Effect of irradiation on the quality characteristics of raw beef round eye

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Summary and Implications

The objective of this study was to elucidate the relationships among lipid/protein oxidation, color changes, off-taste and off-odor in irradiated raw beef round eye. Raw beef round eye was irradiated at 0, 1.5, 3.0 and 4.5 kGy using a linear accelerator. Significant increases in lipid oxidation and protein oxidation were found in irradiated raw beef round eye, while significant decreases were observed in the color values (L*-, a*-, and b*-value). The degradation of nucleotides can contribute to the taste changes (increase in sourness and decrease in umami taste) in the irradiated raw beef round eye, which was further confirmed by the electronic tongue data. The sulfur volatiles (e.g.: dimethyl disulfide) from the sulfur-containing amino acids increased significantly after irradiation, indicating these are closely related to the off-odor of irradiated beef round eye.

Introduction

Food irradiation technology has been confirmed as an effective method for the prevention of food spoilage as well as the control of pathogens. However, irradiation can change the oxidation-reduction potential of meat systems, which results in accelerated lipid and protein oxidation, color changes, and off-taste and off-odor production. Irradiation increased the redness of light meats due to carbon monoxide myoglobin formation. Conventionally, the sensory characteristics of meat products are assessed by the trained sensory panels, but has difficulties in training, standardization of measurements, high cost, reproducibility, and taste saturation of the panelists. In this regard, the electronic tongue is considered as a promising tool for assessing meat products. The electronic tongue is a robotic system with an array of sensors and has good reproducibility with low detection limits and high sensitivity for screening the taste attributes of foodstuffs. With the approval of irradiation to improve the safety of raw meat, concerns have been raised about the negative effects of irradiation on meat quality, which include lipid oxidation, protein oxidation, color changes, and off-taste and off-odor production. However, the relationships among lipid/protein oxidation, color changes, off-taste (especially the taste profiles), and off-odor in irradiated raw beef round eye are not clear yet. The objectives of this study were to 1) evaluate the effect of irradiation on the lipid/protein oxidation, color, nucleotides and nucleotide degradation products, and volatiles of raw beef round eye, 2) determine the changes of taste profiles under different irradiation doses using the electronic tongue, 3) interpret the relationship among those quality-related parameters using multivariate statistical analysis, and 4) elucidate the key taste components or volatiles responsible for the off-taste and off-odor.

Materials and Methods

Raw beef round eye samples were cut into 50-g pieces and individually vacuum-packaged in vacuum bags (nylon/polyethylene vacuum bags, 9.3 ml O_2/ m^2/24 h at 0 °C). The packaged meats were irradiated at four target dose levels (0, 1.5, 3.0 and 4.5 kGy) using an electron beam accelerator. Following irradiation, packaged meat samples were immediately placed in coolers with crushed ice and transported to the lab and stored at 4 °C. Lipid oxidation, protein oxidation, color, nucleotides and volatiles were determined within 24 h after irradiation. Lipid oxidation was measured using the thiobarbituric acid reactive substances (TBARS) method. The color of meat was measured using a Konica Minolta Color Meter. Nucleotides and nucleotides degradation products were measured using the HPLC method. Volatile compounds were analyzed using a Solatek 72 Multimatrix-Vial Autosampler/Sample Concentrator 3100 connected to a GC/MS. Electronic tongues was used to profile the tastes of raw beef round eye.

Statistical analysis: Data were analyzed by the GLM procedure of SAS, and mean values and standard error of the means were reported ($P < 0.05$). Principal component analysis was conducted in order to explore relationships between quality characteristics and raw beef round eye under different irradiation doses.

Results and Discussion

Lipid oxidation, protein oxidation and color changes: Irradiation increased lipid oxidation by 44% and protein oxidation by 11% from the control. However, all the color values (L*-value, a*-value and b*-value) significantly decreased by irradiation (Table 1). Irradiation can break water molecules to produce oxidizing (hydroxyl radical) as well as reducing compounds (aqueous electrons, hydrogen atoms). The hydroxyl radicals produced from water by ionizing radiation can easily convert myoglobin to metmyoglobin, or even can remove the ferric iron from heme and force it to become a catalyst to accelerate lipid oxidation. In fresh meat, meat pigments are in ferrous form and O_2 can form ligands with myoglobin to produce cherry red color. However, the declining trends of a*-value indicated the degradation or denaturation of meat pigments by irradiation.

Nucleotides and nucleotide degradation products: Nucleotides and nucleotide degradation products were also significantly impacted by irradiation: 23% decrease in ADP under irradiation doses from 0 to 4.5 kGy and 4-fold increase in AMP under the same irradiation dose range. The amounts of IMP and inosine decreased with 75% and 58%, respectively, by 4.5 kGy irradiation. A 1.2-fold increase of hypoxanthine was observed with 3.0 kGy irradiation. As the irradiation dose increased further, however, the concentration of hypoxanthine decreased ($P < 0.05$) (Table 2). IMP improves the meat odor and flavor, but inosine and hypoxanthine are known to contribute to bitter taste and off flavor.

Volatile profiles: Twenty-eight volatiles including 1 sulfur compound, 3 aldehydes, 3 ketone, 1 benzene and 20 hydrocarbons were identified from the meat samples (Table 3). The amount of dimethyl disulfide increased linearly with irradiation, but hexanal, 2-methyl-butanal and 3-methyl-butanal were the three aldehydes detected in the irradiated raw beef round eye. The significant increase of lipid oxidation and hexanal, an indicator of lipid oxidation, in the irradiated raw beef round eye from 0 to 4.5 kGy confirmed this claim. 2-Methyl-butanal and 3-methyl-butanal were usually associated with the Strecker degradation of leucine and isoleucine, which was validated by the newly produced volatiles of 2-methyl-butanal and 3-methyl-butanal at 4.5 kGy. Ketones were usually formed through a ketonic decarboxylation converting two carboxylic acids to a ketone: Two of the three ketones (2-propanone and 2,3-butanedione) were newly produced after irradiation. Benzene was detected in all the irradiated raw beef round eye, but not in the control group. This suggested that the side chains of aromatic amino acids are the major sources of benzene and benzene derivatives by irradiation. Twenty hydrocarbons were found in the irradiated raw beef round eye. Octane, 1-octene and 2-octene were the only volatiles detected in all beef round eye under different doses, and ten hydrocarbons whose carbon number of the main chain was smaller than octane such as 2,3,3- trimethyl-pentane, 2,2,3,4-tetramethyl-pentane and 3,3,5-trimethyl-heptane, and two other carbons larger than octane including 2,5,6-trimethyl-decane and 2,2,8-trimethyl-decane were newly produced. This observation suggested that octane plays as a central role in producing new volatiles after irradiation through cracking, isomerizing or polymerizing.

Principal component analysis (PCA): PCA was performed on volatile compounds in order to provide visualization of the data set in a reduced dimension and two principle components were retained to determine treatment scores. The first principal component (PC1) explained 87.38 % and the second principal component (PC2) explained 10.28 % of the variations (Fig. 1.). The lower right quadrant of PC indicated that the major volatile component contributing to the irradiated raw beef round eye at 1.5 kGy were 2-propanone. On the other hand, 2-butanone and dimethyl disulfide were located in near the positive axis of PC1 and PC2 (upper right quadrant), which indicated that the irradiated raw beef round eye at 3.0 kGy and 4.5 kGy were highly associated with those volatiles. In contrast, other volatiles contributed little to the off-odor in the irradiated raw beef round eye.

Electronic tongues analysis: The first principal component (PC1) explained 70.26 % and the second principal component (PC2) explained 13.75 % of the variations. In the upper left quadrant of PC1, the major sensory characteristics contributing to the non-irradiated raw beef round eye were umami, sweetness, saltiness and bitterness (Fig. 2). For those attributes, the non-irradiated and irradiated meat samples were separated. Near the positive axis of PC1 and PC2 (upper right quadrant), the irradiated meat at 3.0 kGy was highly associated with sourness. In addition, the irradiated meat at 4.5 kGy was in the opposite directions to the control group, which further confirmed that irradiation can change the taste properties of meat by increasing sour notes and degrading of umami-related chemical compounds.

Conclusion

Irradiation can change the oxidation-reduction potential and taste/odor profiles of meat. The degradation of nucleotides could be attributed to the taste changes in irradiated meat, which was further confirmed by electronic tongue data (increased sourness but depleted umami taste). Hydrocarbons had little effects on the odor of irradiated raw beef round eye, but a detectable irradiation odor was produced by dimethyl disulfide, the major radiolytic degradation product of sulfur-containing amino acids. Although, 2-butanone has a very high threshold value, the amount was significantly increased by irradiation due to the ketonic decarboxylation reaction. This finding suggested that the use of antioxidants (e.g.: ascorbic acid) or masking agents (e.g.: garlic) could be helpful to minimize the changes of oxidation-reduction potential and off-taste/odor production by irradiation. Thus, the negative effect of the irradiation on the sensory quality of meat products can be reduced.

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

	0 kGy	1.5 kGy	3.0 kGy	4.5 kGy	SEM
Lipid oxidation[1]:	0.25 [b]	0.23 [b]	0.31 [a]	0.36 [a]	0.004
Protein oxidation[2]:	0.44 [c]	0.43 [c]	0.47 [b]	0.49 [a]	0.002
Color:					
*L**-value:	46.30 [a]	45.14 [ab]	44.25 [bc]	42.62 [c]	0.20
*a**-value:	14.71 [a]	11.50 [b]	10.20 [c]	9.64 [c]	0.12
*b**-value:	5.19 [a]	4.65 [b]	4.34 [c]	3.68 [d]	0.02

[a-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 and nucleotide degradation products in the raw beef loin in vacuum packaging at day 0

	0 kGy	1.5 kGy	3.0 kGy	4.5 kGy	SEM
ADP	3.58 [a]	3.79 [a]	3.13 [b]	2.74 [c]	0.02
AMP	0.11 [c]	0.19 [c]	0.28 [b]	0.55 [a]	0.01
IMP	3.06 [a]	3.02 [a]	1.86 [b]	0.77 [c]	0.02
Inosine	6.78 [a]	6.88 [a]	5.87 [b]	2.88 [c]	0.02
Hx	15.37 [b]	15.77 [b]	17.93 [a]	15.52 [b]	0.10

[a-d]Means with different letters within a row differ significantly (*P*<0.05). n = 3.

Table 3. Effect of irradiation on the volatile profiles of irradiated raw beef loin in 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 [c]	225 [c]	1138 [b]	2208 [a]	28
Aldehydes					
Hexanal	0 [d]	239 [b]	158 [c]	549 [a]	1
2-Methyl-butanal	0 [b]	0 [b]	0 [b]	79 [a]	1
3-Methyl-butanal	0 [b]	0 [b]	0 [b]	213 [a]	1
Ketones					
2-Propanone	0 [c]	6136 [a]	0 [c]	4976 [b]	12
2-Butanone	196 [d]	664 [c]	2280 [a]	1179 [b]	29
2,3-Butanedione	0 [d]	117 [c]	257 [a]	150 [b]	1
Benzene					
Benzene	0 [c]	116 [b]	123 [b]	396 [a]	4
Hydrocarbons					
2,3,3-Trimethyl- pentane	0 [c]	97 [b]	93 [b]	173 [a]	7
2,3,4-Trimethyl- pentane	0 [b]	0 [b]	0 [b]	57 [a]	1
2,2,3,4-Tetramethyl-pentane	0 [b]	56 [a]	53 [a]	55 [a]	3
3,5-dimethyl-2-hexene	0 [b]	0 [b]	0 [b]	102 [a]	1
2,2,5-Trimethyl-hexane	0 [b]	0 [b]	0 [b]	182 [a]	1
2,2,5,5-Tetramethyl-hexane	0 [c]	107 [a]	59 [b]	0 [c]	2
Heptane	0 [c]	148 [b]	0 [c]	475 [a]	7
1-Heptene	0 [b]	0 [b]	0 [b]	97 [a]	1
2,2,4-Trimethyl-heptane	0 [b]	0 [b]	124 [a]	108 [a]	5
3,3,5-Trimethyl-heptane	0 [c]	114 [a]	57 [b]	138 [a]	5
Octane	79 [c]	335 [b]	309 [b]	637 [a]	18
1-Octene	65 [c]	193 [b]	157 [b]	387 [a]	8
2-Octene	41 [c]	106 [b]	117 [b]	348 [a]	1
4-Octene	0 [b]	0 [b]	0 [b]	88 [a]	1
2,2-Dimethyl-octane	0 [b]	346 [a]	0 [b]	0 [b]	1
3,5-Dimethyl-octane	0 [b]	54 [a]	0 [b]	0 [b]	1
2,2,7,7-Tetramethyl-octane	0 [b]	123 [a]	0 [b]	0 [b]	1
2,2,6-Trimethyl-decane	61 [c]	106 [b]	132 [a]	0 [d]	2
2,5,6-Trimethyl-decane	0 [b]	0 [b]	58 [a]	0 [b]	1
2,2,8-Trimethyl-decane	0 [b]	0 [b]	0 [b]	180 [a]	1

[a-d]Means with different letters within a row differ significantly ($P<0.05$). n = 4.

Fig. 1. Principal component (PC) analysis for the volatile compounds (●) of irradiated raw beef loin (✚)