Analysis of Volatile Components and Sensory Characteristics of Irradiated Raw Pork

D. U. Ahn, C. Jo, and D. G. Olson,
Department of Animal Science

ASL-R1711

Summary and Implications

Longissimus dorsi muscle strips of pig packaged either aerobically or under vacuum were irradiated at 0, 5, or 10 kGy and stored at 4°C for 5 days. Lipid oxidation, the amount and identity of volatile components, and sensory characteristics of raw pork strips were determined at 0 and 5 days of storage.

Irradiated muscle strips produced more 2-thiobarbituric acid reactive substances (TBARS) than nonirradiated only in aerobic packaging during storage. Irradiation had no effect on the production of volatiles related to lipid oxidation, but produced a few sulfur-containing compounds not found in nonirradiated meat. This indicates that the major contributor of off-odor in irradiated meat is not lipid oxidation, but radiolytic breakdown of sulfur-containing amino acids. Many of the irradiation-dependent volatiles reduced to 50 to 25% levels during the 5-d storage under aerobic conditions. Irradiated muscle strips produced stronger irradiation odor than nonirradiated, but no irradiation dose or storage effect was found. Irradiation had no negative effect on the acceptance of meat, and approximately 70% of sensory panels characterized irradiation odor as barbecued-cornlike odor.

Introduction

Buzby and Roberts (6) reported that microbial pathogens in food cause between 6.5 million and 33 million cases of human illness and up to 9,000 deaths in the United States each year, and the estimated annual cost of human illness caused by foodborne pathogens ranges from $5.6 billion to $9.4 billion. Irradiation is among the best known methods for control of potentially pathogenic microorganisms in raw meat (10). Although recent consumer surveys and market analysis indicated that about 70% of consumers were willing to pay a premium price for irradiated chicken breast (13), one of the major concerns in irradiating meat is its effect on the generation of off-odor and lipid oxidation, either of which can impact negatively upon acceptance of such treated meat products in the marketplace. Considering a series of recent outbreaks of pathogenic bacteria in meat, the expanded application of irradiation technology in meat and meat products becomes especially important to improve safety and public confidence. Little attention, however, has been paid to these quality aspects of meat in irradiation studies, especially at low-dose irradiation (<10 kGy).

Huber et al. (15) reported that sterilized meat through irradiation developed a characteristic odor, which has been described as metallic, sulfide, wet dog, wet grain, or brunt. They assumed that the off-odor was the result of free radical oxidation that was initiated by the irradiation process. Patterson and Stevenson (20) found that dimethyltrisulfide is the most potent off-odor compound, and the changes that occur following irradiation are distinctly different from those of warmed-over flavor in oxidized meat. Thayer et al. (22) reported that irradiation dose, processing temperature, and packaging conditions strongly influence microbial and nutritional quality of meat. Heath et al. (14) reported that irradiating uncooked chicken breast and thigh at 2 or 3 kGy produced a hot fat, burned oil, or burned feathers odor that remained after the thighs were cooked. Hashim et al. (22) reported that irradiating uncooked chicken breast and thigh produced a characteristic bloody and sweet aroma that remained after the thighs were cooked, but was not detectable after the breasts were cooked.

Irradiation-induced oxidative chemical changes are dose-dependent, and the presence of oxygen has a significant effect on the rate of oxidation (17). Diehl (9) indicated that there is a substantial difference between the radiation chemistry of pure substances and of the same substances when they are components of complex food systems. The differences, however, are mostly quantitative, rather than qualitative. Ahn et al. (1) indicated that irradiated meat, regardless of packaging methods, produced more volatiles than nonirradiated patties and developed a characteristic aroma after irradiation. Raw meat has very strong antioxidant effects unless it is heated, denatured, or contains added prooxidants. Irradiation accelerated lipid oxidation of raw pork patties when stored in oxygen-permeable bags during and after irradiation (1). Chen et al. (8) reported that irradiation before cooking did not influence lipid oxidation of cooked pork during storage. Cooked meat, however, is highly susceptible to lipid oxidation because the cooking process denatures antioxidant components, damages cell structure, and exposes membrane lipids to the environment. (2).

Irradiation dose affected production of volatiles in vacuum- and aerobic-packaged cooked pork sausage, but its effect on 2-thiobarbituric acid reactive substances (TBARS) was minor (2).

The objectives of this study are to identify and quantify volatile compounds produced in raw pork by irradiation, and to determine sensory characteristics of irradiated raw pork.

Materials and Methods

Sample preparation. Longissimus dorsi muscles from four different pigs were obtained within 48 h after slaughter and used for the irradiation treatments and sample analysis. Muscle strips, approximately 20 mm in length, 40 mm in width and 5 mm in thickness (4 g), were prepared. Four muscle strips (one strip per each pig) were placed in a single layer into each labeled bag and either aerobic or vacuum packaged. Polyethylene oxygen permeable bags were used for aerobic packaging and nylon/polyethylene bags (9.3 ml O_2/m_2/24 h at 0°C; Koch, Kansas City, MO) were used for vacuum packaging. Samples in the bags were irradiated at 0, 5, or 10 kGy and stored at 4°C for 5 day. The meat from each of the four pigs represented four experimental replications. Fluorescence TBARS method (16) was used to analyze lipid oxidation, and a purge-and-trap/gas chromatography-mass spectrometry (GC-MS) method was used to determine the amount and identity of volatiles components.

Volatile compounds analysis. A purge-and-trap apparatus connected to a GC unit was used to analyze the volatiles potentially responsible for the off-odor in meat. Precept II and Purge-and-Trap Concentrator 3000 (Tekmar-Dorham, Cincinnati, OH) were used to purge and trap volatiles from the samples. A GC unit (Model 6890, Hewlett Packard Co., Wilmington, DE) equipped with a mass selective detector (MSD, HP 5973, Hewlett Packard Co., Wilmington, DE) was used to characterize and quantify the volatile compounds influenced by headspace oxygen during sample holding periods as described by Ahn et al. (3). A 5-g sample was used for raw meat and a 3-g sample was used for cooked meat analyses.

Sensory analysis. The intensity and descriptive characteristics of odor of meat samples were determined using 13 trained sensory panelists. Training sessions were conducted to familiarize panelists with the irradiation odor, the scale to be used, and with the range of attribute intensities likely to be encountered during the study. For evaluation of odor, samples in coded, capped scintillation vials (glass) were presented to each panelist in isolated booths. A 15-cm linear hedonic scale, anchored with the words “no irradiation odor” and ‘very strong irradiation odor', and “not acceptable” and “highly acceptable” at opposite ends, were used to rate the samples on the intensity of irradiation odor and acceptance of irradiation odor. The responses from the panelists were expressed in numerical values ranging from 0 (no irradiation odor or not acceptable) to 15 (strong irradiation odor or highly acceptable) to the nearest 0.5 cm. Sensory panels also were asked to characterize the odor that best describe it. The relationship between lipid oxidation, volatile composition, and odor intensity and characteristics was evaluated using correlation coefficients.

Statistical analysis. The experiment was designed primarily to determine the effect of irradiation dose on lipid peroxidation, volatiles, and off-odor production in muscle strips with different packaging. The TBARS, volatiles, and off-odor production of raw pork were analyzed independently by SAS software (21). Analyses of variance were conducted to test the effects of irradiation dose and packaging, and the Student-Newman-Keuls multiple range test was used to compare differences among mean values. The relationship between lipid oxidation, volatile production, and odor intensity was evaluated using correlation coefficients. Mean values and standard errors of the mean (SEM) were reported when necessary.

Results and Discussion

Lipid oxidation. Irradiation produced more TBARS than nonirradiated control, but only in aerobic-packaged muscle strips at day 0. *Longissimus dorsi* muscle strips stored for 5 days in aerobic packaging produced higher TBARS than those of zero-day storage (Table 1). Ahn et al. (2) reported that irradiation and high fat content accelerated the lipid oxidation in raw pork patties during storage. However, oxygen availability during storage was more important than irradiation on the lipid oxidation and volatiles of raw and cooked meat (2,3).

Volatiles production of L. dorsi muscle strips. At day 0 with vacuum packaging, irradiated muscle strips produced a few volatiles that were not found in nonirradiated meat (Table 2). They were thiobismethane, 3-methoxy-1-propene, thioacetic acid methyl ester, 2,3-dimethyl disulfide, toluene, and 2,3-dimethyl trisulfide. Most of the newly created volatiles were sulfur compounds, and the amount of 2,3-dimethyl disulfide was the highest, which accounted for approximately 75% of all the total new volatiles produced by irradiation. We assume that these new volatile compounds are responsible for the irradiation odor and are originated

from proteins by radiolytic reactions of irradiation. However, irradiation-dose effect on the production of new radiolytic products was significant only for 3-methoxy-1-propene, 2,3-dimethyl disulfide, and toluene. However, the amount of carbon disulfide, 1-octanol, 3-chloropyridine, piperdine carboxyaldehyde, 2,2,8-trimethyl decane, 2,2,4,6,6-pentamethyl heptane, 2,6-dimethyl octane, and 2,8-dimethyl undecane in vacuum-packaged muscle strips at day 0 were decreased by irradiation. The amounts of lipid oxidation products, such as aldehydes, ketones, and alcohols, were either not influenced or decreased by irradiation. This indicates that the major contributor of off-odor in vacuum-packaged irradiated meat is not lipid oxidation, but radiolytic breakdown of sulfur-containing amino acids (Table 2). Champaign and Nawar (7) found that hydrocarbons are the major radiolytic products in fat and are related to the fatty acid composition of the fat. Merritt et al. (19) postulated that carbonyls are formed in irradiated meats due to the reactions of hydrocarbon radicals with molecular oxygen, which follows the same pathway as normal lipid oxidation. Hansen et al. (11) reported that the amount of octane, 1-octene, hexanal, and nonane in irradiated chicken increased with the irradiation dose, but the volatile compounds were not unique products of irradiation.

At day 0 with aerobic packaging, all the new volatiles, except for 2,3-dimethyl trisulfide, found in vacuum-packaged irradiated muscle strips also were found in aerobic-packaged meat (Table 2). The amount of carbon disulfide in aerobic-packaged irradiated meat was also significantly lower than that in vacuum-packaged irradiated meat. However, the amounts and the changes of volatiles influenced by irradiation were smaller in aerobic packaging than in vacuum packaging. This indicates that most of these volatiles either newly produced or influenced by irradiation are highly volatile (Table 2).

After 5 days of storage in vacuum packaging, the volatile compounds found in muscle strips were very similar to those at day 0, but the compositions of volatiles in muscle strips were different from those of day 0 (Table 3). The amount of dimethyl sulfide increased by four- to sixfold and propanal by 50%, but that of octanol was decreased to 40-70%, 3-chloropyridine to 25-50%, 2,3-dimethyl disulfide to 50-70%, piperdine carboxyaldehyde to 25-30%, and 3,5-dimethyl octane to 50-60% of the day 0 values over the 5-days storage period. 1-Butene, not found at day 0, was also found in muscle strips at day 5. However, these changes in volatiles during the 5-dday storage in vacuum packaging were not of sufficient magnitude to influence overall odor characteristics of the muscle strips (Table 3).

After 5 days of storage in aerobic packaging, the amount of all volatile components except propanal, dimethyl sulfide, and carbon disulfide decreased to 25 to 50% of the day 0 values. Many of the new volatile compounds formed by irradiation disappeared or reduced to very low levels during the 5-day storage in aerobic conditions, and the amounts of total volatiles were also reduced to 50 to 25% of the original levels. The amounts of total volatiles in aerobic-packaged muscle strips were less than one-half or one-third of those found in vacuum packaged meat with the same irradiation dose (Table 3). Results from Tables 2 and 3 indicate that irradiation has the strongest, packaging the intermediate, and storage time the lowest effect on the volatile production and composition in raw muscle strips. Irradiation-induced oxidative chemical changes are dose dependent, and the presence of oxygen has a significant effect on the development of oxidation and odor intensity (15,17,18). Ahn et al. (3) reported that irradiated meat produced more volatiles than found in nonirradiated patties, and the proportion of volatiles varied by the packaging-irradiation conditions of the patties.

With vacuum packaging, only 2,5-dimethyl undecane had a significant negative correlation with TBARS of nonirradiated muscle strips. 3-Methoxy-1-propene, toluene, 3-ethyl-4-methyl hexane, 2,2,8-trimethyl decane, 2,2,4,6,6-pentamethyl heptane, 2,5-dimethyl undecane, and 2,8-dimethyl undecane were positively correlated with TBARS of irradiated muscle strips (Table 4). However, the reasons why these specific branched hydrocarbons were significantly correlated to TBARS of vacuum packaged meat are not understood. With aerobic packaging, 3-methoxy-1-propene, 1-octanal, and piperdine carboxyaldehyde had significant correlations with TBARS of nonirradiated muscle strips. However, none of the volatiles produced in irradiated muscle strips had significant correlations with TBARS (Table 4). This indicates that volatiles produced in aerobic-packaged nonirradiated meat are related to lipid oxidation, but most of the volatiles produced by irradiation are not related to lipid oxidation. Apparently, the majority of the branched hydrocarbons listed in Tables 2 and 3 should be originated from lipids and sulfur-containing compounds from amino acids. Therefore, the compositions of fatty acid and amino acid in meat should have significant effect on the profiles of the volatiles. However, the contribution of lipids and protein (amino acids) interactions on the production of new volatiles during irradiation and subsequent storage should not be overlooked. It is difficult to draw any conclusion on the mechanisms of off-odor production in irradiated meat with current study.

In vacuum packaging, irradiated *L. dorsi* muscle strips produced significantly stronger irradiation odor than found in nonirradiated, but no irradiation dose or storage effect was found (Table 5). Many of the sensory panels characterized irradiation odor as barbecued cornlike odor, but some described it as burnt, bloody, sweet, old, sulfur, or pungent. Many sensory panels were used to barbecued cornlike odor and showed little objection to the irradiation odor. As in vacuum packaging, irradiation produced a significant irradiation odor in aerobic-packaged muscle strips. Irradiation of muscle strips at 10 kGy produced stronger irradiation odor than that at 5 kGy, and 5-day storage reduced the intensity of irradiation odor in muscle strips, but the reduction was significant in samples irradiated at 5 kGy. Irradiation had no negative effect on the acceptance of meat under all packaging and storage conditions (Table 5).

Huber et al. (15) reported that meat sterilized through irradiation developed a characteristic odor, which has variously been described as "metallic," "sulfide," "wet dog," "wet grain," or "burnt." Batzer and Doty (5) found that methyl mercaptan and hydrogen sulfide were important to irradiation odor, and the precursors of the undesirable odor compounds in irradiated meat were sulfur-containing compounds that were water soluble. GC separation and odor evaluation of volatiles indicated that hydrocarbons have very high odor thresholds. However, most sulfur and carbonyl compounds had low odor thresholds and were considered as important to irradiation odor (4,23). These results indicate that sulfur-containing compounds could be the major volatile components responsible for irradiation odor in meat. Patterson and Stevenson (20) found that dimethyl trisulfide is the most potent off-odor compound, followed by *cis*-3- and *trans*-6-nonenals, oct-1-en-3-one, and bis(methylthio-)methane in irradiated chicken meat. These studies also provided evidence to support the concept that the changes that occur following irradiation are distinctly different from those of warmed-over flavor in oxidized meat.

Conclusion

Sulfur-containing volatiles, not lipid oxidation-dependent volatiles, were responsible for the off-odor in irradiated pork. Irradiation-dependent production of sulfur compounds was not dose-dependent at <10 kGy level, but was related to radiolytic degradation of amino acids. Studies are needed to determine the interactions of sulfur-containing and other volatile compounds from amino acids and lipid groups, and the lowest irradiation dose level that produces sulfur compounds in meat. Irradiation produced irradiation odor but the odor was found to be acceptable. The sensory characteristics of irradiated meat were characterized as barbecued corn-like odor, and sensory panels showed no objection to the odor. We assume that this would be true for the majority of U.S. customers, but more detailed sensory studies are required to confirm it.

References

1. Ahn, D. U., D. G. Olson, C. Jo, X. Chen, C. Wu, and J. I. Lee, 1998a. Effect of muscle type, packaging, and irradiation on lipid oxidation, volatile production and color in raw pork patties. Meat Sci. 49: 27-39.
2. Ahn, D. U., D. G. Olson, J. I. Lee, C. Jo, X. Chen, and C. Wu, 1998b. Packaging and irradiation effects on lipid oxidation and volatiles in pork patties. J. Food Sci. 63: 15-19.
3. Ahn, D. U., D. G. Olson, C. Jo, J. Love, and S. K. Jin, 1999. Volatiles production and lipid oxidation on irradiated cooked sausage as related to packaging and storage. J. Food Sci. 64:226-229.
4. Angelini, P., C. Merritt, Jr., J. M. Mendelshon, and F. J. King, 1975. Effect of irradiation on volatile constituents of stored haddok flesh. J. Food Sci. 40: 197-199.
5. Batzer, O. F. and D. M. Doty, 1955. Nature of undesirable odors formed by gamma irradiation of beef. J. Agric. Food Chem.3: 64-69.
6. Buzby, J. C. and T. Roberts, 1995. ERS estimates U.S. food borne disease costs. Food Review 18 (May-Aug.): 37-42, USDA Economics Research Services.
7. Champaign, J. R. and W. W. Nawar, 1969. The volatile components of irradiated beef and pork fats. J. Food Sci. 34: 335-339.
8. Chen, X., C. Jo, C. Wu, J. I. Lee, and D. U. Ahn, 1999. Effect of natural antioxidants on lipid oxidation, volatiles and color changes of irradiated pork patties. J. Food Sci. 64:16-19.
9. Diehl, J. F. 1995 Safety of Irradiated Foods, 2nd ed. Marcel Dekker, Inc., New York, NY.
10. Gants, R. 1996. Pathogen countdown. Meat and Poultry. Dec. p. 26-29.
11. Hansen, T. J., G. C. Chen, and J. J. Shieh, 1987. Volatiles in skin of low dose irradiated fresh chicken. J. Food Sci. 52: 1180-1182.
12. Hashim, I. B., A.V.A. Resurreccion, and K. H. MaWatters, (995. Disruptive sensory analysis of irradiated frozen or refrigerated chicken. J. Food Sci. 60: 664-666.
13. Hayes, D. J., J. F. Shogren, J. A. Fox, and J. B. Kliebenstein, 1995. Market tests of irradiated meat. (Abstract). Food Safety Consortium

Annual Conference Progress Report, p. 73. Kansas City, MO.
14. Heath, J. L., S. L. Owens, S. Tesch, and K. W. Hannah, 1990. Effect of high-energy electron irradiation of chicken on thiobarbituric acid values, shear values, odor, and cook yield. Poultry Sci. 69: 313-319.
15. Huber, W., A. Brasch, and A. Waly, 1953. Effect of processing conditions on organoleptic changes in foodstuffs sterilized with high intensity electrons. Food Technol. 7, 109-115.
16. Jo, C. and D. U. Ahn, 1998. Use of fluorometric analysis of 2-thiobarbituric acid reactive substances in meat. Poultry Sci. 77: 475-480.
17. Katusin-Razem, B., B. Mihaljevic, and D.Razem, 1992. Time-dependent post irradiation oxidative chemical changes in dehydrated egg products. J. Agric. Food Chem. 40: 1948-1952.
18. Merritt, C. Jr., P. Angelini, E. Wierbicki, and G. W. Shuts, 1975. Chemical changes associated with flavor in irradiated meat. J. Agric. Food Chem. 23: 1037-1043.
19. Merritt, C. Jr., P. Angelini, and R. A. Graham, 1978. Effect of radiation parameters on the formation of radiolysis products in meat and meat substances. J. Agric. Food Chem. 26: 29-34.
20. Patterson, R.L.S. and M. H. Stevenson, 1995. Irradiation-induced off-odor in chicken and its possible control. Br. Poultry Sci. 36: 425-441.
21. SAS Institute. 1989. SAS User's Guide. SAS Institute, Inc., Cary, NC.
22. Thayer, D. W., J. B. Fox, and L. Lakritz, 1993. Effects of ionizing radiation treatments on the microbiological, nutritional, and structural quality of meats. ACS Symposium Series 528. P. 293. American Chemical Society, Washington, D.C.
23. Wick, E. L., E. Murray, J. Mizutani, and M. Koshika. 1967. Irradiation flavor and volatile components of beef. In *Radiation Preservation of Foods*. Advanced Chemistry Series, American Chemical Society, Washington, D.C.

Table 1. TBARS values of irradiated pork *L. dorsi* muscle strips with different packaging.[a]

	Vacuum packaging			Aerobic packaging		
IR (kGy)	0 d	5 d	SEM	0 d	5 d	SEM
	---------- TBARS value (mg MDA/kg meat) ----------					
0	0.42	0.48	0.061	0.33by	0.86a	0.112
5	0.41	0.60	0.075	0.52bx	0.93a	0.047
10	0.54	0.60	0.022	0.50bx	1.04a	0.030
SEM	0.037	0.072		0.038	0.095	

[a]Samples were analyzed using a fluorometric method. n=4.

[a,b]Different letters within a row with same packaging are significantly different (P<.05).

[x-z]Different letters within a column are significantly different (P<.05).

TBARS, 2-thiobarbituric acid reactive substances; MDA, malonaldehyde.

Table 2. Production of volatiles in irradiated pork *L. dorsi* muscle strips after zero days of storage.[a]

	Vacuum packaging				Aerobic packaging			
Volatiles	0 kGy	5 kGy	10 kGy	SEM	0 kGy	5 kGy	10 kGy	SEM
	Area (ion counts x 1000)							
Propanal	673	622	803	92.4	557	633	729	74.2
Dimethyl sulfide	ndb	216a	138a	42.2	ndb	61a	95a	11.8
Carbon disulfide	457a	19b	20b	25.3	241a	65b	44b	38.5
3-Methoxy-1-propene	ndc	132b	271a	29.5	ndc	96b	175a	8.2
2-Ethyl-1-butanol	99	94	119	12.1	80	100	86	16.9
Cloroform	131	87	72	26.9	62	58	73	10.4
1-Octanol	461a	187b	163b	63.3	47	40	25	13.3
Thioacetic acid methyl ester	ndb	158a	191a	45.1	ndb	53ab	122a	25.4
2,3-Dimethyl disulfide	ndb	2701a	3044b	401.1	ndc	685b	1457a	192.9
Toluene	ndc	191b	321a	14.1	ndb	133a	224a	33.7
3-Chloropyridine	1225a	568b	492b	130.9	206	169	136	53.2
3-Ethyl-4-methyl hexane	241	93	138	40.5	169	214	298	74.8
2,3-Dimethyl trisulfide	ndb	121a	69ab	28.5	nd	nd	nd	-
Piperdine carboxyaldehyde	534a	218b	265b	67.0	184	231	208	48.4
2,2,8-Trimethyl decane	317a	103b	188b	38.4	260	400	527	127.4
2,2,4,6,6-Pentamethyl heptane	142a	41b	77b	16.9	106	170	223	59.5
3,5-Dimethyl octane	940	844	908	148.2	1077	1274	1592	277.4
Undecane	92	52	77	17.4	85	124	162	36.6
2,6-Dimethyl octane	524a	206b	342ab	66.5	542	804	1026	221.2
2,5-Dimethyl undecane	271a	103b	171ab	31.7	275	421	537	114.3
2,8-Dimethyl undecane	276a	90b	167b	31.8	270	405	516	109.8
Total volatiles	6382	6844	8033	792.2	4159	6143	8253	1127.4

[a]Samples (4g) were purged immediately after sampling. n=4.

[a-c]Different letters within a row with same packaging are significantly different (P<.05).
SEM, standard error of the mean.

Table 3. Production of volatiles in irradiated pork *L. dorsi* muscle strips after 5-day storage at 4°C.[a]

Volatiles	Vacuum packaging				Aerobic packaging			
	0 kGy	5 kGy	10 kGy	SEM	0 kGy	5 kGy	10 kGy	SEM
	Area (ion counts x 1000)							
1-Butene	37c	248b	358a	18.1	ndc	76b	169a	11.4
Propanal	889	960	1185	108.7	601	841	762	82.8
Dimethyl sulfide	36b	1387a	554b	172.2	ndc	76a	38b	9.4
Carbon disulfide	780a	413ab	233b	123.6	248	134	91	42.8
3-Methoxy-1-propene	ndb	160a	214a	20.1	54b	105a	132a	11.2
2-Ethyl-1-butanol	88	84	153	19.0	60	53	46	8.5
Cloroform	110	94	95	15.8	42a	ndb	ndb	7.1
1-Octanol	323a	77b	40b	34.3	nd	nd	nd	-
Thioacetic acid methyl ester	nd	87	180	55.6	nd	nd	nd	-
2,3-Dimethyl disulfide	ndb	1947a	1765a	333.3	nd	nd	nd	-
Toluene	ndb	113a	155a	13.4	ndb	40a	155a	13.4
3-Chloropyridine	608a	203b	132b	75.1	132	97	49	23.4
3-Ethyl-4-methyl hexane	68	74	93	13.6	37	29	44	8.7
2,3-Dimethyl trisulfide	ndc	28b	59a	5.3	nd	nd	nd	-
Piperdine carboxyaldehyde	148	72	68	20.7	42	39	28	3.8
2,2,8-Trimethyl decane	125	86	141	23.7	67	45	74	16.5
2,2,4,6,6-Pentamethyl heptane	52	36	54	11.0	30	23	31	4.2
3,5-Dimethyl octane	562	417	606	75.6	386	260	348	58.7
Undecane	50	34	38	9.3	21	22	27	4.0
2,6-Dimethyl undecane	399	249	341	75.5	236	171	237	52.8
2,5-Dimethyl undecane	271	105	197	58.4	126	85	111	30.2
2,8-Dimethyl undecane	187	92	183	40.2	136	88	105	38.4
Total volatiles	4729	6963	6832	613.5	2217	2182	2351	261.5

[a]Samples (4g) were purged immediately after sampling. n=4.

[a-c]Different letters within a row with same packaging are significantly different (P<.05). nd, not detected. SEM, standard error of the mean.

Table 4. Correlation coefficients between the amount of volatile compounds and TBARS of irradiated and nonirradiated pork *L. dorsi* muscle strips.

	Vacuum packaging		Aerobic packaging	
Volatiles	Nonirradiated	Irradiated	Nonirradiated	Irradiated
1-Butene	-0.24	-0.13	-	0.32
Propanal	-0.43	-0.06	-0.31	-0.28
Dimethyl sulfide	-0.37	-0.48	-	-0.41
Carbon disulfide	-0.50	-0.46	0.30	-0.17
3-Methoxy-1-propene	-	0.53*	-0.74*	0.39
2-Ethyl-1-butanol	-0.26	0.28	0.11	-0.44
Cloroform	0.04	-0.21	0.56	-0.10
1-Octanol	0.32	0.37	0.90**	-0.20
Thioacetic acid methyl ester	-	-0.15	-	0.09
2,3-Dimethyl disulfide	-	0.12	-	0.03
Toluene	-	0.52*	-	-0.10
3-Chloropyridine	0.33	0.33	0.61	-0.27
3-Ethyl-4-methyl hexane	0.17	0.57*	0.68	-0.23
2,3-Dimethyl trisulfide	-	-0.02	-	-
Piperdine carboxyaldehyde	0.35	0.38	0.79*	-0.35
2,2,8-Trimethyl decane	-0.03	0.64**	0.59	-0.23
2,2,4,6,6-Pentamethyl heptane	-0.04	0.62*	0.49	-0.25
3,5-Dimethyl octane	-0.19	0.42	0.68	-0.23
Undecane	-0.18	0.38	0.59	-0.25
2,6-Dimethyl octane	-0.50	0.40	0.49	-0.23
2,5-Dimethyl undecane	-0.81*	0.58*	0.43	-0.23
2,8-Dimethyl undecane	-0.55	0.61*	0.32	-0.23
Total volatiles	-0.19	0.25	0.60	-0.21

n=8 for nonirradiated and n=16 for irradiated.

*significant at p<0.05, **significant at p<.01.

Table 5. Sensory characteristics of irradiated pork *L. dorsi* muscle strips refrigerated for 5 days.[a]

	Vacuum packaging			Aerobic packaging		
Irradiation	0 d	5 d	SEM	0 d	5 d	SEM
Irradiation odor intensity						
0 kGy	3.49y	3.27y	0.808	5.09y	3.10z	0.966
5 kGy	9.90x	8.40x	0.804	8.19ax	5.26by	0.769
10 kGy	10.49x	8.94x	0.670	9.27x	7.72x	0.577
SEM	0.730	0.768		0.858	0.652	
Acceptance of meat odor						
0 kGy	7.40	5.63	0.889	5.07	6.61	0.884
5 kGy	6.11	4.68	1.000	5.40	5.10	0.916
10 kGy	6.15	3.74	1.049	6.22	6.30	1.154
SEM	1.039	0.864		1.055	0.841	

[a]Pork strip (5g) was put in a sample vial (20ml), capped, and stored at 4°C until analyzed. Thirteen trained sensory panels were used.

[a,b]Different letters within a row with same packaging are significantly different (P<.05).

[x-z]Different letters within a column are significantly different (P<.05).

Irradiation odor intensity: 0, no irradiation odor; 15, very strong irradiation odor. Acceptance of meat odor: 0, not acceptable; 15, highly acceptable.