Effect of Muscle Type, Packaging, and Irradiation on Lipid Oxidation, Volatile Production, and Color in Raw Pork Patties

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Summary and Implications

Irradiation and high fat content accelerated the lipid oxidation in raw meat during storage. Oxygen availability during storage, however, was more important than irradiation on the lipid oxidation and color values of raw patties. Irradiated meat produced more volatiles than nonirradiated patties, and the proportion of volatiles varied by the packaging-irradiation conditions of patties. Irradiation produced many unidentified volatiles that could be responsible for the off-odor in irradiated raw meat. No single volatile components but total volatiles, however, could be used to predict lipid oxidation status of raw meat.

The results show that if patties are vacuum-packaged before irradiation and during storage, raw patties can be stored for 2 weeks without problems in lipid oxidation. Many volatile components produced by irradiation were not directly related to the lipid oxidation status of raw meat but were related to the irradiation odor. Identification of these components would shed light on the mechanisms and the source of the volatiles produced by irradiation.

Introduction

Buzby and Roberts (6) reported that microbial pathogens in food cause between 6.5 million and 33 million cases of human illness every year in the United States. The estimated annual costs of human illness caused by foodborne pathogens range from $5.6 billion to $9.4 billion, and meat and poultry are the primary sources of foodborne pathogens. In response to societal pressure to enhance the safety of fresh meats and poultry, various technologies such as irradiation, carcass wash with organic acids, sanitizers, hot water, steam pasteurization, chlorine, phosphates, and ozone to prevent, reduce, or eliminate pathogenic bacteria on raw meat have been pursued. Among these technologies, irradiation is considered to be the technology that ensures safety by eliminating pathogenic bacteria in raw meat (8).

One of the major concerns in irradiating meat, however, is its effect on meat quality. The influence of irradiation on meat quality is mainly related to the production of free radicals. Thayer et al. (21) reported that irradiation dose, processing temperature, and packaging conditions strongly influence microbial and nutritional quality of meat. Irradiation-induced oxidative chemical changes are dose dependent, and the presence of oxygen has a significant effect on the rate of oxidation (12). Lee et al. (14) reported that pre-rigor beef, irradiated with an absorbed dose of 2 kGy and stored at 2°C in modified atmosphere packaging (25% CO_2 and 75% N_2), did not increase lipid oxidation. Irradiation, at 1.5 to 10 kGy dosages, however, increased thiobarbituric acid values and decreased thiamin and tocopherols in turkey breast and fish muscles when aerobic or vacuum packaged in oxygen-permeable bags (3,9).

Heath et al. (11) reported that irradiating uncooked chicken meat produced a characteristic bloody and sweet aroma. Merritt (15) suggested that the volatile compounds responsible for the off-odor in irradiated meat are produced by the radiation impact on protein and lipid molecules and are different from those of lipid oxidation. Schweigert et al. (19) reported that the precursors of the undesirable odor compounds in irradiated meat were water soluble and contained nitrogen and/or sulfur. Methyl mercaptan and sulfur dioxide formed from the sulfur (S)-containing compounds (e.g., glutathione) contributed some of the irradiation odor. Patterson and Stevenson (16) showed that dimethyltrisulfide is the most potent off-odor compound in irradiated raw chicken meat. Others reported that irradiation had no detrimental effect on the flavor of vacuum-packaged raw meat (20).

Heme pigments, especially myoglobin, are responsible for meat color and also are considered as strong prooxidants when they are activated by hydrogen peroxide (10). The changes in heme pigments by irradiation could change color and generate off-flavor in irradiated raw meat. It is postulated that heme pigments can catalyze lipid oxidation in irradiated meat because irradiation can influence the release of iron from heme pigments or

the formation of ferryl radicals. Therefore, muscles with different heme pigment and lipid contents could react differently under various packaging and irradiation conditions. At present, little information on lipid oxidation, color changes, and off-odor generation in various pork muscles by low-dose irradiation (<10 kGy) is available.

The objective of this research is to determine the effects of muscle type, packaging, and irradiation levels on lipid oxidation, off-flavor, and color changes of raw pork patties during storage. *Longissimus dorsi, psoas,* and *Rectus femoris* muscles of pig were used in this study because they have distinct differences in heme pigment and lipid contents, and could have different responses to packaging and irradiation treatments.

Materials and Methods

Sample preparation. Longissimus (L.) dorsi (L. thoracis and lumborum), psoas, and *Rectus (R.) femoris* muscles of pig were obtained 24 hour after slaughter from a local meat packer. Muscles were transported to the Meat Laboratory at Iowa State University, and ground twice through a 3-mm plate. Patties (approximately 100 g each) were prepared from each of the ground meat sources, packaged either in oxygen permeable polyethylene (Nasco Whirl-Pak bags, Nasco, Fort Atkinson, WI), or vacuum packaged (-1.0 bar) using a Multi Vac vacuum packager (AG-800, Wolfertschwenden/Allgau, W. Germany) into the impermeable nylon/polyethylene bags (O_2 permeability, 9.3 ml O_2/m^2/24 hour at 0°C; Koch, Kansas City, MO), irradiated with an electron beam at 0 or 4.5 kGy dose (127 kGy/min) by using a Linear Accelerator (Circe IIIR, Thomson CSF Linac, France) and then stored up to 2 weeks at 4°C. Lipid oxidation and color of the patties were determined after 0, 3, 7, and 14 days of storage. Zero-day samples were analyzed 3 hour after irradiation. Volatiles were determined 24 hour after irradiation. Total fat content of raw patties from the three muscle types also was determined by the Folch's extraction method (7) from the day 0 samples.

Lipid oxidation and color measurement Lipid oxidation was determined by the modified method of Buege and Aust (5). A 5-g meat sample was placed in a 50-ml test tube and homogenized with 15 ml of deionized distilled water (DDW) by using a Brinkman Polytron (Type PT 10/35, Westbury, NY) for 15 s at speed 7-8. Meat homogenate (1 ml) was transferred to a disposable test tube (13 x 100 mm), and butyrated hydroxyanisole (50 µl, 7.2%) and thiobarbituric acid/trichloroacetic acid (TBA/TCA) solution (2 ml) was added. The mixture was vortexed and then incubated in a boiling water bath for 15 min to develop color. After color development, the samples were cooled in cold water for 10 min and then centrifuged for 15 min at 2,000 x *g*. The absorbance of the resulting supernatant solution was determined at 531 nm against a blank containing 1 ml DDW and 2 ml TBA/TCA solution. Malonaldehyde standard curves were prepared by using 1,1,3,3-tetra-ethoxypropane (5). The TBARS numbers were calculated from the standard curve, and were expressed as milligrams malondialdehyde (MDA) per kilogram of meat.

Color (Hunterlab a-, b-, L-values) was measured by using a Minolta colorimeter (CR-300, Ramsey, NJ). Two readings were made from the surface of patties immediately after opening packages.

Volatiles analysis Precept II and Purge-and-Trap Concentrator 3000 (Tekmar-Dohrmann, Cincinnati, OH) were used to purge and trap the volatiles potentially responsible for the off-odor in irradiated meat. A Hewlett Packard GC (Model 6890, Wilmington, DE) equipped with a flame ionization detector (FID) was used to analyze volatiles after thermally desorbing the trapped volatiles. In preparation for volatiles analysis, meat (2 g) was weighed into a sample vial (40 ml), capped tightly with a Teflon-lined, open-mouth cap, and placed in a refrigerated (4°C) sample tray. The sample was transferred to a Precept II sample holder by using a robotic arm, heated to 32°C, and then purged with helium gas (40 ml/min) for 11 min. Volatiles were trapped by using a Tenax/Silica gel/Charcoal column (Tekmar-Dohrmann, Cincinnati, OH) and desorbed for 2 min at 220°C. The temperature of transfer lines connecting Precept II and the Concentrator 3000, and the Concentrator 3000 and the GC inlet, was maintained at 135°C.

A split inlet (split ratio, 29:1) was used to inject the desorbed volatiles into a GC column. A DB-Wax capillary column (0.53-mm i.d., 30 m, and 1-µm film thickness; Supelco, Bellefonte, PA), and ramped oven temperature conditions (30°C for 1 min, increased to 40°C @40°C/min, increased to 100°C @30°C/min, increased to 180°C @20°C/min and held for 1 min) were used. Inlet temperature was set at 180°C, and the detector temperature was 220°C. Helium was used as a carrier gas, and a constant column flow of 5.8 ml/min was used. FID air, H_2, and make-up gas (He) flows were 300 ml/min, 30 ml/min, and 28 ml/min, respectively. Individual peaks were identified by the retention time of volatile standards. Standard kits (aldehyde-ketones, alcohols,

hydrocarbons, and alkenes C6-C10) were purchased from Chromatography Research Supplies, and total 44 standards (9 aldehydes, 11 alcohols, 8 ketones, and 16 hydrocarbones) were used to identify peaks in meat volatiles. The area of each peak was integrated by using ChemStation software (Hewlett Packard Co., Wilmington, DE), and the total peak area (pA*sec) was reported as an indicator of volatiles generated from the meat samples.

Statistical analysis The experiment was designed to determine the effect of packaging-irradiation conditions on the lipid peroxidation, color changes, and volatiles production of raw meat patties from three different muscles during storage. TBARS values of muscles were compared within a storage time under different packaging-irradiation conditions. The data for volatiles and color values from different muscles were analyzed independently by SAS software (18). Analyses of variance were conducted to test the effect of packaging and irradiation conditions within a storage time, and storage effect within packaging and irradiation conditions. The Student-Newman-Keuls 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 When vacuum-packaged, TBARS values of patties from *L. dorsi* muscle increased very slowly during the 2-week storage period regardless of irradiation conditions and the increases were very small (Figure 1A). Under oxygen permeable packaging conditions, the TBARS values of patties from *L. dorsi* muscle increased by approximately 10-fold from day 0 values to 14 days of storage. The TBARS values of aerobic-packaged patties from *L. dorsi* muscle increased rapidly from day 0 in irradiated and after day 7 in nonirradiated. After 3 days of storage, the TBARS values of *L. dorsi* patties were the highest in aerobic-packaged irradiated, followed by aerobic-packaged nonirradiated, and were the lowest in vacuum-packaged patties.

Patties from *psoas* and *R. femoris* had lower TBARS values than those from *L. dorsi* muscle at all storage times (Figures 1B and 1C). The increases of TBARS values in vacuum-packaged *psoas* and *R. femoris* patties as well as aerobic-packaged nonirradiated patties during the 14-day storage periods were small (Figures 1B and 1C). TBARS values of aerobic-packaged irradiated patties from *psoas* and *R. femoris* muscles also were increased during the 14-day storage periods. However, the increases in TBARS values of aerobic-packaged irradiated patties from *psoas* and *R. femoris* muscles were slower than that of *L. dorsi* patties: aerobic-packaged irradiated *L. dorsi* patties reached a TBARS value of 1.0 after 7 days and 3.5 after 14 days of storage whereas the TBARS value of *psoas* patties was 0.70 (Figure 1B) and *R. femoris* was 1.5 after 14 days of storage (Figure 1C).

Figure 1 illustrates that prior irradiation causes accelerated lipid oxidation in raw meat during subsequent storage. But oxygen exposure is a more important factor than irradiation in catalyzing lipid oxidation of raw meat patties during storage. Significant differences in TBARS values among patties from different muscles also were observed. There are many factors such as fat content, prooxidant concentrations (e.g., iron), antioxidant types and concentrations (e.g., tocopherol and antioxidant enzymes), and lipid membrane concentrations (e.g., amount of mitochondria) that could be responsible for some of the differences in oxidation rates of the patties from three different muscles. However, fat content in meat might have played an important role in lipid oxidation of raw meat. The role of triglycerides in lipid oxidation is minor compared with that of phospholipids (22), and phospholipids in muscle cell membranes are responsible for about 90% of lipid oxidation in meat (4,17). However, Ahn et al. (1,2) showed that fat content and the composition of fatty acids in the lipid of meat patties also was very important in determining the development of lipid oxidation of aerobic-packaged broiler and pork loins during storage. Considering high fat content (6.64%) and rapid lipid oxidation in *L. dorsi* patties, and low fat content (1.8 for *psoas* and 2.4% for *R. femoris*) and a slow increase in TBARS values from *psoas* and *R. femoris* patties indicated that total fat content of raw meat was an important factor closely related to the storage stability of meat (Figure 1).

Volatiles Figure 2 shows typical gas chromatograms of volatiles from irradiated and nonirradiated raw pork meat patties of all muscles studied. The chromatogram of the irradiated patty is much more complicated than that of the nonirradiated patty. The major difference in the profiles of volatiles between irradiated and nonirradiated was in the early part (less than 3 min) of the chromatograms. These unidentified volatiles in irradiated meat could be responsible for the characteristic off-odor in irradiated raw meat (bloody and sweet aroma) and the sizes of unidentified volatile peaks in irradiated meat remain unchanged during the whole storage periods. Many of the major volatiles in raw meat could not be identified using the FID.

Tables 1-3 present the amount of total volatiles in raw meat from three different muscles and the proportion of each volatile component to total volatiles. The volatile components shown in irradiated and nonirradiated meat patties were similar in all three muscles, but their proportions to total volatiles were different in the different muscles. The proportions of each volatile to total volatiles also were significantly influenced by the packaging/irradiation conditions. Total volatiles were highly correlated (r^2 =0.49, $P < 0.01$) with the oxidation status of raw meat patties in all three muscles; however, none of the individual volatile components was well correlated with the lipid oxidation status of raw meat.

In *L. dorsi* patties (Table 1), irradiation-related volatiles were about 33% of total volatiles in vacuum-packaged and 22% in aerobic-packaged patties. Mesityl oxide, 2-methyl propanal, and butanone were the major volatiles of vacuum-packaged nonirradiated *L. dorsi* patties, and the sum of the three volatiles was more than 70% of the total volatiles. In aerobic-packaged nonirradiated *L. dorsi* patties, the proportion of 1-pentene of total volatiles increased greatly and became one of the major volatile components. In irradiated *L. dorsi* patties, the proportion of ethanol increased ($P < 0.05$) as with other volatiles not found in nonirradiated patties. The amount of total volatiles was the highest in aerobic-packaged irradiated patties, followed by vacuum-packaged irradiated, aerobic-packaged nonirradiated, and the lowest in vacuum-packaged nonirradiated.

In *psoas* patties (Table 2), the proportions of irradiation-related volatiles were more than 50% of total volatiles in vacuum-packaged but less than 15% in *psoas* and *R. femoris* muscles (13). In all three muscles, the L-values of patties increased to the highest levels after 7 days of storage and then decreased after 14 days; however, there were no consistent trends in L-values by the packaging-irradiation treatments during storage.

Color a-values of raw meat patties during storage were influenced ($P < 0.05$) by the packaging-irradiation treatments (Table 5). *Longissimus* (*L.) dorsi* patties had lower a-values than those of *psoas* and *R. femoris* patties because of the lower myoglobin content in *L. dorsi* muscles than *psoas* and *R. femoris*. Irradiation effect on the color of the meat was not the same in all muscles. Within the same packaging treatment, color a-values of patties increased in the patties from *L. dorsi* muscle, but decreased by the irradiation in *psoas* and *R. femoris*. The color a-values (redness) of the patties stored in vacuum-packaging were higher than those in aerobic-in aerobic-packaged patties. In *R. femoris* patties (Table 3), the proportions of irradiation-related volatiles were about 38% of total volatiles in vacuum-packaged and 15% in aerobic-packaged patties. Mesityl oxide, 2-methyl propanal, and butanone were the major volatiles of vacuum-packaged nonirradiated *psoas* and *R. femoris*, and the proportion of 1-pentene increased greatly as in *L. dorsi* patties (Tables 2 and 3). In irradiated vacuum-packaged *psoas* and *R. femoris* patties, the proportion of the unknown component eluted at 2.043 min increased to over 20% of the total volatiles. In irradiated aerobic-packaged *psoas* and *R. femoris* patties, the proportion of ethanol increased ($P < 0.05$) as in *L. dorsi*. The amount of total volatiles in irradiated meat was higher than that of nonirradiated meat with their respective packaging methods and was the highest in vacuum-packaged irradiated patties and the lowest in vacuum-packaged nonirradiated. The volatiles data presented in Tables 1-3 were obtained from the meat stored 1 day after irradiation, and the changes in volatile profiles during the storage of the raw meat patties are not shown, but hexanal started to appear in raw meat with high TBARS values. Therefore, hexanal along with total volatiles could be used as indicators of lipid oxidation in stored raw meat.

Color Table 4 presents the influence of packaging-irradiation conditions on color L-values of raw pork patties prepared from *L. dorsi*, *psoas*, or *R. femoris* muscle during storage. The L-values of patties from *L. dorsi* muscle were higher than those of the *psoas* and *R. femoris* because of the lower heme pigment content in *L. dorsi* than that
packaging, and had gradually decreasing trends as the storage time increased in all muscles. The data indicated that irradiation has no adverse effect on the redness of raw meat patties during storage when vacuum-packaged. However, oxygen reduced ($P < 0.05$) the redness of irradiated and nonirradiated raw pork patties during storage. When irradiation was combined with aerobic conditions, further reduction in a-values were observed in all three muscles during the first 3 days of storage.

Color b-values of raw meat patties during storage also were influenced ($P < 0.05$) by the packaging-irradiation treatments (Table 6). Aerobic-packaged patties had higher b-values than vacuum-packaged patties, and storage generally increased b-values of patties. Irradiation effects were not consistent in all muscles but irradiation decreased the b-values of aerobic-packaged *psoas* and *R. femoris* patties.

The color data in patties with different packaging-irradiation (Tables 4-6) indicated that irradiation had a significant ($P < 0.05$) effect on color components (L-, a-, b-values) but packaging conditions of meat also would be an important factor. Irradiation would not have adverse effect on the acceptability of raw meat patties during storage when vacuum-packaged. Color changes of meat patties were not directly related to lipid oxidation and the generation of off-flavor in irradiated raw meat.

Conclusions

If patties are vacuum-packaged before irradiation and during storage, raw patties can be stored for 2 weeks without problems in lipid oxidation; however, vacuum-packaged irradiated meat produced more volatiles than nonirradiated patties either in vacuum or aerobic packages. Many volatile components with short GC retention time were produced by irradiation. The volatile components with short retention time, however, were not directly related to the lipid oxidation status of raw meat but could be related to the irradiation odor. Identification of these components would shed light on the mechanisms and the source of the volatiles produced by irradiation. No single volatile component predicts lipid oxidation status in raw meat, but total volatiles does.

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Table 1. Volatiles composition (%) of irradiated and nonirradiated raw pork *L. dorsi* muscle patties with vacuum or aerobic packaging.[1]

Retention time (min)	compound name	vacuum-pkg nonirradiated	vacuum-pkg irradiated	aerobic-pkg nonirradiated	aerobic-pkg irradiated
		% of total volatiles			
1.255	unknown	–	3.26	–	0.85
1.283	unknown	–	7.41	–	3.45
1.312	unknown	–	5.34	–	2.15
1.341	unknown	–	6.81	–	5.10
1.392	unknown	–	1.87	–	0.64
1.480	1-pentene	3.69	3.59	21.77	4.96
1.543	unknown	–	–	0.94	2.77
1.669	unknown	–	–	1.12	–
1.761	unknown	–	1.28	–	1.90
1.976	unknown	–	1.94	–	0.82
2.043	unknown	–	4.71	–	0.70
2.368	propanal	–	–	–	1.48
2.538	2-methyl propanal	17.54	9.61	14.82	13.92
3.079	butanone	16.06	10.66	13.54	10.88
3.254	isopropanol, 1-nonene	8.19	6.19	10.87	3.67
3.306	ethanol	4.94	12.55	4.17	22.06
3.581	pentanal, 2-pentanone	–	–	–	0.66
3.927	propanol	2.39	1.49	1.88	1.46
3.999	unknown	–	–	–	0.71
4.178	hexanal, 2-hexanone	–	–	–	1.12
4.527	mesityl oxide	36.11	18.31	22.65	14.89
4.620	1-butanol	1.54	0.83	1.76	2.55
5.418	4-heptanol	9.54	4.17	5.04	3.23
5.624	unknown	4.27	–	1.44	–
6.673	unknown	1.75	–	–	–
Total volatiles (pA*sec)		99.27[d]	178.61[b]	137.05[c]	238.10[a]
Mean			163.26		
SEM			9.33		

[1]Irradiated at 0 or 4.5 kGy dose and stored at 4°C for 24 hour before volatiles analysis (n=4).

[a-d]Different letters within a row are different ($P < 0.05$).

Table 2. Volatiles composition (%) of irradiated and nonirradiated raw pork *psoas* muscle patties with vacuum or aerobic packaging.[1]

Retention time (min)	compound name	vacuum-pkg nonirradiated	vacuum-pkg irradiated	aerobic-pkg nonirradiated	aerobic-pkg irradiated
		% of total volatiles			
1.255	unknown	–	3.51	–	0.69
1.283	unknown	–	5.95	–	3.08
1.312	unknown	–	4.49	–	1.65
1.341	unknown	–	7.76	–	3.65
1.392	unknown	–	0.60	–	–
1.480	1-pentene	3.46	2.23	18.06	5.83
1.543	unknown	–	–	1.54	–
1.761	unknown	–	1.24	1.73	–
1.976	unknown	–	0.63	–	–
2.043	unknown	–	26.34	–	4.82
2.368	propanal	–	0.45	–	–
2.538	2-methyl propanal	15.14	4.87	9.23	13.54
3.079	butanone	20.40	7.38	10.26	11.48
3.254	isopropanol, 1-nonene	5.28	2.55	5.95	2.83
3.306	ethanol	3.48	10.23	3.03	14.52
3.927	propanol	–	0.43	1.68	1.58
3.999	unknown	–	1.09	–	1.33
4.178	hexanal, 2-hexanone	–	2.25	–	–
4.527	mesityl oxide	35.34	11.73	38.06	23.87
4.620	1-butanol	1.63	0.43	1.76	2.47
5.418	4-heptanol	9.25	1.25	5.54	3.07
5.624	unknown	4.27	0.64	2.04	2.37
6.539	unknown	–	–	–	1.34
6.673	unknown	1.75	–	1.13	1.89
Total volatiles (pA*sec)		114.01[c]	374.49[a]	175.86[b]	221.08[b]
Mean			221.36		
SEM			17.24		

[1]Irradiated at 0 or 4.5 kGy dose and stored at 4°C for 24 hour before volatiles analysis (n=4).

[a-c]Different letters within a row are different ($P < 0.05$).

Table 3. Volatiles composition (%) of irradiated and nonirradiated raw swine *R. femoris* muscle patties with vacuum or aerobic packaging.[1]

Retention time (min)	compound name	vacuum-pkg nonirradiated	vacuum-pkg irradiated	aerobic-pkg nonirradiated	aerobic-pkg irradiated
		---------- % of total volatiles ----------			
1.255	unknown	–	2.67	–	0.57
1.283	unknown	–	4.29	–	1.42
1.312	unknown	–	3.56	–	0.69
1.341	unknown	–	4.06	–	2.87
1.480	1-pentene	3.54	2.61	20.94	3.13
1.543	unknown	–	–	1.58	2.67
1.669	unknown	–	–	1.40	–
2.043	unknown	–	21.77	–	7.15
2.538	2-methyl propanal	12.80	5.64	13.17	12.73
2.981	unknown	–	–	–	1.77
3.079	butanone	14.02	11.54	10.68	14.90
3.254	isopropanol, 1-nonene	3.96	2.50	7.06	2.26
3.306	ethanol	4.02	8.30	3.99	16.06
3.927	propanol	1.41	0.52	1.07	–
3.999	unknown	–	1.29	–	1.19
4.178	hexanal, 2-hexanone	–	0.53	–	0.72
4.527	mesityl oxide	43.32	23.12	29.18	23.72
4.620	1-butanol	1.94	0.90	1.86	1.46
5.418	4-heptanol	8.81	3.64	5.14	3.02
5.624	unknown	6.19	3.06	2.77	2.77
6.539	unknown	–	–	1.88	0.94
Total volatiles (pA*sec)		110.64[c]	252.10[a]	158.06[b]	267.49[a]
Mean			197.07		
SEM			11.12		

[1]Irradiated at 0 or 4.5 kGy dose and stored at 4°C for 24 hour before volatiles analysis (n=4).

[a-c]Different letters within a row are different ($P < 0.05$).

Table 4. The influence of packaging-irradiation conditions on color L-values of raw pork patties prepared from *L. dorsi*, *psoas*, or *R. femoris* muscle during storage.[1]

Storage time (day)	vacuum-pkg control	vacuum-pkg irradiated	aerobic-pkg control	aerobic-pkg irradiated	SEM
L. dorsi					
0	60.56^{ay}	60.58^{ay}	59.65^{abz}	59.08^{by}	0.26
3	60.08^{ay}	60.13^{ay}	61.12^{ay}	58.15^{by}	0.33
7	62.68^{x}	62.69^{x}	62.92^{x}	63.27^{x}	0.42
14	60.83^{by}	62.32^{ax}	62.31^{ax}	62.12^{ax}	0.32
SEM	0.27	0.28	0.32	0.44	
Psoas					
0	45.29^{ay}	44.27^{abz}	45.21^{az}	43.33^{bz}	0.34
3	45.43^{ay}	43.93^{bz}	45.44^{az}	44.56^{aby}	0.27
7	47.33^{x}	47.07^{x}	48.64^{x}	47.24^{x}	0.41
14	46.18^{y}	45.87^{y}	46.73^{y}	46.65^{x}	0.24
SEM	0.33	0.35	0.27	0.32	
R. femoris					
0	44.14^{by}	43.44^{by}	46.33^{ay}	46.55^{ay}	0.30
3	43.68^{cy}	42.20^{dz}	47.99^{ax}	46.21^{by}	0.27
7	48.86^{bx}	48.03^{abx}	48.81^{ax}	48.98^{ax}	0.46
14	44.02^{by}	43.87^{by}	48.52^{ax}	48.29^{ax}	0.37
SEM	0.42	0.29	0.33	0.37	

[1]Samples were irradiated at 0 or 4.5 kGy dose (avg.) and then stored at 4°C (n=6).

$^{a\text{-}d}$Different letters within a row are different ($P < 0.05$).

$^{x\text{-}z}$Different letters within a column of same muscle are different ($P < 0.05$).

SEM=standard error of the mean.

Table 5. The influence of packaging-irradiation conditions on color a-values of raw pork patties prepared from *psoas*, *L. dorsi*, or *R. femoris* muscle during storage.[1]

Storage time (day)	vacuum-pkg control	vacuum-pkg irradiated	aerobic-pkg control	aerobic-pkg irradiated	SEM
L. dorsi					
0	17.69^{bx}	18.84^{ax}	15.67^{cx}	12.69^{d}	0.32
3	16.46^{by}	18.76^{ax}	16.95^{bx}	13.54^{c}	0.23
7	14.55^{bz}	17.71^{ay}	14.21^{by}	12.18^{c}	0.32
14	15.37^{bz}	18.15^{axy}	12.72^{cz}	12.54^{c}	0.55
SEM	0.30	0.23	0.47	0.45	
Psoas					
0	21.09^{ay}	19.04^{by}	17.19^{cx}	15.06^{dy}	0.33
3	20.58^{ay}	17.96^{bz}	17.35^{bcx}	16.74^{cx}	0.24
7	22.46^{ax}	18.42^{bz}	14.68^{cy}	14.95^{cy}	0.31
14	20.69^{ay}	20.37^{ax}	12.27^{cz}	15.49^{by}	0.25
SEM	0.24	0.20	0.33	0.35	
R. femoris					
0	19.43^{ay}	19.20^{ay}	17.53^{bx}	14.59^{cy}	0.27
3	18.55^{az}	17.73^{bz}	17.76^{bx}	16.37^{cx}	0.21
7	20.83^{ax}	18.03^{bz}	14.75^{dy}	16.36^{cx}	0.31
14	19.55^{ay}	20.04^{ax}	13.62^{cz}	14.74^{by}	0.39
SEM	0.27	0.19	0.29	0.37	

[1]Samples were irradiated at 0 or 4.5 kGy dose (avg.) and then stored at 4°C (n=6).

$^{a\text{-}d}$Different letters within a row are different ($P < 0.05$).

$^{x\text{-}z}$Different letters within a column of same muscle are different ($P < 0.05$).

SEM=standard error of the mean.

Table 6. The influence of packaging-irradiation conditions on color b-values of raw pork patties prepared from *psoas*, *L. dorsi*, or *R. femoris* muscle during storage.[1]

Storage time (day)	vacuum-pkg control	vacuum-pkg irradiated	aerobic-pkg control	aerobic-pkg irradiated	SEM
L. dorsi					
0	7.62^{bz}	7.64^{bz}	8.57^{az}	8.57^{ay}	0.19
3	9.02^{bxy}	8.87^{by}	10.97^{ay}	11.27^{ax}	0.23
7	8.36^{by}	9.66^{by}	10.57^{ay}	11.22^{ax}	0.23
14	9.27^{cx}	10.42^{bx}	11.72^{ax}	11.29^{ax}	0.27
SEM	0.23	0.22	0.25	0.22	
Psoas					
0	5.70^{b}	4.82^{cy}	7.81^{az}	5.96^{bz}	0.21
3	5.22^{c}	3.86^{dz}	9.19^{ay}	6.99^{by}	0.26
7	5.91^{c}	4.67^{dy}	10.21^{ax}	8.54^{bx}	0.24
14	5.82^{b}	5.45^{bx}	9.25^{ay}	9.16^{ax}	0.22
SEM	0.25	0.19	0.21	0.27	
R. femoris					
0	4.00^{cx}	4.18^{cy}	7.03^{az}	5.34^{bz}	0.28
3	2.94^{cy}	2.98^{cz}	10.21^{ax}	8.14^{by}	0.13
7	4.12^{dx}	5.17^{cx}	9.62^{axy}	7.56^{by}	0.31
14	3.81^{bx}	4.35^{by}	8.92^{ay}	9.25^{ax}	0.23
SEM	0.25	0.21	0.25	0.27	

[1]Samples were irradiated at 0 or 4.5 kGy dose (avg.) and then stored at 4°C (n=6).

$^{a\text{-}d}$Different letters within a row are different ($P < 0.05$).

$^{x\text{-}z}$Different letters within a column of same muscle are different ($P < 0.05$).

SEM=standard error of the mean.

Figure 1. Effect of muscle types and storage on the TBARS values of raw meat patties irradiated under different packaging conditions (□,vacuum-packaged nonirradiated; ■, vacuum-packaged irradiated; ○, aerobic-packaged nonirradiated; ●, aerobic-packaged irradiated). $^{a-c}$Different letters within a same storage are different ($P < 0.05$).

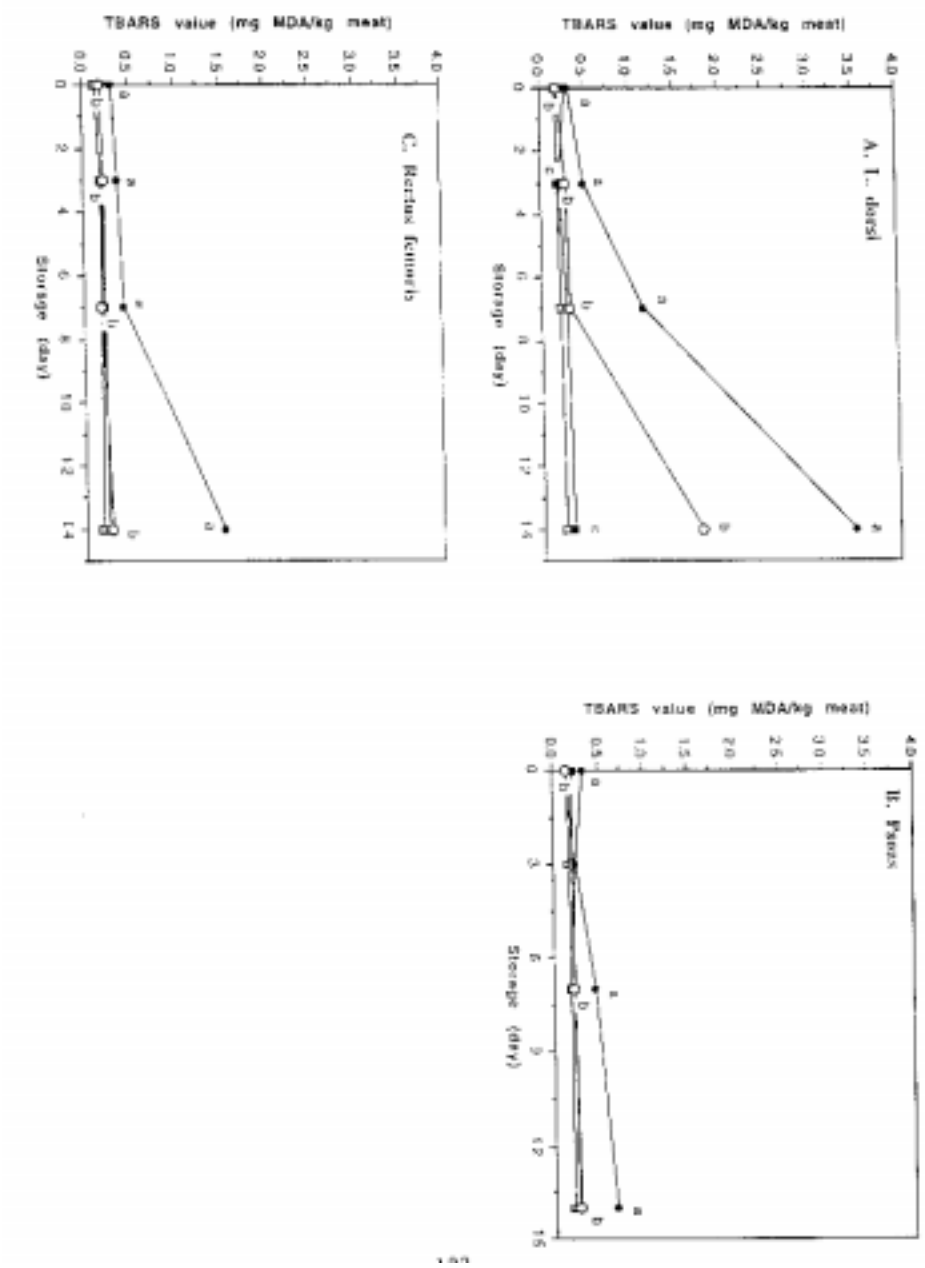

Figure 2. Gas chromatograms of volatiles from raw meat patties. A. Vacuum-packaged nonirradiated raw *psoas* meat patty; B. Vacuum-packaged irradiated raw *psoas* meat patty.