Effect of Electron Beam Irradiation and Storage on the Quality Attributes of Sausages with Different Fat Contents

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Summary and Implications

The 2-thiobarbituric acid reactive substances (TBARS) value of sausages was not affected by fat content, but increased after irradiation (5 kGy). Storage for 60 days increased the TBARS of nonirradiated sausages ($P < 0.05$), but had no effect on irradiated ones. The numbers of volatile compounds and the amounts of total volatiles increased by irradiation in both high-fat (29% fat) and low-fat (16% fat) sausages. Dimethyl sulfide was detected only in irradiated sausages regardless of fat content ($P < 0.05$), but disappeared after 60 days of storage. Pentane and 1-heptene were detected only in irradiated samples after 60 days of storage. Low-fat sausages had higher L*-value, but had lower a*- and b*-values than high fat sausages. Irradiation and storage had little effects on both the exterior and interior color (L*-, a*-, and b*-values) of sausages. Fat content had no effect on the sensory parameters of sausages regardless irradiation and storage. However, irradiated sausages had significantly stronger off-odor and off-taste than non-irradiated ones regardless of fat contents ($P < 0.05$). This indicated that fat content in sausages had minimal effects on the quality of irradiated sausages during storage.

Introduction

The primary purposes of treating foods by irradiation are to control pathogens, spoilage microorganisms, and pests without compromising the nutritional and sensory properties of foods. Processed meat products are the popular in the U.S., but are frequently contaminated with pathogens such as *Listeria monocytogenes* due to post-processing contamination. Due to its ability to grow at refrigerated temperature and its resistance to salt and nitrite, any contaminated *L. monocytogenes* in cured meat products (e.g., sausages), which usually have long shelf-life could proliferate to a threatening level during refrigerated storage. Irradiation is an effective way of destroying vegetative foodborne pathogens, including *L. monocytogenes*. However, quality changes such as development of lipid oxidation and off-odor production after irradiating sausages are important concerns because irradiation is known to accelerate lipid oxidation in meat products. The breakdown products of lipid oxidation such as aldehydes, ketones, alcohols, hydrocarbons, and furans can contribute to flavor deterioration of muscle foods. Fat is one of the most important constituents for quality changes in meat and meat products, but the effect of fat content on the development of lipid oxidation, volatile production, sensory properties, and color changes in irradiated sausages is hardly investigated. The objective of this work was to determine the effect of electron beam irradiation and subsequent storage on lipid oxidation, volatile production, color, and sensory properties of commercial sausages with different fat contents.

Materials and Methods

Sample preparation Frankfurter-type (cured) sausages with two different fat contents (16% and 29%, made with turkey and pork) were vacuum-packaged in oxygen-impermeable nylon/polyethylene bags (9.3 ml $O_2/m^2/24$ h at 0 °C), and stored overnight at 4 °C to minimize changes before irradiation. The samples were irradiated at 0 or 5 kGy using a linear accelerator.

Lipid oxidation measurement 2-Thiobarbituric acid reactive substances (TBARS) value was used to determine lipid oxidation in meat.

Volatile compounds analysis A vial autosampler (Solatek 72 Multimatrix, Tekmar-Dohrmann, Cincinnati, OH) and a Purge-and-Trap concentrator (3100, Tekmar-Dohrmann) were used to purge and trap volatile compounds.

Color measurement The exterior and interior color of sausages was measured using a Hunter LabScan Colorimeter.

Sensory evaluation Eight-trained sensory panelists evaluated overall color, texture (hardness), off-odor and off-taste of the samples stored for 0 and 60 days at 4 °C.

Results and Discussion

The TBARS values were higher in high-fat sausages (29% fat) than those of low-fat ones (16% fat), and significantly increased by irradiation at 5 kGy and the subsequent storage at 4 °C. The difference in TBARS values between the non-irradiated and irradiated samples, however, was not significant after 60 d storage at 4 °C ($P < 0.05$) (Table 1).

The changes in volatiles of irradiated commercial sausages with different fat contents (16%, 29%) were analyzed after 60 d of storage at 4 °C. Electron-beam irradiation newly produced dimethyl sulfide, but the sulfur compound was not detected after 60 d of storage (Tables 2 and 3). After 60 d of storage, alpha-terpinolene was detected in both non-irradiated and irradiated sausages, while pentane and 1-heptene were detected only in irradiated samples. Higher amounts of pentane, 1-heptene and 1-

nonene were detected in irradiated high-fat than irradiated lower-fat sausages. There were no other specific volatiles increased by irradiation and subsequent storage in both samples with different fat contents. Although propanal, a major lipid oxidation product, was not found in sausages irradiated at 5 kGy, 2-propanol and pentanal in low-fat samples showed the same trend as TBARS values, which increased by irradiation and storage.

Irradiation at 5 kGy did not cause significant changes in exterior color L*- and b*-values of the sausages regardless of fat content. However, high-fat sausages (29%) had higher (P < 0.05) exterior L*-value and lower a*- and b*-values than low-fat sausages (16%) (Table 4). Irradiation and increase in fat content caused decreases in interior colors a*- and b*-values (P < 0.05). The interior of sausages had higher color L*-value (lightness), but lower b*-(yellowness) and a*-values (redness) than the exterior. Storage of sausages for 60 d at 4 °C had little effect on the interior as well as exterior colors regardless of irradiation and fat content (Tables 4 and 5).

The sensory scores on color intensities of non-irradiated sausages ranged from 4.6 to 5.0 in the 9-unit linear scale (1: none, 9: extremely) with no significant difference due to fat content (Table 6). Storage also had no effect on the color of sausages. The hardness of sausages was not influenced by fat content, but irradiation at 5 kGy significantly decreased (P < 0.05) the hardness of low-fat sausages at Day 0 (Table 6). The changes of off-odor and off-taste in sausages during storage as well as by fat content were negligible, but irradiation produced a significant irradiation off-odor in both low-fat and high-fat sausages. The differences in the intensities of off-odor and off-taste between irradiated and nonirradiated sausages were 1.5 to 2 sensory unit ranges in both low-fat and high-fat sausages, but all the irradiated sausages were still within the acceptable ranges (Table 6). Some panelists characterized irradiation odor as weak sweet or weak sulfide. Sulfur (S)–containing volatiles such as dimethyl disulfide and dimethyl trisulfide formed by radiolytic amino acids are regarded as the major compounds responsible for the characteristic off-odor in irradiated meat. However, dimethyl sulfide was the only sulfur compound detected in the irradiated sausages and disappeared after 60 d of storage (Tables 1 and 2), indicating sulfur volatiles had little influence on the odor of sausages after 60 d storage. Therefore, irradiation can be applied to cured meat products such as sausages with little negative effects on the sensory characteristics.

In summary, higher-fat sausages were more susceptible to oxidative changes than low-fat sausages regardless irradiation treatment. However, both high-fat and low-fat sausages developed significant oxidation during storage regardless irradiation treatments. Dimethyl sulfide and 1-heptene were detected only in the irradiated samples, but dimethyl sulfide could not be detected after storage. Irradiation caused no changes in exterior colors of the samples even though a*- and b*-values of the interior colors decreased significantly by irradiation (P < 0.05). Fat content had no effect on the sensory parameters of sausages regardless irradiation and storage. However, irradiated sausages had significantly stronger off-odor and off-taste than non-irradiated ones regardless fat contents (P < 0.05). This indicated that fat content in sausages is not an important factor that influences the quality of sausages by irradiation. The off-odor or off-taste of irradiated sausages was stronger than that of non-irradiated ones, but the taste and odor of irradiated sausages were still acceptable.

Table 1. **Effect of irradiation and storage at 4 °C on lipid oxidation of sausages with different fat contents.**

Fat content	0 day			60 day		
(%)	0 kGy	5 kGy	SEM	0 kGy	5 kGy	SEM
	-------------------- TBARS (mg malonaldehyde/kg meat) -------------------					
16	0.48^{bx}	0.88^{ax}	0.02	0.80^{ax}	0.82^{ax}	0.02
29	0.56^{bx}	0.94^{ax}	0.04	0.81^{ax}	0.89^{ax}	0.04
SEM	0.03	0.03		0.03	0.03	

^{a,b}Different superscript letters within a row are significantly different (P < 0.05); n = 3.
^{x,y}Different superscript letters within a column are significantly different (P < 0.05).
SEM: standard error of mean.
TBARS: 2-thiobarbituric acid reactive substances.

Table 2. Volatiles of irradiated sausage with 16% of fat during storage at 4 °C.

	0 day			60 day		
Volatiles	0 kGy	5 kGy	SEM	0 kGy	5 kGy	SEM
Pentane	0	0	0	0^b	777^a	37
2-Propanone	14286^b	41497^a	2288	12077^b	39795^a	1243
Ethanol	2069^b	12277^a	1189	2615^b	17081^a	363
2-Propanol	13895^a	13497^a	1473	15296^a	17142^a	662
2-Butanone	5748^a	7415^a	886	4583^b	9373^a	194
Ethyl acetate	1143^a	1082^a	42	0^b	857^A	26
3-Methyl butanal	1610^a	1836^a	277	1867^b	2332^a	78
2-Methyl butanal	970^a	819^b	38	1043^a	1419^a	106
3-Methylthio-1-propene	1816^a	186^b	359	0	0	0
1-Heptene	0	0	0	0^b	671^a	19
2-Pentanone	0	0	0	1583^a	1495^a	64
Pentanal	0^b	929^a	134	1751^a	1652^a	54
Dimehtyl disulfide	0^b	1922^a	380	0	0	0
Octane	289^b	427^a	17	0	0	0
Hexanal	1635^a	2369^a	449	2151^a	2228^a	277
Cyclopentanone	1002^a	1096^a	97	1127^a	1313^a	51
Heptanal	863^a	924^a	108	545^a	412^b	17
Alpha-thujene	832^a	615^a	110	630^a	676^a	22
Alpha-pinene	4765^a	3639^a	645	3585^b	4228^a	117
Camphene	498^a	566^a	77	434^a	533^a	49
Sabinene	2037^a	1531^a	255	971^a	977^a	45
Beta-pinene	4365^a	3259^a	486	3251^b	3512^a	66
Myrcene	1275^a	972^a	145	1146^b	1274^a	22
1-Phellandrene	1030^a	816^a	163	763^a	892^a	48
3-Carene	2989^a	2374^a	380	2500^b	3130^a	90
Alpha-terpinene	1185^a	889^a	132	1896^a	1893^a	163
Octanal	1683^a	1323^a	203	722^a	693^a	32
Limonene	5599^a	4350^a	596	5276^b	5962^a	107
Para-cymene	6592^a	4876^a	687	4877^b	5341^a	78
Trans-beta-ocimene	0	0	0	485^a	660^a	45
Gamma-terpinene	2406^a	1910^a	322	7619^a	6067^b	181
2-Furancarboxaldehyde	16644^a	6987^b	805	0	0	0
1-Octene-3-ol	938^a	613^a	95	0	0	0
Alpha-terpinolene	0	0	0	1249^a	1477^a	108
Nonanal	2104^a	2020^a	92	1133^a	889^a	181
Linalool	1423^a	703^b	78	3019^a	312^a	75
Camphor	4195^a	3251^a	350	692^b	732^a	4

[a,b]Different superscript letters within a row of the same storage day are significantly different ($P < 0.05$); n = 3.
SEM: standard error of mean.

Table 3. **Volatiles of irradiated sausage with 29% of fat during storage at 4 °C.**

	0 day			60 day		
Volatiles	0 kGy	5 kGy	SEM	0 kGy	5 kGy	SEM
Pentane	0	0	0	0^{b}	1382^{a}	170
Carbon disulfide	19647^{a}	19052^{a}	249	14494^{a}	18703^{a}	1999
2-Propanone	1246^{b}	17527^{a}	1471	2818^{b}	12772^{a}	463
Ethanol	1241^{b}	13935^{a}	1718	2625^{b}	16789^{a}	534
2-Propanol	5876^{b}	18175^{a}	3127	7453^{a}	8778^{a}	442
2-Butanone	0^{b}	8658^{a}	466	1089^{b}	3552^{a}	61
3-Methyl butanal	1602^{b}	2338^{a}	117	1401^{b}	2422^{a}	97
2-Methyl butanal	939^{a}	922^{a}	171	1173^{b}	1921^{a}	46
1-Heptene	0	0	0	0^{b}	1202^{a}	114
Heptane	0	0	0	0^{b}	633^{a}	75
Pentanal	0^{b}	879^{a}	61	0^{b}	421^{a}	34
Dimehtyl disulfide	0^{b}	2644^{a}	364	0	0	0
Octane	474^{a}	458^{a}	50	479^{a}	675^{a}	61
Hexanal	2099^{b}	3056^{a}	98	1242^{b}	2979^{a}	118
Heptanal	858^{a}	837^{a}	80	0^{b}	537^{a}	14
Alpha-thujene	922^{a}	432^{a}	126	1047^{a}	835^{a}	69
Alpha-pinene	19982^{a}	14634^{b}	625	21473^{a}	18106^{a}	1494
Camphene	1254^{a}	489^{a}	334	1093^{a}	777^{b}	61
Methyl-2-propenyl disulfide	578^{a}	349^{b}	26	743^{a}	385^{a}	114
Sabinene	929^{a}	282^{b}	43	3169^{a}	2189^{b}	112
Beta-pinene	0	0	0	10511^{a}	9364^{a}	525
Myrcene	1877^{a}	944^{b}	83	1847^{a}	1055^{b}	142
1-Phellandrene	2253^{a}	1418^{a}	577	1999^{a}	889^{b}	202
3-Carene	2969^{a}	1571^{a}	625	3399^{a}	2386^{b}	215
Alpha-terpinene	1961^{a}	2119^{a}	85	3009^{a}	1930^{b}	253
Octanal	1643^{a}	2695^{a}	993	1045^{a}	622^{b}	70
Limonene	4321^{a}	3329^{a}	263	4772^{a}	3767^{b}	216
Para-cymene	0	0	0	4063^{a}	3860^{a}	97
1,3,7-Octatriene	0	0	0	1652^{a}	707^{b}	233
Heptadecane	0	0	0	4501^{a}	3060^{b}	198
Gamma-terpinene	2714^{a}	2343^{a}	328	1456^{a}	629^{b}	131
Nonane	0	0	0	2331^{a}	794^{b}	310
2-Furan carboxaldehyde	9237^{a}	8871^{a}	616	2156^{a}	806^{b}	282
Dodecane	2389^{a}	907^{b}	193	787^{a}	854^{a}	272
Alpha-terpinolene	0	0	0	3613^{a}	1683^{b}	347
1-Octene-3-ol	0	0	0	3409^{a}	1451^{a}	592
Nonanal	2210^{a}	2755^{a}	248	848^{a}	792^{a}	152
Camphor	601^{b}	2932^{a}	514	459^{a}	568^{a}	31

^{a,b}Different superscript letters within a row of the same storage day are significantly different ($P < 0.05$); n = 3.

Table 4. Effect of irradiation and storage at 4 °C on exterior color characteristics of sausages with different fat contents.

Color parameter	Fat content (%)	0 day			60 day		
		0 kGy	5 kGy	SEM	0 kGy	5 kGy	SEM
L*	16	51.74^{ay}	52.26^{ay}	0.33	51.87^{ay}	52.37^{ay}	0.29
	29	59.32^{ax}	58.83^{ax}	0.52	56.45^{ax}	56.91^{ax}	0.42
a*	16	30.79^{ax}	29.52^{bx}	0.33	29.73^{ax}	28.58^{ax}	0.44
	29	26.29^{ay}	25.89^{ay}	0.41	26.86^{ay}	24.85^{by}	0.66
b*	16	41.96^{ax}	40.83^{ax}	0.74	40.18^{ax}	39.77^{ax}	0.60
	29	34.74^{ay}	34.41^{ay}	0.71	36.09^{ay}	35.69^{ay}	0.52

^{a,b}Different superscript letters within a row of the same storage day are significantly different ($P < 0.05$); n = 3.
^{x,y}Different superscript letters within a column are significantly different ($P < 0.05$).

Table 5. Effect of irradiation and storage at 4 °C on interior color characteristics of sausages with different fat contents.

Color parameter	Fat content (%)	0 day			60 day		
		0 kGy	5 kGy	SEM	0 kGy	5 kGy	SEM
L*	16	69.16^{ay}	69.10^{ay}	0.13	68.26^{by}	68.89^{ay}	0.16
	29	71.38^{ax}	71.04^{ax}	0.26	70.09^{ax}	70.68^{ax}	0.21
a*	16	21.74^{ax}	19.24^{bx}	0.12	21.80^{ax}	18.59^{bx}	0.08
	29	17.97^{ay}	16.67^{by}	0.09	18.48^{ay}	16.94^{by}	0.12
b*	16	25.44^{ax}	23.38^{bx}	0.10	25.84^{ax}	23.93^{bx}	0.15
	29	18.08^{ay}	18.00^{ay}	0.13	18.77^{ay}	18.66^{ay}	0.24

^{a,b}Different superscript letters within a row of the same storage day are significantly different ($P < 0.05$); n = 3.
^{x,y}Different superscript letters within a column are significantly different ($P < 0.05$).

Table 6. Sensory properties of irradiated and nonirradiated sausages with different fat contents after 60 days of storage.

Sensory parameter	Fat content (%)	0 day			60 day		
		0 kGy	5 kGy	SEM	0 kGy	5 kGy	SEM
Color	16	4.88^{a}	4.63^{a}	0.16	5.00^{a}	4.13^{b}	0.25
	29	5.00^{a}	5.00^{a}	0.13	4.75^{a}	4.63^{a}	0.26
Texture (hardness)	16	5.13^{a}	4.38^{a}	0.34	5.13^{a}	4.75^{a}	0.24
	29	5.13^{a}	4.00^{b}	0.34	4.88^{a}	4.75^{a}	0.38
Off-odor	16	1.50^{b}	3.00^{a}	0.38	1.63^{a}	3.13^{a}	0.52
	29	1.50^{b}	3.00^{a}	0.33	1.38^{b}	2.13^{a}	0.21
Off-taste	16	1.25^{b}	2.63^{a}	0.32	1.63^{b}	2.75^{a}	0.32
	29	1.25^{b}	3.63^{a}	0.35	1.25^{b}	2.50^{a}	0.26

^{a,b}Different superscript letters within a row of the same storage day are significantly different ($P < 0.05$); n = 8.
Color score: 1, very light; 9, very dark; Texture score: 1, very soft; 9, very hard;
Off-odor and off-taste score: 1, none; 9, extreme off-odor or off-taste.