Lipid Oxidation, Color, Volatiles, and Sensory Characteristics of Aerobically Packaged and Irradiated Pork with Different Ultimate pH

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ABSTRACT: Irradiation and storage increased lipid oxidation of normal and pale-soft-exudative (PSE) muscles, whereas dark-firm-dry (DFD) muscle was very stable and resistant to oxidative changes. Irradiation increased redness regardless of pork-quality type, and the increases were proportional to irradiation dose. Irradiation increased the production of sulfur-containing volatiles, but not lipid oxidation products. The total volatiles produced in normal and PSE pork were higher than the DFD pork. Some volatiles produced in meat by irradiation evaporated during storage under aerobic packaging conditions. Nonirradiated normal and DFD pork had higher odor preference scores than the nonirradiated PSE, but irradiation reduced the preference scores of all 3 pork-quality types.

Key Words: irradiation, pork ultimate pH, color, lipid oxidation, volatiles

Introduction

Irradiation is the best available technology to control microorganisms and parasites and to extend shelf life in raw meats. Nutritional disadvantages of irradiation have not been reported other than that thiamin is reduced in irradiated beef; more thiamin, however, is lost when beef is cooked than irradiated (Giroux and Lacroix 1999). Many researchers have reported that irradiation induces oxidative chemical changes, the formation of off odor, and color changes. Irradiation also increases 2-thiobarbituric acid (TBARS) values in meats. Initiators of lipid oxidation in irradiated meat are considered to be hydroxyl radicals generated by the interaction of ionizing energy with water molecules in muscle tissues or in meat products (Thakur and Singh 1994). Regardless of packaging type, irradiated raw pork patties produced more volatiles than nonirradiated ones and developed a characteristic aroma immediately after irradiation (Ahn and others 1998). Hashim and others (1995) 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. Millar and others (1995) reported that the redness of chicken breast increased after ionizing irradiation in oxygen-permeable film. The changes in meat color after irradiation were highly dependent on animal species, muscle type, and location in a muscle (Nanke and others 1998).

The impacts of irradiation on meat color could be related to oxygen availability and the amount of free radicals formed at the time of irradiation.

The ultimate pH of meat is also known to be a crucial factor for meat quality. Pork, depending on the ultimate pH, can be classified as normal, pale-soft-exudative (PSE), or dark-firm-dry (DFD); and each classification has its own distinctive color, texture, and flavor characteristics. The distribution and proportion of free and bound water in normal, PSE, and DFD pork are different. PSE pork upon irradiation would be more susceptible to oxidative changes and produce more off-flavor volatiles than irradiated normal or DFD meat due to its denatured muscle structure. Chen and Waimaleongora-Ek (1981) reported that the lower the pH value in the raw chicken meat sample, the higher the TBARS values. Silva and others (1999) showed that DFD pork was more susceptible to bacterial spoilage and was less flavorful than the normal pork. In addition, the response of normal, PSE, and DFD muscles to color changes upon irradiation could be different from each other. However, little work has been done to determine the effect of irradiation on the quality changes of raw pork with different ultimate pH.

The objective of this study was to determine and compare the effects of irradiation on lipid oxidation, off-odor volatiles, and color of aerobically packaged normal, PSE, and DFD pork during refrigerated storage.

Materials and Methods

Sample preparation

Twenty-four pork loin (Longissimus dorsi) muscles, 8 each of normal (pH 5.7 to 5.8), PSE (pH 5.4 or less) and DFD (pH 6.2 to 6.8) meat, were purchased from a local packing plant. The pork loins were trimmed of all fat from the surface, and the lean muscle was sliced to 3-cm thick steaks and packaged in polyethylene oxygen permeable bags. After packaging, they were stored overnight at 4°C and then irradiated using a Linear Accelerator (Circe IHIR, Thomson CSF Linae, Saint-Aubin, France). The target doses of irradiation were 0, 2.5, and 4.5 kGy. The energy and power level used were 10 MeV and 10 kw, respectively, and the average dose rate was 92.0 kGy/min. The max/min ratio was approximately 1.12 for 2.5 kGy and 1.15 for 4.5 kGy. To confirm the target dose, 2 alanine dosimeters per cart were attached to the top and bottom surfaces of the sample. The alanine dosimeter was read using a 104 Electron Paramagnetic Resonance Instrument (Bruker Instruments Inc., Billerica, Mass., U.S.A.). The pork steaks were stored at 4°C for up to 10 d. The pH of meat samples was measured after 0, 5, and 10 d of storage after homogenizing samples with 9 vol. of deionized distilled water (DDW). Color and lipid oxidation in aerobically packaged irradiated pork loins were determined at 0, 5, and 10 d, volatile production at 0 and 10 d, and sensory analysis at 7 d of storage.
Sensory and Nutritive Qualities of Food Irradiation Impact on the Quality of Pork with Different Ultimate pH

Color measurement

Color measurements were conducted on the surface of samples with a LabScan spectrophotometer (Hunter Associates Labs., Inc., Reston, Va., U.S.A.) that had been calibrated against white and black reference tiles. Hunter L- (lightness), a- (redness), and b- (yellowness) values were obtained (American Meat Science Assn. 1991) using a setting of D65 (daylight, 65-degree light angle). An average value from 2 random locations on each sample surface was used for statistical analysis.

TBARS value

The fluorometric 2-thiobarbituric reactive substances (TBARS) method (Jo and Ahn 1998) was used to determine the extent of lipid oxidation in raw meat. Minced sample (3 g) was weighed and placed in a test tube (50 mL). Nine mL of deionized distilled water (DDW) was added, and the mixture homogenized with a Brinkman polytron (Type PT 10/35, Brinkman Instrument Inc., Westbury, N.Y., U.S.A.) for 15 s at high speed. The meat homogenate (0.5 mL), sodium dodecyl sulfate (8.1% 200 μL), hydrochloric acid (0.5 M, 1.5 mL), thiobarbituric acid (20 mM, 1.5 mL), butylated hydroxytoluene (7.2%, 50 μL), and DDW (250 μL) were added in a test tube. The sample was vortexed and heated in a 90°C water bath for 15 min. After cooling for 10 min in cold water, 1 mL of DDW and 5 mL of n-butanol/pyridine solution (15:1, v/v) were added. The sample was vortexed and centrifuged 3000 × g for 15 min, and the resulting upper layer was read by a fluorometer (Model 450, Barnstead/Thermolyne, Dubuque, Iowa, U.S.A.) with 520 nm excitation and 550 nm emission. The amounts of TBARS were expressed as milligrams of malondialdehyde per kilogram of meat.

Volatiles compound analysis

A purge-and-trap apparatus (Precept II and purge-and-trap 3000, Tekmar-Dohrmann) connected to a gas chromatograph/mass spectrometry (GC/MS, Hewlett-Packard) was used to analyze the volatiles responsible for the off odor in samples. Two-g of minced sample and 1 pack of oxygen absorber (Ageless type Z-100, Mitsubishi Gas Chemical America Inc., New York, N.Y., U.S.A.) were placed in a 40-mL sample vial. The vials were then flushed with helium gas (99.999%) for 5 s. The maximum holding time in a refrigerated (4°C) sample tray before analysis was less than 10 h to minimize the oxidation during the holding time. The meat sample was purged with helium gas (40 mL/min) for 11 min. Volatiles were trapped at 30°C using a Tenax/Silica gel/Charcoal column (Tekmar-Dohrmann) and desorbed for 2 min at 220°C, focused in a cryofocusing unit at ~100°C, and then thermally desorbed into a column for 30 s at 220°C. A combined column—an HP-624 (8 m, 250 μm i.d., 1.4 μm nominal) column with an HP-1 column (44 m, 250 μm i.d., 0.25 μm nominal) using a zero dead-volume column connector—was used for volatile analysis. Ramped oven temperature was used (10°C for 2.5 min, increased to 10°C at 2.5°C/min, increased to 80°C at 10°C/min, increased to 150°C at 20°C/min, increased to 180°C at 10°C/min, and held for 1 min). Inlet temperature was 180°C. Liquid nitrogen was used to cool the oven below ambient temperature. Helium was the carrier gas at a constant pressure of 20.5 psi. The ionization potential of MS was 70 eV, and the scan range was 18.1 to 300 m/z.

Identification of volatiles was achieved by comparing mass spectral data of samples with those of the Wiley Library (Hewlett-Packard) and standards, when available. The area of each peak was integrated using ChemStation™ software (Hewlett-Packard), and the total peak area (pA*sec) × 10^4 was reported as an indicator of volatiles generated from the meat samples. The peaks produced by mass spectral data were grouped into 5 major volatile classes—ketones, alcohols, aldehydes, sulfur (S)-containing compounds, and hydrocarbons—and reported.

Sensory analysis

The intensity of off odor and preference for the odor of meat samples were determined at 7 d of storage using 76 sensory panelists. For evaluation of odor, samples containing 3-g muscle in coded, capped glass scintillation vials were presented to each panelist in isolated booths. A 15-cm linear hedonic scale, anchored at opposite ends with the words “no off odor” and “very strong odor,” and “not preferable” and “highly preferable,” was used to rate the samples on the intensity of irradiation odor and on the preference for the irradiation odor. The responses from the panelists were expressed in numerical values ranging from 0 (no off odor or not preferable) to 15 (very strong odor or highly preferable) to the nearest 0.1 cm.

Statistical analysis

The experimental design was to determine the effects of different meat type, irradiation, and storage time on lipid oxidation, volatiles content, and color changes in samples during the 10-d storage. Data were analyzed using SAS software (SAS Institute Inc. 1985) by the generalized linear model procedure; the Student-Newman-Keul’s multiple range test was used to compare differences among means. Mean values and standard error of the means (SEM) were reported. Significance was defined at P < 0.05.

Results and Discussion

pH

The pH values for the nonirradiated and irradiated normal, PSE, and DFD pork (Table 1) showed that irradiation had no effect on the pH of all 3 quality types of pork Longissimus dorsi muscle with aerobic packaging. The original ultimate pH of normal, PSE, and DFD meat has been maintained throughout the 10-d storage.

Color

The lightness, redness, and yellowness of 3 different grades of pork loins with aerobic packaging were compared by irradiation dose and storage time (Table 2). The most important factor influencing the values was meat type (P.

| Table 1—The pH of aerobically packaged normal, PSE, and DFD pork Longissimus dorsi muscle affected by irradiation dose and storage time at 4°C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Storage | 0 kGy | 2.5 kGy | 4.5 kGy |
| time | Norm | PSE | DFD | Norm | PSE | DFD | Norm | PSE | DFD | Norm | PSE | DFD | SEM^2 |
| Day 0 | 5.69^b | 5.47^b | 6.39^a | 5.64^b | 5.46^b | 6.35^a | 5.67^b | 5.46^b | 6.30^a | 0.04 |
| Day 5 | 5.68^b | 5.46^bc | 6.42^a | 5.60^b | 5.46^b | 6.36^a | 5.66^b | 5.46^b | 6.30^a | 0.05 |
| Day 10 | 5.64^b | 5.45^cd | 6.53^a | 5.59^b | 5.47^cd | 6.47^a | 5.58^b | 5.49^cd | 6.40^a | 0.06 |

^2SEM: Standard errors of the mean among different storage time within a meat type.

^3SEM: Standard errors of the mean among different meat type x irradiation within a storage time.

SEM^2: Standard errors of the mean among different storage time within a meat type.
PSE pork, which has low pH, had the highest L-value, whereas DFD pork had the lowest L-value among the 3 meat types. Irradiated pork loin had (P < 0.01) greater a-values than nonirradiated pork chops regardless of meat type, and the increase in a-values was proportional to irradiation dose. Furthermore, the redness was not decreased during the 10-d storage period even in aerobic packaging conditions. Although there have been several inconsistent results (Satterlee and others 1971; Luchsiniger and others 1996) in terms of the stability of increased redness in irradiated meat, the red/pink pigment formed by irradiation in this experiment was not easily oxidized. Therefore, irradiation could have a desirable effect on improving the color of PSE pork, which has a detrimental pale color and reduced pigment stability (Livingston and Brown 1981; Sorheim and others 1997). The b-values of PSE loin meats were higher (P < 0.01) than the normal and DFD samples at 0 d of storage. Color b-value increased during storage in all 3 pork types, but yellowness usually does not have much impact on the overall color of meat. Irradiation had no effect on the b-values of pork loin.

### Table 2—Color L-, a-, and b-values of aerobically packaged normal, PSE, and DFD pork Longissimus dorsi muscle affected by irradiation dose and storage time at 4 °C

<table>
<thead>
<tr>
<th>Storage time (d)</th>
<th>Norm PSE</th>
<th>DFD PSE</th>
<th>Norm PSE</th>
<th>DFD PSE</th>
<th>Norm PSE</th>
<th>DFD PSE</th>
<th>SEM²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td>48.1³v</td>
<td>54.9a²</td>
<td>42.3³c</td>
<td>49.5³</td>
<td>56.7³x</td>
<td>37.0³w</td>
<td>47.5³</td>
</tr>
<tr>
<td>Day 5</td>
<td>51.3³v</td>
<td>53.3³b²</td>
<td>41.9³g</td>
<td>52.1³</td>
<td>55.3³g³</td>
<td>43.1³x</td>
<td>49.5³</td>
</tr>
<tr>
<td>Day 10</td>
<td>48.3³v</td>
<td>51.3³g³</td>
<td>44.8³e</td>
<td>51.7³</td>
<td>58.3³e³</td>
<td>44.6³x</td>
<td>50.2³</td>
</tr>
<tr>
<td>SEM²</td>
<td>0.8</td>
<td>0.9</td>
<td>1.1</td>
<td>1.0</td>
<td>1.0</td>
<td>1.1</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table 3—TBARS values of aerobically packaged normal, PSE, and DFD pork Longissimus dorsi muscle affected by irradiation dose and storage time at 4 °C

<table>
<thead>
<tr>
<th>Storage time (d)</th>
<th>Norm PSE</th>
<th>DFD PSE</th>
<th>Norm PSE</th>
<th>DFD PSE</th>
<th>Norm PSE</th>
<th>DFD PSE</th>
<th>SEM²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td>11.0³</td>
<td>12.7³a</td>
<td>9.5³d²</td>
<td>10.9³</td>
<td>12.7³a²</td>
<td>8.6³d²</td>
<td>11.9³</td>
</tr>
<tr>
<td>Day 5</td>
<td>13.2³g³</td>
<td>13.9³g³</td>
<td>9.8³g³</td>
<td>14.4³g³</td>
<td>14.1³g³</td>
<td>10.8³g³</td>
<td>12.5³g³</td>
</tr>
<tr>
<td>Day 10</td>
<td>13.6³g³</td>
<td>14.6³g³</td>
<td>11.8³g³</td>
<td>14.8³g³</td>
<td>14.9³g³</td>
<td>12.8³g³</td>
<td>14.4³g³</td>
</tr>
<tr>
<td>SEM²</td>
<td>0.2</td>
<td>0.2</td>
<td>0.5</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Volatile compounds

Meat type as well as storage time affected (P < 0.05) the production and the composition of volatiles in aerobically packaged pork loins (Table 4). At d 0 of storage, nonirradiated normal pork loins produced the higher amount of ketones than the PSE and DFD porks, but PSE pork produced the higher amount of alcohols and total volatiles than the normal and DFD porks. The
Table 4—Relative production of volatiles in aerobically packaged normal, PSE, and DFD pork Longissimus dorsi muscle affected by irradiation dose at different storage times at 4 °C

<table>
<thead>
<tr>
<th>Storage</th>
<th>Norm 0.0 kGy</th>
<th>PSE 2.5 kGy</th>
<th>DFD 4.5 kGy</th>
<th>Norm 0.0 kGy</th>
<th>PSE 2.5 kGy</th>
<th>DFD 4.5 kGy</th>
<th>SEM1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ketones</td>
<td>15867a</td>
<td>550c</td>
<td>3041c</td>
<td>761c</td>
<td>195a</td>
<td>335a</td>
<td>5308b</td>
</tr>
<tr>
<td>Alcohols</td>
<td>2402b</td>
<td>2635o</td>
<td>4014o</td>
<td>160b</td>
<td>1192b</td>
<td>0b</td>
<td>420c</td>
</tr>
<tr>
<td>Aldehydes</td>
<td>1055b</td>
<td>763b</td>
<td>1863b</td>
<td>472b</td>
<td>844b</td>
<td>684c</td>
<td>633b</td>
</tr>
<tr>
<td>S-compounds</td>
<td>189b</td>
<td>1738b</td>
<td>65d</td>
<td>10037a</td>
<td>4643b</td>
<td>1274c</td>
<td>5142c</td>
</tr>
<tr>
<td>Ketones</td>
<td>2402b</td>
<td>2635o</td>
<td>4014o</td>
<td>160b</td>
<td>1192b</td>
<td>0b</td>
<td>420c</td>
</tr>
</tbody>
</table>

Table 5—Sensory characteristics of aerobically packaged irradiated normal, PSE, and DFD pork Longissimus dorsi muscle refrigerated for 7 d

<table>
<thead>
<tr>
<th>Irradiation</th>
<th>Norm</th>
<th>PSE</th>
<th>DFD</th>
<th>SEM1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kGy</td>
<td>2.90k</td>
<td>4.00k</td>
<td>3.12k</td>
<td>0.26</td>
</tr>
<tr>
<td>2.5 kGy</td>
<td>6.91k</td>
<td>6.72k</td>
<td>6.47k</td>
<td>0.35</td>
</tr>
<tr>
<td>4.5 kGy</td>
<td>7.33k</td>
<td>7.32k</td>
<td>6.79k</td>
<td>0.35</td>
</tr>
</tbody>
</table>

a,bDifferent letters within a row are significantly different (P < 0.05). n = 4
SEM: Standard errors of the mean among different meat type x irradiation within a volatile group.

Sensory characteristics

Meat type and irradiation dose affected (P < 0.05) the intensity of off odor and the preference for a meat odor (Table 5). The off-odor intensity of PSE was higher than normal and DFD meats in nonirradiated samples. Irradiation increased (P < 0.05) the intensity of irradiation odor, which was not significantly different among irradiated normal, PSE, and DFD meats. The preference for a meat odor also was consistent with the result of intensity of off odor. As the off odor in meat became more intense, the preference for the meat odor decreased because most trained panelists considered irradiation odor as an off odor. Huber and others (1953) reported that meat sterilized by irradiation developed a characteristic odor, which has been described as metallic, sulfide, wet dog, wet grain, or burnt.

In nonirradiated samples, the preference for a meat odor for normal and DFD meats was higher than the PSE meat. After irradiation, however, there was no difference in odor preference for the 3 pork types. Ahn and others (2000) reported that sensory characteristics of irradiated meat were described as having a barbecued corn-like odor, and sensory panels showed no objection to the odor. However, irradiation of pork at the 2.5 kGy level decreased (P < 0.05) the odor preference for all 3 pork types in this study.
Irradiation Impact on the Quality of Pork with Different Ultimate pH

Conclusion

Irradiation increased TBARS and off odor in aerobically packaged pork. But DFD pork, which usually is underutilized because of its microbial susceptibility, was more stable and resistant to lipid oxidation and off-odor production by irradiation than the normal pork. This suggests that irradiation can significantly increase the utilization of DFD pork, and can greatly benefit pork and beef industries.

References

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