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Lipid Oxidation, Volatiles, and Off-Odor Production of Aerobic-Packaged Pork Patties Irradiated and Stored in Refrigerated or Frozen Conditions

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Abstract

Pork loins were ground twice through a 9-mm plate and patties (approximately 80 g each) were made. Patties were individually packaged in oxygenpermeable polyethylene zipper bags, stored overnight either at 4 or -40° C, and irradiated the next day at 0, 1.5, 3.0, or 4.5 kGy absorbed dose for refrigerated patties, and at 0, 2.5, 5.0, or 7.5 kGy for frozen ones. Samples were analyzed for lipid oxidation, volatile production, and off-odor. Refrigerated samples were analyzed at 0, 1 and 2 weeks of storage at 4°C, and frozen ones were analyzed after 0, 1.5 and 3 months of storage at -40°C. 2-Thiobarbituric acid reactive substances (TBARS) of refrigerated pork patties increased with storage time. TBARS of pork patties increased as irradiation dose increase at 0 day, but the irradiationdose effect disappeared after 1-week of storage at 4°C. Irradiated pork patties produced significant irradiation odor at day 0, but disappeared following storage. Nonirradiated samples were preferred to the irradiated ones at beginning (day 0), but the preference disappeared after 1-week of storage. With frozen storage, TBARS values of irradiated pork patties were not increased by storage. However, patties irradiated at higher dose (7.5 kGy) had higher TBARS value than the nonirradiated or irradiated patties at lower levels. Nonirradiated patties had higher preference scores than the irradiated ones and the difference lasted for 1.5 month in frozen storage. Sulfur-containing compounds such as 2,3- dimethyldisulfide were responsible for most of the irradiation off-odor, but volatilized quickly under aerobic conditions. However, aerobic packaging was not recommended for irradiated meat because of oxidative changes in pork patties during storage.

Keywords

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Summary and Implications

Pork loins were ground twice through a 9-mm plate and patties (approximately 80 g each) were made. Patties were individually packaged in oxygen-permeable polyethylene zipper bags, stored overnight either at 4 or -40° C, and irradiated the next day at 0, 1.5, 3.0, or 4.5 kGy absorbed dose for refrigerated patties, and at 0, 2.5, 5.0, or 7.5 kGy for frozen ones. Samples were analyzed for lipid oxidation, volatile production, and off-odor. Refrigerated samples were analyzed at 0, 1 and 2 weeks of storage at 4°C, and frozen ones were analyzed after 0, 1.5 and 3 months of storage at -40°C.

2-Thiobarbituric acid reactive substances (TBARS) of refrigerated pork patties increased with storage time. TBARS of pork patties increased as irradiation dose increase at 0 day, but the irradiation-dose effect disappeared after 1-week of storage at 4°C. Irradiated pork patties produced significant irradiation odor at day 0, but disappeared following storage. Nonirradiated samples were preferred to the irradiated ones at beginning (day 0), but the preference disappeared after 1-week of storage. With frozen storage, TBARS values of irradiated pork patties were not increased by storage. However, patties irradiated at higher dose (7.5 kGy) had higher TBARS value than the nonirradiated or irradiated patties at lower levels. Nonirradiated patties had higher preference scores than the irradiated ones and the difference lasted for 1.5 month in frozen storage. Sulfur-containing compounds such as 2,3-dimethyldisulfide were responsible for most of the irradiation off-odor, but volatilized quickly under aerobic conditions. However, aerobic packaging was not recommended for irradiated meat because of oxidative changes in pork patties during storage.

Introduction

Irradiation is one of the best methods to control pathogenic microorganisms in meat and meat products. However, one of the major concerns with irradiating meat is its effect on lipid oxidation, color, and off-odor production. Ionizing radiation generates hydroxyl radicals and may increase the rate of lipid oxidation. When molecules absorb ionizing energy they become very reactive and form ions or free radicals. These ions and free radicals react and form stable radiolytic products (12). It was suggested that volatile compounds responsible for off-odor in irradiated meat are produced by radiation impact on protein and lipid molecules and are different from those of lipid oxidation (2). Patterson and Stevenson (9) showed that dimethyltrisulfide is the most potent off-odor compound in irradiated raw chicken meat. Recent study (7) showed that irradiation produced characteristic new volatile compounds from meat model system containing leucine, valine, isoleucine, phenylalanine, methionine, or cysteine by radiolytic degradations. This indicated that both radiolysis of proteins and oxidation of lipids were important for off-odor generation in irradiated meat. The objective of this study is to determine the effect of different doses of irradiation on lipid oxidation, odor, and volatile compound production in aerobic-packaged pork loin patty during refrigerated or frozen storage.

Materials and Methods

Sample preparation and irradiation. Pork loins were ground twice through a 9-mm plate separately, and patties (approximately 80 g each) were prepared. Individual patties were packaged in oxygen-permeable polyethylene zipper bags and stored either in a refrigerator (4°C) or a freezer (-40°C). The next day, the refrigerated patties were irradiated at 0, 1.5, 3.0 or 4.5 kGy, and frozen ones at 0, 2.5, 5.0, or 7.5 kGy using a linear accelerator (Circe IIIR, Thomson CSF Linac). The refrigerated pork patties were stored at 4°C for 2 weeks, and the frozen ones at -40°C for 3 months. Samples were analyzed for lipid oxidation, volatile production, and off-odor during refrigerated (0, 1, and 2 weeks) or frozen storage (0, 1.5, and 3 months).

Lipid oxidation and volatiles measurements. 2-thiobarbituric reactive substances (TBARS) method (Jo and Ahn, 1998) was used to indicate the extent of lipid oxidation using a fluorometer (Model 450, Barnstead/Thermolyne Corp.) with 520nm excitation and 550nm emission. Sample (5 g) was taken into a 50-mL test tube, 15 mL of deionized distilled water was added, and homogenized with a Brinkman Polytron for 10 sec at high speed. The meat homogenate (0.5 ml), SDS (8.1%, 200 µl), HCl (0.5 M, 1.5 ml), TBA (20 mM, 1.5 ml), BHT (7.2%, 50 µl) and deionized distilled water (DDW, 250 µL) were added into a test tube, vortexed and heated in a 90° C waterbath for 15 min. After cooling for 10 min, 1 mL of DDW and 5 mL of n-butanol/pyridine solution (15:1 v/v) were added. The sample was mixed, and centrifuged 3,000*g* for 15 min, and upper layer was measured. A Precept II and purge-and-trap concentrator 3000 (Tekmar-Dohrmann) were used to purge and trap volatile compounds as described by Ahn et al. (2).

Odor intensity and preference. An 11-member trained panel was used to evaluate the irradiation odor intensity and odor preference for both refrigerated or frozen pork patties. Refrigerated patties were tempered about 20 min at room temperature (22°C) and frozen patties were thawed about 2 hrs at 22°C before presenting to the sensory panels. Samples (3g) were presented in a tightly capped scintillation vial (20 ml), and a 15-cm linear scale was used to rate the samples on each sensory attributes. Three questions were asked: irradiation odor intensity (very weak = 0 and very strong = 15), odor preference (highly acceptable = 0 and not acceptable = 15), and odor description. Panels were given a sufficient time (20 min or more) to analyze sample accurately.

Statistical analysis. Two-way analyses of variance (10) were used to determine the effect of irradiation dosage and storage. The four different sources of pork loin were used as replications and significance level was determined at $p<0.05$. The Student-Newman-Keul's multiple range test was used to compare differences among mean values. Mean values and standard errors of the mean (SEM) were reported.

Results and Discussion

Lipid oxidation. Aerobic-packaged patties irradiated at 4.5 kGy had higher TBARS than those at 1.5 kGy or nonirradiated control (Table 1). The TBARS of irradiated patties increased sharply during the refrigerated storage in aerobic packaging, but the effect of irradiation disappeared after 1 week of storage. This result agreed to previous studies (8) and could be interpreted that storage conditions or oxygen availability was more important for the development of lipid oxidation than irradiation. In frozen storage, aerobic-packaged patties irradiated at 7.5 kGy had the highest TBARS, and sample irradiated at 5 kGy had higher TBARS than those with 2.5 kGy or nonirradiated control (Table 2). TBARS, however, were not changed during the 3-month frozen storage. This result indicated that radiation chemistry of refrigerated and frozen meat could be different. Tarte (11) reported that temperature have significant effects on the formation of radiolytic products, and the reactive intermediates of water radiolysis were trapped in deep-frozen materials and thus were kept from reacting with each other or with the substrates. During the warming process, however, they reacted preferentially with each other rather than with the substrates (3).

Irradiation odor intensity and odor preference. Sensory test indicated that the panel clearly detected irradiation odor from irradiated pork patties at day 0, but could not separate irradiation dose effect (Table 3). After 1 week and 2 weeks of refrigerated storage, the panel could not find any difference in irradiation odor between nonirradiated and irradiated samples. We assume that panels confused the irradiation off-odor with oxidative rancidity after 1-week of storage. Sensory panel preferred nonirradiated to irradiated pork loin patties at day 0 (Table 3), but no preference was found in patties with different irradiation levels. The preference of nonirradiated samples decreased over the 2-week storage periods, but that of the irradiated ones increased with storage.

Panels also detected irradiation odor in frozen samples at day 0 and the irradiation odor lasted for 6 weeks in frozen storage (Table 4). Panel preferred nonirradiated to irradiated samples until 6 weeks of frozen storage, which coincide with the intensity of irradiation odor in pork patties. The odor intensity of frozen patties lasted longer than that of the fresh ones. Irradiation odor description by the panels included rotten egg, sweet, bloody, cooked meat or barbecued corn, burnt, sulfur, metallic, alcohol or acetic acid after irradiation, which were similar to others (Huber et al., 1953; Heath et al., 1990). After 1 week of refrigerated storage, however, other sensory traits such as sour, pungent, spicy, acidic, and rancid appeared probably because of volatiles formed by oxidative degradation of fat. Generally, frozen patties with aerobic packaging were described as bland, and had not as strong an odor as refrigerated ones.

Volatile compound analysis. Irradiation had no effect on the production of n-hexanal in refrigerated pork patties. Storage in aerobic conditions, however, significantly increased the production of n-hexanal in all irradiated pork patties (Table 5). This indicates that oxygen availability is important for the progress of oxidative chain-reactions. Jo et al. (8) indicated that both TBARS and volatiles in meat should be used to determine oxidative changes in irradiated meat accurately because TBARS decreased after 3 days of storage in both aerobic and vacuum packaging. Ahn et al. (1) reported that irradiated muscle strips produced a few volatile compounds that were not found in nonirradiated meat. Most of them were sulfur-containing compounds and the amount of 2,3-dimethyldisulfide was the highest. Jo and Ahn (6) reported that 2,3-dimethyldisulfide produced from irradiated oil emulsion containing methionine. The refrigerated patty showed that the amount of 2,3-dimethyldisulfide in irradiated meat increased dramatically with the increase of irradiation doses (Table 5), but nonirradiated sample did not produce the compound. Patterson and Stevenson (9) reported that dimethyltrisulfide was the primary contributor to the irradiation off-odor in meat. We also found small amounts of dimethyltrisulfide from the irradiated pork patties but it disappeared very quickly during storage. After 2 weeks of storage at 4°C, the amount of 2,3-dimethyldisulfide decreased significantly from day 0 because of high volatility of this odor compound.

The amounts of n-hexanal in irradiated frozen samples were higher than that of the nonirradiated, which lasted for 6 weeks in frozen storage (Table 6). The amount of n-hexanal, however, was not changed during storage, which coincided well with TBARS results. A large difference in 2,3-dimethyldisulfide content between frozen and refrigerated pork patties was observed. The amount of 2,3-dimethyl disulfide in frozen pork patties stored for 6 weeks had higher than that of the day 0 storage, which was opposite to the refrigerated storage. In addition to 2,3-dimethyldisulfide, several other irradiation-dependent volatile compounds such as 2-propenal, methanthiol, and 2,3-methyltriulfide, 2-methylbutanal, and 3-methylbutanal were also found. The results indicated that oxygen contact rather than irradiation was more important in oxidative changes of meat during storage. The results indicated that aerobic-packaging is not a good method to irradiate and store pork patties for the long term. However, aerobic packaging for short-term may be useful because compounds responsible for irradiation off-odor can escape easily during the refrigerated storage.

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Table 1. TBARS of aerobic-packaged pork patties irradiated and stored at 4°C.

	Irradiation dose				
Storage (week)	0	2.5 kGy	5.0 kGy	7.5 kGy	SEM
	----------------- (mg malondialdehyde/kg meat) ---------------------				
0	0.08by	0.07cy	0.11cxy	0.12cx	0.009
1	0.34a	0.45b	0.43b	0.43b	0.055
2	0.40a	0.85a	0.65a	0.82a	0.122
SEM	0.026	0.077	0.068	0.098	

a-cDifferent letter within a column is significantly different (P<.05).
x-zDifferent letters within a row are significantly different (P<.05).
SEM, standard errors of the mean.

Table 2. TBARS of aerobic-packaged pork patties irradiated and stored at -40°C.

	Irradiation dose				
Storage (month)	0	2.5 kGy	5.0 kGy	7.5 kGy	SEM
	----------------- (mg malondialdehyde/kg meat) ---------------------				
0	0.15z	0.19az	0.29y	0.39ax	0.030
1.5	0.15y	0.21ay	0.28x	0.32abx	0.021
3	0.11y	0.12by	0.24z	0.26bx	0.025
SEM	0.014	0.018	0.033	0.031	

a-cDifferent letters within a column are significantly different (P<.05).
x-zDifferent letter within a row is significantly different (P<.05).
SEM, standard errors of the mean.

Table 3. Irradiation odor intensity[1] and odor preference[2] of aerobic-packaged pork patties irradiated and stored at 4°C.

	Irradiation dose				
Storage (week)	0	2.5 kGy	5.0 kGy	7.5 kGy	SEM
Irradiation odor intensity					
0	1.9y	7.8x	9.4x	7.7x	1.23
1	5.7	5.5	6.6	6.4	1.28
2	6.5	6.6	5.4	7.1	1.38
SEM	1.31	1.17	1.32	1.35	
Odor preference					
0	3.8by	9.4x	9.5ax	8.7x	1.07
1	7.9a	7.8	8.1ab	7.2	1.10
2	8.8a	9.9	5.7b	6.9	1.14
SEM	1.12	1.17	1.05	1.07	

a,bDifferent letter within a column with the same category is significantly different (P<.05).
x,yDifferent letter within a row is significantly different (P<.05).
[1]0, very weak; 15, very strong; [2]0, strongly like; 15, not acceptable.
[3]SEM, standard errors of the mean.

Table 4. Irradiation odor intensity[1] and odor preference[2] of aerobic-packaged pork patties irradiated and stored at -40 °C.

	Irradiation dose				
Storage (month)	0	2.5 kGy	5.0 kGy	7.5 kGy	SEM
Irradiation odor intensity					
0	1.1by	4.8x	7.8x	7.7x	1.21
1.5	2.0by	8.7x	7.3x	7.9x	1.09
3	5.8a	7.5	6.9	8.9	1.29
SEM	0.90	1.25	1.43	1.36	
Odor preference					
0	3.1by	6.0bxy	7.3bx	7.8x	1.09
1.5	6.2aby	10.3ax	10.0ax	7.8xy	0.97
3	8.3a	8.2ab	6.3b	8.2	1.07
SEM	1.09	1.05	0.94	1.24	

a,bDifferent letter within a column with the same category is significantly different (P<.05).
x,yDifferent letter within a row is significantly different (P<.05).
[1]0, very weak; 15, very strong;
[2]0, Strongly like; 15, not acceptable
[3]SEM, standard errors of the mean.

Table 5. n-Hexanal and 2,3-dimethyldisulfide production of aerobic-packaged pork patties irradiated and stored at 4°C.

	Irradiation dose				
Storage (week)	0	2.5 kGy	5.0 kGy	7.5 kGy	SEM
	(ion count x 1000)				
n-Hexanal					
0	54b	31a	46b	48b	8.2
1	173b	160ab	299b	812ab	239.6
2	634a	306b	1923a	1976a	441.8
SEM	138.0	51.5	397.3	396.7	
2,3-Dimthyldisulfide					
0	0z	430az	3498ay	6706ax	312.7
1	0y	55bxy	50bxy	77bx	15.7
2	0y	25bxy	64bx	73bx	15.3
SEM	-	69.9	320.7	152.8	

a,bDifferent letter within a column with same compound is significantly different (P<.05).
x,yDifferent letters within a row are significantly different (P<.05).
SEM, standard errors of the mean.

Table 6. n-Hexanal and 2,3-dimethyldisulfide production of aerobic-packaged pork patties irradiated and stored at -40°C.

	Irradiation dose				
Storage(month)	0	2.5 kGy	5.0 kGy	7.5 kGy	SEM
	(ion count x 1000)				
n-Hexanal					
0	0y	74by	99by	288bx	30.4
1.5	0y	154ay	857ax	1190ax	133.8
3	96az	188ayz	302by	555bx	42.2
SEM	24.3	18.1	41.8	157.6	
2,3-Dimethyldisulfide					
0	0z	0bz	48y	127x	12.3
1.5	0y	121ay	502xy	1100x	257.1
3	0	0	0	96	16.9
SEM	-	7.9	114.6	274.8	

a,bDifferent letter within a column with same compound is significantly different (P<.05).
x,yDifferent letter within a row is significantly different (P<.05).
SEM, standard errors of the mean.