Effects of ascorbic acid and antioxidants on color, lipid oxidation and volatiles of irradiated ground beef

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Abstract

Beef loins with 3 different aging times after slaughter were ground, added with none, 0.1% ascorbic acid, 0.01% sesamol + 0.01% \( \alpha \)-tocopherol, or 0.1% ascorbic acid + 0.01% sesamol + 0.01% tocopherol. The meats were packaged in oxygen-permeable bags, irradiated at 2.5 kGy, and color, oxidation–reduction potential (ORP), lipid oxidation and volatile profiles were determined. Irradiation decreased the redness of ground beef, and 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 lower ORP than control, and the low ORP of meat helped maintaining the heme pigments in reduced form. During aerobic storage, S-volatiles disappeared while volatile aldehydes significantly increased in irradiated beef. Addition of ascorbic acid at 0.1% or sesamol + \( \alpha \)-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.

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1. Introduction

Ground beef comprises over 40% of beef consumption in the US (AMI, 1998), and is the most susceptible form of meat to microbial contamination during processing and handling. Therefore, prevention of pathogens from ground beef is the most demanding. Irradiation is the most effective technology in controlling pathogenic microorganisms in ground beef, but can influence color, lipid oxidation and odor of beef significantly.

Meat color is a prime quality parameter that determines the consumer acceptance of meat. Liu et al. (1995) indicated that the loss of value due to discoloration in beef at the retail level in the US 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 (Ahn et al., 1998). In general, light meat such as pork loin and poultry breast meat produced pink color, while dark meat such as beef became brown or gray after irradiation (Millar et al., 1995; Nanke et al., 1998; Kim et al., 2002a). The pink color compounds in irradiated light meat was characterized as a carbon monoxide-heme pigment complex (Nam and Ahn, 2002a,b), but the mechanisms and cause of color changes in irradiated beef is not known yet.

The major volatile compounds responsible for odor in irradiated meats are mainly sulfur compounds (Ahn et al., 1999, 2000, 2001). The volatile sulfur compounds were produced from the radiolytic degradation of the side chains of sulfur-containing amino acids,
methionine and cysteine (Ahn, 2002; Ahn and Lee, 2002). Unlike popular belief, ground beef oxidized faster than ground pork or poultry (Nam et al., 2001; Kim et al., 2002a). Despite the intrinsic antioxidant activities in fresh meat, irradiation accelerated lipid oxidation in raw pork and beef patties under aerobic conditions (Ahn et al., 1998; Kim et al., 2002b).

Ascorbic acid is a reducing agent, which inhibits myoglobin oxidation and brown color development in nonirradiated beef (Sanchez-Escalante et al., 2001). 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 (Nam and Ahn, 2003).

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.

2. Materials and methods

2.1. Sample preparation

Beef loins (Longissimus dorsi) with 3 different aging times after slaughter were used. The freshest loins were obtained from 4 animals 2 d after slaughter. One group of the loins purchased 2 week 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 separately through a 3-mm plate. Five treatments were prepared: (1) nonirradiated control, (2) irradiated control, (3) 0.1% (w/w) L-ascorbic acid-added and irradiated, (4) 0.01% sesamol + 0.01% α-tocopherol-added and irradiated, and (5) 0.1% ascorbic acid + 0.01% sesamol + 0.01% tocopherol-added and irradiated. Each additive was added to the ground beef and then mixed for 1 min in a bowl mixer. Ground beef was individually packaged in oxygen-permeable bags (polyethylene), stored at 4°C overnight, and irradiated next day morning.

2.2. Ionizing radiation

The aerobically packaged ground beef were irradiated at 2.5 kGy using a Linear Accelerator Facility with 10 MeV energy and 10.2 kW power level. After irradiation, the irradiated and nonirradiated meat samples were immediately returned to a 4°C cold room and stored for 7 d. Color, ORP values, lipid oxidation and volatile profiles of the samples were determined on 1, 4, and 7 d of storage.

2.3. Chemical analyses

CIE color values were measured on the surface of meat samples using a LabScan colorimeter. Oxidation-reduction potential was measured using a pH/ion meter equipped with a platinum electrode. Lipid oxidation was determined using a TBARS method (Ahn et al., 1999). Volatiles of samples were analyzed using a Solatek 72 Multimatrix-Vial Autosampler/Sample Concentrator 3100 connected to a GC/MS according to the method of Ahn et al. (2001).

3. Results and discussion

3.1. Color values

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 did not influence the L* values of beef from all stages of aging. Addition of ascorbic acid and/or sesamol + tocopherol had no effect on the L* values of irradiated ground beef. Irradiation reduced the redness (a* value) of ground beef significantly, but with varying degree depending on aging time (Table 1). Immediately after irradiation, the color of ground beef changed from a bright red to a greenish brown, which would be unattractive beef color for consumers. The color of irradiated beef was totally different from that of irradiated pork or poultry breast, which was pink or red. Nam and Ahn (2002a) reported that the complex of heme pigments with carbon monoxide produced by irradiation was responsible for the increased redness in irradiated turkey breast. The formation of CO-heme complex, however, could not explain the color changes in beef after irradiation because, while the production of carbon monoxide in beef by irradiation was similar to those of light meats (Kim et al., 2002a), the pigment content in beef is >10-fold higher than that in light meats. Thus, the contribution of CO-heme pigment to the color of ground beef was much smaller than that of light meats.

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. Satterlee et al. (1971) reported that the formation of red, MbO2−-like pigment formed from MbFe3+ was greatest in a nitrogen atmosphere, slightly inhibited in air and greatly inhibited in an oxygen atmosphere. Oxygen is an effective scavenger of aqueous electrons (eaq). Therefore, in the absence of oxygen, a reducing environment is established in the irradiated meat, which converts MbFe3+ to MbFe2+. (Giddings and Markakis, 1972). Addition of
Ascorbate further increased the reducing power in beef and increased the red color intensity of ground beef. On the other hand, sesamol + tocopherol had no effect in preventing color changes, and did not show any synergistic effect between ascorbic acid and sesamol + tocopherol in ground beef by irradiation.

The \( a^* \) values of “pre-aged” beef was not changed much during the storage, and the redness was higher in nonirradiated than irradiated beef. “Long-term-aged” beef, however, showed drastic decreases in \( a^* \) values during storage and nonirradiated ground beef had lower \( a^* \) values than irradiated beef. Therefore, in “long-term-aged” ground beef, the color of irradiated meat looked better than nonirradiated meat during storage. This difference in color between fresh and old meats could be related to the loss of reducing power in old meat (“long-term-aged”).

Ascorbic acid increased the \( a^* \) values of irradiated ground beef and the color stabilizing effects of ascorbic acid was more distinct in “long-term-aged” than in “pre-aged” irradiated ground beef. 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. However, addition of strong antioxidants along with ascorbic acid would be more beneficial in controlling lipid oxidation in irradiated ground beef during storage.

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. With increased storage time after irradiation, ORP values of meat increased steadily in all treatments but ascorbic acid-added ground beef still maintained lower values than others over the storage time.

### 3.2. Lipid oxidation of irradiated 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 (0.01%, w/w) and sesamol + \( \alpha \)-tocopherol combination (100 ppm each) 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. TBARS of irradiated ground beef added with ascorbic acid was 40% lower than that
of irradiated control, but sesamol+tocopherol had stronger antioxidant effect than ascorbic acid. The incorporation of ascorbic acid prevented color changes while sesamol+α-tocopherol showed a very strong antioxidant effect in irradiated beef during storage. This suggested that the combined use of these additives could prevent color changes and lipid oxidation in “long-term-aged” irradiated ground beef during storage.

3.3. Volatiles of irradiated beef

Irradiation increased the amounts of sulfur compounds (Fig. 1). The S-volatiles newly generated or greatly increased by irradiation were ethanethioic acid S-methyl ester, dimethyl disulfide, and dimethyl trisulfide. Ahn et al. (2000) reported that S-containing volatiles were highly dependent upon irradiation dose and the off-odor in irradiated pork was produced by the compounding effects of volatiles from lipid oxidation and radiolytic degradation of various amino acid side chains. 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.

When irradiated ground beef were stored for 7 d under aerobic conditions, the profiles of volatile compounds were totally different from those at day 1. 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. Ketones such as 2-propanone, 2-butanone, and 2,3-butanediene were the predominant compounds in ground beef after 7-d storage, irrespective of irradiation. Hexanal, a good indicator of lipid oxidation, was the most predominant aldehyde compound and was significantly detected at even “pre-aged” beef at day 7. As aging time before irradiation increased, many more volatile aldehydes (propanal, pentanal, hexanal, and heptanal) were found and their amounts also increased. As storage time after irradiation increased, considerable amounts of ethanol were produced in “aged” and “long-term-aged” non-irradiated beef, which could be attributed to microbial growth. The S-volatiles predominant immediately after irradiation were not found in irradiated ground beef after 7 d of aerobic storage. Although aerobic packaging was very 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.

Addition of antioxidant was very effective in inhibiting not only a few hydrocarbons but volatile aldehydes also in irradiated beef at day 7. Especially, volatile aldehydes were not detected in ground beef incorporated with sesamol + tocopherol, while ascorbic acid produced some aldehydes. Therefore, when irradiated beef is aerobically stored, the generation of lipid oxidation products is of more concern than S-volatiles.

4. Conclusion

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 of beef red. 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.

References