Packaging and Irradiation Effects on Lipid Oxidation and Volatiles in Cooked Pork Patties

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Summary and Implication

Packaging, irradiation, and the length of storage of raw meat were important factors in lipid oxidation of cooked meat. Preventing oxygen exposure after cooking, however, was more important in preventing lipid oxidation of cooked meat than the raw meat treatments. Cooking itself did not increase thiobarbituric acid-reactive substances (TBARS) values. The structural damages caused by the cooking process made it easy for oxygen to contact with membrane lipids and accelerated lipid oxidation. Propanal, pentanal, hexanal, 1-pentanol, and total volatiles were highly correlated ($P<0.01$) with TBARS values of cooked meat. Among the volatile components, hexanal and total volatiles content provided the best criteria for determining lipid oxidation status and off-odor production in cooked meat. However, the relationships between TBARS values and aldehydes of cooked meat from various muscles were different from each other, and the explanation for different aldehydes/TBARS values in cooked meat from different muscle types requires further study.

Introduction

Irradiation is the best known method to control pathogenic microorganisms in raw meat (6). Recent consumer surveys and market analyses indicate that irradiated meat is accepted by a majority of consumers (9). One of the major concerns in irradiating meat, however, is its effect on meat quality, mainly related to the free radicals reaction and off-odor generation by irradiation. Ionizing radiation is known to generate hydroxyl radicals in aqueous (20) or oil emulsion systems (14). Because a large proportion of muscle cells (75%) is composed of water and these cells are surrounded by lipid bilayers, irradiating meat may produce hydroxyl radicals and could initiate lipid oxidation. The development of lipid oxidation in irradiated raw and cooked meat, however, would be influenced by packaging, storage, and further processing conditions before and after irradiation.

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 (11). Lee et al. (12) 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. But irradiation, at 1.5 to 10 kGy dosages, was shown to increase TBARS values, and decrease thiamin and tocopherols in turkey breast and fish muscles (3, 7).

Irradiating uncooked chicken meat produced a characteristic bloody and sweet aroma that remained after the meat was cooked (8,10). Merritt (13) suggested that the volatile compounds responsible for off-odors in irradiated meat are produced by changes in the protein and lipid molecules and are different from those of lipid oxidation. Schweigert et al. (17) reported that the precursors of the undesirable odor compounds in irradiated meat were water soluble and contained nitrogen and/or sulfur and that methyl mercaptan and sulfur dioxide formed from the sulfur (S)-containing compounds (e.g., glutathione) contributed to the irradiation odor. Others reported, however, that irradiation had no detrimental effect on the flavor of vacuum-packaged raw meat and cured meat, and electron beam treatment had little effect on the odor and flavor of reheated meat with sous vide treatment (18, 19). At present, however, little information on the lipid oxidation and volatiles production in irradiated cooked meat, especially at low-dose irradiation (<10 kGy), is available.

The major objective of irradiating meat is to control pathogenic microorganisms in raw meat during handling and storage. The irradiated meat, however, should be cooked before human consumption, and the quality characteristics of irradiated raw meat after cooking are very important for the acceptance of the irradiation technology. Different raw-meat packaging and irradiation, and cooked meat packaging and storage conditions were used in this study because (1) the storage time after irradiation and the fate of irradiated raw meat after cooking would be dependent upon end users, and (2) the development of lipid oxidation and flavor of cooked meat could be influenced by packaging conditions of raw meat during irradiation, storage time after irradiation, and packaging and storage conditions of the meat after cooking.

The objective of this research was to determine the effect of raw-meat packaging, irradiation, cooked-meat packaging conditions, and storage on lipid oxidation and volatile production in meat patties prepared from various pork muscles.

Materials and Methods

Sample preparation *Longissimus* (*L.) dorsi*, *L. psoas*, and *Rectus* (*R.) femoris* were the pig muscles selected because they have distinct differences in heme pigments and lipid contents, and could have different responses to packaging, irradiation, and storage treatments. Freshly removed *L. dorsi*, *L. psoas*, and *R. femoris* muscles from market-weight pigs were obtained from a local meat packer. Muscles were transported to the Meat Laboratory at Iowa State University and individually ground twice through a 3-mm plate. Patties (approximately

100 g each) were prepared from the ground pork and packaged either in oxygen-permeable or -impermeable nylon/polyethylene bags (O_2 permeability, 9.3 ml $O_2/m^2/24$ h at 0°C; Koch, Kansas City, MO), then irradiated (IR) with accelerated electrons from a Linear Accelerator (Circe IIIR, Thomson CSF Linac, Saint-Aubin, France) to a dose of 0 or 4.5 kGy (average) (127 kGy/min). Two hours or 3 days after irradiation (storage at 4°C), the meat patties were cooked in an electric oven (300°C) to an internal temperature of 78°C. Immediately after cooking, the patties were either vacuum-packaged in oxygen-impermeable bags or loosely packaged in oxygen-permeable bags and then stored at 4°C. TBARS and volatiles in the cooked-meat patties were determined after 0, 3, and 7 days of storage. Zero-day samples were prepared within 1 hour after cooking. The flow diagram for the sample preparation procedure is shown in Figure 1.

Lipid oxidation: Lipid peroxidation 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 deionized distilled water (DDW) by using a Brinkman Polytron (Type PT 10/35) for 15 s at speed 7-8. Meat homogenate (1 ml) was transferred to a disposable test tube (13 x 100 mm) and butylated 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. The TBARS numbers were expressed as milligrams malondialdehyde (MDA) per kilogram of meat.

Analysis of volatiles 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 cooked meat. A Hewlett Packard GC (Model 6890, Hewlett Packard Co., Wilmington, DE) equipped with flame ionization detector was used to analyze volatiles after thermally desorbing the trapped volatiles. In preparation for volatiles analysis, minced, cooked meat (2 g) was weighed into a sample vial (40 ml), an oxygen absorber (Ageless type ZPT-50, Mitsubishi Gas Chemical America, Inc., New York, NY) added, and the vial was capped tightly with a Teflon-lined, open-mouth cap and was placed in a refrigerated (3°C) sample tray. The sample was purged by using an auto sampling unit (Precept II) equipped with a robotic arm. The sample was 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 volatiles into a DB-Wax capillary GC column (0.53 mm i.d., 30 m, and 1-µm film thickness, J & W Scientific, Folsom, CA), and ramped oven temperature conditions (32°C for 0.5 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. Detector air, H_2, and make-up gas (He) flows were 300 ml/min, 30 ml/min, and 28 ml/min, respectively. 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 raw-meat packaging, irradiation, storage time and conditions, and the packaging of cooked meat on the lipid peroxidation and volatiles production in patties prepared from different muscles. TBARS values of patties prepared from the three muscles were pooled because they showed similar trends within the same packaging, irradiation, and storage conditions. Analyses of variance were conducted to test the effect of raw- and cooked-meat packaging for different cooked-meat and raw-meat storage times. The volatiles data of patties from each muscle were analyzed independently by SAS software (17). The volatiles data from *R. femoris* and *L. psoas* were pooled after finding no differences in volatile characteristics between the two muscles. Analyses of variance were conducted to test the effect of raw and cooked-meat packaging by a storage time and storage effect for different raw- and cooked-meat treatments. Correlation coefficients between TBARS, volatile components, and total volatiles of *L. dorsi* and *R. femoris* and *L. psoas* muscles also were calculated. 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 Table 1 presents the effect of raw-meat packaging, irradiation, and cooked-meat packaging on the lipid oxidation of cooked pork patties during storage. One set of the patties with different packaging and irradiation combinations from all three muscles was cooked 2 hour after irradiating raw meat (Day 0 after IR) and the other set 3 days after irradiation (Day 3 after IR). In both sets of cooked-meat patties, the TBARS values at Day 0 were not influenced by the packaging and irradiation conditions of raw meat. After 3 and 7 days of storage, the TBARS values of cooked meat with vacuum-packaging (A-C-V, A-IR-V, and V-IR-V, see Table 1 for abbreviations) remain unchanged or increased slightly. The TBARS values of cooked meat with aerobic packaging (A-C-A, A-IR-A, and V-IR-A), however, increased by 6- to 9-fold from the Day 0 values. The pork patties cooked 3 days after irradiation had higher TBARS values than those cooked 2 hour after irradiation, and continued to have higher TBARS values throughout the storage period. This indicated that the initial oxidation status of cooked meat is determined by the degree of lipid oxidation in raw meat before cooking. Also, significant amounts of primary and secondary lipid oxidation by-products, which influenced the TBARS values of cooked meat, were formed in the raw meat during storage before cooking. Therefore, the baseline lipid oxidation status of raw meat is very important on the progression of lipid oxidation in

cooked meat. Table 1 also shows the importance of the effect of oxygen exposure on the oxidation of cooked meat during storage. As shown in our previous reports (1, 2), preventing oxygen exposure after cooking was more important than the packaging, irradiation, or storage of raw meat for maintaining low TBARS values.

Volatiles Figure 2 shows a typical chromatogram of volatiles in cooked pork. Aldehydes were the major components in cooked, oxidized meat, and their proportion to total volatiles increased gradually as the lipid oxidation of meat increased. The correlation coefficients between TBARS value, and major volatile components and total volatiles of cooked pork patties prepared from *L. dorsi*, *R. femoris*, and *L. psoas* muscles are presented in Table 2. Because the relationships between TBARS values, major volatile components, and total volatiles of cooked pork patties prepared from *R. femoris* and *L. psoas* muscles were very similar, the combined data are presented. The correlation coefficients between TBARS values and major volatile components of cooked patties from *L. dorsi* are somewhat different from those from *R. femoris* and *L. psoas* muscles. Propanal, pentanal, hexanal, 1-pentanol, and total volatiles, however, were highly correlated ($P<0.01$) to lipid oxidation (TBARS values) of cooked-meat patties from all three muscles (Table 2).

The relationships between the TBARS value of *L. dorsi* meat and a volatile detected at 1.54 min, 1-pentene, and 2-methyl propanal are quite different from those of *L. psoas* or *R. femoris* meat. TBARS values of cooked-meat patties from *L. dorsi* muscle had a high correlation ($r^2>0.7$) with 1-pentene, and medium high correlations ($0.4<r^2<0.7$) with a component showing up at 1.54 min and 2-methyl propanal. In patties from *L. psoas* or *R. femoris*, however, 1-pentene and 2-methyl propanal had low correlations ($r^2<0.4$) but a volatile component detected at 1.54 min had a high correlation coefficient ($r^2>0.7$) with TBARS values (Table 2).

The high correlation coefficients of propanal, pentanal, hexanal, 1-pentanol, and total volatiles among each other, and with TBARS values of meat from all three muscles indicated that any one or all of these components could be used to predict the oxidation and volatile status of cooked meat accurately. Among the individual volatiles and total volatiles, however, hexanal and total volatiles represented the lipid oxidation status of cooked meat better than any other volatile components. Thus, total volatiles and hexanal content together would provide the best criteria for determining lipid oxidation status and off-odor production in cooked meat.

Figure 3 clearly shows that the relationship between TBARS values and hexanal or total volatiles of cooked patties from *L. dorsi*, and *L. psoas* and *R. femoris* muscles were different. Less hexanal and total volatiles were produced from the cooked-meat patties prepared from *L. dorsi* than those from *L. psoas* or *R. femoris* muscle at the same TBARS values. The production of propanal and pentanal also was less in *L. dorsi* than in *L. psoas* or *R. femoris* patties. The differences in total volatiles were mainly due to the differences in aldehydes (propanal, pentanal, and hexanal) in the muscles, and other volatile components were not affected. The reason for the low aldehydes/TBARS value in *L. dorsi* patties cannot be explained.

Our raw meat data indicated that the patties from *L. dorsi* had about 2.5 to 3 times higher fat content than those from *L. psoas* or *R. femoris* muscle (*L. dorsi*, 6.64%; *L. psoas*, 2.38%; *R. femoris*, 1.83%). However, the TBARS values of cooked *L. dorsi* patties during storage were not different from those of *L. psoas* or *R. femoris* muscle (Table 1, separate TBARS data not shown). A large proportion of fat in *L. dorsi* patties was from the backfat (triglycerides) still attached to the *L. dorsi* muscle after trimming but no visible fat patches were available for *L. psoas* and *R. femoris* muscles. Phospholipids are considered to be responsible for about 90% of lipid oxidation (4,16) and the role of triglycerides in warmed-over flavor of meat is minor compared with that of phospholipids (23). However, the relationship between fat content, lipid oxidation, and the amount of aldehydes and total requires further study.

The effect of raw-meat packaging, irradiation, and cooked-meat packaging conditions on the production of hexanal in cooked patties is shown in Table 3. At Day 0, cooked samples from *L. dorsi* patties showed no differences in hexanal content due to the raw-meat packaging, irradiation, or cooked-meat packaging conditions. At Day 0, cooked samples from *L. psoas* (PS) and *R. femoris* (RF) muscles, however, showed that irradiation of raw meat (A-IR and V-IR) produced higher hexanal than found in nonirradiated (A-C) samples. Further, irradiation in aerobic-packaged (A-IR) samples produced more hexanal than found in irradiated vacuum-packaged(V-IR) patties. Differences in hexanal content between that of *L. dorsi* and that of *L. psoas* and *R. femoris* were found only in aerobic-packaged irradiated meats.

After 3 days of storage, the hexanal content in vacuum-packaged meat after cooking (A-C-V, A-IR-V, and V-IR-V) remained unchanged but aerobic-packaged meat (A-C-A, A-IR-A, and V-IR-A) increased hexanal content by 4- to 15-fold from the Day 0 values. The amount of hexanal in aerobic-packaged patties (A-C-A, A-IR-A, and V-IR-A) was 4 to 5 times greater than vacuum-packaged patties (A-C-V, A-IR-V, and V-IR-V). The amount of hexanal in A-C-A treatment was the highest, A-IR-A was the second highest, and V-IR-V was the lowest in both *L. dorsi* (LD), and *L. psoas+R. femoris* (PS+RF) patties (Table 3). After 7 days of storage, the hexanal content in nonirradiated meat (A-C-A, A-C-V) remained unchanged from the hexanal content in irradiated patties stored 3 days. But, the amounts of hexanal in irradiated meats (A-IR and V-IR) continued to increase between the 3- to 7-day storage periods, and the amounts were higher than those in nonirradiated meats after 7 days of storage. This indicated that the production of hexanal reached its maximal point faster in nonirradiated meat than irradiated, but the final content was higher in irradiated than nonirradiated meats (Table 3).

Total volatiles in day-0 cooked samples indicated that aerobic-packaged irradiated raw patties (A-IR) produced more total volatiles than nonirradiated or vacuum-packaged irradiated (A-C and V-IR) (Table 4). After 3 days of storage, the total volatiles content in vacuum-packaged meat after cooking (A-C-V, A-IR-V, and V-IR-V) remained unchanged or increased slightly the same as for hexanal; however, aerobic-packaged meat (A-C-A, A-IR-A, and V-IR-A) increased by 2.5- to 5-fold from the Day 0 values. The amounts of total

volatiles in aerobic-packaged patties (A-C-A, A-IR-A, and V-IR-A) were 2 to 3 times greater than those in vacuum-packaged patties (A-C-V, A-IR-V, and V-IR-V). After 7 days of storage, large increases in total volatiles were observed in irradiated PS+RF patties with aerobic packaging (A-IR-A and V-IR-A). The amounts of total volatiles in aerobic-packaged patties (A-C-A, A-IR-A, and V-IR-A) from PS+RF were significantly greater than those of LD at Day 3 and Day 7 (Table 4). Propanal, pentanal, hexanal, 1-pentanol, and total volatiles were highly correlated ($P<0.01$) to TBARS values; however, hexanal was the largest volatile component in oxidized meat, and hexanal and total volatiles provided the best representation of the lipid oxidation status of cooked meat. Thus, we conclude that total volatiles and hexanal content together provide the best criteria for determining lipid oxidation status in cooked meat.

References

1. Ahn, D. U., Wolfe, F. H., Sim, J. S., and Kim, D. H. 1992. Packaging cooked turkey meat patties while hot reduces lipid oxidation. J. Food Sci. 57:1075-1077, 1115.
2. Ahn, D. U., Ajuyah, A., Wolfe, F. H., and Sim, J. S. 1993. Oxygen availability effects in prooxidant catalyzed lipid oxidation of cooked turkey patties. J. Food Sci. 58:278-282.
3. Al-Kahtani, H. A., Abu-Tarboush, H. M., Bajaber, A. S., Atia, H., Abou-Arab, A. A., and El-Mojaddidi, M. A. 1996. Chemical changes after irradiation and post-irradiation storage in tilapia and Spanish mackerel. J. Food Sci. 61:729-733.
4. Buckley, D. J., Gray, J. I., Ashgar, A. Price, J. F. Crackle, R. L., Booren, A. M. Pearson, A. M. and Miller, E. R. 1989. Effects of dietary antioxidants and oxidized oil on membranal lipid stability and pork product quality. J. Food Sci. 54:1193-1197.
5. Buege, J. A. and Aust, S. D. 1978. Microsomal lipid peroxidation. In *Methods in Enzymology*. 52:302. AP, New York, NY.
6. Fernandes, G., and Venkatraman, J. T. 1993. Role of omega-3 fatty acids in health and disease.
7. Gants, R. 1996. Pathogen countdown. Meat Poult. Dec. p. 26.
8. Hampson, J. W., Fox, Jr. J. B., Lakritz, L., and Thayer, D. W. 1996. Effect of low-dose gamma radiation on lipids in five different meats. Meat Sci. 42:271-276.
9. Hashim, I. B., Resurreccion, A. V. A., and MacWatters, K. H. 1995. Disruptive sensory analysis of irradiated frozen or refrigerated chicken. J. Food Sci. 60:664-666.
10. Hayes, D. J., J. F. Shogren, J. A. Fox, and J. B. Kliebenstein, 1995. Market tests of irradiated meat. (Abstract). Food Safety Consortium Annual Meeting. Progress Report, p 73. Kansas City, MO.
11. Heath, J. L., Owens, S. L., Tesch, S., and Hannah, K. W. 1990. Effect of high-energy electron irradiation of chicken on thiobarbituric acid values, shear values, odor, and cook yield. Poult. Sci. 69:313-319.
12. Katusin-Razem, B., Mihaljevic, K. W., and Razem, D. 1992. Time-dependent post irradiation oxidative chemical changes in dehydrated egg products. J. Agric. Food Chem. 40:1948-1952.
13. Lee, M, Sebranek, J., and Parrish, Jr. F. C. 1996. Accelerated postmortem aging of beef utilizing electron-beam irradiation and modified atmosphere packaging. J. Food Sci. 61:133-136.
14. Merritt, C. Jr. 1966. Chemical changes induced by irradiation in meats and meat components. In "Food Irradiation" (STI/PUB/127). Int. Atomic Energy Agency, Vienna.
15. O'Connell, M. J. and Garner, A. 1983. Radiation-induced generation and properties of lipid hydroperoxide in liposomes. Int. J. Radiat. Biol. 44:615-625.
16. Pikul, J., Leszczynski, D. E., and Kummerow, F. A. 1984. Relative role of phospholipids, triacylglycerols and cholesterol esters on malonaldehyde formation in fat extracted from chicken meat. J. Food Sci. 49:704-708.
17. SAS Institute, 1989. *SAS User's Guide*. SAS Institute, Inc., Cary, NC.
18. Schweigert, B. S., Doty, D. M., and Niven Jr. C. F. 1954. A summary of studies on the irradiation of meats. In *Radiation Sterilization: Review of the Literature in Selected Fields*. Chicago Quartermaster Depot, U.S. Army, Chicago, IL.
19. Shahidi, F., Pegg, R. B., and Shamsuzzaman, K. 1991. Color and oxidative stability of nitrite-free cured meat after gamma-irradiation. J. Food Sci. 56:1450-1452.
20. Shamsuzzaman, K., Chuaqui-Offermann, N., Lucht, L., McDougall, T., and Borsa, J. 1992. Microbial and other characteristics of chicken breast meat following electron-beam and sous-vide treatments. J. Food Prot. 55:528-533.
21. Thakur, B. R. and Singh, R. K. 1994. Food irradiation. Chemistry and applications. Food Rev. Int. 10 (4):437-473.
22. Thayer, D. W., Fox, Jr. J. B., and Lakritz, L. 1993. Effects of ionizing radiation treatments on the microbiological, nutritional, and structural quality of meats. American Chem. Soc. ACS Symp. Ser. 528. p 293. Washington D.C.
23. Wilson, B. R., Pearson, A. M., and Shorland, F. B. 1976. Effect of total lipids and phospholipids on warmed-over flavor in red and white muscles from several species as measured by TBA analysis. J. Agric. Food Chem. 24:7-11.

Table 1. Effect of raw-meat packaging, irradiation, and cooked-meat packaging on lipid oxidation of cooked pork patties.[1]

	A-C-A*	A-C-V	A-IR-A	A-IR-V	V-IR-A	V-IR-V	SEM
	---------- TBARS (mg MDA/kg meat) ----------						
0 day storage after cooking[2]							
0 day after IR[3]	0.26^{b}	0.19^{b}	0.34^{b}	0.26^{b}	0.32^{b}	0.20^{b}	0.04
3 days after IR	0.61^{a}	0.61^{a}	0.67^{a}	0.67^{a}	0.59^{a}	0.59^{a}	0.06
SEM	0.03	0.03	0.07	0.07	0.04	0.05	
3 days of storage after cooking							
0 day after IR	2.46^{bx}	0.32^{bz}	2.83^{bx}	0.34^{bz}	1.68^{by}	0.36^{bz}	0.12
3 days after IR	5.34^{ax}	0.71^{az}	4.85^{ax}	0.66^{az}	4.11^{ay}	0.79^{az}	0.15
SEM	0.21	0.05	0.19	0.05	0.12	0.07	
7 days of storage after cooking							
0 day after IR	3.48^{bx}	0.44^{bz}	3.44^{bx}	0.39^{bz}	2.44^{by}	0.45^{bz}	0.09
3 days after IR	5.46^{ax}	0.81^{ay}	5.88^{ax}	0.79^{ay}	5.47^{ax}	0.75^{ay}	0.13
SEM 0.16	0.05	0.12	0.06	0.14	0.05		

[1]Raw-meat patties were irradiated at 0 or 4.5 kGy dose (ave.). TBARS data of cooked patties from *L. psoas*, *L. dorsi*, and *R. femoris* were combined. n=12.
[2]Samples were analyzed within 1 hour after cooking.
[3]Storage of raw meat before cooking. The 0 d after IR samples were stored 2 hour after irradiation.
[x-z]Different letters within a row are significantly different (P<0.05).
[ab]Values with different superscript letters within a column of the same storage time after cooking are different (P<0.05).
*Abbreviation of treatments: A, aerobic packaging; V, vacuum-packaging; C, nonirradiated; IR, irradiated at 4.5 kGy. SEM, standard error of the mean; MDA, malondialdehyde.

Table 2. Correlation coefficients between TBARS value and major volatile components of cooked pork patties prepared with *L. dorsi* muscle, and *R. femoris* and *L. psoas* muscle data combined.[1]

Muscle	1-pentene	retention 1.54 min	2-methyl propanal	propanal	pentanal	pentanone	hexanal	1-pentanol	total volatiles
L. dorsi	0.40	0.72	0.79	0.53	0.93	0.00	0.94	0.94	0.93
R. femoris + *L. psoas*	0.71	0.23	0.93	0.31	0.91	0.00	0.94	0.90	0.95

[1]Data obtained from the patties stored for 3 days before cooking were used for the calculation of correlation coefficients.

Table 3. Effect of raw-meat packaging, irradiation, and cooked-meat packaging conditions on the production of hexanal in cooked patties from pork *L. dorsi*, *L. psoas*, and *R. femoris* muscle during storage.[1]

	Day 0[2]			Day 3			Day 7		
Treatment	LD	PS+RF	SEM	LD	PS+RF	SEM	LD	PS+RF	SEM
	Hexanal (pA*sec)								
A-C-A*	88.68	55.28^{c}	11.03	561.30^{ay}	872.93^{ax}	41.88	448.20^{by}	749.58^{cx}	36.39
A-C-V	88.68	55.28^{c}	11.03	113.55^{c}	119.41^{d}	12.40	108.78^{cy}	153.90^{dx}	8.07
A-IR-A	99.05^{y}	135.03^{ax}	6.96	418.93^{by}	702.91^{bx}	48.05	613.88^{ay}	1067.88^{ax}	41.90
A-IR-V	99.05^{y}	135.03^{ax}	6.96	81.35^{cy}	155.63^{dx}	10.23	160.28^{c}	201.44^{d}	16.22
V-IR-A	82.40	101.48^{b}	9.98	380.73^{by}	544.43^{cx}	23.56	460.95^{by}	896.80^{bx}	39.95
V-IR-V	82.40	101.48^{b}	9.98	83.88^{cy}	129.44^{dx}	6.26	108.10^{cy}	179.85^{dx}	7.67
SEM	5.65	8.85		23.56	25.62		24.21	25.94	

[1]Raw-meat patties were irradiated at 0 or 4.5 kGy dose (ave.) and cooked 3 days after storage. n=4 for LD, and 8 for PS+RF.
[2]Sampled 2 hour after cooking.
[a-d]Different letters within a column are significantly different (P<0.05).
[xy]Values with different superscript letters within a row of the same storage time are different (P<0.05).
*Abbreviation of treatments: A, aerobic packaging; V, vacuum-packaging; C, nonirradiated; IR, irradiated at 4.5 kGy dose. SEM, standard error of the mean.

Table 4. Effect of raw-meat packaging, irradiation, and cooked-meat packaging conditions on the production of total volatiles in cooked patties from pork *L. dorsi* (LD), *L. psoas* (PS), and *R. femoris* (RF) muscle during storage.[1]

	Day 0[2]			Day 3			Day 7		
Treatment	LD	PS+RF	SEM	LD	PS+RF	SEM	LD	PS+RF	SEM
	Total volatiles (pA*sec)								
A-C-A*	270.33^{b}	308.30^{b}	15.18	1118.55^{ay}	1528.54^{ax}	54.11	899.80^{cy}	1281.28^{cx}	47.82
A-C-V	270.33^{b}	308.30^{b}	15.18	385.58^{e}	413.55^{d}	11.95	348.65^{ey}	431.89^{dx}	15.89
A-IR-A	396.28^{a}	364.94^{a}	14.67	1012.53^{by}	1266.26^{bx}	73.33	1115.23^{ay}	1684.79^{ax}	54.34
A-IR-V	396.28^{a}	364.94^{a}	14.67	478.88^{d}	457.85^{d}	25.59	525.60^{d}	502.08^{d}	21.98
V-IR-A	316.45^{b}	334.95^{ab}	12.20	833.45^{cy}	1067.28^{cx}	26.90	998.10^{by}	1460.41^{bx}	50.97
V-IR-V	316.45^{b}	334.95^{ab}	12.20	283.90^{fy}	380.50^{dx}	17.49	346.63^{ey}	443.99^{dx}	12.59
SEM	13.12	12.32		29.60	37.55		27.75	34.82	

[1]Raw-meat patties were irradiated at 0 or 4.5 kGy dose (ave.) and cooked 3 days after storage. n=4 for LD, and 8 for PS+RF.
[2]Sampled 2 hour after cooking.
[a-d]Different letters within a column are significantly different (P<0.05).
[xy]Values with different superscript letters within a row of the same storage time are different (P<0.05).
*Abbreviation of treatments: A, aerobic packaging; V, vacuum-packaging; C, nonirradiated; IR, irradiated at 4.5 kGy dose. SEM, standard error of the mean.

Figure 1. Flow diagram of sample preparation procedure.

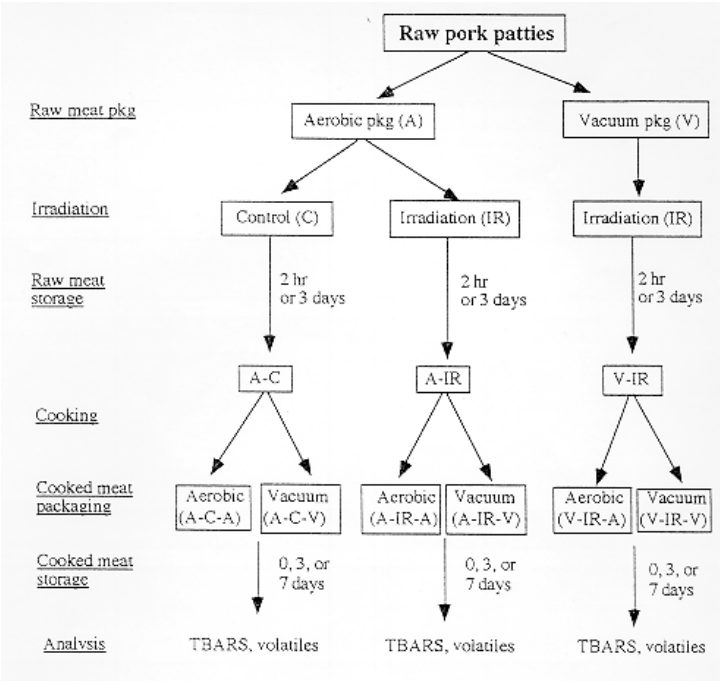

Figure 2. Gas chromatogram of volatiles from cooked pork.

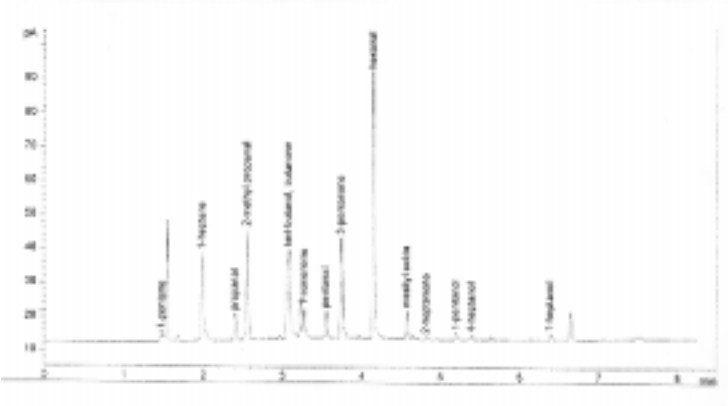

Figure 3. The relationships between TBARS values, and hexanal and total volatiles of cooked-meat patties prepared from three different pork muscles. A. Hexanal; B. Total volatiles (◆ , *L. dorsi* muscle; ×, *L. psoas* and *R. femoris* muscles).