Thesis for Degree of Master of Science

Changes of Volatile Organic Compounds of Irradiated Dried Red Pepper (*Capsicum annum* L.)

by

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ABSTRACT

Changes of Volatile Organic Compounds of Irradiated Dried Red Pepper (Capsicum annum L.)

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The present study was conducted to compare volatile organic compounds in irradiated and unirradiated dried red pepper. The volatile organic compounds of control, 1, 3, 5, 10 and 20 kGy irradiated samples were extracted by simultaneous steam distillation and extraction (SDE) method and identified with GC/MS (gas chromatography/mass spectrometer) analysis. 61 compounds were identified in control sample and 62, 61, 62, 62 and 62 compounds were identified in irradiated samples at dose of 1, 3, 5, 10 and 20 kGy, respestively. These compounds included esters, aldehydes, ketones, alcohols and N-containing compounds, furans, hydrocarbons, terpenes and micellaneous compounds. The compounds, α-zingibirene, furfural, benzaldehyde, linalool, nerolidol and α-curcumene were detected as the major volatile organic compounds of dried red peppers. The yield of volatile compounds of unirradiated sample was approximately 15.86mg/kg while irradiated samples at 1, 3, 5, 10 and 20 kGy were 27.664, 39.463, 22.806, 23.320 and 21.565 mg/kg, respectively. These were increased after

irradiation but the sample irradiated at 5 kGy was reduced. Irradiated samples showed a new compound, 1,3-bis [1,1-dimethylethyl]-benzene, which increased in propotion to radiation dosages. Therefore, 1,3-bis [1,1-dimethylethyl]-benzene, can play an important role as a marker compound to measure previous irradiation in dried red pepper.

INTRODUCTION

Food irradiation is a physical process in which high energy ionizing radiation passes through food sample. This radiation is capable of damaging microorganisms that contaminate food or cause food spoilage and deterioration. It is gaining wider recognition and acceptance throughout the world as an effective method of food preservation by the food industry, governments and consumers (1). The application of ionizing irradiation to control spoilage microorganisms can increases the shelf life of strawberries, lettuce, onions and carrots (2). This technology can contribute siginificantly to eliminating biological hazards, increasing the shelf life of food, alleviating the food loss. Several studies on the effect of irradiation on processing characteristics and physicochemical properties of irradiated products have been reported (3). Irradiation has several advantages over tradiational post-harvest fumigants as it is a sustainable and environment-friendly technology. Normal heat treatment is not suitable for sterilization of spices because of its effect on their flavor properties. Similarly, fumigation has several disadvantages such as toxic residues and changes in the organoleptic properties of spices (4). Although exemptions allowing the use of methyl bromide for post-harvest treatments have been granted, it is expected to be phased out by the year 2010 in developed countries (5).

In 1981, the JECFI (FAO/IAEA/WHO Joint Expert Committee on the Wholesomeness of Food Irradiation) stated "the irradiation of any food commodity upto an overall average dose of 10 kGy presents no toxicological

hazards" and "Introduces no special nutritional or microbiological problems". It has been recently reported that food irradiated to any dose appropriate to achieve technically satisfactiory results is safe to consume and is nutritionally adequate (6). The treatment of food with ionizing radiation is one of the most thoroughly verified techniques available for food processing. Its use is currently permitted in 52 countries for the treatment of approximately 250 food products (7). Therefore, ever-increasing numbers of countries have approved many irradiated food items; spices, grains, fruit, vegetables, meats, poultry and seafoods (8). Due to their natural source of origin, spices usually suffer from high microbiological contamination, requiring them to be irradiated immediately.

Red pepper comes from the plant *Capsicum annuum L.* (Solanaceae family) and is widely used for vegetables, spices, pickles, pastes and sauces. It is a good source of vitamins A and C, which are important antioxidants. Red pepper powder of is prepared by drying and pulverizing perfectly ripened pepper and is used as a spice and flavoring ingredient in the food industry. Bosland, reported that red pepper has a wide range of medical applications, from increasing appetite, to relieving pain associated with arthritis (9). Red pepper is one of the main agricultural products in Korea. Um *et. al.* (10) reported that red pepper fiber can be used as a short fiber for special uses. Red peppers are harvested from early August to early October. After harvesting, it is difficult to store them for along time due to environmental conditions and microbial contamination. Alternative drying methods have been used for long periods of storage, but there have been problems with microbial and insect contamination.

Although numerous studies have been performed on unirradiated and

irradiated samples, the effects of irradiation on volatile organic compounds have not been studied in detail. The aim of the present work is, therefore, to study the effects of irradiation on flavor compounds in dried red peppers.

MATERIALS AND METHODS

A. Materials and analytic apparatus

1. Materials

Dried red peppers (*Capsicum annum* L.) were purchased from a local supermarket. They were irradiated at doses of 1 kGy, 3 kGy, 5 kGy, 10 kGy and 20 kGy at 12 ± 1℃ using a Co-60 γ-irradiator at the Korea Atomic Energy Research Institute. The dose rate was 2.5 kGy/h with a dose rate error of ± 0.02 kGy. The unirradiated dried red pepper was considered as a control and both irradiated and unirradiated dried red peppers were stored at -18℃ until required for the experiments.

2. Reagents

The reagents used in experiments were purchased from Sigma Co. (USA) and Fisher Scientific (USA). The organic solvents used for extraction and chromatography were redistilled using a wire spiral packed double distilling apparatus (Germany) and Milli-Q water that was generated with a water purification system (Millepore Corporation, Bedford, USA).

3. Analytic apparatus

a. Irradiator : Cobalt-60 γ-irradiator
(at the Korea Atomic Energy Research Institute)

b. Distilling apparatus : Wire spiral packed double distilling apparatus
(Normschliff Geratebau, Germany)

c. Blender : Multi mixer (Braun MR 550 CA, Braun, Spain)

d. pH meter : pH/ION meter (DMS, Korea)

e. Extraction apparatus : Likens & Nickerson type simultaneous steam ditillation & extraction apparatus, (SDE, Normschliff, Wertheim, Germany)

f. Concentration column : Vigreux column (250 mL Normschliff, Wertheim, Germany)

g. Gas chromatography/mass spectrometer : Shimadzu GC/MS QP-5000 equipped with mass spectrum library WILEY 139, NIST 62, NIST 12 (Shimadzu, Japan)

h. Capillary column : DB-Wax (60 m × 0.25 mm i.d., 0.25 μm film thickness, J&W, USA)

B. Methods

1. Extraction of volatile flavor compounds

Each 50 g sample was taken, homogenized in a blender (MR 350CA, Braun, Spain) and mixed with 500 mL distilled water. By maintaining the pH at 6.5, 1㎕ of n-butyl benzene was added as an internal standard and the resultant slurry was used for the quantitative analysis. The volatile compounds were extracted for 2 hours with 200 mL redistilled n-pentane/diethylether (1:1, v/v) mixture using a simultaneous steam distillation and extraction (SDE, Likens & Nickerson type) apparatus as modified by Schultz *et. al.* (11, 12) under atmospheric pressure (Figure 1). The extract was dehydrated for 12 hours with anhydrous sodium sulfate and concentrated to final volume approximately 1 mL using a vigreux column. This sample was finally used for the GC/MS analysis.

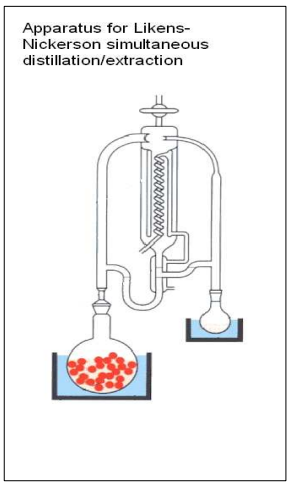

Figure 1. Apparatus for Likens and Nickerson simultaneous distillation and extraction (SDE) of volatile compounds.

2. Establishment of retention index

Kovats (13) suggested RI (retention index or Kovats index) as a suitable rule for retention indication which was indicated by the same spice or compound to retention time for standard alkane.

Retention index as a parameter used for checking a solute from chromatogram by comparing the retention time of both alkanes that appeared the above and below of the solute.

$$RI_i = 100\ Z + 100\ \{ \frac{\text{Log } V_{R(i)} - \text{Log } V_{R(Z)}}{\text{Log } V_{R(Z+1)} - \text{Log } V_{R(Z)}} \}$$

RI_i : Retention index of compound i

$V_{R(i)}$, $V_{R(Z)}$, $V_{R(Z+1)}$: Each space revision time of alkane of compound I, carbon each number Z, Z+1

According to definition, retention time of alkane has the value as multiplying carbon number that the compound has to be unrelated with column solid phase, the temperature of separation and requirements of other chromatography. Therefore, n-alkane was indicated as a standard index for CH_4 (RI=100), C_2H_6 (RI=200) … C_nH_{2n+2} (RI=100n), and even anything in analysis column (14).

For retention index, the dilution mixture of n-alkane; I (C_7~C_{17}) and II (C_{13} ~ C_{23}), was used as an internal standard. 1 μL mixture was analysed to find out the retention time of the internal standard by GC-FID under the condition of Table 1. RI of each peak was established by a basic program

that substituted the RT of each peak of n-alkane confirmed at GC chromatogram.

3. Analysis and identification of volatile flavor compounds

a. Analysis of gas chromatography/mass spectrometer (GC/MS)

Shimadzu GC/MS QP-5000 (Kyoto, Japan) in the EI (electron impact) mode was used for the analysis of volatile compounds in dried red peppers. The ionization voltage and temperature of injector and ion source were 70 eV, 250℃ and 230℃ respectively. The mass spectrometer scanned from 41 to 450 *m/z*. A DB-WAX capillary column (60 m × 0.25 mm i.d., 0.25 ㎛ film thickness, J&W, USA) was used for the separation. The oven temperature was programed at 40℃ (isothermal for 3 min) which was ramped to 150℃ at 2℃/min and then to 210℃ at 4℃/min. Helium was used as the carrier gas at a flow rate of 1.0 mL/min with an injector volume of 1 ㎕ using a 1:20 split ratio (Table 2).

Table 1. GC conditions for identification of volatile compounds

GC	Hewlett-Packard 5890 series Ⅱ Plus
Column	DB-Wax(60 m × 0.25 mm I.D., 0.25 μm film thickness, J&W)
Detector	FID
Carrier gas	He(1.0 mL/min)
Make up gas	N_2(30 mL/min)
Temp. program	40℃(3 min)-2℃/min-150℃-4℃/min-220℃(5 min)
Detector temp.	300℃
Injector temp.	250℃
Injection volume	1 μL

Table 2. GC/MS conditions for identification of volatile compounds

GC/MS	Shimadzu GC/MS QP-5000
Column	DB-Wax(60 m × 0.25 mm I.D., 0.25 μm film thickness, J&W)
Carrier gas	Helium(1.0 mL/min)
Temp. program	40℃(3 min)-2℃/min-150℃-4℃/min-210℃(5 min)
Injector	250℃
Ion source and interface temp.	230℃
Ionization	Electron impact ionization(EI)
Ionization voltage	70 eV
Mass range(m/z)	41~450
Injection volume	1 μL

b. Identification and quantitative analysis of volatile compounds

Mass spectra were identified with the aid of our own mass spectral data and those contained within the WILEY 139, NIST 62 and NIST 12 libraries and mass spectral data books (15, 16) as well as by the comparison of retention indices to reference data (17, 18). The resultant slurry was used for the quantitative analysis with 1㎕ of n-butyl benzene added as an internal standard.

$$\text{Content of Component (mg/kg of sample)} = \frac{C\% \times 1000\ g}{A\% \times B\ g}$$

A% : Peak area% of each sample of internal standard

B : Amount of sample

C% : Peak area% of each component in sample

c. Identification of marker compound

Irradiation induced marker compound, 1,3-bis[1,1-dimethylethyl]-benzene (1,3-di-*tert*-butyl benzene) from irradiated dried red pepper was conformed by comparison of its spectrum with standard sample. Standard sample of this compound was prepared to 500 ppm by mixing with redistilled n-pentane/ diethylether (1:1, v/v) used for GC/MS analysis.

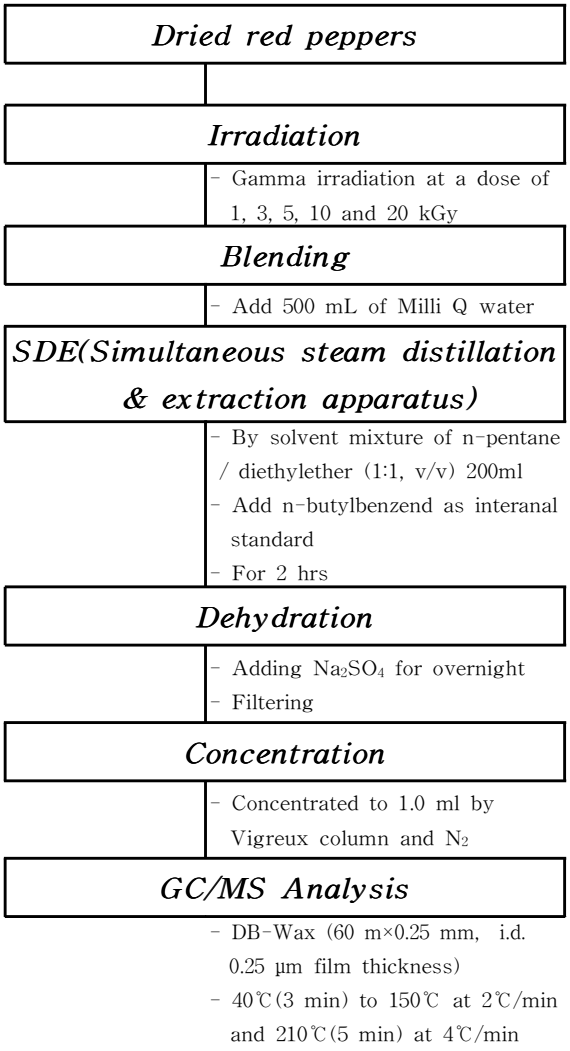

Figure 2. Extraction, concentration and identification of volatile compounds from unirradiated and irradiated dried red peppers.

RESULTS AND DISCUSSION

A. Analysis of volatile flavor compounds in dried red peppers

1. Extraction of volatile flavor compounds in dried red peppers

Extraction method using SDE apparatus was suggested as an effective method for volatile flavor compounds in foods (11, 12). Therefore, this method was used to extract the volatile flavor compounds.

2. Volatile flavor compounds in dried red peppers by GC/MS analysis

Shimadzu GC/MS QP-5000 (Kyoto, Japan) in the EI (electron impact) mode was used for the quantitative analysis. The ionization voltage was 70 eV. The mass spectrometer scanned from 40 to 350 m/z. A DB-WAX capillary column (60 m × 0.25 mm i.d., 0.25 μm film thickness, J&W, USA) was used for the separation. The oven temperature was programed at 40℃ (isothermal for 3 min) which was ramped to 150℃ at 2℃/min, and then to 210℃ at 4℃/min. The injector and ion source temperature were 230 ℃ respectively. Helium was used as the carrier gas at a flow rate of 1.0 mL/min with an injector volume of 1 μL using a 1:20 split ratio.

3. Retention index of n-alkane

The standard value of retention index was determined by two different mixture of n-alkane, mixture I (C_7～C_{17}), mixture II (C_{13}～ C_{23}) considering as an internal standard. 1μL mixture of n-alkane sample was analysed to find out the retention time of internal standard by GC-FID (Figure 2). RI of each peak was established by a basic program that substituted the RT of each peak of n-alkane confirmed at GC chromatogram (Table 3).

Table 3. Retention time of n-alkane mixture for gas chromatographic retention index

Alkanes	Retention time	Alkanes	Retention time	Alkanes	Retention time
$C_{7:0}$	5.153	$C_{13:0}$	30.446	$C_{19:0}$	66.439
$C_{8:0}$	6.141	$C_{14:0}$	37.341	$C_{20:0}$	70.156
$C_{9:0}$	8.194	$C_{15:0}$	44.079	$C_{21:0}$	73.446
$C_{10:0}$	11.828	$C_{16:0}$	50.509	$C_{22:0}$	76.548
$C_{11:0}$	17.136	$C_{17:0}$	56.629	$C_{23:0}$	79.183
$C_{12:0}$	23.57	$C_{18:0}$	62.005		

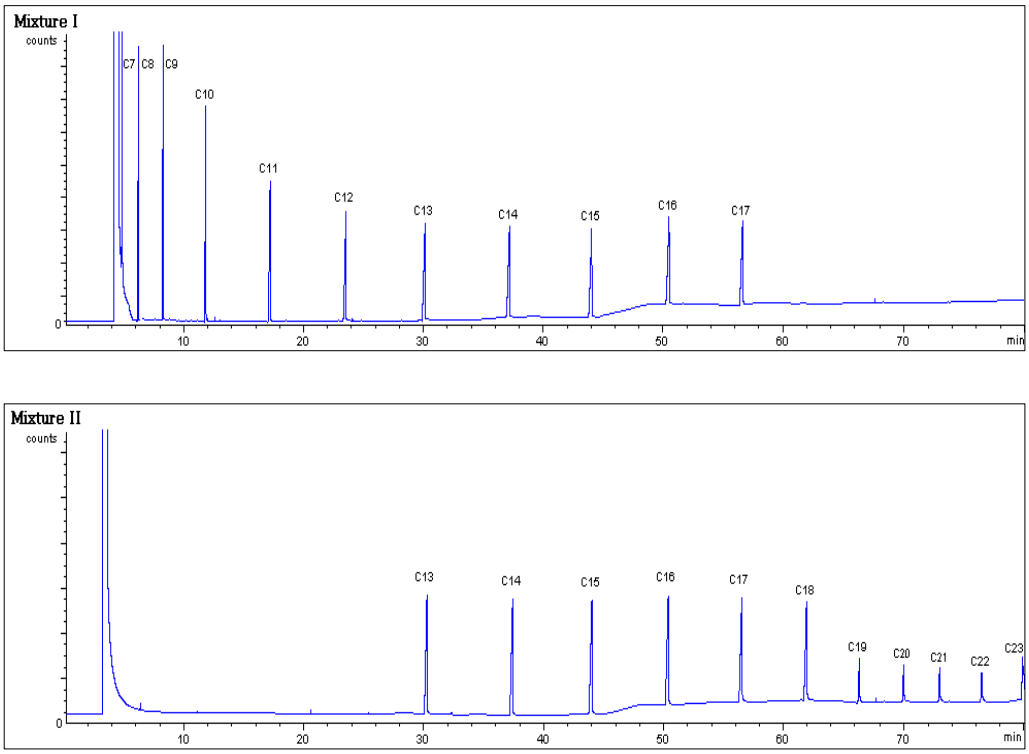

Figure 3. GC chromatograms of n-alkane standard mixture Ⅰ *and* Ⅱ.

B. Quantitative analysis of volatile flavor compounds in unirradiated and irradiated dried red peppers

1. Volatile flavor compounds in unirradiated dried red peppers

The total ion chromatograms of volatile compounds of unirradiated dried red pepper is shown in Figure 4 and the concentrations of these compounds are listed in Table 4. A total of 61 flavor compounds were identified in unirradiated dried red pepper; 6 alcohols (3.40%), 13 aldehydes (28.94%), 2 esters (4.65%), 6 furans (3.05%), 3 hydrocarbons (4.72%), 7 ketones (7.45%), 4 N-containing compounds (3.65%), 18 terpenes (41.42%) and 2 miscellaneous (2.72%). Specifically, the major compounds were furfural (7.73%), benzaldehyde (6.10%), nerolidol (5.43%), 4-Hydroxy-β-ionone (5.08%), α-curcumene (5.00%), linalool (4.46%), 3-methyl butanal (4.22%) and longiborneol (4.02%).

Previous investigations on the flavor quality of dried peppers revealed the presence of hexanal, ethyl acetate, α-ionone and β-ionone (19). Similar results were observed in our study. The compound furfural (7.73%) accounted for the largest portion and was detected as a prime constituent. Mateo *et. al.* (20) reported furfural was attributable to Maillard reactions. The second largest constituent was identified as benzaldehyde which puts out a sweet fragrance from cherries, apricots and peaches (21). 2-Methylbutanal and 3-methylbutanal were also detected in a large amounts. Methyl-branched aldehydes were probably generated by enzymatic catabolism or Strecker reaction, and their corresponding acids may have been produced by oxidation

of aldehydes (20). Furthermore, hexanal was detected as a green note (22) from C_6 lipid peroxidation products released when samples were pulverized.

Some alcohols such as ethanol, pentanol, phenetylalcohol, furfuryl alcohol, 4-methyl pentanol and octanol were identified in unirradiated dried red pepper. Luning *et. al.* (23) suggested C_5 - C_6 alcohols are primarily characteristic of the fresh note of green bell peppers. A total of 5 furan compounds were detected; 2-acetyl furan and 2-pentyl furan, have been found in bell peppers and pepper paste(24, 25).

A total of 3 hydrocarbon compounds were detected, including o-xylene, toluene and 4-ethyl undecane. 4-Hydroxy-3-methylacetophenone and 2,3-butanedione were identified as the major ketones present, with concentrations of 0.561 mg/kg and 0.219 mg/kg in unirradiated dried red pepper.

Terpenes were the biggest class of substances in dried red pepper, which contained 18 of these compounds; (E)-β-ocimene, safranal, linalool, isoborneol, β-himachalene, terpinyl acetate, α-zingibirene, α-ylangene, α-curcumene, α-ionone, longiborneol, β-ionone, β-ionone epoxide, nerolidol, 4-hydroxy-β-ionone, geranyl acetone, geranyl propionate and hexahydrofarnesyl acetone. Compounds such as linalool, nerolidol and the "flower oil" α-curcumene were the major terpene compounds identified in dried red peppers. Pyrazines and pyrrole were identified as the N-containing compounds of dried red peppers. Pyrazines can be produced by Strecker degradation, which involves interaction of N-containing molecules with dicarbonyls resulting from carbohydrate decomposition in a classic Maillard reaction.

2. Volatile flavor compounds in irradiated dried red peppers

The total ion chromatogram of volatile compounds from irradiated dried red pepper is shown in Figure 4 and their concentrations are given in Tables 5-9. The types of volatile compounds in irradiated dried red peppers (at 1, 3, 5, 10 and 20 kGy) were similar to those of unirradiated samples but the concentrations of these compounds differed between treatments. A total of 62 flavor compounds were identified in dried red pepper irradiated at 1 kGy. The major volatile organic compounds in sample irradiated at 1 kGy were α-zingibirene (3.785 mg/kg), α-curcumene (1.893 mg/kg), furfural (1.889 mg/kg) and linalool (1.491 mg/kg). Interestingly, a new compound appeared after irradiation. It was 1,3-bis [1,1-dimethylethyl]-benzene (0.100 mg/kg), which was not detected in unirradiated dried red pepper. A total of 61 flavor compounds were identified in dried red pepper irradiated at 3 kGy. No 2-ethyl furan was detected in sample irradiated at 3 kGy. Initial levels of this chemical may have been low or some may have been lost during the experiment. Another compound, α-zingibirene (4.960 mg/kg) was detected as a major compound in dried red pepper irradiatedat 3 kGy. Jun *et. al.* (26) reported α-zingibirene was detected in Mexican red pepper, but the content was different from that seen in the present study. The content of 4-hydroxy-β-ionone was increased by 3 kGy doses of radiation. β-ionone (0.783 mg/kg) and its derivative, 4-hydroxy-β-ionone (2.065 mg/kg), were reported to be derived from β-carotene, whereas α-ionone (0.006 mg/kg) was known to be derived from α-carotene (27, 28). A total of 62 compounds were identified in dried red pepper irradiated at 5 kGy. Major compounds detected

at 5 kGy irradiated samples were α-zingibirene, furfural and 2-formyl-5-methylthiophene with concentration of 2.830 mg/kg, 1.310 mg/kg and 1.218 mg/kg, respectively.

A total of 62 flavor compounds were identified in dried red pepper irradiated at 10 kGy. The predominant flavor compound was identified as α-curcumene, with the concentration of 2.082 mg/kg and followed in descending order of concentration by furfural and benzaldehyde with the concentration of 1.976 and 1.403 mg/kg respectively. Terpenes- such as linalool, α-zingibirene and nerolidol were the largest functional group present in sample irradiated at 10 kGy, making up 40.33% of the total volatile compounds. Aldehydes, including furfural, 3-methylbutanal and hexanal were the second largest group of volatile compounds at 27.29%.

A total of 62 flavor compounds were identified in dried red pepper irradiated at 20 kGy. Levels of 1,3-bis[1,1-dimethylethyl]-benzene greatly increased at this dose with concentration of 0.701 mg/kg in comparison with other samples. The concentration of this compound increased linearly with increases in radiation dosages.

According to these results, aldehydes and terpenes were found in a large amounts in unirradiated and irradiated dried red peppers. Overall, the volatile compounds found in irradiated dried red peppers were similar to those in unirradiated samples, but the propotions of these compounds were different.

Table 4. Volatile flavor compounds identified in unirradiated dried red pepper

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.648	873	Ethyl acetate	$C_4H_8O_2$	88	0.446	2.81
2	8.337	902	2-Methyl-butanal	$C_5H_{10}O$	86	0.322	2.03
3	8.467	906	3-Methyl-butanal	$C_5H_{10}O$	86	0.670	4.22
4	9.160	930	Ethanol	C_2H_6O	46	0.225	1.42
5	9.402	938	3-Buten-2-one	C_4H_6O	70	0.038	0.24
6	9.661	946	2-Ethyl furan	C_6H_8O	96	0.063	0.40
7	10.521	971	2,3-Butanedione	$C_4H_6O_2$	86	0.219	1.38
8	13.348	1038	Toluene	C_7H_8	92	0.040	0.25
9	14.338	1057	2,3-Pentanedione	$C_5H_8O_2$	100	0.110	0.69
10	15.639	1080	Hexanal	$C_6H_{12}O$	100	0.106	0.67
11	18.173	1123	3-Penten-2-one	C_5H_8O	84	0.093	0.59
12	18.975	1137	1-Methyl pyrrole	C_5H_7N	81	0.067	0.42
13	19.074	1138	o-Xylene	C_8H_{10}	106	0.588	3.71
14	22.015	1183	Pyridine	C_5H_5N	79	0.326	2.06
15	24.170	1215	(E)-2-Hexenal	$C_6H_{10}O$	98	0.043	0.27
16	25.114	1230	2-Pentyl-furan	$C_6H_{14}O$	138	0.103	0.65
17	26.485	1251	(E)-β-Ocimene	$C_{10}H_{16}$	136	0.076	0.48
18	26.695	1254	Pentanol	$C_5H_{12}O$	88	0.094	0.59
19	27.307	1262	Dihydro-2-methyl-3[2H]-furanone	$C_5H_8O_2$	100	0.052	0.33
20	27.568	1266	Methylpyrazine	$C_5H_6N_2$	94	0.043	0.27
21	29.904	1298	3-Hepten-2-one	$C_7H_{12}O$	112	0.108	0.68
I.S[5)]	30.680	1309	Butylbenzene	$C_{10}H_{14}$	134	-	-
22	31.117	1316	4-Methyl pentanol	$C_6H_{14}O$	102	0.014	0.09
23	31.442	1321	(E)-2-Heptenal	$C_7H_{12}O$	112	0.106	0.67

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight, I.S.[5)]: Internal standard.

Table 4. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
24	33.749	1356	4-Ethyl undecane	$C_{13}H_{28}$	184	0.121	0.76
25	35.993	1387	3,4-epoxy-2-pentanone	$C_6H_{10}O_2$	114	0.052	0.33
26	40.343	1454	Acetic acid	$C_2H_4O_2$	60	0.079	0.50
27	40.860	1462	Furfural	$C_5H_4O_2$	96	1.225	7.73
28	42.921	1492	(E,E)-2,4-Heptadienal	$C_7H_{10}O$	110	0.178	1.12
29	43.653	1503	2-Acetylfuran	$C_6H_6O_2$	110	0.136	0.86
30	44.802	1522	Benzaldehyde	C_7H_6O	106	0.968	6.10
31	46.567	1550	Linalool	$C_{10}H_{18}O$	154	0.707	4.46
32	47.354	1562	Octanol	$C_8H_{18}O$	130	0.047	0.30
33	48.012	1571	5-Methylfurfural	$C_6H_6O_2$	110	0.057	0.35
34	49.389	1592	5-Methyl-2-acetylfuran	$C_7H_8O_2$	124	0.079	0.50
35	51.166	1621	4-Methylbenzaldehyde	C_8H_8O	120	0.096	0.60
36	52.304	1640	Phenylethanal	C_8H_8O	120	0.388	2.55
37	52.725	1647	Safranal	$C_{10}H_{14}O$	150	0.264	1.67
38	53.596	1661	Furfuryl alcohol	$C_5H_6O_2$	98	0.085	0.54
39	53.881	1666	Isoborneol	$C_{10}H_{18}O$	154	0.064	0.40
40	54.533	1676	2-Butanoylfuran	$C_8H_{10}O_2$	138	0.049	0.31
41	55.648	1694	β-Himachalene	$C_{15}H_{24}$	204	0.273	1.72
42	55.940	1698	Terpineol acetate	$C_{12}H_{20}O_2$	196	0.116	0.73
43	57.141	1721	α-Zingibirene	$C_{15}H_{24}$	204	0.470	2.96
44	57.595	1729	2-Formyl-5-methylthiophene	C_6H_6OS	126	0.352	2.22
45	59.686	1767	(E,Z)-2,4-Decadienal	$C_{10}H_{16}O$	152	0.035	0.22
46	59.944	1772	α-Ylangene	$C_{15}H_{24}$	204	0.265	1.67
47	60.102	1774	α-Curcumene	$C_{15}H_{22}$	202	0.808	5.09
48	61.737	1804	α-Ionone	$C_{13}H_{20}O$	192	0.344	2.17

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 4. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
49	62.011	1811	[*E,E*]-2,4-Decadienal	$C_{10}H_{16}O$	152	0.382	2.41
50	63.770	1851	Geranyl propionate	$C_{13}H_{22}O_2$	210	0.146	0.92
51	64.017	1857	Geranyl acetone	$C_{13}H_{22}O$	194	0.166	1.04
52	66.508	1915	Phenethyl alcohol	$C_8H_{10}O$	122	0.073	0.46
53	67.332	1938	Logiborneol	$C_{15}H_{26}O$	222	0.638	4.02
54	67.677	1947	β-Ionone	$C_{13}H_{20}O$	192	0.200	1.26
55	68.831	1979	2-Acetyl pyrrole	C_6H_7NO	109	0.142	0.90
56	69.639	2000	β-Ionone epoxide	$C_{13}H_{20}O_2$	208	0.165	1.04
57	70.977	2040	Nerolidol	$C_{15}H_{26}O$	222	0.862	5.43
58	74.078	2138	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	0.217	1.37
59	74.821	2165	Pentadecyl acetate	$C_{17}H_{34}O_2$	270	0.292	1.84
61	75.485	2190	4-Hydroxy-β-ionone	$C_{13}H_{20}O_2$	208	0.806	5.08
61	77.119	2245	4-Hydroxy-3-methylacetophenone	$C_9H_{10}O_2$	150	0.561	3.54
						15.320	100.00

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 5. Volatile flavor compounds identified in irradiated dried red pepper at 1 kGy

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.613	872	Ethyl acetate	$C_4H_8O_2$	88	1.163	4.37
2	8.309	901	2-Methyl-butanal	$C_5H_{10}O$	86	0.286	1.08
3	8.441	905	3-Methyl-butanal	$C_5H_{10}O$	86	0.652	2.44
4	9.134	929	Ethanol	C_2H_6O	46	1.110	4.17
5	9.361	936	3-Buten-2-one	C_4H_6O	70	0.149	0.23
6	9.630	945	2-Ethyl furan	C_6H_8O	96	0.082	0.18
7	10.489	970	2,3-Butanedione	$C_4H_6O_2$	86	0.177	0.29
8	13.321	1037	Toluene	C_7H_8	92	0.099	0.16
9	14.325	1056	2,3-Pentanedione	$C_5H_8O_2$	100	0.082	0.16
10	15.614	1080	Hexanal	$C_6H_{12}O$	100	0.121	0.45
11	18.550	1130	3-Penten-2-one	C_5H_8O	84	0.017	0.05
12	18.850	1135	1-Methyl pyrrole	C_5H_7N	81	0.023	0.04
13	19.049	1138	o-Xylene	C_8H_{10}	106	0.782	2.93
14	21.995	1183	Pyridine	C_5H_5N	79	0.208	0.77
15	23.730	1208	(E)-2-Hexenal	$C_6H_{10}O$	98	0.035	0.13
16	25.102	1230	2-Pentyl-furan	$C_6H_{14}O$	138	0.292	0.45
17	26.459	1250	(E)-β-Ocimene	$C_{10}H_{16}$	136	0.202	0.75
18	26.669	1253	Pentanol	$C_5H_{12}O$	88	0.138	0.52
19	27.291	1262	Dihydro-2-methyl-3[2H]-furanone	$C_5H_8O_2$	100	0.071	0.11
20	27.592	1266	Methylpyrazine	$C_5H_6N_2$	94	0.034	0.11
21	29.878	1297	3-Hepten-2-one	$C_7H_{12}O$	112	0.080	0.31
I.S.[5)]	30.660	1309	Butylbenzene	$C_{10}H_{14}$	134	-	-
22	31.296	1319	4-Methyl pentanol	$C_6H_{14}O$	102	0.014	0.02
23	31.437	1321	(E)-2-Heptenal	$C_7H_{12}O$	112	0.004	0.02

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight, I.S.[5)]: Internal standard.

Table 5. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
24	33.724	1356	4-Ethyl undecane	$C_{13}H_{28}$	184	0.107	0.40
25	35.925	1386	3,4-Epoxy-2-pentanone	$C_6H_{10}O_2$	114	0.007	0.02
26	38.654	1428	1,3-Bis[1,1-dimethylethyl]-benzene	$C_{14}H_{22}$	190	0.100	0.38
27	40.247	1453	Acetic acid	$C_2H_4O_2$	60	0.408	1.53
28	40.840	1462	Furfural	$C_5H_4O_2$	96	1.889	7.08
29	42.913	1492	[*E,E*]-2,4-Heptadienal	$C_7H_{10}O$	110	0.365	1.37
30	43.632	1503	2-Acetylfuran	$C_6H_6O_2$	110	0.149	0.56
31	44.780	1521	Benzaldehyde	C_7H_6O	106	1.152	4.31
32	46.551	1549	Linalool	$C_{10}H_{18}O$	154	1.491	5.59
33	47.933	1570	Octanol	$C_8H_{18}O$	130	0.033	0.13
34	48.604	1580	5-Methylfurfural	$C_6H_6O_2$	110	0.310	1.17
35	49.348	1591	5-Methyl-2-acetylfuran	$C_7H_8O_2$	124	0.083	0.31
36	51.162	1621	4-methylbenzaldehyde	C_8H_8O	120	0.087	0.32
37	52.400	1641	Phenylethanal	C_8H_8O	120	0.108	0.41
38	52.714	1647	Safranal	$C_{10}H_{14}O$	150	0.385	1.44
39	53.647	1662	Furfuryl alcohol	$C_5H_6O_2$	98	0.226	0.36
40	53.844	1665	Isoborneol	$C_{10}H_{18}O$	154	0.052	0.20
41	54.404	1674	2-Butanoylfuran	$C_8H_{10}O_2$	138	0.014	0.05
42	55.622	1693	β-Himachalene	$C_{15}H_{24}$	204	0.429	1.60
43	55.946	1698	Terpineol acetate	$C_{12}H_{20}O_2$	196	0.502	1.89
44	57.056	1719	α-Zingibirene	$C_{15}H_{24}$	204	3.785	14.18
45	57.567	1729	2-Formyl-5-methylthiophene	C_6H_6OS	126	0.255	0.95
46	59.625	1766	[*E,Z*]-2,4-Decadienal	$C_{10}H_{16}O$	152	0.434	1.62
47	59.878	1770	α-Ylangene	$C_{15}H_{24}$	204	0.780	2.93
48	59.917	1771	α-Curcumene	$C_{15}H_{22}$	202	1.893	7.05

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 5. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
49	61.625	1802	α-Ionone	$C_{13}H_{20}O$	192	0.106	0.40
50	61.987	1810	[*E,E*]-2,4-Decadienal	$C_{10}H_{16}O$	152	0.572	2.14
51	63.761	1851	Geranyl propionate	$C_{13}H_{22}O_2$	210	0.332	1.24
52	63.892	1854	Geranyl acetone	$C_{13}H_{22}O$	194	0.490	0.77
53	66.659	1919	Phenethyl alcohol	$C_8H_{10}O$	122	0.429	1.60
54	67.316	1937	Logiborneol	$C_{15}H_{26}O$	222	0.646	2.43
55	67.648	1947	β-Ionone	$C_{13}H_{20}O$	192	0.521	1.96
56	68.808	1978	2-Acetyl pyrrole	C_6H_7NO	109	0.178	0.66
57	69.636	2000	β-Ionone epoxide	$C_{13}H_{20}O_2$	208	0.226	0.84
58	70.953	2039	Nerolidol	$C_{15}H_{26}O$	222	0.972	3.65
59	74.062	2137	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	0.436	1.64
61	74.789	2164	Pentadecyl acetate	$C_{17}H_{34}O_2$	270	0.260	0.97
61	75.455	2189	4-Hydroxy-β-ionone	$C_{13}H_{20}O_2$	208	1.073	4.03
62	77.106	2245	4-Hydroxy-3-methylacetophenone	$C_9H_{10}O_2$	150	0.558	2.08
						27.664	100.00

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 6. Volatile flavor compounds identified in irradiated dried red pepper at 3 kGy

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.613	872	Ethyl acetate	$C_4H_8O_2$	88	1.305	3.30
2	8.309	901	2-Methyl-butanal	$C_5H_{10}O$	86	0.436	1.10
3	8.441	905	3-Methyl-butanal	$C_5H_{10}O$	86	0.912	2.31
4	9.134	929	Ethanol	C_2H_6O	46	0.420	1.07
5	9.361	936	3-Buten-2-one	C_4H_6O	70	0.157	0.30
6	9.630	945	2-Ethyl furan	C_6H_8O	96	-	-
7	10.489	970	2,3-Butanedione	$C_4H_6O_2$	86	0.406	1.02
8	13.321	1037	Toluene	C_7H_8	92	0.100	0.25
9	14.325	1056	2,3-Pentanedione	$C_5H_8O_2$	100	0.178	0.44
10	15.614	1080	Hexanal	$C_6H_{12}O$	100	0.233	0.58
11	18.550	1130	3-Penten-2-one	C_5H_8O	84	0.287	0.72
12	18.850	1135	1-Methyl pyrrole	C_5H_7N	81	0.035	0.08
13	19.049	1138	o-Xylene	C_8H_{10}	106	1.032	2.61
14	21.995	1183	Pyridine	C_5H_5N	79	0.829	2.12
15	23.730	1208	(E)-2-Hexenal	$C_6H_{10}O$	98	0.143	0.36
16	25.102	1230	2-Pentyl-furan	$C_6H_{14}O$	138	0.224	0.58
17	26.459	1250	(E)-β-Ocimene	$C_{10}H_{16}$	136	0.133	0.33
18	26.669	1253	Pentanol	$C_5H_{12}O$	88	0.186	0.47
19	27.291	1262	Dihydro-2-methyl-3[2H]-furanone	$C_5H_8O_2$	100	0.128	0.33
20	27.592	1266	Methylpyrazine	$C_5H_6N_2$	94	0.051	0.14
21	29.878	1297	3-Hepten-2-one	$C_7H_{12}O$	112	0.196	0.50
I.S.[5)]	30.660	1309	Butylbenzene	$C_{10}H_{14}$	134	-	-
22	31.296	1319	4-Methyl pentanol	$C_6H_{14}O$	102	0.027	0.08
23	31.437	1321	(E)-2-Heptenal	$C_7H_{12}O$	112	0.160	0.41

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight, I.S.[5)]: Internal standard.

Table 6. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
24	33.724	1356	4-Ethyl undecane	$C_{13}H_{28}$	184	0.175	0.44
25	35.925	1386	3,4-Epoxy-2-pentanone	$C_6H_{10}O_2$	114	0.119	0.30
26	38.654	1428	1,3-Bis[1,1-dimethylethyl]-benzene	$C_{14}H_{22}$	190	0.196	0.50
27	40.247	1453	Acetic acid	$C_2H_4O_2$	60	0.485	1.24
28	40.840	1462	Furfural	$C_5H_4O_2$	96	1.718	4.37
29	42.913	1492	[*E,E*]-2,4-Heptadienal	$C_7H_{10}O$	110	0.383	0.96
30	43.632	1503	2-Acetylfuran	$C_6H_6O_2$	110	0.077	0.19
31	44.780	1521	Benzaldehyde	C_7H_6O	106	1.455	3.69
32	46.551	1549	Linalool	$C_{10}H_{18}O$	154	1.245	3.16
33	47.933	1570	Octanol	$C_8H_{18}O$	130	0.192	0.50
34	48.604	1580	5-Methylfurfural	$C_6H_6O_2$	110	0.151	0.39
35	49.348	1591	5-Methyl-2-acetylfuran	$C_7H_8O_2$	124	0.137	0.36
36	51.162	1621	4-methylbenzaldehyde	C_8H_8O	120	0.380	0.96
37	52.400	1641	Phenylethanal	C_8H_8O	120	0.285	0.72
38	52.714	1647	Safranal	$C_{10}H_{14}O$	150	0.661	1.68
39	53.647	1662	Furfuryl alcohol	$C_5H_6O_2$	98	0.075	0.19
40	53.844	1665	Isoborneol	$C_{10}H_{18}O$	154	0.328	0.83
41	54.404	1674	2-Butanoylfuran	$C_8H_{10}O_2$	138	0.265	0.66
42	55.622	1693	β-Himachalene	$C_{15}H_{24}$	204	0.523	1.32
43	55.946	1698	Terpineol acetate	$C_{12}H_{20}O_2$	196	0.495	1.27
44	57.056	1719	α-Zingibirene	$C_{15}H_{24}$	204	4.960	12.60
45	57.567	1729	2-Formyl-5-methylthiophene	C_6H_6OS	126	0.372	0.94
46	59.625	1766	[*E,Z*]-2,4-Decadienal	$C_{10}H_{16}O$	152	0.200	0.50
47	59.878	1770	α-Ylangene	$C_{15}H_{24}$	204	1.371	3.49
48	59.917	1771	α-Curcumene	$C_{15}H_{22}$	202	3.015	7.63

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 6. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
49	61.625	1802	α-Ionone	$C_{13}H_{20}O$	192	0.006	0.03
50	61.987	1810	[*E,E*]-2,4-Decadienal	$C_{10}H_{16}O$	152	1.197	3.03
51	63.761	1851	Geranyl propionate	$C_{13}H_{22}O_2$	210	0.422	1.07
52	63.892	1854	Geranyl acetone	$C_{13}H_{22}O$	194	0.453	1.16
53	66.659	1919	Phenethyl alcohol	$C_8H_{10}O$	122	1.006	2.56
54	67.316	1937	Logiborneol	$C_{15}H_{26}O$	222	1.412	3.58
55	67.648	1947	β-Ionone	$C_{13}H_{20}O$	192	0.783	1.98
56	68.808	1978	2-Acetyl pyrrole	C_6H_7NO	109	0.449	1.13
57	69.636	2000	β-Ionone epoxide	$C_{13}H_{20}O_2$	208	0.381	0.96
58	70.953	2039	Nerolidol	$C_{15}H_{26}O$	222	1.631	4.13
59	74.062	2137	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	0.688	1.73
61	74.789	2164	Pentadecyl acetate	$C_{17}H_{34}O_2$	270	0.760	1.93
61	75.455	2189	4-Hydroxy-β-ionone	$C_{13}H_{20}O_2$	208	2.065	5.25
62	77.106	2245	4-Hydroxy-3-methylacetophenone	$C_9H_{10}O_2$	150	1.369	3.47
						39.463	100.00

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 7. Volatile flavor compounds identified in irradiated dried red pepper at 5 kGy

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.613	872	Ethyl acetate	$C_4H_8O_2$	88	0.566	2.48
2	8.309	901	2-Methyl-butanal	$C_5H_{10}O$	86	0.264	1.16
3	8.441	905	3-Methyl-butanal	$C_5H_{10}O$	86	0.501	2.20
4	9.134	929	Ethanol	C_2H_6O	46	0.209	0.92
5	9.361	936	3-Buten-2-one	C_4H_6O	70	0.007	0.02
6	9.630	945	2-Ethyl furan	C_6H_8O	96	0.027	0.12
7	10.489	970	2,3-Butanedione	$C_4H_6O_2$	86	0.175	0.76
8	13.321	1037	Toluene	C_7H_8	92	0.082	0.54
9	14.325	1056	2,3-Pentanedione	$C_5H_8O_2$	100	0.077	0.33
10	15.614	1080	Hexanal	$C_6H_{12}O$	100	0.105	0.45
11	18.550	1130	3-Penten-2-one	C_5H_8O	84	0.159	0.68
12	18.850	1135	1-Methyl pyrrole	C_5H_7N	81	0.058	0.26
13	19.049	1138	o-Xylene	C_8H_{10}	106	0.555	2.43
14	21.995	1183	Pyridine	C_5H_5N	79	0.239	1.04
15	23.730	1208	(E)-2-Hexenal	$C_6H_{10}O$	98	0.015	0.07
16	25.102	1230	2-Pentyl-furan	$C_6H_{14}O$	138	0.116	0.52
17	26.459	1250	(E)-β-Ocimene	$C_{10}H_{16}$	136	0.128	0.57
18	26.669	1253	Pentanol	$C_5H_{12}O$	88	0.118	0.52
19	27.291	1262	Dihydro-2-methyl-3[2H]-furanone	$C_5H_8O_2$	100	0.041	0.19
20	27.592	1266	Methylpyrazine	$C_5H_6N_2$	94	0.014	0.07
21	29.878	1297	3-Hepten-2-one	$C_7H_{12}O$	112	0.081	0.35
I.S.[5)]	30.660	1309	Butylbenzene	$C_{10}H_{14}$	134	-	-
22	31.296	1319	4-Methyl pentanol	$C_6H_{14}O$	102	0.019	0.09
23	31.437	1321	(E)-2-Heptenal	$C_7H_{12}O$	112	0.082	0.35

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight, I.S.[5)]: Internal standard.

Table 7. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
24	33.724	1356	4-Ethyl undecane	$C_{13}H_{28}$	184	0.152	0.66
25	35.925	1386	3,4-Epoxy-2-pentanone	$C_6H_{10}O_2$	114	0.103	0.45
26	38.654	1428	1,3-Bis[1,1-dimethylethyl]-benzene	$C_{14}H_{22}$	190	0.266	1.16
27	40.247	1453	Acetic acid	$C_2H_4O_2$	60	0.189	0.83
28	40.840	1462	Furfural	$C_5H_4O_2$	96	1.310	5.74
29	42.913	1492	[*E,E*]-2,4-Heptadienal	$C_7H_{10}O$	110	0.306	1.35
30	43.632	1503	2-Acetylfuran	$C_6H_6O_2$	110	0.153	0.66
31	44.780	1521	Benzaldehyde	C_7H_6O	106	1.091	4.77
32	46.551	1549	Linalool	$C_{10}H_{18}O$	154	1.083	4.75
33	47.933	1570	Octanol	$C_8H_{18}O$	130	0.074	0.33
34	48.604	1580	5-Methylfurfural	$C_6H_6O_2$	110	0.109	0.47
35	49.348	1591	5-Methyl-2-acetylfuran	$C_7H_8O_2$	124	0.127	0.54
36	51.162	1621	4-methylbenzaldehyde	C_8H_8O	120	0.169	0.73
37	52.400	1641	Phenylethanal	C_8H_8O	120	0.589	2.57
38	52.714	1647	Safranal	$C_{10}H_{14}O$	150	0.174	0.76
39	53.647	1662	Furfuryl alcohol	$C_5H_6O_2$	98	0.128	0.57
40	53.844	1665	Isoborneol	$C_{10}H_{18}O$	154	0.037	0.17
41	54.404	1674	2-Butanoylfuran	$C_8H_{10}O_2$	138	0.154	0.66
42	55.622	1693	β-Himachalene	$C_{15}H_{24}$	204	0.276	1.20
43	55.946	1698	Terpineol acetate	$C_{12}H_{20}O_2$	196	0.317	1.39
44	57.056	1719	α-Zingibirene	$C_{15}H_{24}$	204	2.830	12.40
45	57.567	1729	2-Formyl-5-methylthiophene	C_6H_6OS	126	1.218	5.34
46	59.625	1766	[*E,Z*]-2,4-Decadienal	$C_{10}H_{16}O$	152	0.118	0.52
47	59.878	1770	α-Ylangene	$uC_{15}H_{24}$	204	0.942	4.13
48	59.917	1771	α-Curcumene	$C_{15}H_{22}$	202	1.193	5.20

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 7. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
49	61.625	1802	α-Ionone	$C_{13}H_{20}O$	192	0.481	2.10
50	61.987	1810	[*E,E*]-2,4-Decadienal	$C_{10}H_{16}O$	152	0.557	2.43
51	63.761	1851	Geranyl propionate	$C_{13}H_{22}O_2$	210	0.290	1.28
52	63.892	1854	Geranyl acetone	$C_{13}H_{22}O$	194	0.235	1.04
53	66.659	1919	Phenethyl alcohol	$C_8H_{10}O$	122	0.244	1.06
54	67.316	1937	Logiborneol	$C_{15}H_{26}O$	222	0.486	2.13
55	67.648	1947	β-Ionone	$C_{13}H_{20}O$	192	0.322	1.42
56	68.808	1978	2-Acetyl pyrrole	C_6H_7NO	109	0.196	0.85
57	69.636	2000	β-Ionone epoxide	$C_{13}H_{20}O_2$	208	0.177	0.78
58	70.953	2039	Nerolidol	$C_{15}H_{26}O$	222	0.686	3.00
59	74.062	2137	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	0.297	1.30
61	74.789	2164	Pentadecyl acetate	$C_{17}H_{34}O_2$	270	0.234	1.02
61	75.455	2189	4-Hydroxy-β-ionone	$C_{13}H_{20}O_2$	208	1.131	4.96
62	77.106	2245	4-Hydroxy-3-methylacetophenone	$C_9H_{10}O_2$	150	0.724	3.16
						22.806	100.00

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 8. Volatile flavor compounds identified in irradiated dried red pepper at 10 kGy

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.613	872	Ethyl acetate	$C_4H_8O_2$	88	0.709	3.04
2	8.309	901	2-Methyl-butanal	$C_5H_{10}O$	86	0.515	2.21
3	8.441	905	3-Methyl-butanal	$C_5H_{10}O$	86	1.079	4.63
4	9.134	929	Ethanol	C_2H_6O	46	0.386	1.65
5	9.361	936	3-Buten-2-one	C_4H_6O	70	0.078	0.33
6	9.630	945	2-Ethyl furan	C_6H_8O	96	0.091	0.39
7	10.489	970	2,3-Butanedione	$C_4H_6O_2$	86	0.366	1.57
8	13.321	1037	Toluene	C_7H_8	92	0.073	0.31
9	14.325	1056	2,3-Pentanedione	$C_5H_8O_2$	100	0.181	0.78
10	15.614	1080	Hexanal	$C_6H_{12}O$	100	0.164	0.70
11	18.550	1130	3-Penten-2-one	C_5H_8O	84	0.180	0.77
12	18.850	1135	1-Methyl pyrrole	C_5H_7N	81	0.126	0.54
13	19.049	1138	o-Xylene	C_8H_{10}	106	0.884	3.79
14	21.995	1183	Pyridine	C_5H_5N	79	0.642	2.75
15	23.730	1208	(E)-2-Hexenal	$C_6H_{10}O$	98	0.066	0.28
16	25.102	1230	2-Pentyl-furan	$C_6H_{14}O$	138	0.152	0.65
17	26.459	1250	(E)-β-Ocimene	$C_{10}H_{16}$	136	0.107	0.46
18	26.669	1253	Pentanol	$C_5H_{12}O$	88	0.125	0.54
19	27.291	1262	Dihydro-2-methyl-3[2H]-furanone	$C_5H_8O_2$	100	0.113	0.48
20	27.592	1266	Methylpyrazine	$C_5H_6N_2$	94	0.067	0.29
21	29.878	1297	3-Hepten-2-one	$C_7H_{12}O$	112	0.128	0.55
I.S.[5)]	30.660	1309	Butylbenzene	$C_{10}H_{14}$	134	-	-
22	31.296	1319	4-Methyl pentanol	$C_6H_{14}O$	102	0.047	0.20
23	31.437	1321	(E)-2-Heptenal	$C_7H_{12}O$	112	0.115	0.49

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight, I.S.[5)]: Internal standard.

Table 8. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
24	33.724	1356	4-Ethyl undecane	$C_{13}H_{28}$	184	0.160	0.69
25	35.925	1386	3,4-Epoxy-2-pentanone	$C_6H_{10}O_2$	114	0.032	0.14
26	38.654	1428	1,3-Bis[1,1-dimethylethyl]-benzene	$C_{14}H_{22}$	190	0.466	2.00
27	40.247	1453	Acetic acid	$C_2H_4O_2$	60	0.097	0.42
28	40.840	1462	Furfural	$C_5H_4O_2$	96	1.976	8.47
29	42.913	1492	[*E,E*]-2,4-Heptadienal	$C_7H_{10}O$	110	0.070	0.30
30	43.632	1503	2-Acetylfuran	$C_6H_6O_2$	110	0.258	1.11
31	44.780	1521	Benzaldehyde	C_7H_6O	106	1.403	6.01
32	46.551	1549	Linalool	$C_{10}H_{18}O$	154	1.072	4.60
33	47.933	1570	Octanol	$C_8H_{18}O$	130	0.076	0.32
34	48.604	1580	5-Methylfurfural	$C_6H_6O_2$	110	0.089	0.38
35	49.348	1591	5-Methyl-2-acetylfuran	$C_7H_8O_2$	124	0.147	0.63
36	51.162	1621	4-methylbenzaldehyde	C_8H_8O	120	0.126	0.54
37	52.400	1641	Phenylethanal	C_8H_8O	120	0.494	2.12
38	52.714	1647	Safranal	$C_{10}H_{14}O$	150	0.333	1.43
39	53.647	1662	Furfuryl alcohol	$C_5H_6O_2$	98	0.273	1.17
40	53.844	1665	Isoborneol	$C_{10}H_{18}O$	154	0.156	0.67
41	54.404	1674	2-Butanoylfuran	$C_8H_{10}O_2$	138	0.022	0.10
42	55.622	1693	β-Himachalene	$C_{15}H_{24}$	204	0.443	1.90
43	55.946	1698	Terpineol acetate	$C_{12}H_{20}O_2$	196	0.099	0.42
44	57.056	1719	α-Zingibirene	$C_{15}H_{24}$	204	1.057	4.53
45	57.567	1729	2-Formyl-5-methylthiophene	C_6H_6OS	126	0.310	1.33
46	59.625	1766	[*E,Z*]-2,4-Decadienal	$C_{10}H_{16}O$	152	0.103	0.44
47	59.878	1770	α-Ylangene	$C_{15}H_{24}$	204	0.671	2.88
48	59.917	1771	α-Curcumene	$C_{15}H_{22}$	202	2.082	8.93

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 8. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
49	61.625	1802	α-Ionone	$C_{13}H_{20}O$	192	0.178	0.76
50	61.987	1810	[*E,E*]-2,4-Decadienal	$C_{10}H_{16}O$	152	0.167	0.72
51	63.761	1851	Geranyl propionate	$C_{13}H_{22}O_2$	210	0.200	0.86
52	63.892	1854	Geranyl acetone	$C_{13}H_{22}O$	194	0.142	0.61
53	66.659	1919	Phenethyl alcohol	$C_8H_{10}O$	122	0.008	0.03
54	67.316	1937	Logiborneol	$C_{15}H_{26}O$	222	0.571	2.45
55	67.648	1947	β-Ionone	$C_{13}H_{20}O$	192	0.273	1.17
56	68.808	1978	2-Acetyl pyrrole	C_6H_7NO	109	0.206	0.88
57	69.636	2000	β-Ionone epoxide	$C_{13}H_{20}O_2$	208	0.131	0.56
58	70.953	2039	Nerolidol	$C_{15}H_{26}O$	222	0.618	2.67
59	74.062	2137	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	0.318	1.37
61	74.789	2164	Pentadecyl acetate	$C_{17}H_{34}O_2$	270	0.397	1.70
61	75.455	2189	4-Hydroxy-β-ionone	$C_{13}H_{20}O_2$	208	0.948	4.06
62	77.106	2245	4-Hydroxy-3-methylacetophenone	$C_9H_{10}O_2$	150	0.754	3.23
						22.320	100.00

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 9. Volatile flavor compounds identified in irradiated dried red pepper at 20 kGy

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.613	872	Ethyl acetate	$C_4H_8O_2$	88	0.498	2.31
2	8.309	901	2-Methyl-butanal	$C_5H_{10}O$	86	0.421	1.97
3	8.441	905	3-Methyl-butanal	$C_5H_{10}O$	86	0.945	4.40
4	9.134	929	Ethanol	C_2H_6O	46	0.386	1.80
5	9.361	936	3-Buten-2-one	C_4H_6O	70	0.073	0.34
6	9.630	945	2-Ethyl furan	C_6H_8O	96	0.101	0.28
7	10.489	970	2,3-Butanedione	$C_4H_6O_2$	86	0.334	1.56
8	13.321	1037	Toluene	C_7H_8	92	0.142	0.67
9	14.325	1056	2,3-Pentanedione	$C_5H_8O_2$	100	0.152	0.71
10	15.614	1080	Hexanal	$C_6H_{12}O$	100	0.201	0.93
11	18.550	1130	3-Penten-2-one	C_5H_8O	84	0.198	0.91
12	18.850	1135	1-Methyl pyrrole	C_5H_7N	81	0.150	0.71
13	19.049	1138	o-Xylene	C_8H_{10}	106	0.735	3.43
14	21.995	1183	Pyridine	C_5H_5N	79	0.520	2.41
15	23.730	1208	(E)-2-Hexenal	$C_6H_{10}O$	98	0.010	0.04
16	25.102	1230	2-Pentyl-furan	$C_6H_{14}O$	138	0.185	0.85
17	26.459	1250	(E)-β-Ocimene	$C_{10}H_{16}$	136	0.085	0.39
18	26.669	1253	Pentanol	$C_5H_{12}O$	88	0.084	0.39
19	27.291	1262	Dihydro-2-methyl-3[2H]-furanone	$C_5H_8O_2$	100	0.100	0.28
20	27.592	1266	Methylpyrazine	$C_5H_6N_2$	94	0.090	0.26
21	29.878	1297	3-Hepten-2-one	$C_7H_{12}O$	112	0.133	0.63
I.S.[5)]	30.660	1309	Butylbenzene	$C_{10}H_{14}$	134	-	-
22	31.296	1319	4-Methyl pentanol	$C_6H_{14}O$	102	0.007	0.04
23	31.437	1321	(E)-2-Heptenal	$C_7H_{12}O$	112	0.059	0.28

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight, I.S.[5)]: Internal standard.

Table 9. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
24	33.724	1356	4-Ethyl undecane	$C_{13}H_{28}$	184	0.134	0.63
25	35.925	1386	3,4-Epoxy-2-pentanone	$C_6H_{10}O_2$	114	0.006	0.02
26	38.654	1428	1,3-Bis[1,1-dimethylethyl]-benzene	$C_{14}H_{22}$	190	0.701	3.27
27	40.247	1453	Acetic acid	$C_2H_4O_2$	60	0.063	0.28
28	40.840	1462	Furfural	$C_5H_4O_2$	96	1.335	6.23
29	42.913	1492	[*E,E*]-2,4-Heptadienal	$C_7H_{10}O$	110	0.064	0.30
30	43.632	1503	2-Acetylfuran	$C_6H_6O_2$	110	0.133	0.63
31	44.780	1521	Benzaldehyde	C_7H_6O	106	1.051	4.91
32	46.551	1549	Linalool	$C_{10}H_{18}O$	154	0.654	3.04
33	47.933	1570	Octanol	$C_8H_{18}O$	130	0.043	0.20
34	48.604	1580	5-Methylfurfural	$C_6H_6O_2$	110	0.065	0.30
35	49.348	1591	5-Methyl-2-acetylfuran	$C_7H_8O_2$	124	0.064	0.30
36	51.162	1621	4-methylbenzaldehyde	C_8H_8O	120	0.136	0.63
37	52.400	1641	Phenylethanal	C_8H_8O	120	0.459	2.13
38	52.714	1647	Safranal	$C_{10}H_{14}O$	150	0.452	2.11
39	53.647	1662	Furfuryl alcohol	$C_5H_6O_2$	98	0.207	0.97
40	53.844	1665	Isoborneol	$C_{10}H_{18}O$	154	0.029	0.14
41	54.404	1674	2-Butanoylfuran	$C_8H_{10}O_2$	138	0.122	0.57
42	55.622	1693	β-Himachalene	$C_{15}H_{24}$	204	0.306	1.42
43	55.946	1698	Terpineol acetate	$C_{12}H_{20}O_2$	196	0.037	0.18
44	57.056	1719	α-Zingibirene	$C_{15}H_{24}$	204	1.716	7.99
45	57.567	1729	2-Formyl-5-methylthiophene	C_6H_6OS	126	1.088	5.07
46	59.625	1766	[*E,Z*]-2,4-Decadienal	$C_{10}H_{16}O$	152	0.225	1.05
47	59.878	1770	α-Ylangene	$C_{15}H_{24}$	204	0.945	4.40
48	59.917	1771	α-Curcumene	$C_{15}H_{22}$	202	0.848	3.97

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

Table 9. Continued

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
49	61.625	1802	α-Ionone	$C_{13}H_{20}O$	192	0.108	0.51
50	61.987	1810	[*E,E*]-2,4-Decadienal	$C_{10}H_{16}O$	152	0.401	1.87
51	63.761	1851	Geranyl propionate	$C_{13}H_{22}O_2$	210	0.126	0.59
52	63.892	1854	Geranyl acetone	$C_{13}H_{22}O$	194	0.125	0.59
53	66.659	1919	Phenethyl alcohol	$C_8H_{10}O$	122	0.257	1.20
54	67.316	1937	Logiborneol	$C_{15}H_{26}O$	222	0.737	3.43
55	67.648	1947	β-Ionone	$C_{13}H_{20}O$	192	0.312	1.46
56	68.808	1978	2-Acetyl pyrrole	C_6H_7NO	109	0.083	0.39
57	69.636	2000	β-Ionone epoxide	$C_{13}H_{20}O_2$	208	0.164	0.77
58	70.953	2039	Nerolidol	$C_{15}H_{26}O$	222	0.924	4.30
59	74.062	2137	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	0.277	1.30
61	74.789	2164	Pentadecyl acetate	$C_{17}H_{34}O_2$	270	0.338	1.58
61	75.455	2189	4-Hydroxy-β-ionone	$C_{13}H_{20}O_2$	208	0.936	4.36
62	77.106	2245	4-Hydroxy-3-methylacetophenone	$C_9H_{10}O_2$	150	0.285	1.32
						21.565	100.00

R.T.[1)]:Retention time, R.I.[2)]:Retention index, M.F.[3)]:Molecule formula, F.W.[4)]:Formula weight.

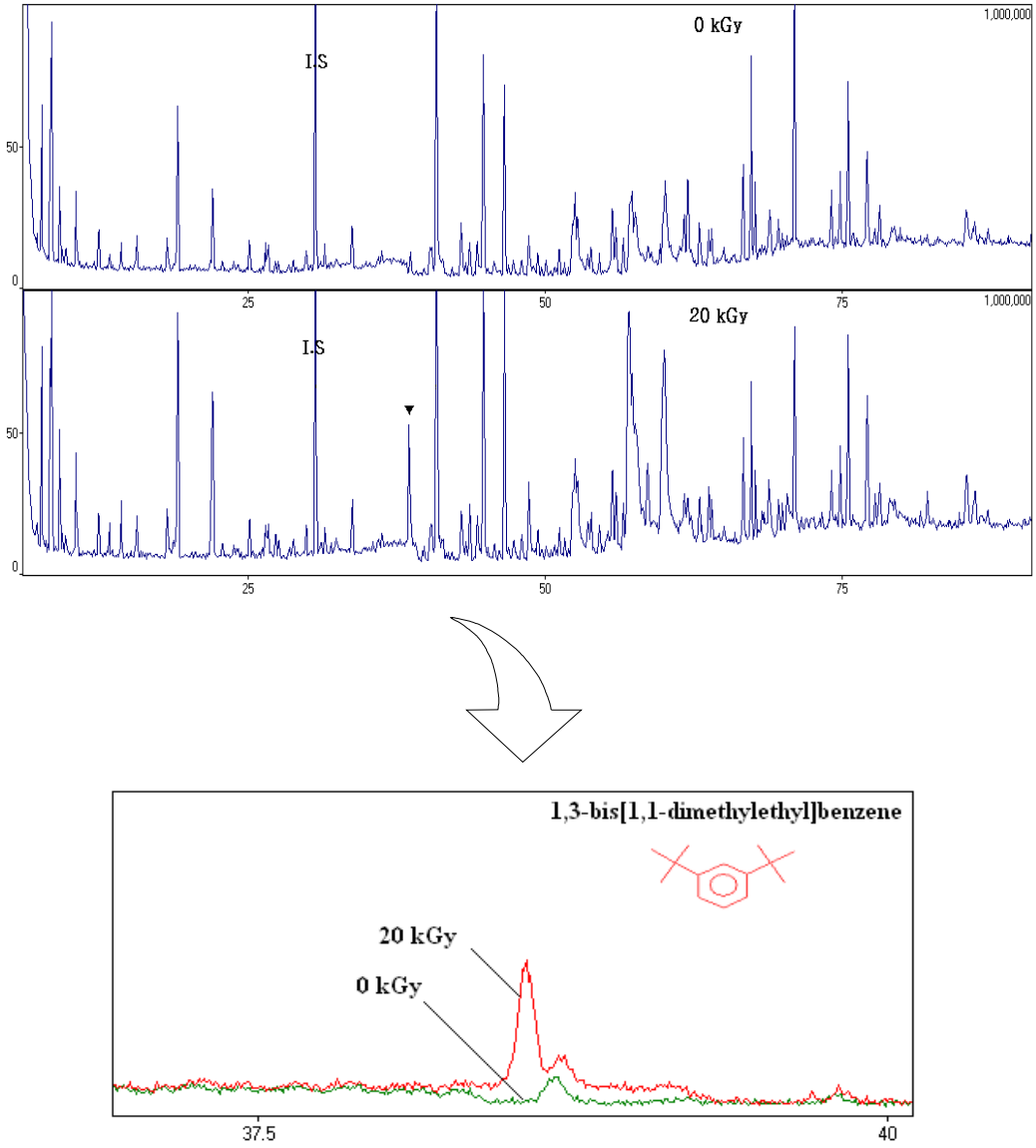

Figure 4. GC/MS total ion chromatograms of the volatile flavor compounds in unirradiated and irradiated dried red peppers at 20 kGy.

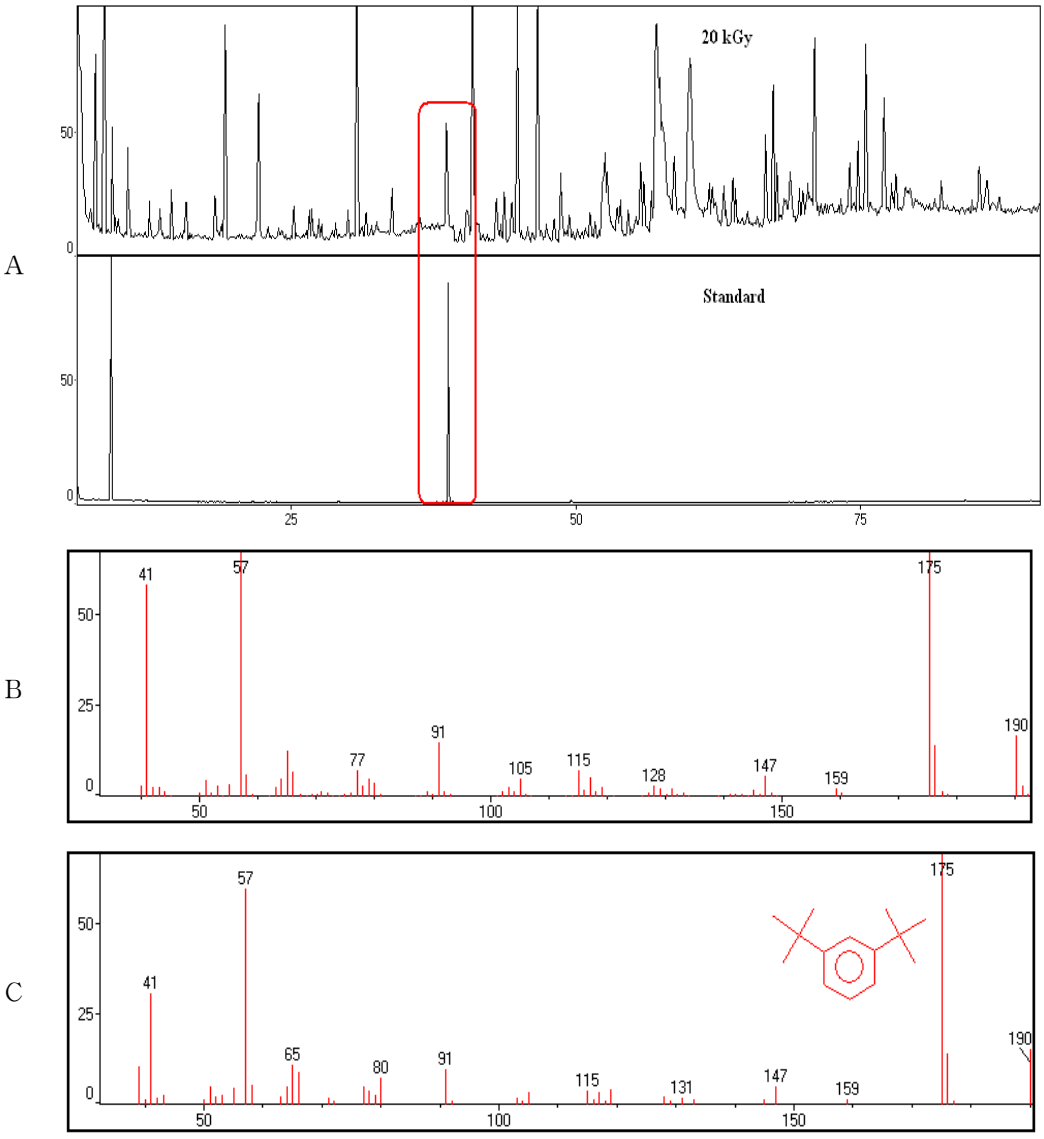

Figure 5. Comparison of mass spectrum of 1,3-bis[1,1-dimethylethyl]-benzene compound from irradiated dried red pepper and standard.
A: chromatograms of irradiated dried red pepper and standard, B: mass spectrum of 1,3-bis[1,1-dimethylethyl]-benzene (standard), C: mass spectrum of same compound obtained from irradiated dried red pepper.

3. Comparison of volatile flavor compounds between unirradiated and irradiated samples

The characteristic flavor compounds, including GC/MS profile of volatile compounds in irradiated dried red peppers were similar to those in untreated control samples. However, the relative amounts of these compounds were changed by irradiation. These changes in the proportions of volatile compounds are shown in Table 10.

The total content of volatile compound of unirradiated sample was approximately 15.860 mg/kg while irradiated samples at 1, 3, 5, 10 and 20 kGy were 27.664, 39.463, 22.806, 23.320 and 21.565 mg/kg, respectively. The total amount of volatile compounds was increased after irradiation, but the ratios of individual substances varied with different doses of radiation. Total levels of volatile compounds were highly increased at irradiation doses of 3 kGy (39.463 mg/kg).

The classification of flavor compounds by functional groups are shown in Table 11. In unirradiated dried red pepper the flavor compounds consisted of 6 alcohols, 13 aldehydes, 2 esters, 6 furans, 7 ketones, 4 N-containing compounds, 3 hydrocarbons, 18 terpenes and 2 miscellaneous compounds. The relative areas obtained for each functional group were alcohols (3.40%), aldehydes (28.94%), esters (4.65%), furans (3.05%), ketones (7.45%), N-containing compounds (3.65%), hydrocarbons (4.72%), terpenes (41.42%) and miscellaneous compounds(2.72%) (Table 11). In 1 kGy irradiated dried red pepper, the flavor compounds consisted of 6 alcohols (6.80%), 13 aldehydes (22.54%), 2 esters (5.34%), 6 furans (1.66%), 7 ketones (3.14%), 4 N-containing compounds(1.58%), 4 hydrocarbons (3.87%), 18 terpenes

(52.59%) and 2 miscellaneous compounds (2.48%)(Table 11). In all samples, the amount of terpene was highest among all other types of flavor compounds. Levels of alcohols, esters and terpenes in dried red peppers were increased after irradiation. In dried red pepper irradiated at 3 kGy, the flavor compounds consisted of 6 alcohols (4.87%), 13 aldehydes (19.38%), 2 esters (5.23%), 5 furans (2.12%), 7 ketones (6.75%), 4 N-containing compounds (3.47%), 4 hydrocarbons (3.80%), 18 terpenes (52.20%) and 2 miscellaneous compounds (2.18%)(Table 11).

In dried red pepper irradiated at 5 kGy, chemical classes were the same as in samples irradiated at 1 kGy. The relative areas obtained for each functional group were alcohols (3.49%), aldehydes (22.81%), esters (3.50%), furans (2.69%), ketones (5.75%), N-containing compounds (2.22%), hydrocarbons (4.79%), terpenes (48.58%) and miscellaneous compounds (6.17%)(Table 11). Miscellaneous compounds showed much higher concentration in samples irradiated at 5 kGy than in control samples because of increases in 2-formyl-5-methylthiophene levels.

In dried red pepper irradiated at 10 kGy, the flavor compounds consisted of 6 alcohols (3.91%), 13 aldehydes (27.29%), 2 esters (4.74%), 6 furans (3.36%), 7 ketones (7.37%), 4 N-containing compounds (4.46%), 4 hydrocarbons (6.79%), 18 terpenes (40.33%) and 2 miscellaneous compounds (1.75%)(Table 11).

In dried red pepper irradiated at 20 kGy, chemical classes observed were the same as those found in irradiated dried red pepper at 10 kGy, but the relative areas obtained for each functional group were different: alcohols (4.60%), aldehydes (25.04%), esters (3.89%), furans (2.91%), ketones (5.49%), N-containing compounds (3.77%), hydrocarbons (8.00%), terpenes (40.95%) and miscellaneous compounds (5.35%)(Table 11).

The ratios of the individual chemical compounds were different among treatment. Each compound showed characteristic behavior upon irradiation that may be due its particular sensitivity to radiation.

In dried red pepper samples, most of the volatile compounds were aldehydes, and terpenes. Terpenes were found to represent the largest chemical class of volatile compounds from dried red peppers, accounting 41.42% in unirradiated sample and 52.59%, 52.20%, 48.58%, 40.33% and 40.95% in 1, 3, 5, 10 and 20 kGy irradiated samples. Except for (E)-β-ocimene, β-himachalene, α-ylangene and α-zingibirene, these compounds were detected as mono-, sesquiterpenes and their derivatives. Many sesquiterpenoid compounds were also identified in dried red peppers; β-himachalene, α-zingibirene, α-ylangene, α-curcumene, nerolidol and longiborneol. Sesquiterpenoids and their derivatives are credited with various biological actions, including antiasthmatic, antibacterial, antifungal, anti-inflammatory and antineoplastic activities (29). Terpenes are the generic name of a group of natural products, structurally based on isoprene(isopentenyl) units. The term may also refer to oxygen derivatives of these compounds that are also known as terpenoids (30). Such molecules as 2- and 3- methylbutanal can be formed in Strecker degradation reactions during the drying and cooking process, while most of the other volatiles can be derived from lipid oxidation reactions (31, 32).

The compound 1,3-bis[1,1-dimethylethyl]-benzene appeared after irradiation. 1,3-Bis[1,1-dimethylethyl]-benzene from irradiated dried red peppers were conformed by comparison of its spectrum, RI and RT with standard sample (Figure 5). *M/Z* were 41, 57, 77, 91, 175, 190. It was similar to irradiated dried red pepper. Thus, playing an important role as a radiation marker. Kim *et. al.* (35) selected this compound as a marker in irradiated chicken. This

compound clearly increased in quantity with increasing radiation dosages. The mechanism of alkyl benzene formation is uncertain, but toluene, xylene and benzene derivates are derived from carotenoids. Carotenoids, such as β-carotene and α-carotene, contribute to the unique color of red peppers. They were also important sources of the terpenes found in our study. All samples contained high levels of 4-hydroxy-β-ionone. β-ionone and its derivative, 4-hydroxy-β-ionone, has been reported to be derived from β-carotene, whereas α-ionone is known to come from α-carotene (27, 28). More diverse volatile components were found in dried red pepper, including aldehydes, ketones and acids. These may be derived from lipid oxidation or carotenoids degradation.

Table 10. Comparison of volatile flavor compounds identified in unirradiated and irradiated dried red peppers at 1, 3, 5, 10 and 20 kGy

No	R.T.[1]	R.I.[2]	Compound name	mg/kg					
				0 kGy	1 kGy	3 kGy	5 kGy	10 kGy	20 kGy
1	7.648	873	Ethyl acetate	0.446	1.163	1.305	0.566	0.709	0.498
2	8.337	902	2-Methylbutanal	0.322	0.286	0.436	0.264	0.515	0.421
3	8.467	906	3-Methylbutanal	0.670	0.652	0.912	0.501	1.079	0.945
4	9.160	930	Ethanol	0.225	1.110	0.420	0.209	0.386	0.386
5	9.402	938	3-Buten-2-one	0.038	0.149	0.157	0.007	0.078	0.073
6	9.661	946	2-Ethyl furan	0.063	0.082	-	0.027	0.091	0.101
7	10.521	971	2,3-Butanedione	0.219	0.177	0.406	0.175	0.366	0.334
8	13.348	1038	Toluene	0.040	0.099	0.100	0.082	0.073	0.142
9	14.338	1057	2,3-Pentanedione	0.110	0.082	0.178	0.077	0.181	0.152
10	15.639	1080	Hexanal	0.106	0.121	0.233	0.105	0.164	0.201
11	18.173	1123	3-Penten-2-one	0.093	0.017	0.287	0.159	0.180	0.198
12	18.975	1137	1-Methyl pyrrole	0.067	0.023	0.035	0.058	0.126	0.150
13	19.074	1138	o-Xylene	0.588	0.782	1.032	0.555	0.884	0.735
14	22.015	1183	Pyridine	0.326	0.208	0.829	0.239	0.642	0.520
15	24.170	1215	(*E*)-2-Hexenal	0.043	0.035	0.143	0.015	0.066	0.010
16	25.114	1230	2-Pentyl furan	0.103	0.292	0.224	0.116	0.152	0.185
17	26.485	1251	(*E*)-β-Ocimene	0.076	0.202	0.133	0.128	0.107	0.085
18	26.695	1254	Pentanol	0.094	0.138	0.186	0.118	0.125	0.084
19	27.307	1262	Dihydro-2-methyl-3[2*H*]-furanone	0.052	0.071	0.128	0.041	0.113	0.100
20	27.568	1266	Methyl pyrazine	0.043	0.034	0.051	0.014	0.067	0.090
21	29.904	1298	3-Hepten-2-one	0.108	0.080	0.196	0.081	0.128	0.133
I.S[3]	30.680	1309	Butylbenzene	-	-	-	-	-	-
22	31.117	1316	4-Methyl pentanol	0.014	0.014	0.027	0.019	0.047	0.007
23	31.442	1321	(*E*)-2-Heptenal	0.106	0.004	0.160	0.082	0.115	0.059

R.T.[1]:Retention time, R.I.[2]:Retention index, I.S.[3]: Internal standard.

Table 10. Continued

No	R.T.[1)]	R.I.[2)]	Compound name	mg/kg					
				0 kGy	1 kGy	3 kGy	5 kGy	10 kGy	20 kGy
24	33.749	1356	4-Ethyl undecane	0.121	0.107	0.175	0.152	0.160	0.134
25	35.993	1387	3,4-Epoxy-2-pentanone	0.052	0.007	0.119	0.103	0.032	0.006
26	38.576	1427	1,3-Bis[1,1-dimethylethyl] -benzene	-	0.100	0.196	0.266	0.466	0.701
27	40.343	1454	Acetic acid	0.079	0.408	0.485	0.189	0.097	0.063
28	40.860	1462	Furfural	1.225	1.889	1.718	1.310	1.976	1.335
29	42.921	1492	(*E,E*)-2,4-Heptadienal	0.178	0.365	0.383	0.306	0.070	0.064
30	43.653	1503	2-Acetyl furan	0.136	0.149	0.077	0.153	0.258	0.133
31	44.802	1522	Benzaldehyde	0.968	1.152	1.455	1.091	1.403	1.051
32	46.567	1550	Linalool	0.707	1.491	1.245	1.083	1.072	0.654
33	47.354	1562	Octanol	0.047	0.033	0.192	0.074	0.076	0.043
34	48.012	1571	5-Methylfurfural	0.057	0.310	0.151	0.109	0.089	0.065
35	49.389	1592	5-Methyl-2-acetylfuran	0.079	0.083	0.137	0.127	0.147	0.064
36	51.166	1621	4-Methylbenzaldehyde	0.096	0.087	0.380	0.169	0.126	0.136
37	52.304	1640	Phenylethanal	0.388	0.108	0.285	0.589	0.494	0.459
38	52.725	1647	Safranal	0.264	0.385	0.661	0.174	0.333	0.452
39	53.596	1661	Furfuryl alcohol	0.085	0.226	0.075	0.128	0.273	0.207
40	53.881	1666	Isoborneol	0.064	0.052	0.328	0.037	0.156	0.029
41	54.533	1676	2-Butanoylfuran	0.049	0.014	0.265	0.154	0.022	0.122
42	55.648	1694	β-Himachalene	0.273	0.429	0.523	0.276	0.443	0.306
43	55.940	1698	Terpinyl acetate	0.116	0.502	0.495	0.317	0.099	0.037
44	57.141	1721	α-Zingibirene	0.470	3.785	4.960	2.830	1.057	1.716
45	57.595	1729	2-Formyl-5-methylthiophene	0.352	0.255	0.372	1.218	0.310	1.088
46	59.686	1767	(*E,Z*)-2,4-Decadienal	0.035	0.434	0.200	0.118	0.103	0.225
47	59.944	1772	α-Ylangene	0.265	0.780	1.371	0.942	0.671	0.945
48	60.102	1774	α-Curcumene	0.808	1.893	3.015	1.193	2.082	0.848

R.T.[1)]:Retention time, R.I.[2)]:Retention index.

Table 10. Continued

No	R.T.[1)]	R.I.[2)]	Compound name	mg/kg					
				0 kGy	1 kGy	3 kGy	5 kGy	10 kGy	20 kGy
49	61.737	1804	α-Ionone	0.344	0.106	0.006	0.481	0.178	0.108
50	62.011	1811	(*E,E*)-2,4-decadienal	0.382	0.572	1.197	0.557	0.167	0.401
51	63.770	1851	Geranyl propionate	0.146	0.332	0.422	0.290	0.200	0.126
52	64.017	1857	Geranyl acetone	0.166	0.490	0.453	0.235	0.142	0.125
53	66.508	1915	Phenethyl alcohol	0.073	0.429	1.006	0.244	0.008	0.257
54	67.332	1938	Longiborneol	0.638	0.646	1.412	0.486	0.571	0.737
55	67.677	1947	β-Ionone	0.200	0.521	0.783	0.322	0.273	0.312
56	68.831	1979	2-Acetyl pyrrole	0.142	0.178	0.449	0.196	0.206	0.083
57	69.639	2000	β-Ionone epoxide	0.165	0.226	0.381	0.177	0.131	0.164
58	70.977	2040	Nerolidol	0.862	0.972	1.631	0.686	0.618	0.924
59	74.078	2138	Hexahydrofarnesyl acetone	0.217	0.436	0.688	0.297	0.318	0.277
61	74.821	2165	Pentadecyl acetate	0.292	0.260	0.760	0.234	0.397	0.338
61	75.485	2190	4-Hydroxy-β-ionone	0.806	1.073	2.065	1.131	0.948	0.936
62	77.119	2245	4-Hydroxy-3-methylaceto-phenone	0.561	0.558	1.369	0.724	0.754	0.285
			Total	15.860	27.664	39.463	22.806	23.320	21.565

R.T.[1)]:Retention time, R.I.[2)]:Retention index.

Table 11. Relative content of functional groups in identified volatile compounds in unirradiated and irradiated dried red pepper at 1, 3, 5, 10 and 20 kGy

Functional group	*Relative peak area %*											
	0		*1*		*3*		*5*		*10*		*20*	
	%	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*
Alcohols	3.4	6	6.80	6	4.87	6	3.49	6	3.91	6	4.60	6
Aldehydes	28.94	13	22.54	13	19.38	13	22.81	13	27.29	13	25.04	13
Esters	4.65	2	5.34	2	5.23	2	3.50	2	4.74	2	3.89	2
Furans	3.05	6	1.66	6	2.12	5	2.69	6	3.36	6	2.91	6
Hydrocarbons	4.72	3	3.87	4	3.80	4	4.79	4	6.79	4	8.00	4
Ketones	7.45	7	3.14	7	6.75	7	5.75	7	7.37	7	5.49	7
N-containing Compounds	3.65	4	1.58	4	3.47	4	2.22	4	4.46	4	3.77	4
Terpenes	41.42	18	52.59	18	52.2	18	48.58	18	40.33	18	40.95	18
Miscellaneous	2.72	2	2.48	2	2.18	2	6.17	2	1.75	2	5.35	2
Total	*100*	*61*	*100*	*62*	*100*	*61*	*100*	*62*	*100*	*62*	*100*	*62*

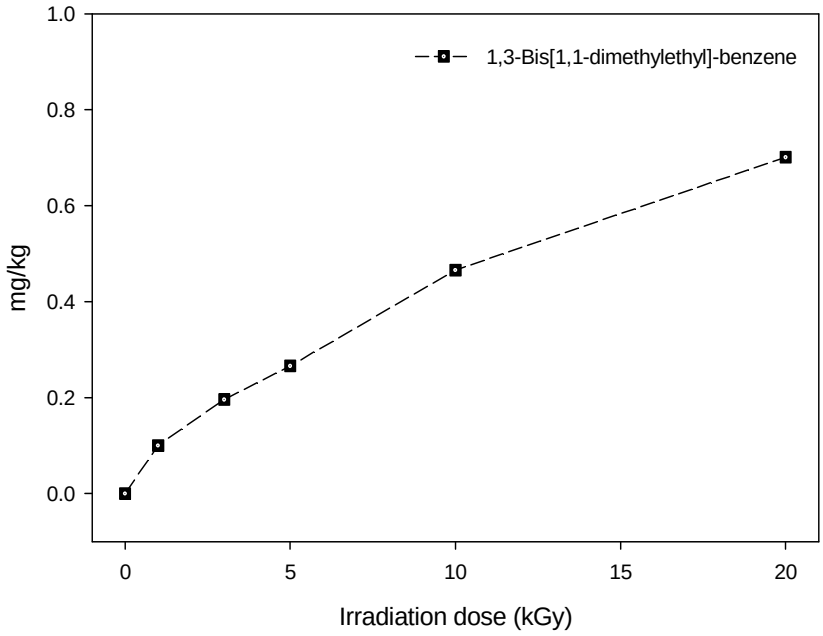

Figure 5. Effect of irradiation on the 1,3-bis[1,1-dimethylethyl]-benzene compound in irradiated dried red pepper.

CONCLUSION

Volatile compounds of dried red peppers irradiated at 1, 3, 5, 10 and 20 kGy were similar to those in unirradiated sample but the proportions of these compounds were different between treatments. The total amount of volatile compounds was highly increased in sample irradiated at 3 kGy. These levels were reduced at 5 kGy, but were still higher than control values. In dried red pepper samples, a large amount of the volatile compounds found were aldehydes and terpenes. The total amount of volatile compounds was not highly changed by irradiation. However, a new compound, 1,3-Bis [1,1-dimethylethyl]-benzene appeared after irradiation. This compound clearly increased in proportion to radiation dosages. And this compound from irradiated dried red pepper was conformed by comparison of its spectra with standard sample. Therefore, it can play an important role as a marker compound to know the history of irradiated dried red pepper.

요 약

본 연구에서는 우리 나라의 대표적인 향신료 중의 하나인 건고추의 휘발성 유기성분을 방사선 조사된 건고추와 비교하였다. n-pentane과 diethylether 혼합용매를 추출용매로 사용하여 연속증류추출장치로 추출하고 이를 GC/MS로 사용하여 분석·확인하였다. 대조군에서 확인된 성분은 61종, 1, 3, 5, 10 및 20 kGy로 방사선 조사된 건고추에서 확인된 성분은 3 kGy에서만 61종, 나머지는 62종이 확인되었다. 관능기별 상대 면적비는 대체적으로 terpene류, aldehyde류가 두드러지는 경향을 보여 건고추의 주요 휘발성 유기화합물에 크게 영향을 미치는 것으로 판단되었다. 건고추의 대표적인 휘발성 유기화합물로는 α-zingibirene, furfural, benzaldehyde, linalool, nerolidol 및 α-curcumene 등이었다. 특히 1,3-bis[1,1-dimethylethyl]-benzene (1,3-di-*tert*-butyl benzene)은 대조군에서는 발견되지 않았고 그 함량 또한 선량이 증가함에 따라 점차 증가하였다. 표준품과 대조해 본 결과, RI 및 스펙트럼이 일치하여 건고추의 방사선 조사여부를 확인하는데 이용가능성이 높을 것으로 판단되었다.

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