11.2^{ay}	0.6	12.2^{x}	9.8^{by}	0.5
A+E+S	11.1^{x}	10.8^{ax}	0.5	13.5^{aw}	9.3^{bx}	0.4	11.9^{x}	10.6^{ay}	0.4

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

Table 4. Carbon monoxide (CO) production from beef with different additives, fat contents, and storage times at 4° C.

(Unit: ppm)

	10 % fat			15 % fat			20 % fat		
	Non-IR	IR	SEM	Non-IR	IR	SEM	Non-IR	IR	SEM
Day 0									
Control	86.32^{a}	132.46	13.98	60.62^{y}	144.82^{x}	8.06	52.08^{y}	146.03^{x}	15.27
A+E	37.92^{by}	101.22^{x}	10.07	39.64^{y}	116.42^{x}	11.50	42.36^{y}	118.66^{x}	6.50
A+E+S	43.85^{by}	110.92^{x}	7.39	45.06^{y}	100.40^{x}	10.15	48.49^{y}	143.83^{x}	13.47
Day 3									
Control	53.41^{y}	106.36^{x}	9.29	47.44^{ay}	126.57^{ax}	14.98	38.51^{y}	97.86^{x}	10.25
A+E	34.50	87.13	15.26	37.32^{aby}	87.28^{abx}	8.17	21.89^{y}	83.90^{x}	10.36
A+E+S	36.84^{y}	84.06^{x}	4.32	28.72^{by}	64.57^{bx}	3.41	17.67^{y}	85.06^{x}	4.87
Day 7									
Control	26.69^{y}	58.9^{abx}	8.06	46.50^{y}	78.30^{ax}	5.15	28.37	60.68	10.56
A+E	27.45^{y}	83.73^{ax}	6.19	$28.1y^{y}$	76.99^{ax}	7.19	20.06^{y}	62.26^{x}	2.72
A+E+S	34.70	40.68^{b}	7.12	26.95	34.65^{b}	6.40	12.14^{y}	63.87^{x}	4.47
Day 14									
Control	26.36	41.07	4.53	32.86	54.64	10.04	21.29^{y}	52.33^{x}	3.56
A+E	26.12^{y}	45.58^{x}	4.21	20.84^{y}	65.50^{x}	9.35	18.45^{y}	58.92^{x}	3.08
A+E+S	26.98	36.9	8.90	23.84	30.95	4.43	11.86^{y}	47.41^{x}	8.89

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