Effect of Irradiation on Lipid Oxidation and Off-flavor Development in Cooked Pork Products with Different Fatty Acids and Packaging

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ASL-R1607

Summary and Implications

Irradiated samples had higher thiobarbituric acid reactive substances (TBARS) than nonirradiated at day 0 but the difference disappeared during storage in both packaging types. Storage increased the production of volatiles and changed the composition of volatiles only in aerobic-packaged sausage. Irradiation and the fatty acid composition had significant effects on lipid oxidation, volatile production, and sensory characteristics of cooked pork sausages during storage but that oxygen availability had a stronger effect than irradiation and fatty acid composition.

Storage increased the production of volatiles and changed the composition of volatiles only in aerobic-packaged sausage. Among the volatile components, 1-heptene and 1-nonene were influenced most by irradiation dose, and aldehydes by packaging type. The TBARS values and volatiles of vacuum-packaged irradiated cooked sausage had very low correlation. The TBARS, however, had very high correlation with the amount of aldehydes and total volatiles, and ketones and alcohols with long retention times in aerobic-packaged pork sausage. The low correlations of irradiation-dependent volatiles (e.g., 1-heptene and 1-nonene) with TBARS values regardless of packaging and storage conditions indicated that volatile compounds responsible for irradiation odor were different from those of lipid oxidation odor in cooked pork sausages.

Irradiation of cooked pork sausage, especially at 4.5 kGy and in aerobic packaging, may result in some diminution of typical meaty aromas and increases in an odor described by the panelists in this study as like wet wool or wet animal hair. The training and controlled test situation used in this study may result in greater discrimination in the panel than would exist in most consumers. Whether the changes caused by irradiation would be noticed by consumers or reduce the acceptability of the product to consumers was not addressed in this study. The data obtained suggest that TBARS values may not be useful in predicting the odor changes in cooked irradiated meat products.

Introduction

Low-dose irradiation treatments are effective in controlling pathogenic microorganisms on meat and in extending the shelf-life of meat. A wide range of processed meat products is marketed in a sliced, vacuum-packaged form. These products are commonly eaten as cold luncheon meats. Irradiation after vacuum packaging could be useful in extending the shelf-life of these products. Few studies of the impact of low-dose irradiation on cooked, vacuum-packaged meats, however, have been conducted. The effects of irradiation on lipid oxidation and off-flavor generation in cooked meat might be different from those in raw meat. This study was conducted to study the effect of irradiation on the development of lipid oxidation and flavor changes in cooked pork products.

Hashim et al. (4) showed 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. Champaign and Nawar (2) found that hydrocarbons are the major radiolytic products in fat and are related to the fatty acid composition of the fat. Hansen et al. (3) 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. Patterson and Stevenson (5) studied odor volatiles in irradiated chicken meat and found that dimethyltrisulfide is the most potent off-odor compound, followed by *cis*-3- and *trans*-6-nonenals, oct-1-en-3-one and bis(methylthio-)methane.

The objective of this study was to determine the effects of irradiation on lipid oxidation and off-flavor development in cooked pork products with different fatty acids and packaging.

Materials and Methods

Sausage was prepared from lean ground pork, fat or oil (10% of lean meat), salt (2%), ice (7.5%), and 1% soy protein concentrate (90% protein). Pork fat, stripped lard, stripped corn oil, or flaxseed oil was added to adjust fatty acid composition of sausages. The sausage was cooked in a smokehouse with steam to an internal temperature of 75°C and chilled in ice water. Half of the cooked sausages were vacuum-packaged in impermeable nylon/polyethylene bags, and the other half in oxygen-permeable bags. After packaging, they were irradiated using electrons from a Linear Accelerator to an absorbed dose of 0, 2.5, or 4.5 kGy. The sausages were stored at 4°C for 8 days. The degree of lipid oxidation, volatiles, and sensory characteristics in cooked sausages was determined after 0, 4, and 8 days of storage. Lipid oxidation was determined by the thiobarbituric acid reactive substances (TBARS) method described in detail elsewhere (1). Precept II and Purge-and-Trap Concentrator 3000 (Tekmar-Dohrmann) were used to purge and trap the volatiles in irradiated, cooked pork sausage. A GC (HP Model 6890) equipped with a flame ionization detector was used to analyze volatiles (1).

For sensory analysis, panelists were recruited based on interest and availability. All of the eight panelists had experience in sensory testing. Group sessions were held to orient the panelists and determine the terms to include on the ballot for sensory testing. The odor terms selected were as follows: cooked meat, wet wool or wet animal hair, cardboard, and rancid. Scales with nine categories were used on the ballot: the first category was labeled with “none” and the ninth category with “extreme.” Panelists evaluated samples under red light in individual panel booths. Samples were presented in small plastic containers covered with lids. A complete-block design was used for panel sessions and samples were presented in a random order independently determined for each panelist. For data analysis, categories were assigned values from one to nine (none = one, extreme = 9). Data was subjected to analysis of variance, with treatment and panelist as the main effects. When main effects were significant at $P<0.05$, treatment means were compared by using Tukey’s honestly-significant-difference (HSD) test.

Results and Discussion

Volatiles production. In vacuum-packaged, cooked sausage, irradiation dose had a significant effect ($P<0.05$) on the production of volatiles but the effects of storage time were minor. At day 0, the amounts of 1-heptene, 2-propanone, and 1-nonene increased as irradiation dose increased. The production of hexanal, 1-pentanol, and 1-heptanol decreased ($P<0.05$) with the increase of irradiation dose. Except for 1-pentene+hexane and nonanal, the amount and profile of volatiles in the sausages changed only slightly during storage. The ups and downs of 1-pentene+hexane and nonanal during storage were not consistent with storage time and could not be explained. The amounts of propanal and pentanal were influenced by irradiation at day 8 but the changes were not consistent with irradiation dose. Irradiated sausages (2.5 or 4.5 kGy) produced more total volatiles than nonirradiated except for those irradiated at 4.5 kGy and stored for 8 days. The amounts of total volatiles during storage were mainly influenced by 1-pentene+hexane, 2-methylpentanal, and trimethylhexane whose changes were not consistent with storage time.

In aerobic-packaged irradiated cooked pork sausage, irradiation dose and storage time had significant effects ($P<0.05$) on the production and composition of volatiles. The amounts of 1-heptene and 1-nonene increased ($P<0.05$) as irradiation dose increased as in vacuum-packaged sausages. Cooked pork sausage irradiated at 2.5 kGy produced higher amounts of 1-pentanol and 1-heptanol than those at 0 and 4.5 kGy at day 0 but the amount of 1-pentanol, 1-hexanol, and 1-heptanol showed decreasing trends as irradiation dose increased at day 4 and day 8. In day 0 samples, irradiation greatly increased ($P<0.05$) the production of 1-pentene+hexane but had no effect on day 4 and day 8 samples. The amounts of propanal, pentanal, 2-methyl pentanal, and hexanal were not influenced by irradiation dose but increased ($P<0.05$) during storage. After 4 days of storage in aerobic-packaging these aldehydes became the major volatile compounds of irradiated cooked pork sausage, and the amounts were two- to four-fold higher than that of the day 0 samples. Other volatiles such as 1-pentene+hexane, 1-pentanol, 1-hexanol, and 1-heptanol also increased ($P<0.05$) during storage in aerobic packaging.

The major volatile components found in irradiated cooked pork sausage analyzed by the purge-and-trap/GC method used in this study were lipid oxidation-related compounds, most of which were aldehydes, alcohols, ketones, and alkenes with low carbon numbers. Little if any sulfur-containing compounds, pyrazines, and furans were detected in the irradiated, cooked pork sausage. As reported by Ramarathnam et al. (6), hexanal was the major lipid oxidation-related volatile in cooked meat, but the contribution of other aldehydes such as heptanal, octanal, and nonanal to off-flavor of cooked meat also would be significant because of their high flavor dilution factors (7).

1-Heptene and 1-nonene increased proportionally with the increase of irradiation doses. Storage in aerobic packaging, however, also increased the amount of 1-heptene and 1-nonene because of lipid oxidation. Other volatile compounds such as aldehydes, ketones, and alcohols were not influenced by irradiation at day 0 but irradiation accelerated lipid oxidation and increased the amount of those compounds after storage.

TBARS values. Sausages with different fatty acid composition produced different levels of lipid oxidation during storage. With vacuum packaging, sausages prepared with lard had the highest TBARS values and those with backfat had the lowest. The low TBARS in sausages prepared with flaxseed oil were caused by the high tocopherol content in that oil. Under aerobic packaging, however, the TBARS of sausages with flaxseed oil increased rapidly and were the highest at 4 and 8 days of storage.

The changes of TBARS values in irradiated, cooked pork sausage with different packaging conditions and storage time indicated that storage time had no effect on the TBARS of vacuum-packaged sausage but had significant ($P<0.05$) effects in aerobic-packaged sausage. The TBARS values of the sausage in vacuum packaging remained constant during the 8-day storage periods, where values of sausage in aerobic packaging increased two- to four fold from day 0 values. Irradiating cooked pork sausage had some effect on the TBARS values of vacuum-packaged sausages at day 0 and those of aerobic-packaged sausages at day 0 and day 4. Compared with storage time in aerobic packaging, however, irradiation effects on the TBARS values of cooked meat were minor.

Relationships of volatile compounds with TBARS. Little relationships between TBARS values and volatiles produced in irradiated, cooked pork sausage with vacuum packaging were found. With aerobic packaging, however, TBARS values of irradiated, cooked pork sausage had very high correlation ($P<0.001$) with the production of 1-pentene+hexane, propanal, pentanal, hexanal, 3-heptanone, 1-pentanol, cyclohexanone, 1-hexanol, 1-heptanol, and total volatiles. The relationships between TBARS values and the amount of 2-methylpentanal, trimethylhexane, and nonanal also were significant. The production of pentanal was the only volatile compound significantly ($P<0.01$) correlated with TBARS in both vacuum- and aerobic- packaged cooked sausages. The production of 1-pentene+hexane, propanal, pentanal, hexanal, 3-heptanone, 1-pentanol, cyclohexanone, 1-hexanol, nonanal, 1-heptanol, and total volatiles had a very high correlation ($P<0.001$) with the TBARS values of irradiated, cooked pork sausage when both vacuum- and aerobic-packaged sausages were combined. 2-Propanone was correlated ($P<0.001$) to TBARS when both aerobic and vacuum packaging were combined but not when packaging type was analyzed separately. This result indicates that the amount of aldehydes, total volatiles, and ketones and alcohols with longer retention times can be good indicators of oxidative changes in cooked irradiated meat.

Sensory characteristics. Some of the odor characteristics were altered by irradiation in sausages made with all of the types of fat. The intensity of cooked meat and cardboard odors differed significantly among treatments. Irradiation tended to reduce the cooked meat odor and increase the cardboard odors, with differences in cooked meat odor being significant ($P<0.05$) between the samples treated with 0 and 4.5 kGy. Cardboard odor was significantly greater in sausage aerobically packaged and irradiated at 4.5 kGy than in unirradiated sausage (either type of packaging). The trend is for an greater wet-hair odor in irradiated samples ($P=0.049$ in the analysis of variance). In general, the effects of storage (4 days at 4°C) on the cardboard odors of sausage were of less magnitude than the effects of irradiation dose. The data suggest that vacuum packaging may somewhat protect against off-odor development, especially at 2.5 kGy. Overall, sausage that had been irradiated, especially at 4.5 kGy, seems to be more likely to have somewhat greater wet-hair and cardboard odors and less cooked meat odor than does unirradiated product. The training and controlled test situation used in this study may result in greater discrimination in the panel than would exist in most consumers. Whether the changes caused by irradiation would be noticed by consumers or reduce the acceptability of the product to consumers was not addressed in this study.

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