Addition of garlic or onion before irradiation on lipid oxidation, volatiles and sensory characteristics of cooked ground beef

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ARTICLE INFO

Article history:
Received 17 September 2010
Received in revised form 17 December 2010
Accepted 9 January 2011

Keywords:
Cooked ground beef
Irradiation
Garlic and onion
Lipid oxidation
Odor and flavor

ABSTRACT

Addition of 0.5% onion was effective in reducing lipid oxidation in irradiated cooked ground beef after 7 day storage. Addition of garlic or onion greatly increased the amounts of sulfur volatiles from cooked ground beef. Irradiation and storage both changed the amounts and compositions of sulfur compounds in both garlic- and onion-added cooked ground beef significantly. Although, addition of garlic and onion produced large amounts of sulfur compounds, the intensity of irradiation odor and irradiation flavor in irradiated cooked ground beef was similar to that of the nonirradiated control. Addition of garlic (0.1%) or onion (0.5%) to ground beef produced a garlic/onion aroma and flavor after cooking, and the intensity was stronger with 0.1% garlic than 0.5% onion treatment. Considering the sensory results and the amounts of sulfur compounds produced in cooked ground beef with added garlic or onion, 0.5% of onion or less than 0.1% of garlic is recommended to mask or change irradiation off-odor and off-flavor.

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1. Introduction

Irradiation has been approved for use in beef since 2000 and is the best known method in controlling pathogens in raw ground beef. However, the amount of irradiated beef sold in the U.S. is less than 1% of total beef consumption because irradiation of meat changes quality, which negatively influences consumer acceptance (Lee, Love, & Ahn, 2003). Huskey (1997) reported that both safety (84%) and taste (83%) of meat are very important for the meat industry and consumers. Although consumer surveys and market analysis indicated that about 70% of consumers were willing to pay a premium price for irradiated chicken breast (Hayes, Shogren, Fox, & Kliebenstein, 1995), the major concerns in irradiating meat are its effect on meat quality. The primary changes in irradiated meat are mainly related to the generation of off-odor, color change, and lipid oxidation. Color and odor of meat at the time of opening packaging bag, and subsequent cooking and eating determine whether consumers will purchase the meat again next time.

Irradiated meat, regardless of packaging methods, produced more volatiles than non-irradiated ones and developed a characteristic aroma (Ahn, Olson, Jo, et al., 1998). Sulfur compounds produced by irradiation are responsible for irradiation off-odor (Jo, Lee, & Ahn, 1999). Volatile sulfur compounds can be produced in two different ways: one is a direct radiolytic cleavage of the side chains of sulfur containing amino acids such as methionine and cysteine (Ahn, 2002), and the other is by secondary reactions of primary sulfur compounds with surrounding compounds (Jo & Ahn, 2000). Significant amino acid–lipid interactions are also involved (Ahn, Nam, Du, & Jo, 2001). Among the sulfur compounds, dimethyl sulfide, dimethyl disulfide and dimethyl trisulfide were the most prominent sulfur compounds produced by irradiation and are responsible for irradiation off-odor in meat (Ahn et al., 1997; Ahn, Olson, Lee, et al., 1998). The perception of odor from samples containing sulfur volatiles is changed somewhat depending on the composition of other volatiles in the sample, but the roles of nonsulfur compounds to the overall odor characteristics of irradiated liposomes prepared with phosphatidyl choline, phosphatic acid, amino acid homopolymers were minor (Ahn & Lee, 2002).

Irradiation is expected to accelerate oxidative changes in meat significantly, but increases TBARS only in aerobically packaged raw meat (Ahn et al., 1997). Exposure to oxygen after cooking was the most important factor in oxidative changes of cooked pork, and hexanal concentrations represented the lipid oxidation status of cooked meat better than any other volatile components (Ahn et al., 1997; Ahn, Olson, Lee, et al., 1998). Dietary vitamin E at >200 IU/kg feed decreased lipid oxidation and reduced total volatiles of raw turkey meat, but has not been shown to be effective in cooked turkey meat stored under aerobic conditions (Ahn, Kawamoto, Wolfe, & Sim, 1995). The addition of tocopherol + gallocate and tocopherol + sesamol is highly effective in reducing lipid oxidation and off-odor volatiles in irradiated cooked turkey and pork patties (Nam & Ahn, 2003b), but has only minor effects on the production of sulfur compounds and off-odor intensity (Nam & Ahn, 2003a).
Sensory analyses of irradiated pork indicated that approximately 70% of sensory panels characterized irradiation odor as “barbecued-corn-like” odor (Ahn, Jo, Du, Olson, & Nam, 2000; Ahn, Jo, & Olson, 2000; Nam, Ahn, Du, & Jo, 2001). Sulfury odor in ready-to-eat (RTE) turkey hams increases as irradiation dose increases, and the contents of sulfur compounds in irradiated hams are higher than those in nonirradiated samples. Irradiation increases the production of acetaldehyde, which could be related to a “metal-like” flavor in irradiated hams (Zhu, Lee, Mendonca, & Ahn, 2004). Masking or preventing off-odor/off-flavor production in irradiated meat is among the most critical factors for consumer acceptance of irradiated ground beef. Garlic (Allium sativum L.) and onion (Allium cepa L.) are two major food ingredients widely used in cookery to complement and enhance the flavor of meat products (Tang & Cronin, 2007). Garlic and onion both produce many sulfur compounds, which provide their unique flavor and odor. Therefore, addition of garlic or onion may change, mask, or improve the odor/flavor characteristics of irradiated cooked meat. Nonfluid seasonings such as garlic and onion are permitted for use in irradiated ground meat and meat byproducts (Electronic Code of Federal Regulation, 2009). Extensive work has been done to determine irradiation effects on raw meat quality, but little information on the quality changes or improvement for irradiated cooked meat is available.

The objective of this study was to determine the effect of garlic and onion on lipid oxidation volatile profiles, and masking or preventing off-odor/off-flavor in irradiated cooked ground beef.

2. Materials and methods

2.1. Sample preparation

Eight beef top rounds from different steers were obtained from a local packing plant 6 days post-slaughter. The animals were 27 month old steers finished on a ration containing grain, by-products, and hay for 4 months. Two rounds from different steers were pooled and treated as a replication. Each round was trimmed of any visible fat and connective tissues. All the muscles from the two rounds were pooled and ground together through a 3-mm plate twice, and used. Six different treatments were prepared: 1) non-irradiated control, 2) irradiated control, 3) non-irradiated added with 0.1% garlic (wt/wt), 4) irradiated added with 0.1% garlic, 5) non-irradiated added with 0.5% onion, and 6) irradiated added with 0.5% onion. Skinned fresh garlic and onion were purchased from a local supermarket, ground until they became a semi-liquid form using a Kitchen Aid food processor (Model KSM 90; Kitchen Aid Inc., St. Joseph, Mich., USA) immediately before use in a fabrication room of meat laboratory (4 °C). The entire homogenate of garlic and onion was used, and the amount of garlic and onion treatments was selected on the basis of our preliminary study to prevent excessive garlic and onion odor in ground beef. Each additive was added to the ground meat and then mixed for 1 min in a bowl mixer (Model KSM 90; Kitchen Aid Inc., St. Joseph, Mich., USA). Ground beef patties (approximately 60 g) were made by hand, packaged individually in oxygen-impermeable bags (O2 permeability, 9.3 mL O2/m2/24 h at 0 °C), stored at 4 °C overnight, and irradiated the next day morning. Only four treatments (non-irradiated control, irradiated control, irradiated added with 0.1% garlic, and irradiated added with 0.5% onion) were used for sensory analysis.

2.2. Ionizing radiation and cooking

The packaged ground beef patties were irradiated at 0 or 2.5 kGy using a linear accelerator facility (Circe III; Thomson CSF Linac, St. Aubin, France) with 10 MeV energy and 5.6 kW power level. The average dose rate was 74.1 kGy/min. Alanine dosimeters were placed on the top and bottom surfaces of a sample and were read using a 104 Electron Paramagnetic Resonance Instrument (Bruker Instruments Inc., Billerica, MS, USA) to check the absorbed dose. The Max/Min ratio was 1.16. The non-irradiated control (0 kGy) samples were exposed to an ambient temperature of linear accelerator facility while other samples were irradiated.

After irradiation, 12 patties per treatment (3 storage times × 4 replications) of the patties were cooked in a 90 °C water bath (Isotemp®, Fisher Scientific Inc., Pittsburgh, PA, USA) until the internal temperature of the patties reached 75 °C. After cooling to room temperature, patties were removed from the cooking bags and re-packaged in oxygen-permeable bags (polyethylene, 10 × 15 cm, 2 mil, Assoc. Bag Co.), stored for 7 days at 4 °C, and used for TBARS and volatile analyses. The rest of the patties were cooked in an electric oven at 175 °C to an internal temperature of 75 °C and used for sensory analysis. Internal temperatures of meat patties during cooking were monitored with thermocouples connected to digital read-out devices. All the cooked meat patties were vacuum-packaged immediately after cooking to minimize oxidative changes during storage and handling before the sensory test. The cooked meats were used for the sensory test without storage.

2.3. 2-Thiobarbituric acid-reactive substance (TBARS)

Lipid oxidation was determined using a TBARS method (Ahn, Olson, Jo, et al., 1998). The meat sample (5 g) was placed in a 50-mL test tube and homogenized with 15 mL deionized distilled water for 15 s at high speed (Type PT 10/35; Brinkman Instrument Inc., Westbury, NY, USA). The meat homogenate (1 mL) was transferred to a disposable test tube, and butylated hydroxytoluene (7.2%, 50 μL) and thiobarbituric acid (TBA)/trichloroacetic acid (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, the samples were centrifuged at 3000 × 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 deionized distilled water and 2 mL TBA/TCA solution. The amounts of TBARS were expressed as mg of malondialdehyde (MDA) per kg of meat.

2.4. Volatile compounds

A purge-and-trap apparatus (SOLUTECH 72 and Concentrator 3100; Tekmar-Dohrmann, Cincinnati, OH, USA) connected to a gas chromatograph/mass spectrometer (HP 6890/HP 5973; Hewlett-Packard Co., Wilmington, DE, USA) was used to analyze volatiles produced. The meat sample (2 g) was placed in a 40-mL sample vial, and the vial was flushed with helium gas (40 psi) 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., 0.5 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, USA). Ramped oven temperature was used to improve volatile separation. An 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 22.5 psi was maintained. The ionization potential of the mass-selective detector (Model 5973; Hewlett-Packard) was 70 eV, and the scan range was 19.1–400 m/z. Identification of volatiles was achieved by comparing the 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 (pkA s) was reported as an indicator of volatiles generated from the sample.
2.5. Sensory training and evaluation

Ten panelists were recruited and trained in 3 training sessions. Ten panelists were screened from potential panelists (total 16 panelists) using basic taste identification tests. Panelists were given samples representing anchor points for each attribute, and training sessions using non-irradiated control and 1.25, 2.5, and 4.5 kGy irradiated samples produced in the meat lab. The panelists were trained using a 5-point scale (“5 extremely intense” and “1 slightly intense”) for irradiation aroma, ground beef aroma, garlic/onion aroma, irradiation flavor, ground beef flavor, and garlic/onion flavor. The final anchor point ratings were decided upon by the training panel after initial evaluation and discussion. They were trained with cooked ground beef patty products for 2 weeks with the product characteristics to be evaluated.

For the samples, panelists evaluated irradiation aroma/flavor, ground beef aroma/flavor and garlic/onion aroma/flavor using a 15-point hedonic scale as described by Meilgaard, Civille, and Carr (1999), where one (1) was “no aroma/flavor” and fifteen (15) was “strong aroma/flavor.” Cooked samples were cut and placed in glass containers (Pyrex, Charleroi, PA) with a plastic cover while they were still hot and tested immediately. Panelists evaluated samples in isolated booths fitted with a breadbox server and red incandescent lighting to make color differences.

2.6. Statistical analysis

Data was analyzed by the procedures of the generalized linear model (GLM) of SAS (2000). The SNK (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. Differences in sensory values were compared using Tukey’s significant differences. For sensory data, mean values and standard deviations were reported. Statistical significance for all comparisons was made at P<0.05.

3. Results and discussion

3.1. Lipid oxidation

Irradiation had no effect on the TBARS of cooked ground beef at Day 0 regardless of the additive treatments, but irradiated control and 0.1% garlic-added beef had higher TBARS values than those of non-irradiated ones at 3 day storage (P<0.05) (Table 1). At Day 7, additive treatments had no effect on the oxidation of nonirradiated cooked ground beef, but 0.5% onion-treatment showed a significant antioxidant effect in irradiated samples (Table 1). Griffiths, Trueman, Crowther, Thomas, and Smith (2002) reported that among vegetables and fruits, onion contains the highest amount of quercetin, a phenolic antioxidant (Hertog, Holman, & Katan, 1992). Over the 7 day storage period, the TBARS of cooked ground beef increased by about 3 times from 0 day values in all treatments. Irradiation is reported to accelerate lipid oxidation of meat under aerobic conditions and oxygen availability during storage was important than irradiation on the lipid oxidation of raw and cooked meat (Ahn, Olson, Jo, Love, & Jin, 1999), but little differences in TBARS values were found between irradiated and nonirradiated cooked ground beef after 7 day storage under aerobic conditions.

3.2. Volatiles

Among the volatiles, only the amounts of aldehydes showed difference by additive treatments in non-irradiated cooked ground beef (Table 2). Irradiation had minor effects on the production of alcohols at Day 0, but irradiated cooked ground beef with garlic or onion produced less amounts of alcohols after 3 day storage. The amounts of aldehydes in cooked ground beef increased during storage, but irradiation had little effect except for nonirradiated cooked ground beef at Day 0 when 0.1% garlic- or 0.5% onion-added ground beef produced more aldehydes than control. The increase of aldehydes in both irradiated and non-irradiated cooked meat should be caused by lipid oxidation under aerobic conditions during storage, but additive treatments had no effect on the amounts of aldehydes at 3 day and 7 day storage. Hexanal, butanal, heptanal, propanal and pentanal were detected in the cooked ground beef, but hexanal was the major volatile aldehyde and the production of aldehydes agreed well with TBARS data (Table 2). Ahn, Olson, Lee, et al. (1998) reported that hexanal was a good indicator of lipid oxidation in meat. Production of hydrocarbons and ketones did not show any consistent trends by irradiation, additive treatments, and storage.

3.3. Sulfur compounds

Addition of garlic or onion greatly increased the amount of sulfur volatiles from irradiated and nonirradiated cooked ground beef (Table 3). Non-irradiated cooked ground beef produced only carbon sulfide, which disappeared after 7 day storage (Table 3). The amount of S-volatiles produced in non-irradiated cooked ground beef with 0.1% garlic or 0.5% onion treatment was much greater than those of the control (P<0.05). The amount of total sulfur volatiles produced from both irradiated and non-irradiated 0.1% garlic-added cooked ground beef was more than 10-fold of the 0.5% onion-added samples. Most of the sulfur compounds in non-irradiated 0.1% garlic-added ground beef remained in the meat, but only a small portion of 3,3-thiobis-1-propene was detected in onion-added cooked ground beef after 7 day storage. Ahn et al. (1999) reported that the sulfur compounds produced by irradiation were highly volatile and readily disappeared during storage under aerobic conditions. The organosulfur compounds and their precursors in garlic such as allin, diallyl sulfide and diallyl trisulfide are reported to be involved in garlic odor and flavor. None of them was detected in this study probably due to their high reactivity and low stability (Kim, Jin, & Yang, 2009; Silagyi & Neill, 1994).

Irradiation produced significant amounts of methanethiol, dimethyl sulfide and dimethyl trisulfide, which are the main sulfur compounds involved in irradiation off-odor in meat (Table 3). Irradiation is also reported to produce various other sulfur compounds such as hydrogen sulfide, carbon disulfide, mercaptomethane, methylthio ethane dimethyl disulfide, bis-methylthio-methane, 3-methylthio-1-propene, ethanoic acid 5-methyl ester, and methyl thioacetate (Ahn, Jo, & Olson, 2000; Fan, Sommers, Thayer, & Lehotay, 2002; Nam, Du, Jo, & Ahn, 2002; Patterson & Stevenson, 1995). Irradiation changed the compositions and amounts of sulfur compounds in both garlic- and onion-added cooked ground beef.
In 0.1% garlic added meat, the amounts of 2-propene-1-thiol and di-2-propenyl disulfide decreased by 80% and 70%, respectively. In onion added meat, the amount of methanethiol increased by 2-fold, but 3,3-thiobis-1-propene disappeared after irradiation. The amounts and compositions of sulfur compounds in garlic- and onion-added cooked ground beef changed dramatically during storage, especially in 0.5% onion added meat, and no sulfur compounds were detected in onion-added irradiated beef after 7 days of storage. No sulfur compounds were detected in irradiated control meat after 3 day storage under aerobic conditions. Most of sulfur compounds produced in irradiated ground beef with 0.5% onion disappeared after 3 day storage and completely disappeared after 7 days (Table 3). After 7 day storage, therefore, the cooked ground beef with onion may not have irradiation odor/flavor nor onion odor/flavor because no sulfur compounds were detected. With 0.1% garlic, most of the sulfur compounds produced in irradiated ground beef with 0.5% onion disappeared after 3 day storage and completely disappeared after 7 days (Table 3). After 7 day storage, therefore, using 0.1% garlic would be more efficient than 0.5% onion to produce sulfur compounds to mask or modify irradiation off-odor.

### Table 2

Alcohols, aldehydes, hydrocarbons and ketone compounds of irradiated and nonirradiated cooked ground beef with different additives during aerobic storage at 4 °C.

<table>
<thead>
<tr>
<th></th>
<th>Non-IR</th>
<th>G0.1%</th>
<th>O0.5%</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alcohols</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol</td>
<td>257</td>
<td>584</td>
<td>112</td>
<td>102</td>
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<tr>
<td>Aldehydes</td>
<td>427</td>
<td>786</td>
<td>918</td>
<td>89</td>
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<tr>
<td>Hydrocarbons</td>
<td>558</td>
<td>825</td>
<td>512</td>
<td>144</td>
</tr>
<tr>
<td>Ketones</td>
<td>416</td>
<td>344</td>
<td>356</td>
<td>61</td>
</tr>
<tr>
<td><strong>3 days</strong></td>
<td></td>
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<tr>
<td>Alcohol</td>
<td>250</td>
<td>105</td>
<td>111</td>
<td>74</td>
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<tr>
<td>Aldehydes</td>
<td>1743</td>
<td>1806</td>
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<td>209</td>
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<td>Hydrocarbons</td>
<td>200</td>
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<td>Ketones</td>
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<td>293</td>
<td>99</td>
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<td><strong>7 days</strong></td>
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<tr>
<td>Alcohol</td>
<td>95</td>
<td>145</td>
<td>96</td>
<td>51</td>
</tr>
<tr>
<td>Aldehydes</td>
<td>1481</td>
<td>1425</td>
<td>1402</td>
<td>222</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>175</td>
<td>816</td>
<td>326</td>
<td>163</td>
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<tr>
<td>Ketones</td>
<td>280</td>
<td>271</td>
<td>220</td>
<td>89</td>
</tr>
</tbody>
</table>

### Notes

- Values with different superscripts within a row of the same irradiation treatment are significantly different (P<0.05).
- Control: without garlic and onion, G0.1%: 0.1% garlic, O0.5%: 0.5% onion, Non-IR: non-irradiated, IR: 2.5 kGy irradiation. SEM: standard error of the means.

**Alcohols**: (ethanol, 1,2-propanol and 1-butanol)

**Aldehydes**: (hexanal, butanal, heptanal, propanal and pentanal)

**Hydrocarbons**: (1-pentane, pentane, 1-hexane, hexane, heptane and octane)

**Ketones**: (2-propanone, 2,3-butanedione, 2-butanone and 2-heptanone).

### Table 3

Sulfur compounds of irradiated and nonirradiated cooked ground beef with different additives during aerobic storage at 4 °C.

<table>
<thead>
<tr>
<th></th>
<th>Non-IR</th>
<th>G0.1%</th>
<th>O0.5%</th>
<th>SEM</th>
<th>IR</th>
<th>Control</th>
<th>G0.1%</th>
<th>O0.5%</th>
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<td><strong>0 day</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methanethiol</td>
<td>0^b</td>
<td>231</td>
<td>91</td>
<td>43</td>
<td></td>
<td>203</td>
<td>468</td>
<td>222</td>
<td>115</td>
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<tr>
<td>Carbon disulfide</td>
<td>26</td>
<td>111</td>
<td>75</td>
<td>55</td>
<td></td>
<td>0</td>
<td>10</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>2-Propan-1-thiol</td>
<td>0^b</td>
<td>2504</td>
<td>0^b</td>
<td>54</td>
<td></td>
<td>135</td>
<td>233</td>
<td>127</td>
<td>38</td>
</tr>
<tr>
<td>Dimethyl disulfide</td>
<td>0^b</td>
<td>152</td>
<td>133</td>
<td>22</td>
<td></td>
<td>0</td>
<td>524</td>
<td>0</td>
<td>78</td>
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<tr>
<td>3,3-Thiobis-1-propene</td>
<td>0^b</td>
<td>598</td>
<td>12^a</td>
<td>53</td>
<td></td>
<td>0</td>
<td>444</td>
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<td>Methyl 2-propenyl disulfide</td>
<td>0^b</td>
<td>185</td>
<td>39^a</td>
<td>14</td>
<td></td>
<td>0</td>
<td>220</td>
<td>24^a</td>
<td>25</td>
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<tr>
<td>Dimethyl trisulfide</td>
<td>0^b</td>
<td>82</td>
<td>34^b</td>
<td>7</td>
<td></td>
<td>0</td>
<td>129</td>
<td>57</td>
<td>27</td>
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<tr>
<td>Di-2-propenyl disulfide</td>
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<td>663</td>
<td>0^b</td>
<td>49</td>
<td></td>
<td>0</td>
<td>186</td>
<td>0^b</td>
<td>27</td>
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<td><strong>3 days</strong></td>
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<tr>
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<td>0</td>
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<td></td>
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<td>11</td>
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<tr>
<td><strong>7 days</strong></td>
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<td>0^b</td>
<td>8</td>
<td></td>
<td>0^a</td>
<td>158</td>
<td>0^b</td>
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<td>Carbon disulfide</td>
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<td>0</td>
<td>0</td>
<td></td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>11</td>
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<td>3,3-Thiobis-1-propene</td>
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<td></td>
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**Notes**

- Values with different superscripts within a row of the same irradiation treatment are significantly different (P<0.05). **n=4.**
- Control: without garlic and onion, G0.1%: 0.1% garlic, O0.5%: 0.5% onion, Non-IR: non-irradiated, IR: 2.5 kGy irradiation. SEM: standard error of the means.
Garlic and onion produce sulfury odor and ground beef remained strong even after cooking, but ground beef with changed or eliminated the irradiation aroma and irradiation irradiated or irradiated control (Table 4), indicating that cooking present in the sample (Ahn, 2002; Ahn & Lee, 2002). Another reason a

15: strong intense), onion/garlic aroma (0: weak and 15: strong intense), irradiation

flavor (0: weak and 15: strong intense), ground beef flavor, but the intensity was signi
cantly lower with the addition of garlic.

considering the sensory results and the amounts of sulfur compounds produced in cooked ground beef with added garlic or onion, 0.5% of onion would be good enough to mask or change odor of irradiated ground beef, but <0.1% of garlic is recommended to reduce the intensity of garlic aroma and garlic flavor.

4. Conclusion

Irradiation accelerated lipid oxidation in cooked ground beef, but storage of cooked meat under aerobic conditions had stronger effect than irradiation. Onion at the 0.5% level showed a significant antioxidant effect in irradiated cooked ground beef after 7 d storage. Addition of garlic or onion greatly increased the amount of sulfur volatiles from cooked ground beef, but the increase was greater with 0.1% garlic than 0.5% onion treatment. Irradiation changed the amounts and compositions of sulfur compounds in both garlic- and onion-added cooked ground beef. The amounts and compositions of sulfur compounds in garlic- and onion-added cooked ground beef changed dramatically during storage, especially in onion added-meat, and no sulfur compounds were detected in onion-added irradiated beef after 7 days storage under aerobic conditions. Although, addition of garlic and onion produced large amounts of sulfur compounds, the intensity of irradiation off-odor and irradiation off-flavor in irradiated cooked ground beef was similar to that of the nonirradiated control. Addition of 0.5% of onion or 0.1% of garlic helped in masking or changing irradiation aroma of cooked ground beef.

Acknowledgements

This study was supported jointly by the Iowa State University, and the WCU (World Class University) program (R31-10056) through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology.

References

Ahn, D. U. (2002). Production of off-odor volatiles from liposome-containing


to health.


patties irradiated and stored in different packaging and storage conditions. Meat


