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Volatile profile, lipid oxidation and protein oxidation of irradiated ready-to-eat cured turkey meat products

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HIGHLIGHTS

- Irradiation had little effects on lipid oxidation of ready-to-eat cured turkey.
- 4.5 kGy irradiation increased protein oxidation.
- Irradiated samples were isolated due to Strecker/radiolytic degradation products.
- 1.5 kGy irradiation had limited effects on the volatile profile of turkey sausages.
- Dimethyl disulfide can be used as a potential marker for irradiated meat products.

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ABSTRACT

Irradiation had little effects on the thiobarbituric acid reactive substances (TBARS) values in ready-to-eat (RTE) turkey meat products, while it increased protein oxidation at 4.5 kGy. The volatile profile analyses indicated that the amount of sulfur compounds increased linearly as doses increased in RTE turkey meat products. By correlation analysis, a positive correlation was found between benzene/ benzene derivatives and alcohols with lipid oxidation, while aldehydes, ketones and alkane, alkenes and alkynes were positively correlated with protein oxidation. Principle component analysis showed that irradiated meat samples can be discriminated by two categories of volatile compounds: Strecker degradation products and radiolytic degradation products. The cluster analysis of volatile data demonstrated that low-dose irradiation had minor effects on the volatile profile of turkey sausages (< 1.5 kGy). However, as the doses increased, the differences between the irradiated and non-irradiated cured turkey products became significant.

1. Introduction

Irradiation has been considered as one of the most effective methods to eliminate potential pathogens in meat and poultry (Farkas, 2006). However, irradiation can also produce free radicals from the water molecules in meat (Thakur and Singh, 1994) and they result in changes in the oxidation-reduction environment within meat products (Nam and Ahn, 2003; Rowe et al., 2004). Cooked meat is more susceptible to oxidation than raw meat because the phospholipid structure in muscle cell membranes are damaged during cooking (Ahn et al., 1992), while cured ready-to-eat meat products are more resistant to oxidative changes and color fading than uncured meat products (Zhu et al., 2004a, 2004c, 2005; Houser et al., 2005a) due to the nitrite added in cured meat products has a strong antioxidant ability (Lee and Ahn, 2011).

Irradiation is also reported to increase the amount of off-odor volatiles in RTE meat products. The off-odor in irradiated meat is considered as the combined effect of sulfur volatiles and lipid oxidation products (Kwon et al., 2012; Lee and Ahn, 2011). Zhu et al. (2004a) reported a dose-dependent increase of sulfur odor in RTE cured turkey ham. Houser et al. (2005b) found that irradiation at 1.6 kGy increased off-odor scores for both RTE cured pork ham and frankfurters. Irradiation processing also resulted in the formation of new volatile compounds, including heptane, trans-1-butyl-2-methylcyclopropanone, 2-octene, and toluene in the ham, and 2-butanone in frankfurters. The amounts of dimethyl disulfide in both ham and frankfurters increased as a result of irradiation, but gradually decreased during the 8-week storage period.

Previous studies interpreted the quality changes in irradiated meat products using a univariate data analysis (ANOVA). However, as the data sets become complex, this statistical method will not

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be useful (Ramsey and Schafer, 2002). Therefore, an efficient statistical analysis methods is needed to explore the interrelationship between the objects and variables. Meanwhile, to extract the maximum useful information from original data, establishing an unsupervised pattern recognition and a visualization is also needed (Guillén-Casla et al., 2011). Correlation analysis is a common measure of analyzing linear association between variables, however, the major limitation is that a cause and effect relationship cannot be established based on the correlation coefficient alone (Ramsey and Schafer, 2002). Principal component analysis is a mathematical tool that can reduce the dimensionality of original data while holding as much information as possible that already existed in the original data (Guillén-Casla et al., 2011), and the relationship between objects and variables can be visualized (Legako et al., 2015; Xiao et al., 2014). In food science it is often of interest to detect the similarities between individuals in their response pattern (Næs et al., 2010). With cluster analysis, the subjects can be classified into homogenous groups according to the values of measured variables (Ramsey and Schafer, 2002), and many researchers are applied such methods, for example to classify wine or honey (Conti et al., 2014; Xiao et al., 2014).

Previous studies on the relationship between lipid/protein oxidation and volatile compounds in irradiated RTE cured meat products has not been conclusive. Therefore, the objective of this study was to 1) determine lipid oxidation, protein oxidation and volatile compounds produced from RTE cured turkey meat products under different radiation doses, 2) interpret the relationship between those components using multivariate statistical analysis, and 3) elucidate the key volatile compounds responsible for the off-odor. The results should provide better understanding of potential advantages or disadvantages of irradiation to turkey meat products.

2. Materials and methods

2.1. Sample preparation

The sliced turkey breast rolls, sliced turkey ham and turkey sausages were purchased from a local grocery store. The turkey meat products were cut to 50-g pieces and individually packaged in vacuum bags (nylon/polyethylene vacuum bags, 9.3 mL O_2/m^2/24 h at 0 °C; Koch, Kansas City, MO). All packages of meat were irradiated at four target dose levels (0, 1.5, 3.0 and 4.5 kGy) using an electron beam accelerator with 10 MeV energy and 5.6 kW power level with the maximum/minimum dose ratio 1.08. Alanine dosimeters were placed on the top and bottom surfaces of a package and read using an Electron Paramagnetic Resonance Instrument to check the absorbed doses. Following irradiation, packaged meat samples were immediately placed in coolers with crushed ice and transported to our lab and stored in a refrigerator at 4 °C. Lipid oxidation, protein oxidation and volatiles were determined on the day of irradiation.

2.2. Lipid oxidation and protein oxidation

Lipid oxidation of turkey breast rolls, ham, or sausages were measured using the thiobarbituric acid reactive substances (TBARS) method of Wang et al. (2012). The amounts of TBARS were calculated as milligrams (mg) of malondialdehyde (MDA) per kilogram (kg^{-1}) of meat. Protein carbonyl content was determined using the 2,4-dinitrophenylhydrazine (DNPH) derivatization method (Lund et al., 2008). The carbonyl content was calculated as nmoles per milligram of protein using an absorption coefficient of 22,000 M^{-1} cm^{-1} (Levine et al., 1994).

2.3. Volatile compounds

Volatiles of samples were analyzed using a Solatek 72 Multimatrix-Vial Autosampler/Sample Concentrator 3100 (Tekmar-Dohrmann, Cincinnati, OH, USA) connected to a GC/MS (Model 6890/5973; Hewlett-Packard Co., Wilmington, DE, USA) according to the method of Nam et al. (2007). Sample (2 g) was placed in a 40 mL sample vial, flushed with nitrogen gas (40 psi) for 3 s, and then capped airtight with a Teflon*fluorocarbon resin/silicone septum (I-Chem Co., New Castle, DE, USA). The meat sample was purged with He (40 mL/min) for 12 min at 40 °C. Volatiles were trapped using a Tenax/charcoal/silica column (Tekmar-Dohrmann) and desorbed for 2 min at 225 °C, focused in a cryofocusing module (−80 °C), and then thermally desorbed into a column for 2 min at 225 °C. An HP-624 column (7.5 m, 0.25 mm i.d., 1.4 μm nominal), an HP-1 column (52.5 m, 0.25 mm i.d., 0.25 μm nominal), and an HP-Wax column (7.5 m, 0.250 mm i.d., 0.25 μm nominal) were connected using zero dead-volume column connectors (J &W Scientific, Folsom, CA, USA). Ramped oven temperature was used to improve volatiles separation. The initial oven temperature of 25 °C was held for 5 min. After that, the oven temperature was increased to 50 °C at 5 °C per min, to 120 °C at 30 °C per min, to 160 °C at 15 °C per min, and finally to 200 °C at 5 °C per min held for 2 min at the temperature. Constant column pressure at 22.5 psi was maintained. The ionization potential of MS was 70 eV, and the scan range was 20.1–350 *m/z*. The identification of volatiles was achieved by the Wiley Library (Hewlett-Packard Co.). The area of each peak was integrated using ChemStation™ software (Hewlett-Packard Co.) and the total peak area was reported as an indicator of volatiles generated from the samples.

2.4. Statistical analysis

Three packages of samples (replications) were used for each analysis. Data were analyzed by the GLM procedure of SAS (SAS 9.4 software package, 2013) for different treatments. The differences in the mean values were compared by Tukey's multiple comparison method, and mean values and standard deviation were reported ($P < 0.05$). The CORR procedure of SAS was used to determine Pearson correlation coefficients. Principal component analysis was conducted in order to explore relationships between multiple volatile compounds and irradiated turkey meat products using XLSTAT (2015). Two principal components, PC1 and PC2 were retained to determine treatment scores. The cluster analysis was applied to samples using the Euclidian distance and average method (Ramsey and Schafer, 2002).

3. Results and discussion

3.1. Lipid oxidation and protein oxidation

Irradiation had little effect on the TBARS ($P > 0.05$). Among the turkey meat products, turkey breast rolls had the highest TBARS values, followed by turkey sausages and then turkey ham (Fig. 1). These results agreed with Houser et al. (2003) who reported that TBARS values of irradiated (4.5 kGy) ham was not practically different from non-irradiated control. Shahidi et al. (1991) reported that sodium nitrite has a strong antioxidant effect on cured meat products. However, when higher doses of radiation was applied (> 8 kGy), lipid oxidation in cured meat increased (Terrell et al., 1981). The higher levels of TBARS values in turkey breast rolls than otheres were consistent with Zhu et al. (2004a, 2004c) findings: the highest TBARS values in turkey breast rolls were due to the quality of the starting materials, which already had relatively high