Prevention of Pinking, Off-Odor, and Lipid Oxidation in Irradiated Pork Loin Using Double-Packaging

A.S. Leaflet R1983

K. C. Nam, postdoctoral research associate
B. R. Min, graduate assistant,
S. C. Lee, Professor of KyungNam University, Korea
J. Cordray, Professor of Animal Science Department
D. U. Ahn, Professor of Animal Science Department

Summary and Implications

Lipid oxidation, color, volatiles, and sensory evaluation of double-packaged pork loin were determined to establish a modified packaging method that can improve the quality of irradiated pork loins. Vacuum-packaged irradiated samples produced dimethyl sulfide and dimethyl disulfide responsible for irradiation off-odor, whereas lipid oxidation was promoted under aerobic conditions. Exposing double-packaged irradiated pork to aerobic conditions for 1 to 3 d was effective in controlling both lipid oxidation and irradiation off-odor, regardless of packaging sequence. Sensory panels could distinguish the decrease in irradiation off-odor intensities by modifying packaging method. However, carbon monoxide-heme pigments, responsible for the increased redness by irradiation, were not effectively controlled by double packaging alone.

Introduction

The quality change in meat by irradiation is a concern to the meat industry and to consumers. Pink color and off-odor in poultry meat produced by irradiation persists throughout the storage period under vacuum conditions. Thus, prevention of pink color defects and off-odor in poultry and pork is critical for the use of irradiation in those meats because consumers associate the presence of a pink color with undercooked or contaminated meat, and off-odor with the formation of undesirable chemical compounds by irradiation. An appropriate use of aerobic and vacuum-packaging conditions (so-called double-packaging) can be effective in minimizing lipid oxidation and off-odor volatiles in irradiated pork loin during storage, which also may affect pink color in irradiated pork.

The objective of this study was to determine the effect of double-packaging conditions on lipid oxidation, volatiles, and color of irradiated pork loins during refrigerated storage.

Materials and Methods

Pork loin (*longissimus dorsi*) muscles were purchased from a local packing plant. The lean muscles were sliced into 2-cm-thick steaks and packaged as follows: 1) oxygen-permeable bags; 2) oxygen-impermeable vacuum bags; 3) doubly packaged: pork loins were individually packaged in oxygen-permeable bags first and then a number of aerobically packaged loins were vacuum-packaged in a larger oxygen-impermeable bag. The packaged meat samples were irradiated at 2.5 kGy using a Linear Accelerator.

For double-packaging model #1, the outer vacuum bags were removed after 3 d (V3/A7), 5 d (V5/A5), 7 d (V7/A3), or 9 d (V9/A1) of storage, respectively, during the 10 d of storage at 4 °C. For double-packaging model #2, aerobically packaged and irradiated loins were stored at 4 °C for 1 d, 3 d, 5 d, or 7 d, and then vacuum-packaged (A1/V9, A3/V7, A5/V5, or A7/V3, respectively). Nonirradiated vacuum-packaged, irradiated under aerobic, and irradiated under vacuum conditions were also prepared as controls. Lipid oxidation, color, gas, oxidation-reduction potential, and volatiles of the samples were determined after 0 d and 10 d of storage. Sensory evaluation was conducted at 10 d.

Results and Discussion

Irradiation increased TBARS, but vacuum conditions prevented lipid oxidation of pork loin (Table 1). The TBARS values of aerobically packaged pork loin were much higher than those of the vacuum-packaged meat after 10 d of storage. The TBARS values of double-packaged meats ranked between the aerobically and the vacuum-packaged ones. Double-packaged loins with model #2 (aerobically then vacuum-packaged) had lower TBARS values than those with model #1 (vacuum- then aerobically packaged), showing that lipid oxidation was accelerated as storage time increased. During the refrigerated storage, exposed time to aerobic conditions was the most critical factor determining the degree of lipid oxidation, and the TBARS values of pork loins at Day 10 were proportional to the days under aerobic conditions. Thus, lipid oxidation can be a concern in irradiated meat when it is only aerobically packaged.

Irradiation changed the color of raw pork loin reddish pink, as indicated by the colorimeter values (Table 1). The increase in redness (a*-values) by irradiation was more distinctive in vacuum-packaged pork loins than in aerobically packaged ones. Therefore, packaging conditions were important in determining color changes in pork loin during the irradiation process. The redness of irradiated pork loin was very stable during the 10-d refrigerated storage irrespective of packaging method. At Day 10, the a*-values of irradiated pork loins were significantly higher than those of nonirradiated pork. A few double-packaged pork loins (A3/V7, A5/V5) had significantly lower a*-values than irradiated vacuum-packaged ones during storage, but the values were still higher than those of nonirradiated vacuum-packaged control. Therefore, the double-packaging method alone was not enough to control redness in pork loin induced by irradiation. L*-values in pork loins were little influenced by irradiation.

Irradiation decreased the oxidation-reduction potential (ORP) of pork loin under vacuum-packaged conditions (Table 1). Hydrated electrons, radiolytic free radicals, could be produced by irradiation and act as a very powerful reducing agent. However, the ORP values of irradiated pork loins increased after 10 d in contrast to the decrease in nonirradiated meat, showing that stronger oxidizing conditions were generated in irradiated meat by oxidizing free radicals such as superoxide and hydroperoxyl radical during storage.

Irradiation produced a few gas compounds (Table 1), one of which was carbon monoxide that could be a ligand of heme pigments in irradiated pork loin and thus increase redness. The production of carbon monoxide was little influenced by packaging conditions regardless of storage, indicating that most of the carbon monoxide produced was bound to heme pigments in meat throughout storage.

Many new volatile compounds were generated and a few volatiles already present in nonirradiated pork loins increased by irradiation (Table 2). The amount of total volatiles produced in irradiated pork loin was 3 times higher than that of the nonirradiated control. At 0 d, sulfur (S)-containing volatiles, 2-propanone, and ethanol were the most predominant volatiles in irradiated pork loin. Among the detected S-volatiles, methanethiol, dimethyl sulfide, methylthio ethane, and dimethyl disulfide could be responsible for the characteristic irradiation off-odor.

The amounts of S-volatiles in irradiated pork loin were highly dependent upon packaging conditions. Higher amounts of S-volatiles were found in vacuum- or double-packaged pork loin than in aerobically packaged ones, indicating that considerable amounts of S-compounds were evaporated under aerobic conditions during the process of irradiation and post-irradiation handling. For the meat that will be consumed fresh, therefore, aerobic packaging is more beneficial than vacuum-packaging in terms of reducing irradiation off-odor. The amounts of dimethyl sulfide and dimethyl disulfide in aerobically packaged pork loin were only 26% and 29% of the vacuum-packaged one, respectively. Lipid oxidation products in irradiated pork loin at 0 d were minimal and only aerobically packaged pork loin had a trivial amount of hexanal.

After 10 d of refrigerated storage, the volatiles profile of irradiated pork loin was highly dependent upon packaging conditions (Table 3). The greatest amounts of total volatiles were detected in vacuum-packaged pork loin because large amounts of S-volatiles still remained under vacuum conditions. Dimethyl disulfide was the most predominant volatile compound in vacuum-packaged pork loins. No S-volatiles were detected in most double-packaged pork loins. S-volatiles such as dimethyl disulfide, dimethyl trisulfide, and S-methyl ethanethioate were found in the V9/A1 double-packaging mod #1 as well as vacuum-packaged samples. On the other hand, those S-volatiles were not detected in the A1/V9 double-packaging model #2. It seems that double-packaging model #2 is better than model #1 in removing S-volatiles because the production of S-volatiles is critical in the middle of irradiation process rather than storage. However, exposing double-packaged irradiated pork to aerobic conditions for 3 d was enough to eliminate the sulfur compounds responsible for irradiation off-odor, regardless of packaging sequences.

Aerobic packaging was effective in eliminating S-volatiles but increased lipid oxidation in pork loins (Table 1). Therefore, double-packaging treatments such as exposing the irradiated meat to aerobic conditions for 1 to 3 d and then keep them in vacuum conditions for the remaining period should be used to control both irradiation off-odor and lipid oxidation in irradiated pork loins.

Pork loins from double-packaging model #1 (V7/A3) and #2 (A3/V7) were selected and the sensory characteristics were compared with those from aerobic and vacuum packaged ones (Table 4). Most panelists easily distinguished the characteristic irradiation odor. The intensity of irradiation odor in irradiated vacuum-packaged pork was ranked the highest, double-packaged loins in the middle, and aerobically packaged the lowest. The result of the irradiation odor intensity was very consistent with the amount of S-volatiles detected in the pork at 10 d (Table 3), showing that S-volatiles are representative compounds responsible for the irradiation odor. On the other hand, panelists could not recognize rancid odor because the degree of lipid oxidation of irradiated raw pork was not high enough to produce detectable rancid odor and was masked by the strong irradiation odor.

Conclusions

Double-packaging methods, exposing the irradiated pork to aerobic conditions for a few days and then keep in vacuum conditions for the remaining storage, were better than vacuum or aerobic packaging in controlling lipid oxidation and irradiation off-odor in pork loin. Although double-packaging model #2 (irradiating meat under aerobic packaging conditions and then storing them under vacuum-packaging conditions a few days later) was better than double-packaging model #1 (irradiating meat under vacuum packaging conditions and then removing the outer vacuum bags a few days before use) in reducing off-odor volatiles, their differences were relatively small.

Table 1. **TBARS, color a*-value, ORP, and O production of irradiated raw pork loin with different packaging conditions during refrigerated storage**

	Nonirr	Irradiated						
Storage	Vacuum	Aerobic	V3/A7[1]	V5/A5[1]	V7/A3[1]	V9/A1[1]	Vacuum	SEM
TBARS	(mg MDA/kg meat)							
0 day	0.12^{cy}	0.23^{ay}	0.21^{ay}	0.21^{az}	0.21^{ay}	0.21^{ay}	0.16^{b}	0.01
10 day[2]	0.15^{ex}	0.44^{ax}	0.33^{cx}	0.37^{bx}	0.31^{cdx}	0.28^{dx}	0.17^{e}	0.01
10 day[3]	0.15^{ex}	0.46^{ax}	0.38^{bx}	0.29^{cy}	0.22^{dy}	0.24^{dy}	0.17^{e}	0.01
SEM	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
A*-value								
0 day	6.6^{c}	8.2^{b}	11.1^{ax}	11.2^{ax}	10.7^{a}	10.5^{ax}	10.6^{a}	0.4
10 day[2]	7.0^{c}	8.9^{b}	9.0^{by}	10.9^{ax}	10.8^{a}	10.1^{abx}	10.0^{ab}	0.4
10 day[3]	6.1^{c}	8.7^{b}	8.4^{by}	8.1^{by}	9.2^{ab}	8.5^{by}	10.1^{a}	0.4
SEM	0.5	0.4	0.5	0.5	0.5	0.5	0.4	
ORP	(mV)							
0 day	-43^{a}	0^{a}	-202^{by}	-202^{by}	-202^{by}	-202^{by}	-225^{by}	21
10 day[2]	-80^{c}	21^{a}	-8^{abx}	-17^{abx}	-26^{abcx}	-61^{bcx}	-67^{bcx}	14
10 day[3]	-55^{b}	9^{a}	4^{ax}	-40^{bx}	-43^{bx}	-41b^{x}	-69^{bx}	10
SEM	11	10	23	21	18	16	7	
Carbon monoxide	(ppm)							
0 day	0^{b}	121^{ax}	123^{ax}	123^{ax}	123^{ax}	123^{a}	121^{ax}	8
10 day[2]	0c	84^{aby}	66^{by}	86^{aby}	108^{abx}	114^{a}	107^{abxy}	11
10 day[3]	0c	50^{by}	56^{by}	80^{aby}	65^{by}	117^{a}	95^{aby}	11
SEM	0	13	6	6	8	13	9	

[a-c] Means with different letters within a row are significantly different ($P < 0.05$), $n = 4$.
[x, y] Means with different letters within a column are significantly different ($P < 0.05$).
[1] Vm/An: Stored under vacuum and aerobic conditions for m d and n d, respectively.
[2] Double-packaging model #1: vacuum-packaged for m d and then aerobically packaged for n d.
[3] Double-packaging model #2: aerobically packaged for m d and then vacuum-packaged for n d.
Nonirr: nonirradiated

Table 2. **Volatile compounds of irradiated raw pork loin with different packaging conditions at Day 0**

	Nonirr	Irradiated			
Compound	Vacuum	Aerobic	Double	Vacuum	SEM
	(Total ion counts $\times 10^4$)				
Acetaldehyde	324	496	648	755	179
Methanethiol	0^c	887^c	3886^a	2238^b	342
Pentane	0^c	526^a	349^b	349^b	27
Dimethyl sulfide	0^b	610^b	2771^a	2345^a	382
2-Propanone	1169	6344	3155	3473	2435
Hexane	0^b	723^a	232^b	217^b	132
Ethanol	3317	2184	1056	1457	934
Methylthio ethane	0	0	85	406	182
2-Propanol	229	777	147	340	360
2-Butanone	74^c	930^a	350^b	417^b	97
Benzene	0	41	83	16	33
1-Heptene	0	111	51	53	40
Heptane	0	373	63	82	190
2-Pentanone	36	0	121	0	41
Dimethyl disulfide	37^c	773^c	1761^b	2678^a	290
Toluene	0	185	0	0	70
Octane	30	582	125	201	187
Hexanal	0	65	0	0	32
Total	4894^b	15207^a	14241^a	14274^a	1457

[a-c] Means with different letters within a row are significantly different ($P < 0.05$), $n = 4$.
Nonirr: nonirradiated

Table 4. **Sensory characteristics of irradiated raw pork loin with different packaging conditions (double-packaging model #1) at Day 10**

	Nonirr	Irradiated			
Off-odor[1]	Vacuum	Aerobic	V7/A3[2]	Vacuum	SEM
Double packaging #1					
Irradiation odor	1.0^d	3.8^c	9.5^b	11.3^a	0.6
Rancid odor	1.4	4.8	3.9	3.6	1.4
Double Packaging #2					
Irradiation odor	1.3^c	4.4^b	5.6^b	12.4^a	1.0
Rancid odor	3.6	5.5	2.7	2.8	1.2

[a-c] Means with different letters within a row are significantly different ($P < 0.05$), $n = 12$.
[1] 0.0: not detectable, 15.0: highly intense.
[2] Aerobically packaged for 3 d then vacuum-packaged for 7 d.
Nonirr: nonirradiated

Table 3. Volatile compounds of irradiated raw pork loin with double-packaging model #1 & #2 at Day 10

	Nonirr	Irradiated						
Compound	Vacuum	Aerobic	V3/A7[1]	V5/A5[2]	V7/A3[3]	V9/A1[4]	Vacuum	SEM
Model #1	---------------------------- (Total ion counts ×10^{4}) ----------------------							
Pentane	38^{b}	997^{a}	597^{ab}	564^{ab}	613^{ab}	450^{ab}	367^{ab}	141
2-Propanone	1388	1790	1673	1617	1713	1548	1958	189
Carbon disulfide	300^{a}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	18
Hexane	412^{b}	3012^{a}	2784^{a}	743^{b}	560^{b}	317^{b}	220^{b}	357
Dimethyl sulfide	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	37^{b}	133^{a}	24
2-Propanol	197	221	245	234	285	275	274	20
2-Butanone	0^{c}	390^{a}	203^{b}	204^{b}	296^{b}	254^{b}	221^{b}	24
1-Heptene	0	127	52	60	91	41	33	35
Heptane	0	90	52	30	31	28	0	22
2-Pentanone	0	65	63	41	57	29	47	16
S-methyl ethanethioate	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	62^{b}	268^{a}	28
Dimethyl disulfide	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	387^{b}	1108^{a}	154
Toluene	49	45	45	45	91	164	155	47
1-Octene	0^{b}	120^{a}	103^{a}	56^{ab}	87^{a}	0^{b}	0^{b}	18
Octane	237	603	653	573	551	337	349	97
2-Octene	0	45	35	45	102	0	0	28
Hexanal	0c	169^{a}	122^{ab}	31^{b}c	57^{b}c	63^{b}c	0c	21
Dimethyl trisulfide	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	54^{b}	246^{a}	33
Total	2621c	7674^{a}	6627^{a}	4243^{b}	4534^{b}	4046^{b}	5379^{ab}	729
Model #2								
Pentane	58^{b}	645^{a}	601^{a}	566^{a}	524^{a}	527^{a}	345^{a}	69
2-Propanone	1388	1790	1650	1562	1610	1810	1958	189
Carbon disulfide	45^{a}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	4
Hexane	412^{b}	3012^{a}	612^{b}	308^{bc}	313^{bc}	367^{bc}	269^{bc}	111
Dimethyl sulfide	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	133^{a}	24
2-Propanol	197^{b}	221^{ab}	248^{ab}	304^{a}	249^{ab}	307^{a}	274^{ab}	20
2-Butanone	0c	34	115	39	42	107	40	41
1-Heptene	0	0	35	0	0	21	0	15
Heptane	0	90	33	33	28	62	28	22
2-Pentanone	0^{b}	65^{ab}	102^{a}	72^{ab}	70^{ab}	53^{ab}	47^{ab}	16
S-methyl ethanethioate	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	268^{a}	28
Dimethyl disulfide	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	1108^{a}	154
Toluene	49	45	188	72	64	192	155	47
1-Octene	0	19	35	23	0	30	28	23
Octane	616	835	1163	1053	831	1086	820	275
2-Octene	219^{a}	0^{b}	0^{b}	34^{b}	18^{b}	31^{b}	297^{a}	33
Hexanal	0^{b}	130^{a}	110^{a}	102^{a}	102^{a}	53^{ab}	0^{b}	24
Dimethyl trisulfide	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	246^{a}	33
Total	2986^{c}	6886^{a}	4892^{b}	4168^{b}	3851^{b}	4646^{ab}	5883^{a}	823

[a-c] Means with different letters within a row are significantly different ($P < 0.05$), $n = 4$.
[1] Aerobically packaged for 7 d then vacuum-packaged for 3 d.
[2] Aerobically packaged for 5 d then vacuum-packaged for 5 d.
[3] Aerobically packaged for 3 d then vacuum-packaged for 7 d.
[4] Aerobically packaged for 1 d then vacuum-packaged for 9 d.
Nonirr: nonirradiated