Quality Characteristics of Vacuum-Packaged, Irradiated Normal, PSE, and DFD Pork

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Summary and Implications

Irradiation increased the redness of vacuum-packaged pork loins regardless of meat type. Irradiation and storage time had no effect on the 2-thiobarbituric acid reactive substances (TBARS) values of normal, PSE and DFD pork. Irradiation increased the production of sulfur (S)-containing volatile compounds and total volatiles in all three pork types. Normal pork had more values of total and S-containing volatile compounds on irradiation than the PSE and DFD pork. The volatiles produced by irradiation remained in the packaging bag during storage. The odor acceptance of the three meat types was not different, but panelists could distinguish irradiated meat from the nonirradiated.

Irradiation and storage of meat in vacuum packaging may be desirable for long-term storage, but may reduce the acceptance of irradiated meat. Double packaging - individual packaging of meat with oxygen permeable film and repackaging multiple individual packages in large vacuum-packaging bags for irradiation and storage – and opening the outside vacuum packaging bag 1-2 days before sale, is recommended to reduce irradiation odor.

Introduction

The objective of this study was to determine and compare the effects of irradiation on lipid oxidation, off-flavor, color, and sensory characteristics of vacuum-packaged normal, PSE, and DFD pork. The results of this study could provide information on irradiation effects related to the pH of the meat, and could be useful to treat efficiently each different grade of pork for irradiation.

Materials and Methods

Sample Preparation: Twenty-four pork loin (*Longissimus dorsi*) muscles, which consisted of each of eight normal (pH 5.7-5.8), PSE (pH 5.4 or less), and DFD (pH 6.2-6.8) meat, were purchased from a local packing plant. The pork loins were trimmed off all surface fat, and the lean muscle was sliced into 3-cm-thick steaks and vacuum-packaged in nylon/polyethylene bags. After packaging, they were stored overnight at 4°C and then were irradiated at 0, 2.5, or 4.5 kGy using a Linear Accelerator.

Color and lipid oxidation in vacuum-packaged irradiated pork loins was determined at 0, 5, and 10 days, volatile production at 0 and 10 days, and sensory characteristics at 7 days of storage. Color measurements were conducted on the packaged surface of samples with a Labscan spectrophotometer that had been calibrated against white and black reference tiles packaged in the same bags as those used for meat packaging. Hunter L- (lightness), a- (redness), and b- (yellowness) values were obtained.

TBARS Analysis : The fluorometric TBARS method was used to determine lipid oxidation in raw meat.

Volatile Compound Analysis: A purge-and-trap apparatus connected to gas chromatograph/mass spectrometer was used to analyze the volatiles responsible for the off-odor in samples. Identification of volatiles was achieved by comparing mass spectral data of samples with those of the Wiley library and standards when available. The peaks produced by mass spectral data were grouped into five major volatile classes – alcohols, ketones, aldehydes, sulfur (S)-containing compounds and hydrocarbons - and reported.

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 10 days of storage. Odor intensity and acceptance by pork meat types within the same irradiation dose were also compared. Data were analyzed using SAS software by generalized linear model procedure, and the Student-Newman-Keuls multiple range test was used to compare differences among means. Mean values and standard errors of the means (SEM) were reported. Significance was defined at $P < 0.05$.

Results and Discussion

pH and Color: The pH values of nonirradiated and irradiated normal, PSE, and DFD pork (Table 1) showed that irradiation had no effect on the pH of all three pork types. The original ultimate pH of normal, PSE, and DFD meat was maintained during the 10-day storage period. Irradiated, vacuum-packaged pork loins had greater a-values than the nonirradiated, and the increase of a-values in pork loins was irradiation dose dependent in all three pork types. The a-value in PSE and DFD pork with vacuum packaging decreased after 5 days of storage, but increased after 10 days of storage (Table 2). The exact reason for this phenomenon is not known, but the residual oxygen in the vacuum packaging bag could have oxidized myoglobin at the early part of the storage time. Meat type and irradiation did not affect b-values. Irradiated DFD samples at 4.5 kGy showed an increasing trend in b-values during storage, but yellowness has little effect on the overall color of meat.

The overall TBARS values of vacuum-packaged pork loins were very low regardless of meat type, irradiation, and storage time (Table 3). At day 0 and Day 10, DFD pork had lower TBARS values than the normal or PSE pork. DFD pork was stable and resistant to both irradiation- and storage-dependent quality changes. Although DFD meat is more susceptible to bacterial spoilage than the other pork types, irradiation with vacuum packaging can extend shelf life and increase the use of DFD pork. Normal and PSE pork became susceptible to lipid oxidation when irradiated and stored. Low pH values in meat play an important role in lipid oxidation by denaturing antioxidant proteins, disrupting cell structure, and exposing membrane lipids to free radicals. The distribution of water and its location, which is where hydroxyl radicals are formed by irradiation and storage, could be critical for the irradiation-dependent reaction. Therefore, it was expected that the denatured membrane structure of PSE pork would make it more susceptible to lipid oxidation than normal and DFD pork. However, irradiation and subsequent storage did not increase lipid oxidation in three types of pork with vacuum packaging because no oxygen was available for hydroperoxide formation. The difference in TBARS among the three types was caused only by the pH of the pork.

Volatiles: At day 0, nonirradiated PSE pork loins produced the highest amount of alcohols, but produced the lowest amounts of ketones and aldehydes among the three pork types (Table 4). The amounts of ketones in PSE and aldehydes in normal pork decreased, but that of sulfur compounds in all three meat types increased with irradiation. The amount of S-containing volatiles in irradiated normal pork at 2.5 kGy was higher than that of the PSE and DFD pork, and that in normal and PSE pork was higher than the PSE pork after 4.5 kGy irradiation. The increase of irradiation dose from 2.5 to 4.5 kGy had minimal impact on the production of any of the major volatile groups in all three pork types except for ketones, and sulfur compounds in DFD pork. The major ketones identified were 2-propanone and 2-butanone, and the major aldehydes were acetaldehyde, 3-methyl butanal, pentanal, and hexanal. Sulfur-containing volatile compounds were mercaptomethane, dimethyl sulfide, carbon disulfide, methyl thioacetate, and dimethyl disulfide, and they increased greatly after irradiation regardless of meat types. After 10 days of storage, the amounts of alcohols in nonirradiated normal pork and ketones in nonirradiated PSE pork were the highest of all as in day 0 (Table 4). The amount of sulfur compounds in irradiated pork were higher than the day 0 values, and showed similar differences in the production of S-compounds among three irradiated pork types. Irradiated pork produced more hydrocarbons than nonirradiated after 10 days of storage. The amounts of total volatiles in both irradiated and nonirradiated normal pork were higher than those of PSE and DFD pork, and PSE pork produced the least amount of sulfur compounds after irradiation. Unlike in aerobically packaged meat, the general composition and the amount of volatiles did not show any dramatic changes during the 10-day storage periods.

Sensory characteristics: Meat type and irradiation dose influenced the intensity of irradiation odor and the acceptance of the meat odor (Table 5). Before irradiation, the off-odor intensity of normal and PSE pork was higher than the DFD pork. Irradiation increased the intensity of irradiation odor in all three pork types, but normal pork had higher irradiation odor than the PSE and DFD pork. This result agrees with the result of total volatile production, but does not agree with that of S-containing volatiles in pork (Table 4). Because S-containing volatiles are the major volatile group that influences irradiation odor, PSE pork was expected to have the lowest irradiation odor of all three pork types. However, DFD pork had the lowest irradiation odor. This suggests that the presence and amounts of other volatiles such as aldehydes, ketones, and alcohols are also important for the manifestation of irradiation odor in meat.

The acceptance of the meat odor was consistent with the irradiation odor intensity. As the irradiation odor intensity increased, the preference of meat odor decreased. Most trained panelists rated irradiation odor as an off-odor. No difference in odor preference among meat types was found when irradiated at 0 or 4.5 kGy. At 2.5 kGy irradiation, however, the odor preference of DFD pork was higher than that of the normal and PSE pork. Panelists could easily distinguish between odors of irradiated and nonirradiated meat, but not between the three meat types.

Conclusion

Irradiation increased redness, off-odor intensity, and S-containing volatiles regardless of the pH of pork loins in vacuum packaging. Irradiating meat with vacuum packaging improved color intensity and color stability even in PSE pork. With vacuum packaging, irradiated PSE and DFD pork were not different from the normal pork in lipid oxidation, volatile production, and sensory preference. Among three meat types, therefore, DFD pork could benefit the most from irradiation because the shelf life of DFD meat, the most limiting factor for the use of DFD meat, can be extended significantly.

Table 1. The pH of vacuum-packaged normal, PSE, and DFD pork *L. dorsi* muscle affected by irradiation dose and storage time at 4°C.

	0 kGy			2.5 kGy			4.5 kGy			
Storage time	Norm	PSE	DFD	Norm	PSE	DFD	Norm	PSE	DFD	SEM[1]
Day 0	5.76[b]	5.42[c]	6.36[a]	5.66[bc]	5.43[c]	6.35[a]	5.66[bc]	5.47[c]	6.43[a]	0.06
Day 5	5.62[bc]	5.47[bc]	6.36[a]	5.61[bc]	5.42[c]	6.47[a]	5.63[b]	5.49[bc]	6.38[a]	0.05
Day 10	5.62[b]	5.37[c]	6.36[a]	5.58[b]	5.33[c]	6.40[a]	5.58[b]	5.33[c]	6.40[a]	0.05
SEM[2]	0.08	0.02	0.07	0.04	0.03	0.06	0.04	0.03	0.07	

PSE, pale-soft-exudative; DFD, dark-firm-dry.
[a-c]Means with different letters within a row are different ($P < 0.05$).
[1]SEM: standard error of the means among meats within a storage time.
[2]SEM: standard error of the means within a meat type.

Table 2. Color L-, a-, and b-values of vacuum-packaged normal, PSE, and DFD pork *L. 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	SEM[1]
L-value										
Day 0	50.5[b]	59.6[ax]	43.4[d]	52.0[bx]	60.6[ax]	47.2[cx]	52.4[b]	57.2[a]	43.0[dxy]	1.1
Day 5	49.9[bc]	52.3[abz]	43.1[d]	48.8[cy]	54.7[ay]	42.8[dy]	48.4[c]	54.6[a]	40.9[dy]	0.9
Day 10	54.2[abc]	55.8[aby]	47.2[de]	52.4[bcx]	56.9[aby]	49.5[cdx]	56.6[ab]	59.5[a]	46.0[ex]	1.6
SEM[2]	1.3	1.1	1.6	1.0	0.9	1.5	1.3	1.4	1.1	
a-value										
Day 0	5.8[cx]	3.7[dy]	6.8[cx]	9.8[bx]	9.7[bx]	10.4[bx]	12.9[ax]	12.4[ax]	11.9[ax]	0.5
Day 5	2.6[dz]	2.9[dy]	3.6[dy]	7.1[by]	7.3[bz]	6.0[cy]	10.0[ay]	9.7[ay]	9.4[ay]	0.4
Day 10	4.4[cy]	5.2[cx]	6.2[cx]	8.6[bxy]	8.7[by]	10.3[abx]	11.3[axy]	11.4[ax]	11.0[abx]	0.7
SEM[2]	0.4	0.5	0.6	0.6	0.3	0.6	0.6	0.6	0.4	
b-value										
Day 0	11.2[y]	12.5[x]	9.5	11.1	12.2	10.1[xy]	11.0	11.7[y]	9.5[y]	0.3
Day 5	9.8[bcy]	10.7[aby]	9.1[cd]	10.0[ab]	11.0[a]	8.7[dy]	10.1[ab]	10.8[aby]	8.7[dy]	0.3
Day 10	11.7[x]	11.7[xy]	9.4	11.1	12.6	11.6[x]	9.6	12.1[x]	10.7[x]	0.8
SEM[2]	0.3	0.4	0.8	0.4	0.2	0.6	0.6	0.8	0.3	

PSE, pale-soft-exudative; DFD, dark-firm-dry.
[a-e]Means with different letters within a row are significantly different ($P < 0.05$).
[x-z]Means with different letters within a column are significantly different ($P < 0.05$).
[1]SEM: standard error of the means among meats within a storage time.
[2]SEM: standard error of the means within a meat type.

Table 3. TBARS values of vacuum-packaged normal, PSE, and DFD pork *L. 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	SEM[1]
	TBARS (mg MDA/kg meat)									
Day 0	0.09^{abx}	0.11^{ab}	0.07^{b}	0.11^{abx}	0.15^{ax}	0.09^{ab}	0.12^{ab}	0.10^{ab}	0.10^{ab}	0.01
Day 5	0.07^{y}	0.08	0.06	0.08^{xy}	0.09^{y}	0.08	0.10	0.10	0.10	0.04
Day 10	0.10^{abx}	0.09^{bc}	0.07^{d}	0.10^{abxy}	0.11^{aby}	0.07^{d}	0.14^{a}	0.11^{ab}	0.08^{d}	0.09
SEM[2]	0.04	0.03	0.01	0.06	0.10	0.01	0.07	0.07	0.01	

PSE, pale-soft-exudative; DFD, dark-firm-dry.
$^{a-d}$Means with different letters within a row are significantly different (P<0.05).
$^{x-y}$Means with different letters within a column are significantly different (P<0.05).
[1]SEM: standard error of the means among meats within a storage time.
[2]SEM: standard error of the means within a meat type.

Table 4. Relative production of volatiles in vacuum-packaged normal, PSE, and DFD pork *L. dorsi* muscle affected by irradiation dose at storage time at 4°C.

Storage	0 kGy			2.5 kGy			4.5 kGy			
time	Norm	PSE	DFD	Norm	PSE	DFD	Norm	PSE	DFD	SEM
	Peak area (pA*sec)/10^4									
Day 0										
Alcohols	2770^b	17543^a	2959^b	1121^b	553^b	0^b	206^b	458^b	0^b	724
Ketones	11501^a	286^c	1838^c	6742^b	356^c	97^c	1139^c	489^c	614^c	1415
Aldehydes	1309^{ab}	945^{bc}	1691^a	539^c	565^c	367^c	390^c	771^c	508^c	138
S-compounds	134^c	1155^b	55^c	3111^a	895^b	1009^b	3361^a	1128^b	2814^a	191
Hydrocarbons	1511	1720	1130	2229	1621	1584	2611	3363	1542	245
Total volatiles	17613^b	22571^a	8047^c	14539^b	7314^c	3274^c	8526^c	6793^c	5923^c	1868
Day 10										
Alcohols	1957^b	15748^a	82^d	197^d	1490^b	135^d	633^c	1278^b	154^d	286
Ketones	27948^a	432^c	275^c	2703^c	1670^c	670^c	17312^b	1808^c	650^c	1735
Aldehydes	328^{bc}	227^{bc}	149^c	265^{bc}	301^{bc}	184^c	533^a	417^{ab}	152^c	49
S-compounds	211^d	903^d	77^d	6683^a	1364^c	4461^b	7631^a	2411^b	6298^a	459
Hydrocarbons	1302^{cd}	1207^{de}	914^e	3542^a	1978^c	1390^{cd}	3161^a	2822^b	1766^{cd}	177
Total volatiles	32654^a	19167^{bc}	1590^d	14247^{bc}	7479^{cd}	7530^{cd}	31178^a	9684^c	9797^c	1824

PSE, pale-soft-exudative; DFD, dark-firm-dry.
[a-f] Means with different letters within a row are significantly different ($P < 0.05$).
SEM: standard error of the means among meats within a storage time.

Table 5. Sensory characteristics of vacuum-packaged irradiated normal, PSE, and DFD pork *L. dorsi* muscle refrigerated for 7days.

Irradiation	Norm	PSE	DFD	SEM[1]
Irradiation odor intensity[2]				
0 kGy	4.37^{ay}	3.95^{aby}	3.14^{bz}	0.34
2.5 kGy	9.56^{ax}	8.31^{bx}	6.83^{cy}	0.32
4.5 kGy	10.14^{ax}	8.32^{bx}	8.58^{bx}	0.33
SEM[4]	0.30	0.36	0.33	
Acceptance of meat odor[3]				
0 kGy	8.51^{x}	8.75^{x}	9.58^{x}	0.35
2.5 kGy	5.72^{by}	6.01^{by}	7.23^{ay}	0.32
4.5 kGy	5.26^{y}	5.89^{y}	6.34^{y}	0.35
SEM[4]	0.38	0.35	0.34	

PSE, pale-soft-exudative; DFD, dark-firm-dry.
[a-c]Means with different letters within a row are significantly different ($P < 0.05$), N = 76.
[x,y]Means with different letters within a column are significantly different ($P < 0.05$).
[1]SEM: standard error of the means among meats within a storage time.
[2]Irradiation odor intensity: 0, no irradiation odor; 15, very strong irradiation odor.
[3]Acceptance of meat odor: 0, not preferable; 15, highly preferable.
[4]SEM: standard error of the means within a meat type.