Volatile Production of Irradiated Normal, PSE, and DFD Pork

D. U. Ahn, professor
Department of Animal Science
K. C. Nam, M. Du, and C. Jo, graduate assistants
Department of Animal Science

ASL-R694

Summary and implications

With both aerobic and vacuum packaging, irradiation increased the production of sulfur-containing volatiles in all three pork types (normal, PSE, DFD) at day 0, but did not increase hexanal - the major indicator volatile of lipid oxidation. PSE pork produced the lowest amount of total sulfur-containing volatiles in both aerobically and vacuum-packaged pork at day 0. Majority of sulfur-containing volatiles produced in meat by irradiation evaporated during the 10-day storage period under aerobic packaging conditions. With vacuum packaging, however, the all the volatiles produced by irradiation remained in the packaging bag during storage. Irradiation had no relationship with lipid oxidation-related volatiles (e.g., hexanal) in both aerobic and vacuum-packaged raw pork. DFD muscle was very stable and resistant to oxidative changes in both irradiated and nonirradiated pork during storage, suggesting that irradiation can significantly increase the use of raw DFD pork and greatly benefit pork industry.

Introduction

The objective of this research is to determine the effects of irradiation on volatile characteristics of normal, pale soft exudative (PSE), and dark firm dry (DFD) pork during storage with different packaging conditions.

Materials and Methods

Sample preparation: Normal, pale soft exudative (PSE) and dark firm dry (DFD) types of pork loin muscles were purchased from a local packing plant and sliced to 3-cm-thick steaks and packaged either in oxygen-permeable bags or vacuum packaged in oxygen-impermeable bags. Half of the steaks from oxygen permeable and oxygen-impermeable bags were stored overnight at 4°C and then irradiated using a linear accelerator. The target doses of irradiation were 0 and 4.5 kGy. The pork steaks irradiated were stored at 4°C for 10 days, and the volatile characteristics of steaks were determined after 0 and 10 days of storage. Precept II and Purge-and-Trap Concentrator 3000 connected to a gas chromatograph was used to quantify and characterize volatiles responsible for the off-flavor in the pork with different irradiation doses and meat types. Volatiles were analyzed using a dynamic headspace gas chromatography/mass spectrometry method.

Results and Discussion

Volatiles of aerobically packaged pork: Irradiation had significant impact on the amount and profile of volatiles in pork. At day 0, aerobically packaged irradiated pork produced larger number of volatiles than the nonirradiated pork (Table 1). Butane, propane, mercaptomethane, dimethyl sulfide, methyl thioacetate, and dimethyl disulfide, not detected in nonirradiated pork, were produced by irradiation in all three pork types. Among the volatiles produced by irradiation, mercaptomethane, dimethyl disulfide, methyl thioacetate, and dimethyl disulfide - sulfur-containing volatile compounds - were the major ones. The productions of butane, mercaptomethane, dimethyl sulfide, methyl thioacetate, and dimethyl sulfide were the highest in irradiated normal pork and the lowest in irradiated PSE pork in most cases. Carbon disulfide, another sulfur-containing volatile compound, was found in both irradiated and nonirradiated pork, but its amount also increased significantly after irradiation in all three pork types. The production of carbon disulfide was the highest in irradiated PSE pork and the lowest in nonirradiated DFD pork. The total amount of sulfur-containing volatiles in irradiated normal pork was about 2-fold higher than the PSE or DFD pork, suggesting that normal pork would produce stronger irradiation odor than PSE or DFD pork.

The amount of acetaldehyde was the highest in nonirradiated DFD but the lowest in irradiated DFD pork. Propane was the highest in irradiated PSE pork. Pentane, hexane, and heptane content in irradiated normal pork were higher than in nonirradiated normal pork, and also were higher than the irradiated and nonirradiated PSE and DFD pork. As previously reported (3) the amounts of alkenes such as 1-hexene and 1-heptene in pork from a same meat type, except for 1-hexene in DFD pork, increased significantly after irradiation but the amounts were small. Octane content in irradiated DFD pork was lower than that in any other irradiated or nonirradiated pork. The amounts of ethanol, 1-propanol, diacetyl, and 2-pentanone in all three pork types decreased significantly after irradiation, but their amounts were small compared with the sulfur-containing compounds. Hexanal was detected only in irradiated and nonirradiated normal meat. Changes in other volatiles in all three pork types after irradiation were either small or inconsistent. Most sulfur and carbonyl compounds had low odor thresholds and were considered as important to irradiation odor (4). Batzer and Doty (5) reported that methyl mercaptan and hydrogen sulfide were important to irradiation odor, and Patterson and Stevenson (7) found that dimethyl trisulfide is the most potent off-odor compound, followed by *cis*-3- and *trans*-6-nonenals, oct-1-en-3-one, and bis(methylthio-)methane in irradiated chicken meat. This indicated that the sulfur-containing compounds would be the major volatile components responsible for the characteristic odor in irradiated pork. This study also provided evidence to support the concept that the changes that occur after irradiation are distinctly different from those of warmed-over flavor in oxidized meat.

After 10 days of storage in aerobic packaging condition, the amount of total volatiles in all pork but irradiated DFD pork decreased by 30 to 60%. As in day 0 pork, mercaptomethane, dimethyl sulfide, and methyl thioacetate were found only in irradiated, and 2-pentanone in nonirradiated pork (Tables 1 and 2). Propane and dimethyl disulfide, found in irradiated meat at day 0, were not detected after 10 days of storage in aerobic conditions. The amounts of other volatiles such as acetaldehyde, mercaptomethane, furan, and ethanol significantly decreased in all three pork types after 10 days of storage, but the decrease of mercaptomethane was the most significant (Table 2). The amount of methyl thioacetate in irradiated DFD pork, and that of octane in all pork except irradiated DFD also decreased significantly over the 10-day storage in aerobic conditions. The content of dimethyl sulfide was the only sulfur compound increased significantly after 10 days of storage in aerobic conditions. Hexanal was produced in all three pork types except nonirradiated DFD pork after 10 days of storage in aerobic conditions. However, irradiation did not increase hexanal production in all three pork types, but the storage time did in aerobically packaged pork (Table 2). Luchsinger et al. (6) showed that TBARS values of both chilled and frozen boneless pork chops were stable, regardless of display day, dose, and irradiation sources. Ahn et al. (2) reported that hexanal is the best volatile compound that represent the lipid oxidation status in meat. This indicated that DFD pork is less susceptible to oxidative changes during storage. The amount of 3-methyl pentane in irradiated DFD pork also increased during the storage.

Volatiles of vacuum-packaged pork: Volatile profiles of vacuum-packaged pork at day 0 (Table 3) were similar to those of the aerobically packaged pork (Table 1) except for minor differences. In addition to butane, propane, mercaptomethane, dimethyl sulfide, methyl thioacetate, and dimethyl disulfide, a few other volatiles were detected only in vacuum-packaged irradiated pork at day 0 (Tables 1 and 3). The productions of butane, mercaptomethane, dimethyl sulfide, and dimethyl disulfide were the highest in irradiated normal pork and the lowest in irradiated PSE pork as in aerobically packaged pork at day 0 (Table 1). Irradiation increased the production of 1-hexene, 3-octene and nonane in normal and PSE pork. However, irradiation decreased the amounts of ethanol, 1-propanol, diacetyl, and 2-pentanone significantly. Irradiated normal pork produced the highest amounts of butane, carbon disulfide, and 1-octene; nonirradiated DFD pork had the highest acetaldehyde; irradiated DFD pork produced the lowest pentane, ethanol, and 1-propanol; and irradiated PSE pork had the highest 3-methyl butanal. Hexanal was not detected from any of the vacuum-packaged pork (Table 3). The changes of volatiles in pork after 10 days of storage in vacuum packaging were different from those in aerobic packaging. Total volatile content of nonirradiated pork decreased but that of the irradiated increased significantly (Table 4). Unlike in aerobically packaged pork, the amounts of all sulfur-containing volatile compounds except for mercaptomethane and carbon disulfide increased significantly. Among the sulfur compounds, the increase of dimethyl sulfide in irradiated pork during the 10-day storage were the most dramatic (4- to 6-fold increase from the day 0, Tables 3 and 4), but those of methyl thioacetate and dimethyl disulfide were also significant. Normal pork produced the highest amount of total sulfur-containing volatile compounds and DFD pork had the lowest of the three pork types. The amounts of acetaldehyde and 2-butanone in irradiated meat increased but that of ethanol in nonirradiated pork decreased after storage. Hexanal was found in both irradiated and nonirradiated normal and PSE pork, and the production of nonane increased significantly after 10 days of storage in vacuum-packaged pork (Table 4).

Correlations: The production of volatiles was strongly influenced by meat type and irradiation. Storage time had less effect than meat type and irradiation on the content of many volatile compounds, but packaging of raw meat had the least effect on most of the volatiles found in this study. Among the volatiles found in irradiated and nonirradiated pork (Tables 1-4), the production of all the volatile compounds except for: acetaldehyde, dimethyl sulfide, and carbon disulfide were influenced by meat type; 3-pentanol, 3-methyl pentane, 2-butanone, 1-octene, octane, 3-octene, and hexanal were influenced by irradiation; and pentane, ethanol, dimethyl sulfide, carbon disulfide, 1-propanol, 3-methyl butanal, heptane, methyl thioacetate, dimethyl disulfide, and total volatiles were influenced by storage time. Butane, propane, mercaptomethane, dimethyl sulfide, hexane, heptane, 2-octene, and hexanal in pork were influenced by packaging methods. Irradiation was the only factor that influenced the production of all five sulfur-containing volatile compounds in pork. The production of hexanal, the major volatile related to oxidative changes in meat, was not influenced by irradiation but by meat type, storage and packaging methods (Table 5). Ahn et al. (1) also reported that irradiation did not increase lipid oxidation in meat.

Conclusion

Irradiation increased the production of sulfur-containing volatiles, but not lipid oxidation products in all three pork types regardless of packaging conditions. With vacuum packaging, lipid oxidation and volatile production of irradiated PSE and irradiated DFD pork were not different from that of normal pork. Most of sulfur-containing volatiles produced in meat by irradiation evaporated during storage under aerobic packaging conditions. DFD muscle was very stable and resistant to oxidative changes. Irradiation and storage of meat in vacuum packaging may be desirable for long-term storage, but may reduce the acceptance of irradiated meat because of the sustaining off-odor volatiles. Therefore, irradiation of DFD pork in aerobic packaging for short-term storage can be an option for the increased use of pork. Among three meat types 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 with the same or smaller levels of volatile changes than in irradiated normal and PSE pork.

References

1. Ahn, D.U., Jo, C., and Olson, D.G. (1999a). Analysis of volatile components and the sensory characteristics of irradiated raw pork. Meat Sci. 54, 209-215.
2. Ahn, D.U., Olson, D.G., Lee, J.I., Jo, C., Wu, C., and Chen, X. (1998). Packaging and irradiation effects on lipid oxidation and volatiles in pork patties. J. Food Sci. 63, 15-19.
3. Ahn, D.U., Olson, D.G., Jo, C., Love, J. and Jin, S.K. (1999b). Volatiles production and lipid oxidation of irradiated cooked sausage with different packaging during storage. J. Food Sci. 64, 226-229.
4. Angelini, P., Merritt, C. Jr., Mendelshon, J.M., and King, F.J. (1975). Effect of irradiation on volatile constituents of stored haddok flesh. J. Food Sci. 40, 197-199.
5. Batzer, O.F. and Doty, D.M. (1955). Nature of undesirable odors formed by gamma irradiation of beef. J. Agric. Food Chem. 3, 64-69.
6. Luchsinger, S.E., Kropf, D.H., Garcia-Zepeda, C.M., Hunt, M.C., Marsden, J.L., Rubio Canas, E.J., Kastner, C. L., Kuecker, W.G., and Mata, T. (1996). Color and oxidative rancidity of gamma and electron bean-irradiated boneless pork chops. J. Food Sci. 61, 1000-1004, 1093.
7. Patterson, R.L.S. and Stevenson, M.H. (1995). Irradiation-induced off-odor in chicken and its possible control. Br. Poult. Sci. 36, 425-441.

Table 1. Relative production of volatiles of aerobically packaged pork *L. dorsi* muscle at day 0 of storage at 4°C.

Volatile compound	0 kGy			4.5 kGy			
	Normal	PSE	DFD	Normal	PSE	DFD	SEM
	Peak area (pA x sec) x 10^4						
Butane	0^{c}	0^{c}	0^{c}	136^{a}	76^{b}	87^{b}	8
Acetaldehyde	962^{bc}	688^{bc}	1818^{a}	506^{bc}	1093^{b}	356^{c}	153
Propane	0^{c}	0^{c}	0^{c}	87^{b}	142^{a}	77^{b}	10
Mercaptomethane	0^{d}	0^{d}	0^{d}	3024^{a}	676^{c}	1345^{b}	80
Pentane	21^{ab}	224^{b}	286^{ab}	581^{a}	206^{b}	144^{b}	67
Furan	41^{b}	51^{b}	58^{ab}	72^{ab}	93^{a}	72^{ab}	9
Ethanol	956^{a}	692^{a}	789^{a}	233^{b}	98^{b}	52^{b}	80
Dimethyl sulfide	0^{b}	0^{b}	0^{b}	682^{a}	136^{b}	562^{a}	45
Carbon disulfide	185^{cd}	130^{cd}	65^{d}	422^{b}	1162^{a}	352^{b}	67
3-Methyl pentane	31^{b}	0^{c}	0^{c}	48^{b}	97^{a}	0^{c}	6
1-Hexene	29^{b}	0^{b}	0^{b}	74^{a}	25^{b}	0^{b}	6
Hexane	170^{b}	145^{b}	167^{b}	323^{a}	247^{ab}	160^{b}	29
1-Propanol	117^{a}	60^{b}	72^{b}	19^{c}	25^{c}	0^{c}	10
Diacetyl	323^{a}	141^{b}	363^{a}	43^{b}	36^{b}	26^{b}	37
2-Butanone	283^{bc}	431^{ab}	182^{c}	513^{a}	53^{c}	145^{c}	59
3-Methyl butanal	28^{ab}	0^{b}	17^{ab}	45^{a}	27^{ab}	32^{ab}	7
1-Heptene	26^{c}	0^{d}	0^{d}	125^{a}	71^{b}	33^{c}	9
Heptane	148^{b}	124^{b}	71^{b}	284^{a}	196^{ab}	86^{b}	35
2-Pentanone	93^{a}	119^{a}	17^{b}	0^{b}	0^{b}	0^{b}	9
Methyl thioacetate	0^{c}	0^{c}	0^{c}	402^{a}	36^{c}	295^{b}	24
Pentanal	74^{ab}	66^{ab}	31^{b}	103^{a}	55^{ab}	25^{b}	13
Dimethyl disulfide	0^{b}	0^{b}	0^{b}	612^{a}	30^{b}	130^{b}	38
1-Octene	139	137	144	112	103	48	16
Octane	1226^{a}	1353^{a}	1297^{a}	1305^{a}	1139^{a}	526^{b}	144
2-Octene	32	0	23	32	32	18	7
3-Octene	5^{b}	0^{b}	0^{b}	31^{a}	26^{a}	0^{b}	3
Hexanal	16	0	0	16	0	0	9
Nonane	37	29	0	32	19	0	13
Total volatiles	5242^{bc}	4390^{c}	5400^{bc}	9862^{a}	5899^{b}	4571^{c}	419

$^{a-d}$Different letters within a row are different ($P < 0.05$). N = 4.

Table 2. Relative production of volatiles of aerobically packaged pork *L. dorsi* muscle after 10 days of storage at 4°C.

Volatile compound	0 kGy Normal	0 kGy PSE	0 kGy DFD	4.5 kGy Normal	4.5 kGy PSE	4.5 kGy DFD	SEM
	Peak area (pA x sec) x 10^4						
Butane	38^b	26^b	27^b	80^a	91^a	44^b	10
Acetaldehyde	197^b	164^b	434^a	235^{ab}	357^{ab}	257^{ab}	50
Mercaptomethane	0	0	0	37	34	0	9
Pentane	246	205	171	524	394	256	92
Furan	26^a	0^b	0^b	33^a	29^a	26^a	2
Ethanol	64^b	61^b	70^a	112^b	77^b	32^b	56
Dimethyl sulfide	0^b	0^b	0^b	749^a	336^b	873^a	102
Carbon disulfide	139^b	11^b	112^b	216^{ab}	246^a	215^{ab}	25
3-Methyl pentane	50	103	110	64	103	75	21
1-Hexene	22^b	0^c	0^c	22^b	31^a	0^c	2
Hexane	224	324	211	199	321	312	50
1-Propanol	15	35	29	21	25	17	6
Diacetyl	76^b	188^b	515^a	73^b	143^b	127^b	32
2-Butanone	217^c	139^c	173^c	379^b	200^c	707^a	45
3-Methyl butanal	21^{bc}	0^c	34^b	27^{bc}	93^a	18^{bc}	7
1-Heptene	39^{ab}	0^b	0^b	49^a	60^a	55^a	11
Heptane	121^{ab}	59^b	54^b	145^a	172^a	162^a	18
2-Pentanone	166^a	57^b	62^b	0^c	0^c	0^c	12
Methyl thioacetate	0^c	0^c	0^c	194^a	45^{bc}	79^b	12
Pentanal	35	35	22	45	51	29	6
1-Octene	46^b	271^a	27^b	53^b	97^b	88^b	21
Octane	459	601	670	745	766	711	130
2-Octene	14	22	19	18	20	25	4
3-Octene	13^a	24^a	0^b	18^a	19^a	0^b	3
Hexanal	42	181	0	104	360	36	90
Nonane	30^a	41^a	0^b	38^a	53^a	37^a	6
Total volatiles	2300^b	2500^b	2724^b	4180^a	4123^a	4184^a	192

$^{a-c}$Different letters within a row are different ($P < 0.05$). N = 4.

Table 3. Relative production of volatiles of vacuum-packaged pork *L. dorsi* muscle at day 0 of storage at 4°C.

Volatile compound	0 kGy			4.5 kGy			
	Normal	PSE	DFD	Normal	PSE	DFD	SEM
	Peak area (pA x sec) x 10^4						
Butane	0^{c}	0^{c}	0^{c}	96^{a}	67^{b}	64^{b}	3
Acetaldehyde	1261^{ab}	877^{bc}	1651^{a}	326^{c}	699^{bc}	462^{c}	161
Propane	0^{b}	0^{b}	0^{b}	86^{a}	15^{a}	85^{a}	13
Mercaptomethane	0^{c}	0^{c}	0^{c}	2185^{a}	739^{bc}	1408^{b}	247
Pentane	235^{bc}	332^{ab}	160^{c}	419^{a}	436^{a}	190^{c}	33
Furan	54	62	59	77	68	52	6
Ethanol	761^{a}	587^{a}	667^{a}	104^{b}	95^{b}	0^{b}	51
Dimethyl sulfide	0^{d}	0^{d}	0^{d}	759^{b}	354^{c}	978^{a}	29
Carbon disulfide	0^{d}	82^{bc}	55^{cd}	189^{a}	124^{ab}	145^{ab}	18
3-Methyl pentane	0^{b}	0^{b}	0^{b}	0^{b}	45^{a}	0^{b}	2
1-Hexene	0^{b}	0^{b}	0^{b}	53^{a}	43^{a}	0^{b}	4
Hexane	115^{b}	131^{b}	88^{b}	183^{a}	204^{a}	135^{b}	14
1-Propanol	43^{b}	64^{a}	42^{b}	16^{cd}	24^{bc}	0^{d}	6
Diacetyl	204^{a}	72^{b}	181^{a}	0^{c}	0^{c}	44^{bc}	13
2-Butanone	201^{ab}	232^{a}	103^{b}	120^{b}	134^{ab}	196^{ab}	25
3-Methyl butanal	17^{bc}	0^{c}	22^{bc}	41^{b}	114^{a}	26^{bc}	8
1-Heptene	14^{b}	0^{b}	0^{b}	97^{b}	871^{a}	38^{b}	45
Heptane	95^{b}	105^{b}	57^{b}	178^{a}	189^{a}	91^{b}	14
2-Pentanone	46^{a}	53^{a}	0^{b}	0^{b}	0^{b}	0^{b}	3
Methyl thioacetate	0^{b}	0^{b}	0^{b}	187^{a}	153^{a}	137^{a}	16
Pentanal	46	60	25	57	60	27	7
Dimethyl disulfide	0^{c}	0^{c}	0^{c}	239^{a}	55^{c}	145^{b}	14
1-Octene	119^{b}	78^{b}	66^{b}	328^{a}	81^{b}	66^{b}	31
Octane	918^{ab}	992^{ab}	619^{b}	1089^{ab}	1163^{a}	849^{ab}	112
2-Octene	13^{b}	0^{b}	138^{a}	28^{b}	29^{b}	21^{b}	14
3-Octene	0^{b}	0^{b}	0^{b}	20^{a}	21^{a}	0^{b}	1
Nonane	0^{c}	18^{b}	0^{c}	39^{a}	26^{ab}	0^{c}	5
Total volatiles	4142^{d}	3735^{d}	3933^{d}	6916^{a}	5709^{b}	5159^{c}	201

$^{a-d}$Different letters within a row are different ($P < 0.05$). N = 4.

Table 4. Relative production of volatiles of vacuum-packaged pork *L. dorsi* muscle after 10 days of storage at 4°C.

Volatile compound	0 kGy			4.5 kGy			SEM
	Normal	PSE	DFD	Normal	PSE	DFD	
	Peak area (pA x sec) x 10^4						
Butane	0^c	0^c	0^c	331^a	271^a	197^b	20
Acetaldehyde	272^{ab}	57^b	135^b	367^a	278^{ab}	108^b	42
Propane	0^c	0^c	0^c	111^a	110^a	68^b	8
Mercaptomethane	0^b	0^b	0^b	1692^a	1655^a	1684^a	116
Pentane	205^{cd}	96^d	109^d	637^a	382^b	309^{bc}	42
Furan	13^b	0^c	0^c	29^a	34^a	25^a	2
Ethanol	269^{ab}	131^b	0^b	397^a	100^b	62^b	68
Dimethyl sulfide	0^b	0^b	0^b	4877^a	1612^b	3562^a	454
Carbon disulfide	211^b	124^c	77^c	292^a	186^b	204^b	16
3-Methyl pentane	110^{ab}	149^a	68^b	104^{ab}	71^b	39^b	18
1-Hexene	0^c	0^c	0^c	89^a	35^b	10^c	6
Hexane	130^{bc}	88^c	144^{bc}	290^a	201^b	173^{bc}	22
1-Propanol	130^a	38^b	13^b	68^b	20^b	13^b	15
Diacetyl	123^a	152^a	29^b	63^b	23^b	117^a	15
2-Butanone	346^b	308^b	208^c	760^a	196^{bc}	322^b	66
3-Methyl butanal	16^c	0^c	0^c	91^b	129^a	17^c	11
1-Heptene	0^d	0^d	0^d	191^a	66^b	37^c	7
Heptane	65^c	45^c	42^c	273^a	137^b	83^{bc}	18
2-Pentanone	329^a	124^b	50^c	0^c	0^c	0^c	13
Methyl thioacetate	0^b	0^b	0^b	410^a	259^a	374^a	61
Pentanal	31^b	34^b	0^b	79^a	48^b	25^b	5
Dimethyl disulfide	0^c	0^c	0^c	358^{ab}	235^b	473^a	41
1-Octene	30^c	196^b	17^c	141^b	537^a	139^c	23
Octane	718	566	515	880	882	799	90
2-Octene	0^b	0^b	0^b	30^a	25^a	20^a	3
3-Octene	0^c	0^c	0^c	25^a	17^b	10^c	2
Hexanal	22^b	26^b	0^b	128^a	78^{ab}	0^b	19
Nonane	42^{ab}	50^{ab}	17^{bc}	58^a	48^{ab}	10^c	8
Total volatiles	3062^c	2184^c	1424^c	12771^a	7635^b	8880^b	413

[a-d]Different letters within a row are different ($P < 0.05$). N = 4.

Table 5. Statistical significance of effects of meat type, irradiation dose, storage time, and packaging on volatile production from pork *L. dorsi* muscle. [a]

Volatile compound	Meat type d.f. = 2	Irradiation d.f. = 1	Storage d.f. = 1	Packaging d.f. = 1
	Probability			
Butane	0.0001	0.0001	0.0001	0.0004
Acetaldehyde	0.17	0.0001	0.0001	0.12
Propane	0.02	0.0001	0.0001	0.0001
Mercaptomethane	0.0001	0.0001	0.001	0.01
Pentane	0.0001	0.0001	0.88	0.43
Furan	0.0001	0.0002	0.0001	0.77
Ethanol	0.0001	0.0001	0.25	0.65
Dimethyl sulfide	0.19	0.0001	0.09	0.02
Carbon disulfide	0.86	0.01	0.24	0.07
3-Methyl pentane	0.0001	0.62	0.0001	0.05
1-Hexene	0.01	0.002	0.001	0.15
Hexane	0.01	0.0001	0.004	0.0001
1-Propanol	0.0001	0.0001	0.57	0.21
Diacetyl	0.0005	0.0001	0.03	0.0001
2-Butanone	0.02	0.13	0.004	0.14
3-Methyl butanal	0.0001	0.0001	0.38	0.41
1-Heptene	0.0001	0.0001	0.0001	0.93
Heptane	0.0001	0.0001	0.17	0.0008
2-Pentanone	0.0001	0.0001	0.006	0.81
Methyl thioacetate	0.001	0.0001	0.31	0.52
Pentanal	0.0001	0.03	0.003	0.05
Dimethyl disulfide	0.0002	0.0001	0.08	0.99
1-Octene	0.0001	0.05	0.0009	0.05
Octane	0.04	0.11	0.007	0.47
2-Octene	0.0001	0.0001	0.02	0.01
3-Octene	0.03	0.49	0.02	0.80
Hexanal	0.0005	0.20	0.0001	0.006
Nonane	0.0001	0.002	0.0001	0.22
Total volatiles	0.0001	0.0001	0.99	0.56

[a]N = 36 for meat type effect; N = 48 for irradiation, storage, and packaging effect.