Effects of Ascorbic Acid and Antioxidants on Color, Lipid Oxidation and Volatiles of Irradiated Ground Beef

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Summary and Implications

Irradiation significantly decreased the redness of ground beef, and the visible color of beef changed from a bright red to a green/brown depending on the age of meat. Addition of ascorbic acid prevented color changes in irradiated beef, and the effect of ascorbic acid became greater as the age of meat or storage time after irradiation increased. The ground beef added with ascorbic acid had significantly lower ORP than control, and the low ORP of meat helped maintaining the heme pigments in reduced form. During the aerobic storage, the S-volatiles disappeared while volatile aldehydes significantly increased in irradiated beef. Addition of ascorbic acid at 0.1% or sesamol + α-tocopherol at each 0.01% level to ground beef prior to irradiation were effective in reducing lipid oxidation and S-volatiles. As storage time increased, however, the antioxidant effect of sesamol + tocopherol in irradiated ground beef was superior to that of ascorbic acid.

Introduction

The loss of value due to discoloration in beef at the retail level in the U.S. could be over 700 million dollars per year. The color changes induced by irradiation are different depending on animal species, muscle type, irradiation dose, and packaging type. The major volatile compounds responsible for off-odor in irradiated meats are mainly sulfur compounds. The volatile sulfur compounds were produced from the radiolytic degradation of the side chains of sulfur-containing amino acids, methionine and cysteine. Despite the intrinsic antioxidant activities in fresh meat, irradiation accelerated lipid oxidation in raw pork and beef patties under aerobic conditions. Food antioxidants are used in fresh or further processed meat to prevent oxidative rancidity and improve color stability. Ascorbic acid is a reducing agent, which inhibits myoglobin oxidation and brown color development in nonirradiated beef. The combinations of phenolic antioxidants such as gallate, sesamol, and tocopherol, were effective in reducing the oxidative reactions and the production of sulfur volatiles in irradiated pork by scavenging free radicals produced by irradiation.

The objective of this study was to determine the effect of ascorbic acid and selected antioxidants on the color and off-odor volatiles of beef with different postmortem aging time before irradiation and storage time after irradiation.

Materials and Methods

Beef loins with 3 different aging times after slaughter were used in this study. One group of the loins purchased 2 wk before sample preparation was further aged at 4 °C and the other group was purchased 1 d before preparation. For convenience, the three loins were named “pre-aged”, “aged”, and “long-term-aged”, respectively. Each meat block was ground through a 3-mm plate, each additive was added to the ground beef and then mixed for 1 min in a bowl mixer. The aerobically packaged ground beef were irradiated at 2.5 kGy using a Linear Accelerator Facility. Color, ORP values, lipid oxidation and volatile profiles of the samples were determined on 1, 4, and 7 d of storage.

Results and Discussion

The CIE color L* value increased as the aging time of beef increased. During storage after irradiation, L* values of ground beef also showed an increasing trend as the storage time increased, and the increase in L* value was more apparent in meat from “long-term-aged” beef than other ones. Irradiation reduced the redness (a* value) of ground beef significantly, but with varying degree depending on aging time (Table 1). Ascorbic acid incorporated to beef at the level of 0.1% (w/w) was very effective in maintaining redness (a* values) of irradiated ground beef. Addition of ascorbate further increased the reducing power in beef and increased the red color intensity of ground beef. The degree of aging was a critical factor on beef color during storage regardless of irradiation. Only the ground beef added with ascorbic acid produced higher a* values than the meat with ascorbate + sesamol + tocopherol. Thus, the use of ascorbic acid was more effective in stabilizing irradiated beef color than using it with other antioxidants. The addition of ascorbic acid with or without sesamol + tocopherol significantly lowered the ORP values of irradiated ground beef regardless of the age of meat. The lowered ORP values by ascorbic acid maintained heme pigments in ferrous status and stabilized the color of irradiated ground beef.

Irradiation increased TBARS values of “pre-aged” and “aged” ground beef but the difference between irradiated and nonirradiated “long-term-aged” beef was small (Table 2). Both ascorbic acid and sesamol + α-tocopherol combination showed significant antioxidant activities in irradiated ground beef. As the 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 d of storage than at Day 0.

Irradiation increased the amounts of total volatiles and a few S-volatiles. The S-volatiles newly generated or greatly increased by irradiation were ethanethioic acid S-methyl ester, dimethyl disulfide, and dimethyl trisulfide. Sensory panelists characterized the odor of irradiated ground beef as a “steamed” or “rotten vegetables” and regarded it as an obnoxious off-odor. Both ascorbic acid and sesamol + tocopherol lowered the amounts of dimethyl disulfide in irradiated ground beef. Aging time of beef was an important factor influencing volatile production by irradiation. Irradiation of “long-term-aged” ground beef produced greater amounts of total and S-volatiles than “pre-aged” and “aged” beef. This could be related to more severe structural disintegration in “long-term-aged” than “pre-aged” and “aged” beef, and the structural damage should have made the meat susceptible to the attacks of free radicals produced by irradiation. Therefore, irradiation of beef before aging than after aging would be more beneficial in minimizing quality changes.

Almost all volatile compounds produced in ground beef after 7-d storage under aerobic conditions were lipid oxidation-related products such as hydrocarbons and volatile carbonyl compounds (Table 3). Ketones were the predominant compounds in ground beef after 7-d storage, irrespective of irradiation. Volatile aldehydes, however, were the most characteristic compounds in irradiated ground beef. As aging time before irradiation increased, many more volatile aldehydes (propanal, pentanal, hexanal, and heptanal) were found and their amounts also increased. The S-volatiles predominant immediately after irradiation were not found in irradiated ground beef after 7 d of aerobic storage.

Addition of antioxidant was very effective in inhibiting not only a few hydrocarbons but volatile aldehydes also in irradiated beef at Day 7. Sesamol + tocopherol also was effective in reducing the amounts of 1-pentanol in irradiated ground beef.

The volatile profiles of irradiated ground beef were highly dependent upon storage time after irradiation (Fig. 1). Most of S-volatiles detected in ground beef stored for 1 d disappeared after 4 d of storage under aerobic conditions. The disappearance of S-compounds in beef was similar to other meats under aerobic conditions. The S-volatiles responsible for irradiation off-odor were a great concern in irradiated beef at the beginning of storage. The production of dimethyl disulfide in ground beef was decreased by the addition of ascorbic acid or sesamol + tocopherol prior to irradiation. Although aerobic packaging was effective in eliminating the S-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 S-volatiles.

Conclusion

Because color changes in irradiated beef were uniquely distinguishable (from bright red to a green/brown), it would be very difficult to implement irradiation technology in beef without controlling discoloration problems. As in nonirradiated beef, addition of ascorbic acid at 0.1% (w/w) to ground beef prior to irradiation stabilized the color of ground beef during aerobic storage. The color stabilizing effect of ascorbic acid was derived from the reducing power of ascorbic acid, which maintained the heme pigments in beef in a reduced form (redder color).

The S-volatiles produced by irradiation had characteristic odor, but the intensity of irradiation off-odor in ground beef diminished over storage period because S-volatiles disappeared during aerobic storage. As storage time increased, “long-term-aged” irradiated ground beef developed severe lipid oxidation unless antioxidant was added. Sesamol + tocopherol was highly effective in reducing lipid oxidation, and ascorbic acid stabilized color of irradiated beef. Therefore, the combined use of ascorbic acid and sesamol + tocopherol was recommended to control overall quality changes in irradiated ground beef during storage.

Table 1. CIE color a* values of irradiated ground beef treated with different additives during aerobic storage at 4 °C

	Nonir	Irradiated				
Storage	Control	Control	Ascorbic[1]	S+E[2]	A+S+E[3]	SEM
Pre-aged						
Day 1	22.0[ax]	17.4[bx]	21.3[ay]	17.4[by]	21.0[a]	0.3
Day 4	20.1[cy]	17.0[ex]	24.5[ax]	18.6[dx]	22.3[b]	0.4
Day 7	20.1[cy]	14.8[ey]	25.6[ax]	16.6[dy]	22.3[b]	0.4
Aged						
Day 1	19.7[bx]	17.3[cx]	22.7[ay]	19.4[b]	23.2[a]	0.3
Day 4	19.4[cx]	16.9[dx]	25.9[ax]	18.4[c]	23.3[b]	0.4
Day 7	15.4[dy]	15.3[dy]	26.1[ax]	18.2[c]	22.8[b]	0.4
Long-term-aged						
Day 1	19.8[ax]	17.6[bx]	19.0[ay]	14.7[cy]	17.2[by]	0.3
Day 4	8.1[ey]	12.5[dy]	23.0[ax]	15.7[cxy]	19.7[bx]	0.3
Day 7	8.4[ey]	11.9[dy]	23.2[ax]	16.2[cx]	20.0[bx]	0.3

[1]Ascorbic acid 0.1%; [2]Sesamol 100 ppm + α-tocopherol 100 ppm; [3]Ascorbic acid 0.1% + sesamol 100 ppm + α-tocopherol 100 ppm. n = 4.

Table 2. TBARS values of irradiated ground beef treated with different additives during aerobic storage at 4 °C

	Nonir	Irradiated				
Storage	Control	Control	Ascorbic[1]	S+E[2]	A+S+E[3]	SEM
Pre-aged						
Day 1	0.44[bz]	0.58[az]	0.28[cy]	0.20[c]	0.23[c]	0.03
Day 4	0.66[by]	0.96[ay]	0.29[cy]	0.17[d]	0.23[cd]	0.02
Day 7	0.88[bx]	1.90[ax]	0.39[cx]	0.18[c]	0.27[c]	0.08
Aged						
Day 1	0.65[by]	1.27[az]	0.44[cy]	0.35[c]	0.33[c]	0.05
Day 4	0.91[by]	1.79[ay]	0.57[cy]	0.36[d]	0.41[cd]	0.05
Day 7	1.94[bx]	2.81[ax]	0.76[cx]	0.31[c]	0.37[c]	0.14
Long-term-aged						
Day 1	4.13[ay]	4.40[ay]	1.15[by]	0.81[bz]	0.81[bz]	0.11
Day 4	5.05[ay]	4.54[ay]	1.42[by]	0.93[by]	0.92[by]	0.30
Day 7	6.87[ax]	7.23[ax]	2.85[bx]	1.06[cx]	1.07[cx]	0.17

[1]Ascorbic acid 0.1%; [2]Sesamol 100 ppm + α-tocopherol 100 ppm; [3]Ascorbic acid 0.1% + sesamol 100 ppm + α-tocopherol 100 ppm. n = 4. [a-c]Values with different letters within a row are significantly different ($P < 0.05$). [x-z]Values with different letters within a column of the meat are significantly different ($P < 0.05$). SEM: standard error of the mean.

Table 3. Volatiles of ground beef treated with different additives and stored for 7 d under aerobic conditions

	Nonir	Irradiated				
Compound	Control	Control	Ascorbic[1]	S+E[2]	A+S+E[3]	SEM
	------------------------ (Total ion counts x 10^{4}) ----------------------					
Pre-aged						
Hydrocarbons	655^{b}	3623^{a}	1221^{b}	944^{b}	1173^{a}	214
Ketones	10105^{d}	16666^{c}	25389^{b}	14768^{c}	29024^{a}	944
Aldehydes	140^{b}	1572^{a}	0^{b}	0^{b}	0^{b}	127
Alcohols	4810^{b}	10665^{a}	4233^{b}	3376^{c}	2738^{c}	274
Aged						
Hydrocarbons	1902^{d}	4086^{b}	4910^{a}	2272^{d}	3402^{c}	146
Ketones	31817^{b}	37498^{ab}	42686^{a}	316378^{b}	41393^{a}	2124
Aldehydes	349^{c}	3406^{a}	1631^{b}	0^{c}	0^{c}	259
Alcohols	34409^{a}	15646^{b}	12361^{bc}	9901^{c}	8756^{c}	1259
Long-term aged						
Hydrocarbons	8861^{b}	11358^{a}	6384^{c}	2305^{d}	3598^{d}	653
Ketones	55885^{a}	38349^{b}	42879^{b}	20913^{c}	36644^{b}	3188
Aldehydes	25304^{a}	25988^{a}	15974^{a}	0^{b}	0^{b}	3325
Alcohols	233801^{a}	29834^{b}	25413^{b}	23525^{b}	15999^{b}	3027

[1]Ascorbic acid 0.1%; [2]Sesamol 100 ppm + α-tocopherol 100 ppm; [3]Ascorbic acid 0.1% + sesamol 100 ppm + α-tocopherol 100 ppm. n = 4.[a-c]Values with different letters within a row are significantly different ($P < 0.05$).
Hydrocarbons: pentane, 1-hexene, hexane, benzene, 1-heptene, heptane, toluene, 1-octene, octane, 2-octene, 3-methyl-2-heptene; Ketones: 2-propanone, 2-butanone, 2,3-butadione, 2-pentanone; Aldehydes: 3-methyl butanal, propanal, pentanal, hexanal, heptanal; Alcohols: ethanol, 1-pentanol; Sulfur-volatiles: carbon disulfide, ethanethioic acid, S-methyl ester, dimethyl disulfide, dimethyl trisulfide. SEM: standard error of the mean.

Fig. 1. Changes of the amounts of sulfur-volatiles and aldehydes of "aged" ground beef treated with different additives during the aerobic storage at 4 °C.
(●) Nonirradiated control; (❍) irradiated control; (■) irradiated ascorbic acid-added; (❑) Irradiated sesamol + tocopherol-added; (▲) irradiated ascorbic acid + sesamol + tocopherol-added. (a-d) Different letters within a storage time shows that the means are significantly different ($P < 0.05$). n = 4.