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Impact of electron-beam irradiation on the quality characteristics of raw ground beef

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ABSTRACT

The aim of this study was to evaluate the effects of different irradiation doses (0–4.5 kGy) on the quality of raw ground beef. The results showed a significant increase in lipid oxidation and protein oxidation after irradiation, and color fading was observed only at 4.5 kGy irradiation. The increasing spermidine did not trigger any food safety panic button in irradiated raw ground beef, but this issue should be taken into consideration in irradiated cured meat products. Electronic tongue detected higher saltiness in irradiated meat due to increased drip loss by irradiation. Due to the synergistic effect of saltiness on umami, an unexpected increase in umami taste was observed at 4.5 kGy. Dimethyl disulfide produced from the sulfur-containing amino acids, the major irradiation processing biomarker, was only detected at 4.5 kGy irradiation. Thus, electron beam irradiation < 4.5 kGy was effective doses for the vacuum-packaged raw ground beef without influencing its physicochemical characteristics.

1. Introduction

Ground beef products comprise over 62% of beef consumption in the U.S. and are the most susceptible to microbial contamination because they are prepared from the trims from multiple carcasses (Garner, Unruh, Hunt, Boyle, & Houser, 2014). Various pathogen control measures, including improvements in Good Manufacturing Practices (GMP), Hazard Analysis Critical Control Points (HACCP), etc., have been implemented to decrease or eliminate pathogens in meat products (Omer et al., 2015; Sohaib, Anjum, Arshad, & Rahman, 2016). However, 15 meat recalls and 4 cases of alerts were issued by the FSIS due to pathogen contamination in 2018 (FSIS, 2018).

The use of irradiation as an intervention kill-step for microorganisms in meat has an excellent potential to enhance meat safety and extend shelf-life (Giroux & Lacroix, 1998; World Health Organization, 1988). However, the oxidation-reduction environment can be modified by irradiation in meat systems, including acceleration of lipid and protein oxidation, color changes, nucleotide degradation, and off-flavor formations (Feng, Jo, Nam, & Ahn, 2018).

Biogenic amines are basic nitrogenous compounds, which can be formed by decarboxylation of amino acids (Eerola, Hinkkanen, Lindfors, & Hirvi, 1993) or by amination and transamination of aldehydes and ketones (Askar & Treptow, 1986; Maijala, Eerola, Aho, & Hirn, 1993). However, biogenic amines (e.g.: histamine, tyramine, etc), are defined as harmful compounds in food industries. Nausea, respiratory distress, hot flushes, sweating, heart palpitation, headache, bright red rashes, oral burning and hypo−/hypertension are the typical symptoms of biogenic amine intoxication (Rice, Eitenmiller, & Koehler, 1976). Therefore, FDA and European Commission set the guidance level for the histamine in fish, 50 mg/kg and 100 mg/kg, respectively (European Commission, 2005; Food and Drug Administration, 2011). Hungerford (2010) and Zare, Muhammad, Bejo, and Ghazali (2013) reported biogenic amines, such as putrescine and cadaverine, can be present as potentiators for histamine. Drabik-Markiewicz et al. (2011) also found that spermidine could amplify the formation of N-nitrosamine (e.g.: *N*-nitrosodimethylamine, *N*-nitrosopiperidine) when nitrites were present.

Feng, Moon, Lee, and Ahn (2016) showed that the decarboxylation of amino acids is a common chemical reaction in irradiated model systems. Thus, our hypothesis is that irradiation of meat will facilitate biogenic amine formation, which will produce off-taste in irradiated raw ground beef. In addition, as the approval of applying irradiation on

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the raw meat, the negative effect brought should be addressed first. However, the relationships among lipid oxidation, protein oxidation, color changes, nucleotides, biogenic amines, volatiles and taste profiles in irradiated ground meat were unclear yet.

The objectives of this study were to 1) access the impact of electron-beam irradiation on the quality characteristics of raw ground beef, 2) evaluate the changes of taste profiles in the different irradiation doses using electronic tongue, 3) determine the amounts of newly formed biogenic amines and evaluate their implications to human health, 4) interpret the relationships among the quality-related parameters by principal component analysis. The results of this study could provide a deep understanding of the advantages and disadvantages surrounding the irradiation of raw ground beef, and the corresponding compensatory solutions could also be proposed.

2. Materials and methods

2.1. Sample preparation

Three packages of raw ground beef (90% lean, 10% fat) with different lot numbers were purchased from a local grocery. Four 50-g of meat samples were taken from one package and individually vacuum-packaged as a replication. Three replications were prepared. One sample form each package were subjected to irradiation at a dose of 0, 1.5, 3.0 and 4.5 kGy using an electron beam accelerator (Titan Corp., San Diego, CA), with an energy level of 10 MeV and a dose rate at 107.1 kGy/min. Alanine dosimeters (Bruker Instruments Inc., Billerica, MA) were used to record the absorbed dose, and Min/Max ratio was 1.08. Having received irradiation, meat samples were immediately transported to the laboratory and stored at 4 °C. Quality-related parameters were determined within 24 h after irradiation.

2.2. Lipid oxidation and protein oxidation

Thiobarbituric acid reactive substances (TBARS) method of Ahn et al. (1998) was used to measure the lipid oxidation. The amounts of TBARS were expressed as milligrams (mg) of malondialdehyde (MDA) per kilogram (kg^{-1}) of meat. The 2,4-dinitrophenylhydrazine (DNPH) derivatization method was used to determine the extent of protein oxidation and was expressed as the protein carbonyl content. The carbonyl content was calculated as nmoles per milligram of protein (Zhang, Xiao, Lee, & Ahn, 2011).

2.3. Color measurement

A Konica Minolta Color Meter (CR-410, Konica Minolta, Osaka, Japan) was used to measure the color (Feng et al., 2018). Lightness (CIE L*-value), redness (CIE a*-value), and yellowness (CIE b*-value) were recorded under an illuminant C, 2° light source with a 53 mm port size.

2.4. Nucleotides, inosine and hypoxanthine

The extraction of nucleotides, inosine and hypoxanthine was based on methods described by Feng et al. (2018). After extraction, a 1 μL sample was injected into HPLC system (Agilent 1100 Series HPLC system equipped with a diode array detector, Agilent Technologies, Wilmington, DE, USA). Chromatograms were obtained from Synergi Fusion-RP HPLC column (4 μm particle size, 80 Å pore size, 150 mm × 4.6 mm i.d., Phenomenex, Manchester, UK) with a flow rate of 0.5 mL per min. The mobile phase (A: methanol/water 60:40, B: 0.02 M, pH 5.5 KH_2PO_4) was run under gradient conditions: 0–16 min, 3–20% solvent A; 16–21 min, 20% solvent A. The column was re-generated at the end of each run by reversing the solvent gradient from 20 to 3% solvent A in 5 min. Detection was done at 254 nm (Aliani & Farmer, 2005).

2.5. Volatile compounds

A Solatek 72 Multimatrix-Vial Autosampler/Sample Concentrator 3100 (Tekmar-Dohrmann, Cincinnati, OH, USA) linked to a GC/MS (Model 6890/5973; Hewlett-Packard Co., Wilmington, DE, USA) was used to analyze the volatiles of samples (Yang et al., 2011). ChemStation™ software (Hewlett-Packard Co.) integrated the peak area as an indicator of volatiles generated from the samples.

2.6. Biogenic amines

Five grams of minced meat was transferred into a 50-mL centrifuge tube, and then 20 mL of 6% trichloroacetic acid and 1 mL of an internal standard (25 μg/mL 1,7-diaminoheptane) were added, and then vortex-mixed for 3 min. The solution was centrifuged at 8000 × *g* for 10 min at 4 °C, the supernatant collected, and then filtered through a Whatman No. 54 filter paper.

Biogenic amines (tryptamine, putrescine, spermine, spermidine, tyramine, cadaverine, histamine) in the sample extracts were derivatized with benzoyl chloride (Hwang, Chang, Shiua, & Chai, 1997). Briefly, 1.0 mL of 2 N NaOH solution was added to a 2-mL aliquot of sample extract and then 10 μL of the derivatizing agent (benzoyl chloride) was added. The solution was vortex-mixed for 1 min, placed in a water bath at 30 °C for 40 min, vortex-mixed and then incubated again for 20 min. At the end of the incubation, 2 mL of saturated NaCl solution was added to the mixture and extracted two times with 2 mL diethyl ether. The diethyl ether extract was collected and evaporated to dryness with purified nitrogen gas. Finally, 1.0 mL of acetonitrile was added, mixed, and filtered through a 0.45 μm syringe membrane filter before HPLC analysis (Agilent 1100 Series HPLC system equipped with a diode array detector, Agilent Technologies, Wilmington, DE, USA). An aliquot (1 μL) was injected using an auto-sample injector and the biogenic amine derivatives were separated on a Spherisorb ODS2 Column (4 μm particle size, 80 Å pore size, 100 mm × 4.6 mm i.d., Waters, Milford, USA). The mobile phase consisted of 100 mM ammonium acetate (w/v) (Solution A) and acetonitrile (Solution B) with a gradient. Gradient began at 50% and ended at 90% acetonitrile in 19 min. The column was equilibrated for 10 min before the next analysis. The flow rate was 1.0 mL/min; column temperature was set at 40 °C, and the biogenic amines were detected at 254 nm with 550 nm as a reference (Eerola et al., 1993).

2.7. Electronic tongue

The taste profiles of the irradiated raw ground beef were evaluated using the α-Astree 2 E-tongue (Alpha M.O.S., Toulouse, France). A sample of 10 g irradiated raw ground beef was extracted twice with 50 mL distilled water to acquire the water-soluble components of meat.

Hydrochloric acid (0.01 mol/L) was used to condition and calibrate the sensors of the electronic tongue. Hydrochloric acid, sodium chloride, caffeine, glucose, and monosodium glutamate (0.01 mol/L) were used to test the stabilities. Each meat sample was analyzed ten times for a period of 120 s (Liu, Wang, Li, & Wang, 2012).

2.8. Statistical analysis

Three replications were used for each quality characteristic analysis. Data were analyzed by the GLM procedure of SAS (SAS 9.4 software package) for different treatments. The fixed effect of treatments and the random effect of replications were included in the model. Tukey's multiple comparison method was used to compare the differences in mean values ($P < 0.05$). A principal component analysis was conducted to explore relationships among quality characteristics of raw ground beef under different irradiation doses using XLSTAT (2015).

Table 1
Lipid oxidation, protein oxidation and color of the irradiated raw ground beef in vacuum packaging at day 0.

	0 kGy	1.5 kGy	3.0 kGy	4.5 kGy	SEM
Lipid oxidation[1]:	0.09^{b}	0.11^{b}	0.20^{a}	0.23^{a}	0.009
Protein oxidation[2]:	0.47^{d}	0.57^{c}	0.71^{b}	0.77^{a}	0.005
Color:					
L*-value:	48.47^{a}	47.78^{ab}	47.14^{b}	47.11^{b}	0.14
a*-value:	16.04^{a}	15.97^{a}	15.96^{a}	14.89^{b}	0.05
b*-value:	5.00^{a}	4.78^{a}	4.40^{b}	4.10^{b}	0.04

^{a,b,c,d} Means with different letters within a row differ significantly ($P < 0.05$). n = 3.
[1] Thiobarbituric acid reactive substances (TBARS) (mg malonaldehyde/kg meat).
[2] Carbonyl content (nmoles/mg protein).

Table 2
Effect of irradiation on nucleotides, nucleotide degradation products and biogenic amines in the raw ground beef with vacuum packaging at day 0.

	0 kGy	1.5 kGy	3.0 kGy	4.5 kGy	SEM
Nucleotides and nucleotide degradation products[1]					
ADP	1.92^{a}	1.81^{b}	1.78^{b}	1.69^{c}	0.005
AMP	0.06^{b}	0.09^{a}	0.09^{a}	0.10^{a}	0.002
IMP	0.36^{a}	0.32^{b}	0.29^{b}	0.30^{b}	0.003
Inosine	0.18^{a}	0.18^{a}	0.19^{a}	0.18^{a}	0.003
Hypoxanthine	10.51^{b}	10.68^{a}	10.63^{a}	10.66^{a}	0.006
Biogenic amines[2]					
Spermidine	0.14^{b}	0.16^{b}	0.40^{a}	0.48^{a}	0.018

^{a,b,c}Means with different letters within a row differ significantly ($P < 0.05$). n = 3.
[1] Nucleotides and nucleotide degradation products content (μmoles/g).
[2] Biogenic amines content (μmoles/g).

3. Results and discussion

3.1. Lipid oxidation, protein oxidation and color changes of raw ground beef

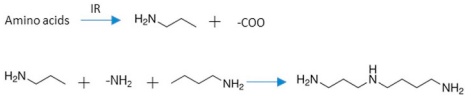
Increasing irradiation dose from 0 to 4.5 kGy increased lipid oxidation by 156% and protein oxidation by 64% (Table 1). This indicated that raw ground beef was more sensitive to the lipid oxidation than the protein oxidation. Ground beef comes from grinding lower quality cuts, trimmings from subprimals (Garner et al., 2014), and the phospholipids in the muscle cell membranes are damaged and antioxidant enzymes are denatured during grinding (Ahn, Wolfe, Sim, & Kim, 1992). Those factors are expected to accelerate oxidative changes to a greater extent in meat lipids than proteins (Toldrá, 2017).

The meat appearance is the most important factor influencing the consumers' purchasing decision (Kim et al., 2018). Consumers use color as a major criterion in selecting meat products and associate meat color with freshness (Kim & Hunt, 2011). L*-value and b*-value were significantly decreased when the irradiation dose was > 3.0 kGy, while a*-values were differentially affected under irradiation (Table 1), indicating that lightness, redness and yellowness have different tolerances under irradiation. As described by Kim, Nam, and Ahn (2002), oxidizing and reducing compounds could be formed during irradiation. The decrease of a*-value showed that the concentration of pigments in meat was decreased due to the myoglobin degradation or denaturation (Ismail, Lee, Ko, & Ahn, 2009).

3.2. Nucleotides, nucleotide degradation products and biogenic amines of raw ground beef

Nucleotides and nucleotide degradation products were also significantly impacted by irradiation: 12% decrease in ADP and 67% increase in AMP by irradiation (from 0 to 4.5 kGy). The amount of IMP decreased by 17% while hypoxanthine increased 2% when irradiated at 4.5 kGy (Table 2). The trends of nucleotides and nucleotide degradation products in irradiated raw ground beef were similar to those in the irradiated beef round and irradiated cooked/raw turkey meat (Feng et al., 2016; Feng et al., 2018). IMP is supposed to generate umami taste in meat products, while inosine and hypoxanthine produce off-taste (e.g.: bitter taste) (Toldrá, 2017). The decrease of IMP and increase of hypoxanthine could possibly contribute to the taste differences in meat before and after irradiation (Carter, Monsivais, & Drewnowski, 2011). However, uric acid and other components can be formed through hypoxanthine degradation when the irradiation dose is above 3.0 kGy (Canzanell, Guild, & Rapport, 1951; Fellig, 1954).

Biogenic amines are nonvolatile amines that may be aliphatic, aromatic or heterocyclic in their chemical structure (Eerola et al., 1993). Low amounts of biogenic amines are essential for physiological functions in living cells. However, uptake of high concentrations of biogenic amines may be harmful to health (Aflaki, Ghoulipour, Saemian, Shiebani, & Tahergorabi, 2015). Amino acid decarboxylation is the main pathway for the formation of biogenic amines (Chong, Abu Bakar, Russly, Jamilah, & Mahyudin, 2011):



The amount of spermidine was increased after beef irradiation. An amount of 69.72 mg/kg was observed after irradiation at 4.5 kGy (Table 2). Similar results were obtained by Eliassen, Reistad, Risøen, and Rønning (2002) in beef (55.20 ± 31.96 mg/kg) and Bardócz, Grant, Brown, Ralph, and Pusztai (1993) in ground beef (71.17–72.63 mg/kg), but higher than that in dry sausage (2.8 mg/kg) (Eerola et al., 1993) and canned fish (1.66–4.12 mg/kg) (Yen & Hsieh, 1991). Korean fermented soybean paste (*Cheonggukjang*) was reported to have 46.95 mg/kg spermidine (Yoon, Park, Choi, Hwang, & Mah, 2015), while the raw ground beef stored at 4 °C for 12 days had 113.3 mg/kg (Ruiz-Capillas & Jiménez-Colmenero, 2004). This indicated that moderate moisture (> 40%, w/w), oxidation reactions and free radicals could have accelerated the formation of spermidine (Ko, Choi, Choi, Lee, & Choi, 2014). Drabik-Markiewicz et al. (2011) reported that spermidine (1000 mg/kg) could amplify the formation of N-nitrosamine (e.g., *N*-nitrosodimethylamine, *N*-nitrosopiperidine) in minced raw meat when nitrites were present. Considering the low level of spermidine in irradiated ground beef at 4.5 kGy (69.72 mg/kg) and no added nitrite in raw ground beef, it may not cause toxicity to human. However, in irradiated cured meat products, this issue should be studied further.

3.3. Volatile profiles of raw ground beef

Twenty-five volatile compounds, including 1 sulfur compound, 2 ketones, 1 benzene and 21 hydrocarbons were identified from the irradiated raw ground beef (Table 3). The amount of dimethyl disulfide increased significantly at 4.5 kGy. Dimethyl disulfide was formed by the radiolysis of methionine, and it is considered as the typical off-odor compounds in the irradiated meat (Fan, Lee, & Ahn, 2011).

2-Propanone and 2-butanone were the two ketones were detected in the irradiated ground beef samples. A linear increase of 2-butanone was observed as the irradiation dose increased ($R^2 = 0.999$). During the irradiation, two carboxylic acids go through the ketonic decarboxylation to form ketones (Oliver-Tomas, Renz, & Corma, 2017). However, no significant differences were found in the amount of 2-propanone before and after irradiation.

Table 3
Effect of irradiation on the volatile profiles of raw ground beef with vacuum packaging at day 0.

	0 kGy	1.5 kGy	3.0 kGy	4.5 kGy	SEM
	Total ion counts × 10^4				
Sulfur compounds					
Dimethyl disulfide	0^{b}	0^{b}	0^{b}	525^{a}	7
Ketones					
2-Propanone	800^{b}	1029^{a}	1006^{a}	979^{a}	6
2-Butanone	0^{d}	330^{c}	664^{b}	1017^{a}	8
Benzene					
Methyl-benzene	0^{b}	0^{b}	0^{b}	71^{a}	2
Hydrocarbons					
2,3,3-Trimethyl-pentane	141^{c}	261^{b}	327^{ab}	370^{a}	8
2,3,4-Trimethyl-pentane	0^{c}	0^{c}	69^{b}	132^{a}	1
2,2,3,4-Tetramethyl-pentane	0^{b}	0^{b}	0^{b}	150^{a}	4
3,5-Dimethyl-2-hexene	91^{a}	109^{a}	0^{b}	0^{b}	4
2,2,5-Trimethyl-hexane	76^{d}	118^{c}	156^{b}	197^{a}	3
2,3,5-Trimethyl-hexane	0^{c}	0^{c}	131^{b}	207^{a}	5
Heptane	0^{c}	127^{b}	114^{b}	582^{a}	2
1,1′-Oxybis-heptane	0^{c}	63^{b}	60^{b}	95^{a}	2
3,3,5-Trimethyl-heptane	111^{c}	210^{b}	276^{b}	347^{a}	6
2,3-Dimethyl-heptane	0^{c}	0^{c}	46^{b}	98^{a}	2
4-Methyl-3-heptene	0^{b}	89^{c}	0^{b}	113^{a}	1
Octane	167^{c}	367^{b}	418^{b}	663^{a}	5
2,2-Dimethyl-octane	73^{c}	373^{b}	324^{b}	645^{a}	7
1-Octene	97^{c}	451^{b}	466^{b}	613^{a}	11
3-Ethyl-1-octene	0^{b}	0^{b}	0^{b}	46^{a}	2
2-Octene	73^{c}	353^{b}	357^{b}	480^{a}	6
3-Octene	88^{a}	0^{b}	0^{b}	0^{b}	5
4-Octene	0^{c}	76^{b}	81^{b}	121^{a}	5
2,2,6-Trimethyl-decane	455^{a}	0^{c}	110^{b}	0^{c}	8
2,2,7-Trimethyl-decane	0^{c}	80^{b}	437^{a}	415^{a}	4
2-Propenamide	46^{a}	0^{b}	0^{b}	0^{b}	1

^{a,b,c,d} Means with different letters within a row differ significantly ($P < 0.05$). n = 3.

Methyl-benzene was detected when the irradiation dose was increased to 4.5 kGy. A similar result was reported in the irradiated Ready-To-Eat turkey breast rolls, which showed a significant increase of benzene when irradiation dose was high (Zhu, Mendonca, Lee, & Ahn, 2004). The cleavages of side chains of aromatic amino acids are the major sources of producing benzene and benzene derivatives (Jo & Ahn, 2000). Toluene is believed to have negative neurological effects, but it is not classified as carcinogens to humans (IARC, 1999). In addition, exposure to marginal amounts of benzene derivatives may not impose health risks to humans (Vinci et al., 2015).

Twenty-one hydrocarbons were detected in the irradiated raw ground beef. The amounts of hydrocarbons, except 3,5-dimethyl-2-hexene, 4-methyl-3-heptene, 3-octene, 2,2,6-trimethyl-decane and 2-propenamide, gradually increased as the irradiation dose increased. This observation indicated that alkenes were unstable under irradiation. Irradiation can break water molecules to produce hydroxyl radical (oxidizing radical) as well as aqueous electrons and hydrogen atoms (reducing compounds) (Sevilla, Becker, Kumar, & Adhikary, 2016), and these protons and electrophiles can initiate reactions to carbon-carbon double bonds (McMurry, 2004). It is unexpected to detect 2-propenamide (acrylamide) in non-irradiated raw ground beef. Acrylamide is proven to be carcinogenic and mainly is formed by the reaction of asparagine with reducing sugars as a part of Maillard reaction during heating (Krishnakumar & Visvanathan, 2014). Fan and Mastovska (2006) reported that ionizing radiation was effective in destroying acrylamide in water. Considering approximately 70% of ground beef is water, no 2-propenamide in the irradiated ground beef is reasonable.

3.4. Principal component analysis (PCA) for volatile compounds

PCA was performed to visualize the data set of volatile compounds in a reduced dimension. Two principal components were retained to determine treatment scores (Fig. 1). The first principal component (PC1) explained 77.01% and the second principal component (PC2) explained 13.67% of the variation. The lower left quadrant of PC showed that major volatile components contributing to the control group were 3-octene, 2-propenamide, and 2,2,6-trimethyl-decane. Raw ground beef irradiated at 1.5 kGy and 3.0 kGy were posited in the opposite side of the control group, but no specific volatile was associated with the two treatments. 2-Butanone, methyl-benzene and dimethyl disulfide were located on the positive axis of PC1 and the negative axis of PC2 (lower right quadrant), indicating that the raw ground beef irradiated at 4.5 kGy were highly associated with that volatiles (Fan et al., 2011; Zhu et al., 2004). In addition, other volatiles, such as hydrocarbons, had little contribution to the irradiated meat off-odor (Ahn et al., 2016).

3.5. Electronic tongue analysis

The taste profiles and quality-related parameters of irradiated raw ground beef were also depicted by principal component analysis (Fig. 2). The first two principal components accounted for 52.46% and 24.34% of the variations, respectively. In the negative axis of PC1, the sweetness and bitterness were represented as the main sensory characteristics in the control group. The amount of ADP was highly associated with non-irradiated raw ground beef. After irradiation, the changes of oxidation-reduction potential of the meat resulted in the removal of hydrophilic groups in ADP (N-containing and phosphate moieties) and degraded it into AMP, IMP, inosine or hypoxanthine (Table 2). In the lower right quadrant, the ground beef irradiated at 3.0 kGy was highly associated with sourness. Similar results were reported by Feng et al. (2018) in the irradiated beef round eye, and both bitterness and sourness were increased in raw round beef by irradiation. The irradiated raw ground beef at 4.5 kGy was in the opposite side of the control group, and was unexpectedly associated with umami and salty tastes. Similar results were reported by Toledo, Canniatti-Brazaca, Spoto, and Arthur (2005) who found that chicken breast irradiated at 8 kGy using Co^{60} had higher saltiness than lower-dose and control group meat. The possible explanation is that irradiation promoted physical alteration in the muscles, which caused irradiated meat to lost more liquid (Kanatt, Chawla, & Sharma, 2015). The increased umami taste in the meat irradiated at higher-dose (4.5 kGy) was due to the synergistic effect of NaCl with umami substances. The enhancing effects of salts on the responses of umami substances was speculated to be due to binding of both cations and anions in salts to the receptor membranes, which leads to the changes in the interaction of the umami substances with the receptor proteins (Ugawa & Kurihara, 1994).

However, no close relationship was found between spermidine and sensory profiles, which was unexpected (Gokoglu, Yerliyaya, & Cengiz, 2004). This result indicated that biogenic amines in irradiated raw ground beef had marginal effects on the sensory changes. But the adjacent locations of spermidines, lipid oxidation and protein oxidations still suggest that the changes of oxidation-reduction environments by irradiation are the main factor for the formation of biogenic amines in ground beef.

4. Conclusion

The oxidation-reduction state and sensory profiles of meat can be changed by irradiation. Lipid and protein oxidation significant increased, while myoglobin in raw ground beef oxidized, degraded or denatured. However, the increase of biogenic amines (e.g.: spermidine) and volatiles (e.g.: hydrocarbons), and the degradation of nucleotides by irradiation had minor effects on the taste changes of irradiated raw ground beef by the electronic tongue. Dimethyl disulfide was shown to be the typical off-odor volatile in irradiated ground beef as in the turkey meat. However, the increase of saltiness due to the loss of water holding

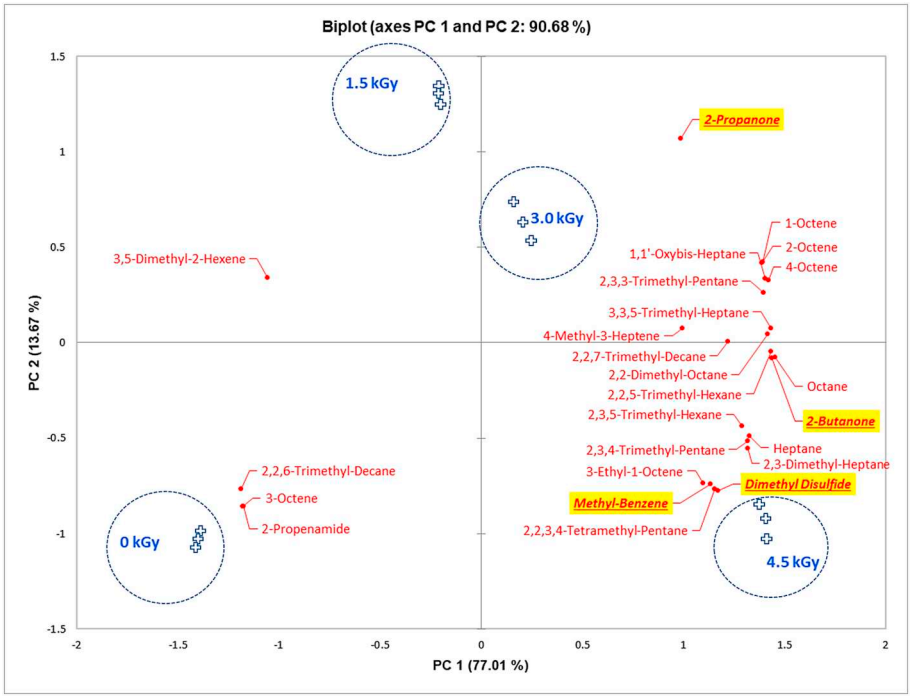


Fig. 1. Principal component (PC) analysis of the volatile compounds (●) from irradiated raw ground beef (⊕) with vacuum packaging at day 0[1].
[1]Volatiles of sulfur compounds, ketones and benzene were shown underlined.

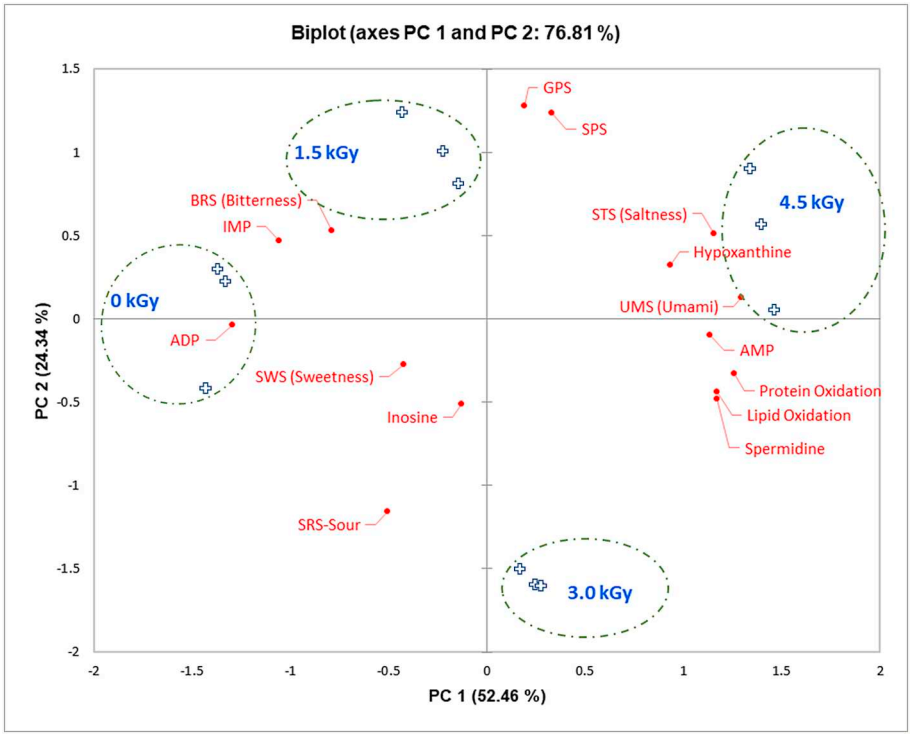


Fig. 2. Principal component analysis of electronic tongue results (●) of irradiated raw ground beef (⊕) with vacuum packaging at day 0.

capacity after irradiation brought a butterfly effect to the taste profile of irradiated raw ground beef. The finding suggested that low-dose irradiation (< 3.0 kGy) produced only limited changes in raw ground beef. When the irradiation dose was increased to 4.5 kGy, however, the method to maintain water holding capacity or the use of masking agents could be useful to minimize the irradiation-related quality defects in raw ground beef. In addition, the increasing spermidine didn't trigger any food safety panic button in irradiated raw ground beef. However, in the irradiated cured meat products, this food safety issue should be taken into consideration.

Abbreviations

ADP	adenosine diphosphate
AMP	adenosine monophosphate
IMP	inosine monophosphate

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