Thesis for Degree of Master of Science

Effect of Gamma-Irradiation on the Volatile Effective Components of Houttuynia cordata Thunb.

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This is to certify that the Master's thesis of

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ABSTRACT

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This study was performed to examine the effect of γ-irradiation on the volatile organic compounds in *Houttuynia cordata* Thunb.. Volatile compounds from *H. cordata* samples were extracted using an SDE apparatus, and analyzed by GC/MS. Total components of 83, 85, 84, 84, 85 and 84 were detected in the control and the 1, 3, 5, 10 and 20 kGy irradiation doses, respectively. The major functional groups in the volatile organic compounds of *H. cordata* were alcohols and ketones. The profile of volatile organic compounds was same in unirradiated and irradiated samples. And, hexahydrofarnesyl acetone, phytol, decanoic acid, dodecanoic acid, octadecanol, caryophyllene oxide, 2-undecanone and menthol were detected as dominant compounds. Also houttuynum, which is characteristic compound of *H. cordata* was analyzed as low amount. The total contents of volatile compounds was increased after irradiation, and the level of irradiated sample at 5 kGy was

more greater than other irradiated samples. However, the tendency was not significant with irradiation doses. Consequently, irradiation may be an effective sanitation process with energy and extraction efficiency, as well as desirable aspects for components, which will prove beneficial for *H. cordata*.

INTRODUCTION

Medicinal herbs are important food material been using as food well as medicines. Recently, medicinal herb consumption is increased because national interested in health. Specially, among the medicinal herbs, *Houttuynia cordata* Thunb have been widely used as the raw materials of the functional food and dietary supplement (1). But, it has many problems on during the all stage of distribution from aspect of medicinal herbs.

Recently data about medicinal herb consumption is 67,240 M/T in 2003. Production of medicinal herbs increased from 2000 to 2005, and the amount was from 23,414 to 44,844 M/T in Korea (2). In the case of the total imported medicinal herbs, the relative percentages of cost for imports are 56.4% (39.83 millions of dollars) from China (3). However, in contrast to increase of distribution, medicinal herbs of domestic and imported products were sold in P.P net and sack without any packing standards of trade unit. So we need proper storage technique for the medicinal herbs (4).

Medicinal herbs are mainly comprised of organic matter, and are high in moisture and abundant in nutrients, making them highly susceptible to microbial growth. Also, during production, processing, distribution, and storage, medicinal herbs are subject to deterioration from chemical and microbial processes. There are several method to protect the medicinal herb, such as methyl bromide (MB), ethylene dibromide (EB), ethylene oxide (ETO) etc. (5). The common method of decontamination has been fumigation with sulfur dioxide, which is a process that is prohibited or increasingly restricted to less than 10 ppm in many countries due to the associated health hazards (6,7). In addition, sulfite has been changed to sulfate by oxidation in

vivo. Sulfate then becomes isolated sulfurous acid that can stimulate the stomach, and is very harmful to humans. For example, a study reported that sulfurous acid caused hypersensitiveness reactions in asthmatic and sensitive normal men. In addition, it may cause organ contraction, headache, stomachache, nausea, vertigo, vomiting, and even death (8).

Consequently, safe alternative hygienic technologies for medicinal herbs are in demand. Various disinfectant technologies have been suggested and include electromagnetic radiation, photo-dynamic pulsing, ultrahigh pressure, and CO_2 treatment (9). The greatest expectations, however, are placed on the developments of irradiation as the new food sanitation and processing method for improving food quality, variety, and safety. Additional aims include the prevention of microbial deterioration and the extermination of vermin (10). In 1981, the JECFI (WHO/FAO/IAEA Joint Expert Committee on the Wholesomeness of Food Irradiation) stated that "the irradiation of any food commodity, up to an overall average dose of 10 kGy, presents no toxicological hazard, and introduces no special nutritional or microbiological problems" (11). The treatment of food with ionizing radiation is one of the most thoroughly researched methods available to the food processing industry, and is currently permitted in 55 countries for the approximately 250 kinds of food products (12). Especially, including France, Belgium, Denmark, and the Netherlands ets. total of 8 countries permitted to treat for the insecticide and sterilization of herbs. In Korea, however, irradiation for the medicinal herbs are not permitted yet (13) (Table 1).

Table 1. Permitted irradiation dose, item, purpose in Korea.

Item	Purpose	Permission dose (kGy)
Potatoes, onions and garlic	Inhibit sprouting	0.15 (max)
Chestnuts	Inhibit sprouting	0.25 (max)
Mushrooms (fresh and dried)	Sterilization Delay ripening	1.00 (max)
Egg powder and raw grain for processed food Beans and beans powder Starch for spiced food	Sterilization Disinfestation	5.00 (max)
Dried meat, fish and shellfish powder for processed food ingredients Soybean paste powder, red pepper paste powder and soy sauce powder Yeast powder and enzyme preparation Aloe powder Ginseng products Dried vegetables for processed food ingredients	Sterilization Disinfestation	7.00 (max)
Spices and dried vegetable seasonings Sterile meals for hospital patients Powdered teas	Sterilization Disinfestation	10.00 (max)

Hottuynia cordata Thunb. (Saururaceae) is a perennial herb native to Southeast Asia (Korea, Japan, China, Himalayas, and Java). It has a thin stalk and heart-like leaf. The leaves are at an alternate phyllotaxis position with long leaf stalks, and are 3-8 cm long and 3-6 cm wide. They have 5 distinct veins, a mild green color, are sharp at the end, and the edge of the leaf is non-saw tooth. The herb grows to 20-50 cm high in moist locations,

with an indefinite spread as a creeping rhizome (14). Two species are native to Korea: *Saururus chinensis* Baill. and *Houttuynia cordata* Thunb. Previous studies have reported that *S. chinensis* is distributed on the eastern marsh of Jeju, and *H. cordata* grows on Ulleung Island and in the central districts (15).

H. cordata posseses a characteristic fishy smell, and has detoxification and diuresis effects. It is also known for mitigating symptoms of pertussis, bronchial problems, hepatitis, pneumonia, etc. *H. cordata* has a variety of prescription names such as"Ji cai" and "Yu xing cao" in China, "Dokudami" in Japan, "Diep ca" in Vietnam, and "E sung cho" and "Yak mo mil" in Korea. The name "E sung cho" originates from the fishy smell of *H. cordata*. In ancient China, *H. cordata* was the smell of salted fish, so it was called "Ji cai". In the case of Japan, it was called "sib yak" because it has efficacy for 10 uses, including the excretion of toxins in vivo, cleaning the blood, various kinds of dermatosis, the treatment of constipation, etc. (16). According to the "bon cho gang mok," *H. cordata* is effective as a fever reducer, detoxifier, diuretic, suppurate, and anti-inflammatory. Also, it has been used for chronic dermatosis and diuresis, and as an anti-inflammatory in traditional Oriental medicine (17). Especially, H. cordata has been using as treatment for skin diseases, such as atopy and allergic symptoms. Recently, also, *H. cordata* increased to use it as health assistance food.

Studies of *H. cordata* have investigated its properties relative to essential oils (18,19), steroids (20), alkaloids (21), flavonoids (22,23), etc. In addition, it provides a wide range of pharmacological activities, including antioxidative (24,29), antimicrobial (31), anticancer (25,31), antileukemic (26), and anti-high cholesterol activities (27), as well as effects against cadmium-induced

cytotoxicity (28), anti-anaphylaxis, and protective effects tohepatotoxicity (30). It wasalso recently studied as a red tide inhibitor (32).

As we have seen, a large amount of research confirms the effects of *H. cordata*. But our study is the first on the changes in its volatile organic compounds by γ-irradiation. Moreover, we must address aspects of Medicinal herb related to sanitation and preservation during distribution. Although numerous studies have been performed on these problems, there is no effective solution. In this study, we used γ-irradiation as a method for improving eating safety and for minimizing harm from insect multiplication and microbial growth. We also identified changes in the volatile organic compounds after irradiation at 1, 3, 5, 10, and 20 kGy doses using a GC/MS.

MATERIALS AND METHODS

A. Materials and analytic apparatus

1. Materials

H. cordata (*Houttuynia cordata* Thumb.) were purchased from a local medicinal herb market in Hawsun of Jeonnam province. They were irradiated at doses of 1, 3, 5, 10 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 *H. cordata* was considered as a control and both irradiated and unirradiated *H. cordata*s 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 (Pittsburg 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 (Pinnacle 530P, Nova Analytics Corporation, woburn, USA)

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 chromatograph/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 organic compounds

Each 30 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 mg 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.* (33,34) under atmospheric pressure (Figure 1).

The extract was dehydrated for 12 hours with anhydrous sodium sulfate and was concentrated to final volume approximately 1 mL using a vigreux column. This sample was finally used for the GC/MS analysis.

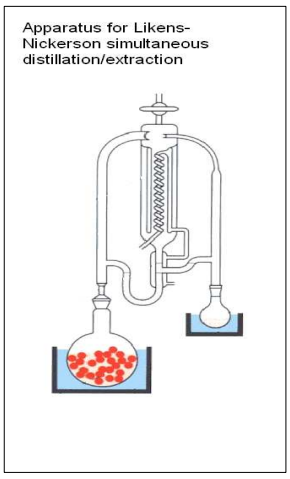

Figure 1. Apparatus for Likens and Nickerson simultaneous distillation and extraction (SDE) of volatile compounds.

2. Establishment of retention index

Kovats(35) 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.

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

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 (36).

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/MS under the

condition of Table 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.

3. Analysis and identification of volatile organic compounds

a. Analysis of gas chromatograph/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 *H. cordata*s. 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 100℃ at 2℃/min to 150℃ at 3℃/min (10 min) and finally 210℃ at 4℃/min (5 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 1:10 split ratio (Table 2).

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)-3℃/min-100℃-2℃/min-150℃(10 min)-3℃/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 (37,38) as well as by the comparison of retention indices to reference data (39,40). The resultant slurry was used for the quantitative analysis with 1 mg of n-butyl benzene added as an internal standard.

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

A : Peak area of each sample of internal standard

B : Amount of sample

C : Peak area of each component in sample

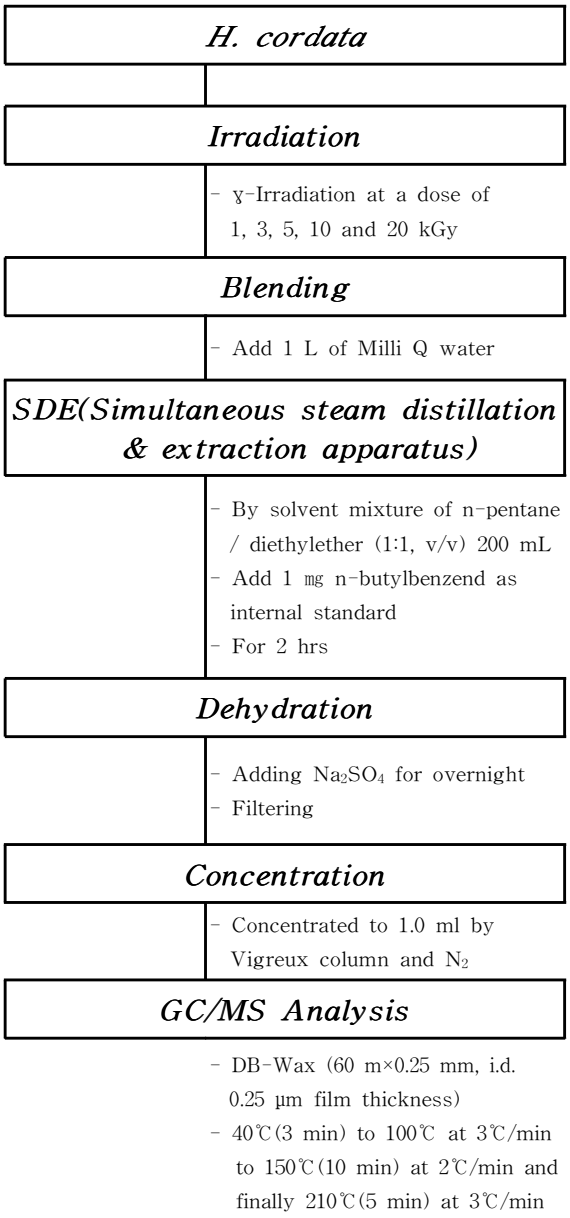

Figure 2. Scheme for analysis of volatile organic compounds of unirradiated and irradiated H. cordatas.

RESULTS AND DISCUSSION

*A. Analysis of volatile organic compounds in H. cordata*s

*1. Extraction of volatile organic compounds in H. cordata*s

Extraction method using SDE apparatus was suggested as an effective method for volatile organic compounds in foods (33,34). Therefore, this method was used to extract the volatile organic compounds.

*2. Volatile organic compounds in H. cordata*s *by GC/MS analysis*

Shimadzu GC/MS QP-5000 (Kyoto, Japan) in the EI (electron impact) mode was used for the analysis of volatile compounds in *H. cordata*s. And the conditions of GC/MS were the same as Table 2.

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. 1 μL mixture of n-alkane sample was analysed to find out the retention time of internal standard by GC/MS (Figure 3). 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	*R.T.*[1)]	*Alkanes*	*R.T.*	*Alkanes*	*R.T.*
$C_{7:0}$	4.957	$C_{13:0}$	24.7	$C_{19:0}$	60.167
$C_{8:0}$	6.119	$C_{14:0}$	29.875	$C_{20:0}$	66.583
$C_{9:0}$	8.289	$C_{15:0}$	35.008	$C_{21:0}$	72.742
$C_{10:0}$	10.908	$C_{16:0}$	40.908	$C_{22:0}$	76.392
$C_{11:0}$	15.033	$C_{17:0}$	46.525	$C_{23:0}$	80.75
$C_{12:0}$	19.808	$C_{18:0}$	52.542		

R.T.[1)]: Retention time

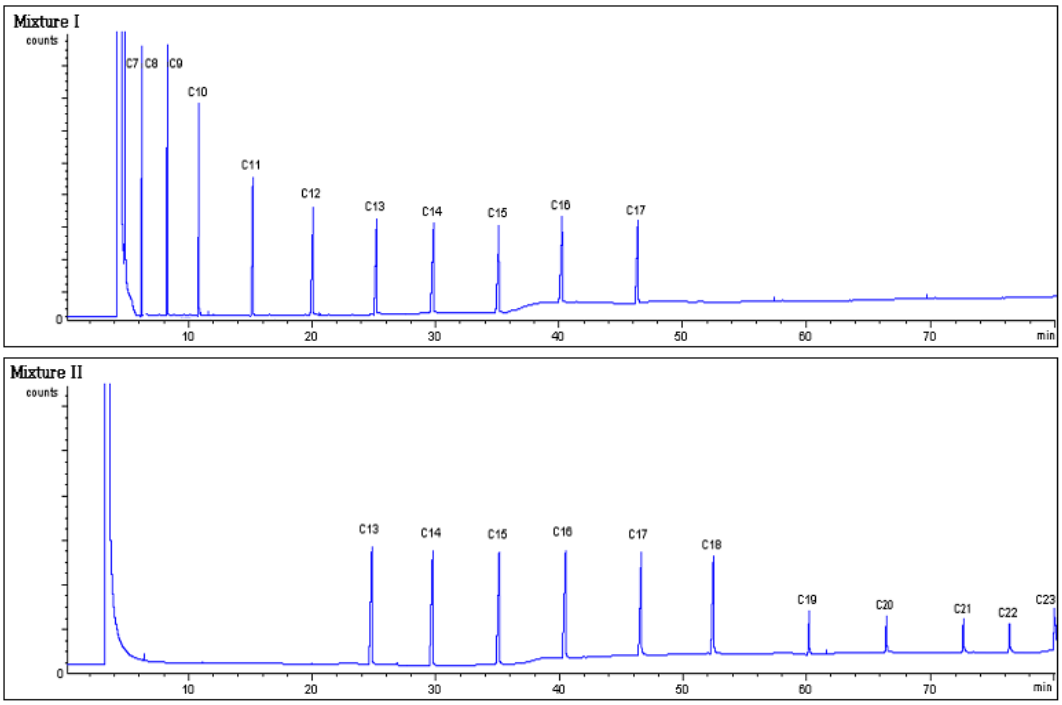

Figure 3. GC chromatograms of n-alkane standard mixture Ⅰ *and* Ⅱ.

B. Quantitative analysis of volatile organic compounds in unirradiated and irradiated H. cordatas

1. Volatile organic compounds in unirradiated H. cordata

The total ion chromatogram (TIC) of volatile organic compounds of *H. cordata* is shown in Figure 6, and the concentrations of these compounds are listed in Table 4. A total of 83 volatile organic compounds were identified in the *H. cordata* control: 5 acids (15.17%), 21 alcohols (26.59%), 12 aldehydes (8.03%), 7 esters (8.44%), 3 ethers (0.86%), 18 hydrocarbons (13.53%), 10 ketones (21.03%), 2 nitrogenous compounds (1.16%) and 5 miscellaneous (5.19%), respectively (Table 11). Specifically, the dominant compounds were hexahydrofarnesyl acetone (12.81%), phytol (8.91%), dodecanoic acid (8.10%), decanoic acid (5.46%), caryophyllene oxide (4.58%), octadecanol (4.55%), ethyl acetate (4.41%), menthol (4.17%) and 2-undecanone (3.80%). The total content of these compounds was 52.99%. Moreover that compounds, *(E)*-β-caryophyllene, β-pinene, β-myrcene, bonyl acetate, nonanol, α-pinene, ρ-menthone, 4-terpineol, undecanol, α-copaene were detected as a significant meterial in the control. hexahydrofarnesyl acetone (6,10,14-trimethyl-2-pentadecanone) was detected as a primary volatile organic compound. In previous investigations it was reported as the most abundant compound in dried red pepper (41), as the major compound of red clover, and as a phytol degradation product and biomarker in chlorophyll (42). Mau, J.L. *et al.* (43) reported it had a slightly fatty aroma and had the third highest concentration in *Terminalia catappa* leaves. However, this compound was not considered important to leaf aroma

because of its insignificant odour in GC sniffing analysis. In the case of this experiment, the content of hexahydrofarnesyl acetone was relatively high (12.81%). But the fishy smell of *H. cordata* was derived from houttuynum (44). So hexahydrofarnesyl acetone was not considered important to *H. cordata.*

The second largest constituent was identified as phytol, which exist in chlorophyll as the green pigment of plant tissue and is hydrolyzed when plant tissue is broken down. It is also present in many plant tissues as the alcohol portion of the chlorophyll ester side-chain, and is the vegetability alcohol component for make vitamine E (45).

The next largest constituent were identified as dodecanoic and decanoic acid. According to the report of Cho *et al.* (46), decanoic acid had been detected as the primary compounds, and the next highest compounds were 2-tridecanone, decanal and dodecanoic acid in *H. cordata*. All the compounds were derivatives of decanoic acid, which is consistent with this study.

Shim (47) reported that houttuynum (decanoyl acetaldehyde), methyl-n-nonylketone, myrcene, lauric aldehyde and capric aldehyde were identified as the major volatile component of *H. cordata*. Yoo et al. (48) reported *β*-myrcene, 3,7-dimethyl-1,3,6-octatriene, 2-ethyl-1-hexanol, decanol, 2-undecanone, *β*-caryophyllene and nonanol as dominant compounds, and Liang, M. *et al.* (44), Qi, M. *et al.* (49) reported 2-undecanone and houttuynum as the dominant compounds in *H. cordata*. Similar results were observed in our research. In this study, the contents of 2-undecanone and houttuynum (decanoyl acetaldehyde) (the compound for the characteristic fishy smell of *H. cordata*) were identified at 12.54 and 2.36 mg/kg, respectively (Table 10). Houttuynum performed similar to a 40,000-fold titer

of sulfamine system antibiotics, so it was called a natural antibiotic with a characteristic fishy smell (44,47,48). Houttuynum is converted into 2-undecanone via both oxydation and decarboxylation as Figure 4. Each of the mass spectrum is shown in Figure 5.

Previous investigations have reported the major terpene compounds from *H. cordata* as (*E*)-*β*-caryophyllene, *β*-myrcene, *β*-ocimene, decanol, caryophyllene oxide, *α*-humulene, *α*-pinene, *β*-pinene, limonene, linalool, geraniol, decanal, dodecanal, borneol, perillen and bonyl acetate (15,44,45,50). In our results for the control, a total of 46 terpenes were identified, and their total amount of these were 193.35 mg/kg (58.57%).

Terpene compounds were classified as mono-, sesqui-, and diterpenes, and derivatives. Among the 46 terpenes, 32 monoterpenes: *α*-pinene, *β*-pinene, *β*-myrcene, limonene, (*Z*)-*β*-ocimene, *γ*-terpinene, *ρ*-cymene, 3,4-dimethyl-2,4,6-octatriene, perillen, *p*-menthone, decanal, linalool, (*Z*)-*p*-2-menthen-1-ol, menthyl acetate, bonyl acetate, 4-terpineol, *β*-cyclocitral, menthol, pulegone, terpinyl acetate, estragole, *α*-terpineol, borneol, piperitone, geranyl acetate, decanol, houttuynum, *β*-damascenone, (*E*)-geraniol, safrole, perilla alcohol, and myristicin 13 sesquiterpenes: *α*-humulene, *α*-copaene, *γ*-elemene, (*E*)-*β*-caryophyllene, *α*-guaiene, *δ*-cadinene, *α*-curcumene, calamenene, citronellyl valerate, caryophyllene oxide, nerolidol, hexahydrofarnesyl acetone, and patchouli alcohol and one diterpene, phytol, were identified.

Terpenoids originate from terpentine, which is called terpene. Terpene is the starting material, which comes from synthesized glucose by photosynthesis in the plant system. Glucose via the glycolysis process is induced to acetyl-CoA, which is synthesized to mevalonic acid. After being

synthesized, 3 ATP are required to phosphorlyate mevalonic acid, and a CO_2 is emitted at the same time that isopentenylpyrophosphate (IPPP) and dimethylallylpyrophosphate (DMAPP) are generated. The isoprene is synthesized by the interaction of both of these compounds. This isoprene synthesizes a high molecular terpene after several stages (51).

When looking at the bioactivity of terpenoids, the monoterpenes were first detected from animals and microbials; however, they are mainly identified as volatile organic compounds of herbals, and are generally used in perfumes. In addition they have antiphlogistic, depressant, expectorant, stomachic, diuretic, antiseptic, and insecticide functions. Sesquiterpenes are generally used as medicines for their anifungal, anticancer, antiphlogistic, and anti-asthmatic properties. Finally, the diterpenes are major components of resin and have functions for carcinogenecity, hinder biting insects, sweetness, skin irritability, and plant hormones (52,53).

Table 4. Volatile organic compounds identified in unirradiated H. cordata

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.745	878	Ethyl acetate	$C_4H_8O_2$	88	14.56	4.41
2	11.664	1021	*α*-Pinene	$C_{10}H_{16}$	136	4.83	1.46
3	15.256	1105	*β*-Pinene	$C_{10}H_{16}$	136	8.44	2.56
4	17.815	1162	*β*-Myrcene	$C_{10}H_{16}$	136	7.22	2.19
5	19.53	1195	Limonene	$C_{10}H_{16}$	136	1.34	0.41
6	20.472	1215	[*E*]-2-Hexenal	$C_6H_{10}O$	98	2.37	0.72
7	21.042	1227	2-Pentylfuran	$C_9H_{14}O$	138	0.35	0.11
8	21.21	1231	[Z]-*β*-Ocimene	$C_{10}H_{16}$	136	0.89	0.27
9	21.83	1244	*γ*-Terpinene	$C_{10}H_{16}$	136	0.79	0.24
10	22.367	1255	2,6-Dimethylpyridine	C_7H_9N	107	1.20	0.36
11	23.008	1268	*ρ*-Cymene	$C_{10}H_{14}$	134	0.79	0.24
12	23.942	1286	Octanal	$C_8H_{16}O$	128	0.18	0.05
13	24.497	1296	5-Butylnonane	$C_{13}H_{28}$	184	0.63	0.19
I.S[5)]	25.231	1311	Butyl benzen	$C_{10}H_{14}$	134	-	-
14	28.135	1368	3,4-Dimethyl-2,4,6-octatriene	$C_{10}H_{16}$	136	0.51	0.15
15	29.1	1386	2-Nonanone	C_9H18O	142	0.25	0.08
16	29.322	1390	Nonanal	C_9H18O	142	1.70	0.52
17	29.6	1395	5-Butyldecane	$C_{14}H_30$	198	0.88	0.27
18	29.906	1401	2-Butoxyethanol	$C_6H_{14}O_2$	118	0.25	0.07
19	30.563	1414	Perillen	$C_{10}H_{14}O$	150	0.52	0.16
20	32.096	1445	Acetic acid	$C_2H_4O_2$	60	1.95	0.59
21	32.325	1450	1-Octen-3-ol	$C_8H_{16}O$	128	0.20	0.06
22	32.724	1457	(*E*)-2-Octenal	$C_8H_{14}O$	126	0.32	0.10
23	32.912	1461	Furfural	$C_5H_4O_2$	96	2.45	0.74
24	33.366	1470	*ρ*-Menthone	$C_{10}H_{18}O$	154	4.99	1.51

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight, [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%*
25	34.89	1498	*α*-Copaene	$C_{15}H_{24}$	204	3.36	1.02
26	35.069	1501	Decanal	$C_{10}H_{20}O$	156	6.51	1.97
27	36.363	1524	Benzaldehyde	C_7H_6O	106	3.66	1.11
28	37.643	1547	Linalool	$C_{10}H_{18}O$	154	0.82	0.25
29	38.028	1553	(*Z*)-*p*-2-Menthen-1-ol	$C_{10}H_{18}O$	154	0.37	0.11
30	38.711	1565	Menthyl acetate	$C_{12}H_{22}O_2$	198	0.49	0.15
31	39.084	1571	5-Methylfurfural	$C_6H_6O_2$	110	0.46	0.14
32	39.81	1583	Bonyl acetate	$C_{12}H_{20}O_2$	196	7.23	2.19
33	40.71	1597	2-Undecanone	$C_{11}H_{22}O$	170	12.54	3.80
34	40.804	1598	(*E*)-*β*-Caryophyllene	$C_{15}H_{24}$	204	5.03	1.52
35	41.006	1602	4-Terpineol	$C_{10}H_{18}O$	154	3.40	1.03
36	42.029	1621	*β*-Cyclocitral	$C_{10}H_{16}O$	152	0.61	0.19
37	42.882	1637	*γ*-Elemene	$C_{15}H_{24}$	204	3.12	0.94
38	43.136	1641	Menthol	$C_{10}H_{20}O$	156	13.75	4.17
39	43.595	1649	Pulegone	$C_{10}H_{16}O$	152	2.97	0.90
40	44.128	1659	Nonanol	$C_9H_{20}O$	144	7.22	2.19
41	44.365	1663	Terpinyl acetate	$C_{12}H_{20}O_2$	196	0.32	0.10
42	44.515	1666	Estragole	$C_{10}H_{12}O$	148	0.39	0.12
43	44.797	1671	*α*-Humulene	$C_{15}H_{24}$	204	0.96	0.29
44	46.255	1695	*α*-Terpineol	$C_{10}H_{18}O$	154	0.44	0.13
45	46.593	1701	Borneol	$C_{10}H_{18}O$	154	2.09	0.63
46	46.845	1706	Dodecanal	$C_{12}H_{24}O$	184	2.40	0.73
47	47.844	1723	*α*-Guaiene	$C_{15}H_{24}$	204	1.46	0.44
48	48.107	1727	Piperitone	$C_{10}H_{16}O$	152	2.34	0.71
49	49.365	1749	Geranyl acetate	$C_{12}H_{20}O_2$	196	2.14	0.65
50	49.583	1752	*δ*-Cadinene	$C_{15}H_{24}$	204	2.12	0.64

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
51	49.858	1757	Decanol	$C_{10}H_{22}O$	158	1.44	0.44
52	50.412	1766	*α*-curcumene	$C_{15}H_{22}$	202	0.64	0.19
53	51.915	1790	Butyrophenone	$C_{10}H_{12}O$	148	0.77	0.23
54	52.839	1804	Houttuynum	$C_{12}H_{22}O_2$	198	2.36	0.72
55	53.758	1817	*β*-Damascenone	$C_{13}H_{18}O$	190	1.10	0.33
56	54.529	1827	Calamenene	$C_{15}H_{22}$	202	1.68	0.51
57	55.574	1841	(*E*)-Geraniol	$C_{10}H_{18}O$	154	1.11	0.34
58	57.047	1861	Undecanol	$C_{11}H_{24}O$	172	3.65	1.11
59	57.438	1866	Safrole	$C_{10}H_{10}O_2$	162	0.53	0.16
60	57.755	1870	Benzyl alcohol	C_7H_8O	108	0.82	0.25
61	60.541	1906	Phenethyl alcohol	$C_8H_{10}O$	122	1.78	0.54
62	61.469	1921	Citronellyl valerate	$C_{15}H_{28}O_2$	240	2.26	0.69
63	65.629	1986	Caryophyllene oxide	$C_{15}H_{24}O$	220	15.13	4.58
64	66.76	2003	Perilla alcohol	$C_{10}H_{16}O$	152	0.77	0.23
65	66.949	2006	Methyleugenol	$C_{11}H_{14}O_2$	178	1.30	0.39
66	67.955	2023	*γ*-Nonalacton	$C_9H_{16}O_2$	156	0.51	0.16
67	68.411	2030	Cinnamaldehyde	C_9H_8O	132	3.50	1.06
68	68.625	2034	Nerolidol	$C_{15}H_{26}O$	222	0.48	0.15
69	70.326	2062	Tridecanol	$C_{13}H_{28}O$	200	0.80	0.24
70	73.183	2112	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	42.28	12.81
71	73.437	2119	1,2-Epoxy octadecane	$C_{18}H_{36}O$	268	0.62	0.19
72	73.853	2131	*γ*-Decalactone	$C_{10}H_{18}O_2$	170	1.67	0.51
73	75.622	2179	Patchouli alcohol	$C_{15}H_{26}O$	222	2.79	0.85
74	76.997	2214	Methyl Hexadecanoate	$C_{17}H_{34}O_2$	270	0.86	0.26
75	78.845	2257	Myristicin	$C_{11}H_{12}O_3$	192	1.13	0.34

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
76	79.213	2265	Decanoic acid	$C_{10}H_{20}O_2$	172	18.02	5.46
77	79.443	2271	Pentadecanol	$C_{15}H_{32}O$	228	1.15	0.35
78	83.948	2362	Undecanoic acid	$C_{11}H_{22}O_2$	186	3.21	0.97
79	87.01	2425	1H-Indole	C_8H_7N	117	2.62	0.79
80	88.788	2465	Dodecanoic acid	$C_{12}H_{24}O_2$	200	26.74	8.10
81	93.327	2569	Octadecanol	$C_{18}H_{38}O$	270	15.01	4.55
82	93.458	2572	Tridecanoic acid	$C_{13}H_{26}O_2$	214	0.18	0.05
83	94.615	2598	Phytol	$C_{20}H_{40}O$	296	29.42	8.91
			Total			*330.12*	*100*

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight

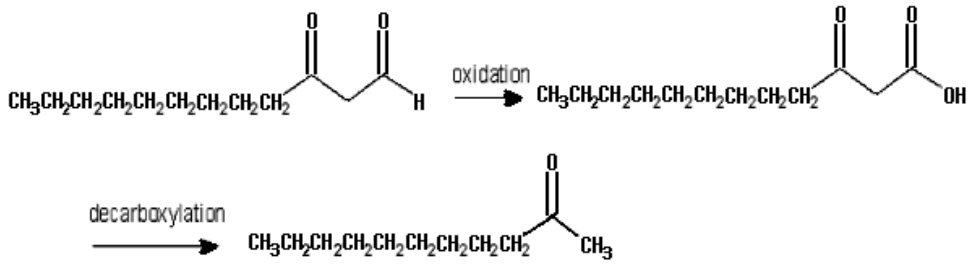

Figure 4. The houttuynum (decanoyl acetaldehyde) converted into 2-undecanone via both oxidation and decarboxylation.

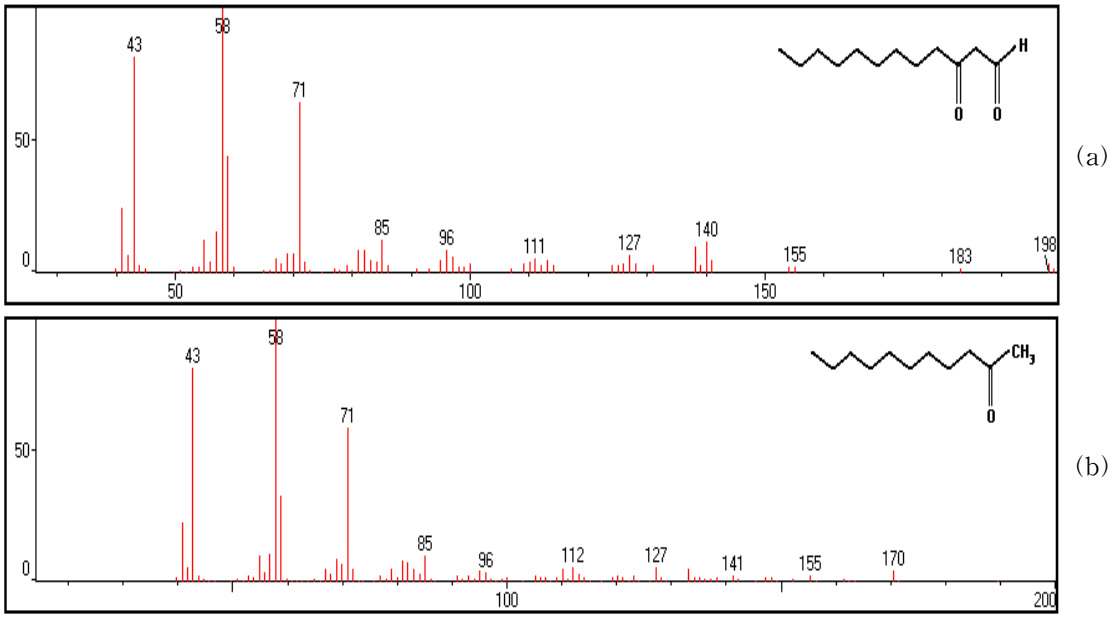

Figure 5. Mass spectrum of (a) houttuynum and (b) 2-undecanone.

2. Volatile organic compounds in irradiated *H. cordata*s

The total ion chromatogram for the volatile compounds from the irradiated *H. cordata* is shown in Figure 6, and their concentrations are given in Tables 5-9. The types of volatile compounds in irradiated *H. cordata*s (at 1, 3, 5, 10 and 20 kGy) were similar to those of the unirradiated samples, but the concentrations of these compounds differed between treatments(Table 11). A total of 85 volatile organic compounds were identified in *H. cordata* irradiated at 1 kGy, and their concentration was 421.94 mg/kg. The major volatile organic compounds in the sample irradiated at 1 kGy were phytol (41.41 mg/kg), hexahydrofarnesyl acetone (41.37 mg/kg), dodecanoic acid (34.37 mg/kg), octadecanol (25.61 mg/kg), 2-undecanone (20.88 mg/kg) and decanoic acid (20.44 mg/kg). The relative area % of the total compounds was detected as 43.63%, encompassing most of the compounds. In comparison with control, it showed similar result. A total of 84 (427.20 mg/kg) organic compounds were identified in the *H. cordata* irradiated at 3 kGy. The major volatile organic compounds in the sample were phytol (43.32 mg/kg), hexahydrofarnesyl acetone (40.56 mg/kg), dodecanoic acid (30.20 mg/kg), caryophyllene oxide (22.77 mg/kg) and octadecanol (21.44 mg/kg). In the *H. cordata* irradiated at 5 kGy, a total of 84 (517.32 mg/kg) compounds were identified. The major compounds detected at 5 kGy were phytol (46.38 mg/kg), hexahydrofarnesyl acetone (44.56 mg/kg), dodecanoic acid (28.27 mg/kg), caryophyllene oxide (26.70 mg/kg), nonanol (24.77 mg/kg), and octadecanol (22.35 mg/kg). Next, a total of 85 (376.80 mg/kg) organic compounds were identified in the *H. cordata* irradiated at 10 kGy. The

predominant organic compounds were identified as hexahydrofarnesyl acetone (41.84 mg/kg), phytol (40.68 mg/kg), dodecanoic acid (32.67 mg/kg), octadecanol (21.39 mg/kg), and caryophyllene oxide (20.18 mg/kg). Finally, a total of 84 (376.13 mg/kg) organic compounds were identified in the *H. cordata* irradiated at 20 kGy. The major volatile organic compounds were hexahydrofarnesyl acetone (54.22 mg/kg), phytol (36.32 mg/kg), dodecanoic acid (28.80 mg/kg), octadecanol (24.52 mg/kg), and caryophyllene oxide (18.85 mg/kg). The ratios of individual chemical compounds were different among the treatments. However, each compound was not shown a characteristic behavior upon irradiation. They have a some different of identified compounds, because of lost during the experiment may be. Especially, houttuynum; characteristic smell of *H. cordata* was identified as 3.55, 3.54, 3.61, 3.57 and 2.94 mg/kg, with the different doses of radiation at 1, 3, 5, 10 and 20 kGy, respectively (Table 10). A total of 47, 46, 46, 47 and 46 compounds were identified in *H. cordata* as the terpene components with bioactivity. They have important medical action in *H. cordata.* The amount were identified as 239.64 (56.80%), 245.16 (57.39%), 315.92 (61.07%), 213.52 (56.67%) and 217.03(57.70%) mg/kg (Table 13). According to the results, alcohols and ketones occurred at high levels in both the unirradiated and irradiated *H. cordata* samples. Phytol, octadecanol and nonanol were identified as the dominant compounds among the alcohols, and hexahydrofarnesyl acetone and 2-undecanone were the major compounds among the ketones. Overall, the volatile organic compounds found in the irradiated *H. cordata*s were similar to those in the control, but the proportions of these compounds were different.

Table 5. Volatile organic compounds identified in irradiated H. cordata at 1 kGy

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.642	873	Ethyl acetate	$C_4H_8O_2$	88	15.32	3.63
2	11.642	1020	*α*-Pinene	$C_{10}H_{16}$	136	4.50	1.07
3	13.417	1065	Camphene	$C_{10}H_{16}$	136	1.88	0.44
4	14.083	1080	Hexanal	$C_6H_{12}O$	100	0.61	0.15
5	15.244	1105	*β*-Pinene	$C_{10}H_{16}$	136	5.89	1.40
6	17.813	1162	*β*-Myrcene	$C_{10}H_{16}$	136	15.94	3.78
7	19.527	1195	Limonene	$C_{10}H_{16}$	136	1.49	0.35
8	20.452	1214	[*E*]-2-Hexenal	$C_6H_{10}O$	98	1.90	0.45
9	21.025	1227	2-Pentylfuran	$C_9H_{14}O$	138	0.47	0.11
10	21.195	1231	[*Z*]-*β*-Ocimene	$C_{10}H_{16}$	136	2.71	0.64
11	21.81	1244	*γ*-Terpinene	$C_{10}H_{16}$	136	0.80	0.19
12	22.347	1255	2,6-Dimethylpyridine	C_7H_9N	107	0.22	0.05
13	22.975	1267	*ρ*-Cymene	$C_{10}H_{14}$	134	0.75	0.18
14	23.942	1286	Octanal	$C_8H_{16}O$	128	0.23	0.05
15	24.487	1296	5-Butylnonane	$C_{13}H_{28}$	212	0.50	0.12
I.S[5)]	25.223	1311	Butyl benzen	$C_{10}H_{14}$	134	-	-
16	28.113	1368	3,4-Dimethyl-2,4,6-octatriene	$C_{10}H_{16}$	136	1.40	0.33
17	29.083	1386	2-Nonanone	$C_9H_{18}O$	142	0.31	0.07
18	29.306	1390	Nonanal	$C_9H_{18}O$	142	2.66	0.63
19	29.596	1395	5-Butyldecane	$C_{14}H_{30}$	198	1.26	0.30
20	29.893	1400	2-Butoxyethanol	$C_6H_{14}O_2$	118	1.24	0.29
21	30.543	1414	Perillen	$C_{10}H_{14}O$	150	0.98	0.23
22	31.706	1438	4,8-Dimethylundecane	$C_{13}H_{28}$	184	0.34	0.08
23	32.073	1445	Acetic acid	$C_2H_4O_2$	60	1.60	0.38
24	32.292	1449	1-Octen-3-ol	$C_8H_{16}O$	128	0.23	0.05

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight, [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%*
25	32.708	1457	(*E*)-2-Octenal	$C_8H_{14}O$	126	0.37	0.09
26	32.887	1461	Furfural	$C_5H_4O_2$	96	1.39	0.33
27	33.331	1469	*p*-Menthone	$C_{10}H_{18}O$	154	3.54	0.84
28	34.872	1498	*α*-Copaene	$C_{15}H_{24}$	204	2.68	0.63
29	35.11	1502	Decanal	$C_{10}H_{20}O$	156	17.91	4.25
30	36.337	1524	Benzaldehyde	C_7H_6O	106	2.32	0.55
31	37.627	1546	Linalool	$C_{10}H_{18}O$	154	0.91	0.22
32	38.008	1553	(*Z*)-*p*-2-Menthen-1-ol	$C_{10}H_{18}O$	154	0.65	0.15
33	38.694	1564	Menthyl acetate	$C_6H_6O_2$	110	0.42	0.10
34	39.052	1570	5-Methylfurfural	$C_6H_6O_2$	110	0.34	0.08
35	39.814	1583	Bonyl acetate	$C_{12}H_{20}O_2$	196	11.86	2.81
36	40.739	1597	2-Undecanone	$C_{11}H_{22}O$	170	20.88	4.95
37	40.81	1598	(*E*)-*β*-Caryophyllene	$C_{15}H_{24}$	204	4.51	1.07
38	40.99	1602	4-Terpineol	$C_{10}H_{18}O$	154	4.91	1.16
39	42.042	1621	*β*-Cyclocitral	$C_{10}H_{16}O$	152	0.47	0.11
40	42.87	1636	*γ*-Elemene	$C_{15}H_{24}$	204	3.27	0.78
41	43.099	1641	Menthol	$C_{10}H_{20}O$	156	9.42	2.23
42	43.573	1649	Pulegone	$C_{10}H_{16}O$	152	2.69	0.64
43	44.152	1659	Nonanol	$C_9H_{20}O$	144	13.14	3.11
44	44.349	1663	Terpinyl acetate	$C_{12}H_{20}O_2$	196	0.63	0.15
45	44.515	1666	Estragole	$C_{10}H_{12}O$	148	0.26	0.06
46	44.786	1670	*α*-Humulene	$C_{15}H_{24}$	204	1.16	0.28
47	46.238	1695	*α*-Terpineol	$C_{10}H_{18}O$	154	0.41	0.10
48	46.528	1700	Borneol	$C_{10}H_{18}O$	154	2.75	0.65
49	47.025	1709	Dodecanal	$C_{12}H_{24}O$	184	1.91	0.45
50	47.837	1723	*α*-Guaiene	$C_{15}H_{24}$	204	2.13	0.51

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
51	48.075	1727	Piperitone	$C_{10}H_{16}O$	2.08	0.49	0.48
52	49.374	1749	Geranyl acetate	$C_{12}H_{20}O_2$	6.47	1.53	1.49
53	49.572	1752	δ-Cadinene	$C_{15}H_{24}$	1.60	0.38	0.37
54	49.84	1757	Decanol	$C_{10}H_{22}O$	2.22	0.53	0.51
55	50.394	1766	α-curcumene	$C_{15}H_{22}$	0.51	0.12	0.12
56	51.888	1790	Butyrophenone	$C_{10}H_{12}O$	0.88	0.21	0.20
57	52.828	1804	houttuynum	$C_{12}H_{22}O_2$	3.55	0.84	0.82
58	53.741	1817	β-Damascenone	$C_{13}H_{1}8O$	0.86	0.20	0.20
59	54.496	1827	Calamenene	$C_{15}H_{22}$	1.59	0.38	0.36
60	55.541	1841	(*E*)-Geraniol	$C_{10}H_{18}O$	1.72	0.41	0.40
61	57.05	1861	Undecanol	$C_{11}H_{24}O$	5.90	1.40	1.35
62	57.395	1865	Safrole	$C_{10}H_{10}O_2$	0.60	0.14	0.14
63	57.711	1869	Benzyl alcohol	C_7H_8O	1.05	0.25	0.24
64	60.397	1904	Phenethyl alcohol	$C_8H_{10}O$	4.63	1.10	1.06
65	61.456	1921	Citronellyl valerate	$C_{15}H_{28}O_2$	2.96	0.70	0.68
66	65.649	1986	Caryophyllene oxide	$C_{15}H_{24}O$	19.88	4.71	5.07
67	66.72	2002	Perilla alcohol	$C_{10}H_{16}O$	1.24	0.29	0.29
68	66.914	2006	Methyleugenol	$C_{11}H_{14}O_2$	1.62	0.38	0.37
69	67.94	2023	γ-Nonalacton	$C_9H_{16}O_2$	0.98	0.23	0.23
70	68.387	2030	Cinnamaldehyde	C_9H_8O	4.20	0.99	0.96
71	68.604	2034	Nerolidol	$C_{15}H_{26}O$	0.56	0.13	0.13
72	70.308	2062	Tridecanol	$C_{13}H_{28}O$	1.69	0.40	0.39
73	73.209	2113	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	41.37	9.80	11.88
74	73.436	2119	1,2-Epoxy octadecane	$C_{18}H_{36}O$	1.05	0.25	0.24
75	73.848	2131	γ-Decalactone	$C_{10}H_{18}O_2$	2.66	0.63	0.61

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
76	75.613	2179	Patchouli alcohol	$C_{15}H_{26}O$	222	3.17	0.75
77	76.984	2214	Methyl Hexadecanoate	$C_{17}H_{34}O_2$	270	1.72	0.41
78	78.828	2257	Myristicin	$C_{11}H_{12}O_3$	192	0.92	0.22
79	79.191	2265	Decanoic acid	$C_{10}H_{20}O_2$	172	20.44	4.85
80	79.424	2270	Pentadecanol	$C_{15}H_{32}O$	228	1.58	0.38
81	83.927	2362	Undecanoic acid	$C_{11}H_{22}O_2$	186	4.02	0.95
82	86.985	2424	1H-Indole	C_8H_7N	117	2.66	0.63
83	88.795	2465	Dodecanoic acid	$C_{12}H_{24}O_2$	200	34.37	8.15
84	93.366	2569	Octadecanol	$C_{18}H_{38}O$	270	25.61	6.07
85	94.657	2598	Phytol	$C_{20}H_{40}O$	296	41.41	9.81
			Total			*421.94*	*100*

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight

Table 6. Volatile organic compounds identified in irradiated H. cordata at 3 kGy

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.629	876	Ethyl acetate	$C_4H_8O_2$	88	13.61	3.18
2	11.637	1020	*α*-Pinene	$C_{10}H_{16}$	136	4.43	1.04
3	13.349	1063	Camphene	$C_{10}H_{16}$	136	1.11	0.26
4	14.083	1080	Hexanal	$C_6H_{12}O$	100	0.75	0.18
5	15.207	1104	*β*-Pinene	$C_{10}H_{16}$	136	6.48	1.52
6	17.809	1161	*β*-Myrcene	$C_{10}H_{16}$	136	18.36	4.30
7	19.52	1195	Limonene	$C_{10}H_{16}$	136	1.72	0.40
8	20.441	1214	[*E*]-2-Hexenal	$C_6H_{10}O$	98	2.70	0.63
9	21.017	1227	2-Pentylfuran	$C_9H_{14}O$	138	0.60	0.14
10	21.188	1231	[*Z*]-*β*-Ocimene	$C_{10}H_{16}$	136	3.62	0.85
11	21.787	1243	*γ*-Terpinene	$C_{10}H_{16}$	136	1.26	0.30
12	22.318	1254	2,6-Dimethylpyridine	C_7H_9N	107	0.53	0.12
13	22.949	1267	*ρ*-Cymene	$C_{10}H_{14}$	134	1.01	0.24
14	23.896	1285	Octanal	$C_8H_{16}O$	128	0.24	0.06
15	24.48	1296	5-Butylnonane	$C_{13}H_{28}$	184	0.72	0.17
I.S[5)]	25.242	1311	Butyl benzen	$C_{10}H_{14}$	134	-	-
16	28.098	1368	3,4-Dimethyl-2,4,6-octatriene	$C_{10}H_{16}$	136	1.63	0.38
17	29.068	1386	2-Nonanone	$C_9H_{18}O$	142	0.33	0.08
18	29.295	1390	Nonanal	$C_9H_{18}O$	142	2.91	0.68
19	29.587	1395	5-Butyldecane	$C_{14}H_{30}$	198	1.35	0.32
20	29.875	1400	2-Butoxyethanol	$C_6H_{14}O_2$	118	1.80	0.42
21	30.527	1414	Perillen	$C_{10}H_{14}O$	150	1.17	0.27
22	31.708	1439	4,8-Dimethylundecane	$C_{13}H_{28}$	184	0.45	0.10
23	32.011	1444	Acetic acid	$C_2H_4O_2$	60	2.38	0.56
24	32.275	1449	1-Octen-3-ol	$C_8H_{16}O$	128	0.22	0.05

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight, [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%*
25	32.68	1457	(*E*)-2-Octenal	$C_8H_{14}O$	126	0.40	0.09
26	32.867	1460	Furfural	$C_5H_4O_2$	96	1.49	0.35
27	33.324	1469	*p*-Menthone	$C_{10}H_{18}O$	154	3.65	0.86
28	34.868	1497	*α*-Copaene	$C_{15}H_{24}$	204	2.32	0.54
29	35.125	1502	Decanal	$C_{10}H_{20}O$	156	14.29	3.35
30	36.318	1524	Benzaldehyde	C_7H_6O	106	3.26	0.76
31	37.6	1546	Linalool	$C_{10}H_{18}O$	154	0.97	0.23
32	37.989	1552	(*Z*)-*p*-2-Menthen-1-ol	$C_{10}H_{18}O$	154	0.81	0.19
33	38.681	1564	Menthyl acetate	$C_6H_6O_2$	110	0.71	0.17
34	39.035	1570	5-Methylfurfural	$C_6H_6O_2$	110	0.44	0.10
35	39.814	1583	Bonyl acetate	$C_{12}H_{20}O_2$	196	11.68	2.73
36	40.743	1597	2-Undecanone	$C_{11}H_{22}O$	170	19.65	4.60
37	40.818	1599	(*E*)-*β*-Caryophyllene	$C_{15}H_{24}$	204	4.47	1.05
38	40.977	1601	4-Terpineol	$C_{10}H_{18}O$	154	5.23	1.22
39	42.005	1621	*β*-Cyclocitral	$C_{10}H_{16}O$	152	0.53	0.12
40	42.853	1636	*γ*-Elemene	$C_{15}H_{24}$	204	3.14	0.74
41	43.095	1640	Menthol	$C_{10}H_{20}O$	156	9.19	2.15
42	43.557	1649	Pulegone	$C_{10}H_{16}O$	152	2.59	0.61
43	44.16	1659	Nonanol	$C_9H_{20}O$	144	13.97	3.27
44	44.334	1663	Terpinyl acetate	$C_{12}H_{20}O_2$	196	0.65	0.15
45	44.766	1670	*α*-Humulene	$C_{15}H_{24}$	204	0.99	0.23
46	46.224	1695	*α*-Terpineol	$C_{10}H_{18}O$	154	0.43	0.10
47	46.53	1700	Borneol	$C_{10}H_{18}O$	154	2.90	0.68
48	46.844	1706	Dodecanal	$C_{12}H_{24}O$	184	5.95	1.39
49	47.844	1723	*α*-Guaiene	$C_{15}H_{24}$	204	2.20	0.51
50	48.057	1727	Piperitone	$C_{10}H_{16}O$	152	1.91	0.45

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
51	49.373	1749	Geranyl acetate	$C_{12}H_{20}O_2$	196	7.06	1.65
52	49.562	1752	δ-Cadinene	$C_{15}H_{24}$	204	1.36	0.32
53	49.828	1756	Decanol	$C_{10}H_{22}O$	158	2.37	0.56
54	50.38	1765	α-curcumene	$C_{15}H_{22}$	202	0.58	0.14
55	51.867	1789	Butyrophenone	$C_{10}H_{12}O$	148	0.95	0.22
56	52.824	1804	houttuynum	$C_{12}H_{22}O_2$	198	3.54	0.83
57	53.721	1816	β-Damascenone	$C_{13}H_{18}O$	190	1.25	0.29
58	54.48	1827	Calamenene	$C_{15}H_{22}$	202	1.37	0.32
59	55.532	1841	(*E*)-Geraniol	$C_{10}H_{18}O$	154	1.82	0.43
60	57.051	1861	Undecanol	$C_{11}H_{24}O$	172	6.64	1.56
61	57.381	1865	Safrole	$C_{10}H_{10}O_2$	162	0.61	0.14
62	57.694	1869	Benzyl alcohol	C_7H_8O	108	1.45	0.34
63	60.482	1905	Phenethyl alcohol	$C_8H_{10}O$	122	3.08	0.72
64	61.457	1921	Citronellyl valerate	$C_{15}H_{28}O_2$	240	2.69	0.63
65	65.658	1986	Caryophyllene oxide	$C_{15}H_{24}O$	220	22.77	5.33
66	66.699	2002	Perilla alcohol	$C_{10}H_{16}O$	152	1.23	0.29
67	66.883	2005	Methyleugenol	$C_{11}H_{14}O_2$	178	1.56	0.37
68	67.935	2023	γ-Nonalacton	$C_9H_{16}O_2$	156	1.12	0.26
69	68.364	2030	Cinnamaldehyde	C_9H_8O	132	4.12	0.96
70	68.575	2033	Nerolidol	$C_{15}H_{26}O$	222	0.69	0.16
71	70.302	2061	Tridecanol	$C_{13}H_{28}O$	200	1.77	0.41
72	73.252	2114	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	40.56	9.49
73	73.468	2120	1,2-Epoxy octadecane	$C_{18}H_{36}O$	268	1.11	0.26
74	73.845	2131	γ-Decalactone	$C_{10}H_{18}O_2$	170	2.63	0.62
75	75.599	2179	Patchouli alcohol	$C_{15}H_{26}O$	222	3.46	0.81

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
76	76.978	2214	Methyl Hexadecanoate	$C_{17}H_{34}O_2$	270	1.41	0.33
77	78.808	2256	Myristicin	$C_{11}H_{12}O_3$	192	0.99	0.23
78	79.183	2265	Decanoic acid	$C_{10}H_{20}O_2$	172	21.36	5.00
79	79.422	2270	Pentadecanol	$C_{15}H_{32}O$	228	2.11	0.49
80	83.901	2361	Undecanoic acid	$C_{11}H_{22}O_2$	186	4.21	0.99
81	86.964	2424	1H-Indole	C_8H_7N	117	3.12	0.73
82	88.791	2465	Dodecanoic acid	$C_{12}H_{24}O_2$	200	30.20	7.07
83	93.413	2571	Octadecanol	$C_{18}H_{38}O$	270	21.44	5.02
84	94.688	2599	Phytol	$C_{20}H_{40}O$	296	43.32	10.14
			Total			*427.20*	*100*

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight

Table 7. Volatile organic compounds identified in irradiated H. cordata at 5 kGy

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.695	876	Ethyl acetate	$C_4H_8O_2$	88	10.67	2.09
2	11.663	1021	*α*-Pinene	$C_{10}H_{16}$	136	6.33	1.24
3	13.375	1064	Camphene	$C_{10}H_{16}$	136	2.36	0.46
4	14.042	1079	Hexanal	$C_6H_{12}O$	100	1.23	0.24
5	15.228	1105	*β*-Pinene	$C_{10}H_{16}$	136	9.56	1.87
6	17.817	1162	*β*-Myrcene	$C_{10}H_{16}$	136	23.33	4.57
7	19.521	1195	Limonene	$C_{10}H_{16}$	136	2.16	0.42
8	20.446	1214	[*E*]-2-Hexenal	$C_6H_{10}O$	98	3.53	0.69
9	21.017	1227	2-Pentylfuran	$C_9H_{14}O$	138	0.71	0.14
10	21.182	1230	[*Z*]-*β*-Ocimene	$C_{10}H_{16}$	136	3.17	0.62
11	21.8	1243	*γ*-Terpinene	$C_{10}H_{16}$	136	1.61	0.31
12	22.337	1254	2,6-Dimethylpyridine	C_7H_9N	107	0.82	0.16
13	22.955	1267	*ρ*-Cymene	$C_{10}H_{14}$	134	1.02	0.20
14	23.888	1285	Octanal	$C_8H_{16}O$	128	0.21	0.04
15	24.493	1296	5-Butylnonane	$C_{13}H_{28}$	184	1.07	0.21
I.S[5)]	25.216	1311	Butyl benzen	$C_{10}H_{14}$	134	-	0.00
16	28.106	1368	3,4-Dimethyl-2,4,6-octatriene	$C_{10}H_{16}$	136	1.92	0.38
17	29.064	1386	2-Nonanone	$C_9H_{18}O$	142	0.32	0.06
18	29.318	1390	Nonanal	$C_9H_{18}O$	142	3.96	0.78
19	29.654	1396	5-Butyldecane	$C_{14}H_{30}$	198	2.27	0.44
20	29.887	1400	2-Butoxyethanol	$C_6H_{14}O_2$	118	1.78	0.35
21	30.529	1414	Perillen	$C_{10}H_{14}O$	150	0.84	0.16
22	31.786	1439	4,8-Dimethylundecane	$C_{13}H_{28}$	184	0.46	0.09
23	31.971	1443	Acetic	$C_2H_4O_2$	60	1.02	0.20
24	32.292	1449	1-Octen-3-ol	$C_8H_{16}O$	128	0.29	0.06

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight, [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%*
25	32.694	1457	(E)-2-Octenal	$C_8H_{14}O$	126	0.58	0.11
26	32.877	1460	Furfural	$C_5H_4O_2$	96	1.75	0.34
27	33.338	1469	*p*-Menthone	$C_{10}H_{18}O$	154	3.87	0.76
28	34.908	1497	*α*-Copaene	$C_{15}H_{24}$	204	2.66	0.52
29	35.218	1504	Decanal	$C_{10}H_{20}O$	156	20.38	3.99
30	36.313	1523	Benzaldehyde	C_7H_6O	106	3.09	0.61
31	37.619	1546	Linalool	$C_{10}H_{18}O$	154	1.42	0.28
32	38.002	1553	(*Z*)-*p*-2-Menthen-1-ol	$C_{10}H_{18}O$	154	1.53	0.30
33	38.699	1564	Menthyl acetate	$C_6H_6O_2$	110	1.11	0.22
34	39.044	1570	5-Methylfurfural	$C_6H_6O_2$	110	0.63	0.12
35	39.838	1583	Bonyl acetate	$C_{12}H_{20}O_2$	196	15.40	3.02
36	40.802	1598	2-Undecanone	$C_{11}H_{22}O$	170	21.35	4.13
37	40.875	1599	(*E*)-*β*-Caryophyllene	$C_{15}H_{24}$	204	5.22	1.02
38	40.995	1602	4-Terpineol	$C_{10}H_{18}O$	154	7.04	1.38
39	42.02	1621	*β*-Cyclocitral	$C_{10}H_{16}O$	152	0.99	0.19
40	42.889	1637	*γ*-Elemene	$C_{15}H_{24}$	204	5.78	1.13
41	43.133	1641	Menthol	$C_{10}H_{20}O$	156	16.61	3.25
42	43.59	1649	Pulegone	$C_{10}H_{16}O$	152	2.53	0.50
43	44.212	1660	Nonanol	$C_9H_{20}O$	144	24.77	4.85
44	44.341	1663	Terpinyl acetate	$C_{12}H_{20}O_2$	196	3.06	0.60
45	44.817	1671	*α*-Humulene	$C_{15}H_{24}$	204	1.02	0.20
46	46.22	1695	*α*-Terpineol	$C_{10}H_{18}O$	154	1.21	0.24
47	46.531	1700	Borneol	$C_{10}H_{18}O$	154	2.72	0.53
48	46.902	1707	Dodecanal	$C_{12}H_{24}O$	184	7.52	1.47
49	47.885	1724	*α*-Guaiene	$C_{15}H_{24}$	204	3.02	0.59
50	48.091	1727	Piperitone	$C_{10}H_{16}O$	152	3.02	0.59

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
51	49.412	1750	Geranyl acetate	$C_{12}H_{20}O_2$	196	12.82	2.51
52	49.592	1752	δ-Cadinene	$C_{15}H_{24}$	204	2.54	0.50
53	49.853	1757	Decanol	$C_{10}H_{22}O$	158	2.65	0.52
54	50.414	1766	a-curcumene	$C_{15}H_{22}$	202	1.29	0.25
55	51.867	1789	Butyrophenone	$C_{10}H_{12}O$	148	1.11	0.22
56	52.863	1804	houttuynum	$C_{12}H_{22}O_2$	198	3.61	0.70
57	53.742	1817	β-Damascenone	$C_{13}H_{18}O$	190	1.32	0.26
58	54.505	1827	Calamenene	$C_{15}H_{22}$	202	3.16	0.62
59	55.53	1841	(E)-Geraniol	$C_{10}H_{18}O$	154	3.01	0.59
60	57.111	1862	Undecanol	$C_{11}H_{24}O$	172	8.72	1.71
61	57.375	1865	Safrole	$C_{10}H_{10}O_2$	162	0.88	0.17
62	57.684	1869	Benzyl alcohol	C_7H_8O	108	2.52	0.49
63	60.48	1905	Phenethyl alcohol	$C_8H_{10}O$	122	5.06	0.99
64	61.515	1922	Citronellyl valerate	$C_{15}H_{28}O_2$	240	4.94	0.97
65	65.747	1988	Caryophyllene oxide	$C_{15}H_{24}O$	220	26.70	5.23
66	66.713	2002	Perilla alcohol	$C_{10}H_{16}O$	152	2.09	0.41
67	66.901	2005	Methyleugenol	$C_{11}H_{14}O_2$	178	2.34	0.46
68	67.942	2023	γ-Nonalacton	$C_9H_{16}O_2$	156	1.21	0.24
69	68.376	2030	Cinnamaldehyde	C_9H_8O	132	5.09	1.00
70	68.584	2033	Nerolidol	$C_{15}H_{26}O$	222	1.03	0.20
71	70.313	2062	Tridecanol	$C_{13}H_{28}O$	200	3.07	0.60
72	73.378	2118	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	44.56	8.73
73	73.56	2123	1,2-Epoxy octadecane	$C_{18}H_{36}O$	268	2.47	0.48
74	73.921	2133	γ-Decalactone	$C_{10}H_{18}O_2$	170	2.72	0.53
75	75.616	2179	Patchouli alcohol	$C_{15}H_{26}O$	222	6.22	1.22

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
76	77.015	2215	Methyl Hexadecanoate	$C_{17}H_{34}O_2$	270	2.21	0.43
77	78.806	2256	Myristicin	$C_{11}H_{12}O_3$	192	1.83	0.36
78	79.221	2266	Decanoic acid	$C_{10}H_{20}O_2$	172	17.39	3.41
79	79.443	2271	Pentadecanol	$C_{15}H_{32}O$	228	3.10	0.61
80	83.896	2361	Undecanoic acid	$C_{11}H_{22}O_2$	186	3.57	0.70
81	86.947	2423	1H-Indole	C_8H_7N	117	2.18	0.43
82	88.859	2467	Dodecanoic acid	$C_{12}H_{24}O_2$	200	28.27	5.54
83	93.473	2572	Octadecanol	$C_{18}H_{38}O$	270	22.35	4.38
84	94.785	2599	Phytol	$C_{20}H_{40}O$	296	46.38	9.08
			Total			*517.32*	*100*

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight

Table 8. Volatile organic compounds identified in irradiated H. cordata at 10 kGy

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.745	878	Ethyl acetate	$C_4H_8O_2$	88	12.46	3.31
2	11.642	1020	*α*-Pinene	$C_{10}H_{16}$	136	5.01	1.33
3	13.4	1064	Camphene	$C_{10}H_{16}$	136	0.99	0.26
4	14.067	1079	Hexanal	$C_6H_{12}O$	100	0.60	0.16
5	15.226	1105	*β*-Pinene	$C_{10}H_{16}$	136	8.18	2.17
6	17.783	1161	*β*-Myrcene	$C_{10}H_{16}$	136	4.59	1.22
7	19.495	1194	Limonene	$C_{10}H_{16}$	136	1.19	0.32
8	20.43	1214	[*E*]-2-Hexenal	$C_6H_{10}O$	98	1.22	0.32
9	21.008	1227	2-Pentylfuran	$C_9H_{14}O$	138	0.39	0.10
10	21.15	1230	[*Z*]-*β*-Ocimene	$C_{10}H_{16}$	136	0.81	0.21
11	21.784	1243	*γ*-Terpinene	$C_{10}H_{16}$	136	0.53	0.14
12	22.342	1255	2,6-Dimethylpyridine	C_7H_9N	107	0.43	0.11
13	22.956	1267	*ρ*-Cymene	$C_{10}H_{14}$	134	0.45	0.12
14	23.899	1285	Octanal	$C_8H_{16}O$	128	0.22	0.06
15	24.494	1296	5-Butylnonane	$C_{13}H_{28}$	184	0.55	0.15
I.S[5)]	25.238	1311	Butyl benzen	$C_{10}H_{14}$	134	-	-
16	28.104	1368	3,4-Dimethyl-2,4,6-octatriene	$C_{10}H_{16}$	136	0.26	0.07
17	29.05	1386	2-Nonanone	$C_9H_{18}O$	142	0.19	0.05
18	29.289	1390	Nonanal	$C_9H_{18}O$	142	1.99	0.53
19	29.587	1395	5-Butyldecane	$C_{14}H_{30}$	198	0.76	0.20
20	29.867	1400	2-Butoxyethanol	$C_6H_{14}O_2$	118	0.32	0.08
21	30.517	1413	Perillen	$C_{10}H_{14}O$	150	0.44	0.12
22	31.698	1439	4,8-Dimethylundecane	$C_{13}H_{28}$	184	0.31	0.08
23	31.98	1443	Acetic acid	$C_2H_4O_2$	60	2.81	0.75
24	32.292	1449	1-Octen-3-ol	$C_8H_{16}O$	128	0.14	0.04

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight, [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%*
25	32.687	1457	(*E*)-2-Octenal	$C_8H_{14}O$	126	0.17	0.04
26	32.866	1460	Furfural	$C_5H_4O_2$	96	1.30	0.35
27	33.338	1469	*p*-Menthone	$C_{10}H_{18}O$	154	4.27	1.13
28	34.872	1498	*a*-Copaene	$C_{15}H_{24}$	204	2.60	0.69
29	35.085	1501	Decanal	$C_{10}H_{20}O$	156	7.99	2.12
30	36.307	1523	Benzaldehyde	C_7H_6O	106	2.96	0.79
31	37.604	1546	Linalool	$C_{10}H_{18}O$	154	0.34	0.09
32	37.992	1553	(*Z*)-*p*-2-Menthen-1-ol	$C_{10}H_{18}O$	154	0.41	0.11
33	38.676	1564	Menthyl acetate	$C_6H_6O_2$	110	0.81	0.21
34	39.039	1570	5-Methylfurfural	$C_6H_6O_2$	110	0.49	0.13
35	39.798	1582	Bonyl acetate	$C_{12}H_{20}O_2$	196	9.24	2.45
36	40.732	1597	2-Undecanone	$C_{11}H_{22}O$	170	19.21	5.10
37	40.792	1598	(*E*)-*β*-Caryophyllene	$C_{15}H_{24}$	204	2.25	0.60
38	40.964	1601	4-Terpineol	$C_{10}H_{18}O$	154	3.78	1.00
39	42.005	1621	*β*-Cyclocitral	$C_{10}H_{16}O$	152	0.41	0.11
40	42.859	1636	*γ*-Elemene	$C_{15}H_{24}$	204	3.06	0.81
41	43.12	1641	Menthol	$C_{10}H_{20}O$	156	15.96	4.23
42	43.57	1649	Pulegone	$C_{10}H_{16}O$	152	3.90	1.04
43	44.109	1659	Nonanol	$C_9H_{20}O$	144	8.17	2.17
44	44.334	1663	Terpinyl acetate	$C_{12}H_{20}O_2$	196	0.76	0.20
45	44.517	1666	Estragole	$C_{10}H_{12}O$	148	0.32	0.08
46	44.771	1670	*a*-Humulene	$C_{15}H_{24}$	204	1.18	0.31
47	46.204	1695	*a*-Terpineol	$C_{10}H_{18}O$	154	0.48	0.13
48	46.524	1700	Borneol	$C_{10}H_{18}O$	154	2.54	0.68
49	46.827	1705	Dodecanal	$C_{12}H_{24}O$	184	3.67	0.97
50	47.821	1723	*a*-Guaiene	$C_{15}H_{24}$	204	1.38	0.37

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
51	48.07	1727	Piperitone	$C_{10}H_{16}O$	152	2.94	0.78
52	49.327	1748	Geranyl acetate	$C_{12}H_{20}O_2$	196	2.73	0.73
53	49.546	1752	δ-Cadinene	$C_{15}H_{24}$	204	1.67	0.44
54	49.809	1756	Decanol	$C_{10}H_{22}O$	158	1.73	0.46
55	50.364	1765	a-curcumene	$C_{15}H_{22}$	202	0.62	0.16
56	51.848	1789	Butyrophenone	$C_{10}H_{12}O$	148	1.08	0.29
57	52.816	1804	houttuynum	$C_{12}H_{22}O_2$	198	3.57	0.95
58	53.704	1816	β-Damascenone	$C_{13}H_{1}8O$	190	1.34	0.36
59	54.459	1826	Calamenene	$C_{15}H_{22}$	202	1.38	0.37
60	55.503	1840	(E)-Geraniol	$C_{10}H_{18}O$	154	1.23	0.33
61	57.019	1860	Undecanol	$C_{11}H_{24}O$	172	4.84	1.29
62	57.359	1865	Safrole	$C_{10}H_{10}O_2$	162	0.47	0.13
63	57.676	1869	Benzyl alcohol	C_7H_8O	108	0.80	0.21
64	60.46	1905	Phenethyl alcohol	$C_8H_{10}O$	122	1.96	0.52
65	61.438	1921	Citronellyl valerate	$C_{15}H_{28}O_2$	240	2.23	0.59
66	65.647	1986	Caryophyllene oxide	$C_{15}H_{24}O$	220	20.18	5.36
67	66.687	2002	Perilla alcohol	$C_{10}H_{16}O$	152	0.90	0.24
68	66.882	2005	Methyleugenol	$C_{11}H_{14}O_2$	178	1.66	0.44
69	67.911	2022	γ-Nonalacton	$C_9H_{16}O_2$	156	1.08	0.29
70	68.348	2030	Cinnamaldehyde	C_9H_8O	132	3.94	1.05
71	68.567	2033	Nerolidol	$C_{15}H_{26}O$	222	0.76	0.20
72	70.29	2061	Tridecanol	$C_{13}H_{28}O$	200	1.65	0.44
73	73.285	2115	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	41.85	11.11
74	73.489	2121	1,2-Epoxy octadecane	$C_{18}H_{36}O$	268	0.76	0.20
75	73.846	2131	γ-Decalactone	$C_{10}H_{18}O_2$	170	2.22	0.59

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
76	75.59	2178	Patchouli alcohol	$C_{15}H_{26}O$	222	4.03	1.07
77	76.981	2214	Methyl Hexadecanoate	$C_{17}H_{34}O_2$	270	1.67	0.44
78	78.786	2256	Myristicin	$C_{11}H_{12}O_3$	192	1.11	0.29
79	79.178	2265	Decanoic acid	$C_{10}H_{20}O_2$	172	19.43	5.16
80	79.419	2270	Pentadecanol	$C_{15}H_{32}O$	228	1.80	0.48
81	83.891	2361	Undecanoic acid	$C_{11}H_{22}O_2$	186	4.35	1.15
82	86.947	2423	1H-Indole	C_8H_7N	117	3.61	0.96
83	88.797	2465	Dodecanoic acid	$C_{12}H_{24}O_2$	200	32.67	8.67
84	93.371	2570	Octadecanol	$C_{18}H_{38}O$	270	21.39	5.68
85	94.681	2599	Phytol	$C_{20}H_{40}O$	296	40.68	10.80
			Total			*376.80*	*100*

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight.

Table 9. Volatile organic compounds identified in irradiated H. cordata at 20 kGy

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound Name*	*M.F.*[3)]	*F.W.*[4)]	*mg/kg*	*Area%*
1	7.7	876	Ethyl acetate	$C_4H_8O_2$	88	16.83	4.47
2	11.662	1021	*α*-Pinene	$C_{10}H_{16}$	136	3.89	1.03
3	13.342	1063	Camphene	$C_{10}H_{16}$	136	0.62	0.16
4	14.05	1079	Hexanal	$C_6H_{12}O$	100	0.54	0.14
5	15.228	1105	*β*-Pinene	$C_{10}H_{16}$	136	5.59	1.49
6	17.781	1161	*β*-Myrcene	$C_{10}H_{16}$	136	9.91	2.64
7	19.525	1195	Limonene	$C_{10}H_{16}$	136	1.07	0.28
8	20.445	1214	[*E*]-2-Hexenal	$C_6H_{10}O$	98	1.92	0.51
9	21.008	1227	2-Pentylfuran	$C_9H_{14}O$	138	0.48	0.13
10	21.185	1230	[*Z*]-*β*-Ocimene	$C_{10}H_{16}$	136	1.90	0.50
11	21.78	1243	*r*-Terpinene	$C_{10}H_{16}$	136	0.64	0.17
12	22.337	1255	2,6-Dimethylpyridine	C_7H_9N	107	0.46	0.12
13	22.95	1267	*ρ*-Cymene	$C_{10}H_{14}$	134	0.72	0.19
14	23.892	1286	Octanal	$C_8H_{16}O$	128	0.27	0.07
15	24.47	1296	5-Butylnonane	$C_{13}H_{28}$	184	0.70	0.19
I.S[5)]	25.203	1311	Butyl benzen	$C_{10}H_{14}$	134		-
16	28.1	1368	3,4-Dimethyl-2,4,6-octatriene	$C_{10}H_{16}$	136	0.79	0.21
17	29.083	1386	2-Nonanone	$C_9H_{18}O$	142	0.15	0.04
18	29.286	1390	Nonanal	$C_9H_{18}O$	142	2.23	0.59
19	29.578	1395	5-Butyldecane	$C_{14}H_{30}$	198	1.06	0.28
20	29.867	1400	2-Butoxyethanol	$C_6H_{14}O_2$	118	0.61	0.16
21	30.515	1413	Perillen	$C_{10}H_{14}O$	150	0.67	0.18
22	31.681	1439	4,8-Dimethylundecane	$C_{13}H_{28}$	184	0.44	0.12
23	32.013	1444	Acetic acid	$C_2H_4O_2$	60	2.40	0.64
24	32.325	1449	1-Octen-3-ol	$C_8H_{16}O$	128	0.40	0.11

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight, [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%*
25	32.693	1457	(*E*)-2-Octenal	$C_8H_{14}O$	126	0.23	0.06
26	32.862	1460	Furfural	$C_5H_4O_2$	96	1.43	0.38
27	33.325	1469	*p*-Menthone	$C_{10}H_{18}O$	154	3.67	0.97
28	34.848	1497	*a*-Copaene	$C_{15}H_{24}$	204	2.53	0.67
29	35.067	1501	Decanal	$C_{10}H_{20}O$	156	9.28	2.47
30	36.308	1523	Benzaldehyde	C_7H_6O	106	3.18	0.85
31	37.603	1546	Linalool	$C_{10}H_{18}O$	154	0.68	0.18
32	37.982	1552	(*Z*)-*p*-2-Menthen-1-ol	$C_{10}H_{18}O$	154	0.55	0.15
33	38.675	1564	Menthyl acetate	$C_6H_6O_2$	110	0.53	0.14
34	39.03	1570	5-Methylfurfural	$C_6H_6O_2$	110	0.46	0.12
35	39.774	1582	Bonyl acetate	$C_{12}H_{20}O_2$	196	7.92	2.11
36	40.684	1596	2-Undecanone	$C_{11}H_{22}O$	170	13.90	3.69
37	40.764	1598	(*E*)-*β*-Caryophyllene	$C_{15}H_{24}$	204	4.53	1.21
38	40.967	1601	4-Terpineol	$C_{10}H_{18}O$	154	3.99	1.06
39	41.963	1620	*β*-Cyclocitral	$C_{10}H_{16}O$	152	0.61	0.16
40	42.842	1636	*γ*-Elemene	$C_{15}H_{24}$	204	2.71	0.72
41	43.079	1640	Menthol	$C_{10}H_{20}O$	156	11.71	3.11
42	43.555	1649	Pulegone	$C_{10}H_{16}O$	152	2.62	0.70
43	44.099	1658	Nonanol	$C_9H_{20}O$	144	8.52	2.26
44	44.321	1662	Terpinyl acetate	$C_{12}H_{20}O_2$	196	0.36	0.10
45	44.744	1670	*a*-Humulene	$C_{15}H_{24}$	204	0.84	0.22
46	46.119	1693	*a*-Terpineol	$C_{10}H_{18}O$	154	0.83	0.22
47	46.518	1700	Borneol	$C_{10}H_{18}O$	154	2.29	0.61
48	46.813	1705	Dodecanal	$C_{12}H_{24}O$	184	3.35	0.89
49	47.806	1722	*a*-Guaiene	$C_{15}H_{24}$	204	1.76	0.47
50	48.051	1727	Piperitone	$C_{10}H_{16}O$	152	1.90	0.51

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
51	49.324	1748	Geranyl acetate	$C_{12}H_{20}O_2$	196	3.97	1.05
52	49.531	1751	δ-Cadinene	$C_{15}H_{24}$	204	1.43	0.38
53	49.804	1756	Decanol	$C_{10}H_{22}O$	158	1.81	0.48
54	50.357	1765	α-curcumene	$C_{15}H_{22}$	202	0.55	0.15
55	51.848	1789	Butyrophenone	$C_{10}H_{12}O$	148	0.77	0.21
56	52.793	1804	houttuynum	$C_{12}H_{22}O_2$	198	2.94	0.78
57	53.703	1816	β-Damascenone	$C_{13}H_{18}O$	190	1.22	0.33
58	54.447	1826	Calamenene	$C_{15}H_{22}$	202	1.23	0.33
59	55.499	1840	(*E*)-Geraniol	$C_{10}H_{18}O$	154	0.95	0.25
60	56.996	1860	Undecanol	$C_{11}H_{24}O$	172	5.05	1.34
61	57.34	1865	Safrole	$C_{10}H_{10}O_2$	162	0.46	0.12
62	57.656	1869	Benzyl alcohol	C_7H_8O	108	0.84	0.22
63	60.455	1905	Phenethyl alcohol	$C_8H_{10}O$	122	1.61	0.43
64	61.404	1920	Citronellyl valerate	$C_{15}H_{28}O_2$	240	2.03	0.54
65	65.598	1985	Caryophyllene oxide	$C_{15}H_{24}O$	220	18.85	5.01
66	66.686	2002	Perilla alcohol	$C_{10}H_{16}O$	152	0.84	0.22
67	66.872	2005	Methyleugenol	$C_{11}H_{14}O_2$	178	1.46	0.39
68	67.905	2022	γ-Nonalacton	$C_9H_{16}O_2$	156	1.03	0.27
69	68.338	2029	Cinnamaldehyde	C_9H_8O	132	3.29	0.87
70	68.558	2033	Nerolidol	$C_{15}H_{26}O$	222	0.56	0.15
71	70.285	2061	Tridecanol	$C_{13}H_{28}O$	200	1.52	0.40
72	73.198	2113	Hexahydrofarnesyl acetone	$C_{18}H_{36}O$	268	54.22	14.42
73	73.575	2123	1,2-Epoxy octadecane	$C_{18}H_{36}O$	268	0.56	0.15
74	73.82	2130	γ-Decalactone	$C_{10}H_{18}O_2$	170	2.51	0.67
75	75.585	2178	Patchouli alcohol	$C_{15}H_{26}O$	222	3.48	0.92

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [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%*
76	76.961	2213	Methyl Hexadecanoate	$C_{17}H_{34}O_2$	270	1.50	0.40
77	78.795	2256	Myristicin	$C_{11}H_{12}O_3$	192	1.02	0.27
78	79.16	2264	Decanoic acid	$C_{10}H_{20}O_2$	172	17.82	4.74
79	79.399	2270	Pentadecanol	$C_{15}H_{32}O$	228	1.76	0.47
80	83.896	2361	Undecanoic acid	$C_{11}H_{22}O_2$	186	3.76	1.00
81	86.945	2423	1H-Indole	C_8H_7N	117	2.73	0.73
82	88.755	2464	Dodecanoic acid	$C_{12}H_{24}O_2$	200	28.80	7.66
83	93.335	2569	Octadecanol	$C_{18}H_{38}O$	270	24.53	6.52
84	94.598	2597	Phytol	$C_{20}H_{40}O$	296	36.32	9.16
			Total			*376.13*	*100*

[1)]Retention time, [2)]Retention index, [3)]Molecule formula, [4)]Formula weight.

Table 10. Relative content of 2-undecanone and houttuynum in identified volatile organic compounds in unirradiated and irradiated H. cordata at 1, 3, 5, 10 and 20 kGy

(unit : mg/kg)

Compound	*Irradiation dose (kGy)*					
	0	*1*	*3*	*5*	*10*	*20*
2-Undecanone	12.54	20.88	19.65	21.35	19.21	13.90
Houttuynum	2.36	3.55	3.54	3.61	3.57	2.94

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

The characteristic organic compounds, including GC/MS profile of volatile compounds in irradiated *H. cordata* samples, were similar to those in the control. However, the relative contents of these compounds were changed by irradiation. These changes in the proportions of volatile compounds are shown in Table 11.

The total volatile compound content of the control was approximately 330.12 mg/kg while irradiated samples at 1, 3, 5, 10 and 20 kGy were 421.94, 427.20, 517.32, 376.80 and 376.13 mg/kg, respectively. The total content of volatile compounds increased after irradiation, but the ratios of individual substances varied with different doses of radiation. The changes in the amounts of volatile compounds are shown in Figure 7. The total levels of volatile compounds were increased at irradiation doses of 5 kGy (517.32 mg/kg). These changes were identified by increases and decreases, without of formation or disappearance of compounds.

The of organic compounds classifications by functional group are shown in Table 12, and the terpenes content of they are shown in Table 13. In the unirradiated *H. cordata* the organic compounds consisted of 5 acids (15.17%), 21 alcohols (26.59%), 12 aldehydes (8.03%), 7 esters (8.44%), 3 ethers (0.86%), 20 hydrocarbones (13.53%), 10 ketones (21.03%), 2 nitrogenous compounds (1.16%) and 5 miscellaneous compounds (5.19%). In the case of the terpenes, a total of 46 (193.35 mg/kg) compounds were identified: 32 at monoterpenes (82.61 mg/kg), 13 at sesquiterpenes (81.32 mg/kg) and one

diterpenes (29.42 mg/kg). The amount of houttuynum [the characteristic smell of *H. cordata* (44)] was identified as 2.36 mg/kg (0.72%) in the control (Table 10). In the 1 kGy irradiated *H. cordata* sample, the volatile organic compounds consisted of 4 acids (14.32%), 21 alcohols (29.49%), 13 aldehydes (8.97%), 7 esters (9.33%), 3 ethers (0.66%), 20 hydrocarbones (13.02%), 10 ketones (18.07%), 2 nitrogenous compounds (0.68%) and 5 miscellaneous compounds (5.44%) (Table 12). In this sample, the terpene content had an additional compound, campene, so there were a total of 47 (239.64 mg/kg) detected (Table 13). However, we suggest this wasn't a created compound, but may have been lost during extraction or by the low amount of detection. Hexanal was detected in all the samples, but it was not detected in the control. Hexanal was identified as a green note (54) from C_6 lipid peroxidation products that are released when samples were pulverized. Moreover, neither tridecanoic acid nor hexanal appeared in the irradiated samples. In the *H. cordata* irradiated at 3 kGy, the organic compounds consisted of 4 acids (13.61%), 21 alcohols (29.24%), 13 aldehydes (9.51%), 7 esters (8.85%), 2 ethers (0.60%), 20 hydrocarbons (13.71%), 10 ketones (17.47%), 2 mitrogenous compounds (0.85%) and 5 miscellaneous compounds (6.15%). Total of 46 (245.16 mg/kg) were analysed as terpenes, and they were detected similar to all samples. In *H. cordata* irradiated at 5 kGy, chemical classes were the same as in samples irradiated at 3 kGy. The relative areas obtained for each functional group were acids (9.71%), alcohols (31.62%), aldehydes (10.16%), esters (9.70%), ethers (0.81%), hydrocarbones (15.45%), ketones (15.85%), nitrogenous compounds (0.58%) and miscellaneous compounds (6.11%). Total of 46 (315.92 mg/kg) terpenes were detected. In *H. cordata* irradiated at 10 kGy, chemical classes were the same as in samples

irradiated at 1 kGy. The relative areas obtained for each functional group were acids (15.73%), alcohols (30.23%), aldehydes (7.57%), esters (7.94%), ethers (0.82%), hydrocarbones (10.02%), ketones (20.72%), nitrogenous compounds (1.07%) and miscellaneous compounds (5.90%). Total of 47 (213.52 mg/kg) terpenes were detected. In *H. cordata* of irradiated 20 kGy, the relative areas obtained for each functional group were 4 acids (14.03%), 21 alcohols (28.94%), 13 aldehydes (7.91%), 7 esters (8.81%), 2 ethers (0.66%), 20 hydrocarbones (11.41%), 10 ketones (21.80%), 2 nitrogenous compounds (0.85%) and 5 miscellaneous compounds (5.59%). Also 46 terpenes (217.03 mg/kg) were identified. The dominant components and terpenes of both the unirradiated and irradiated *H. cordata* samples did not show specific changes. This result was similar for the monoterpenes, sesquiterpenes and diterpenes. In all the samples, the major functional group was alcohols and ketones. The terpens were the dominant group containing more detailed chemical types. Terpene is the generic name for a group of natural products that are structurally based on isoprene (isopentenyl) units. The term may also refer to the oxygen derivatives of these compounds, also known as terpenoids (55). In general terms, in this study, alcohols and ketones were detected as the major volatile chemical classes in the unirradiated and in the samples irradiated at 1, 3, 5, 10 and 20 kGy. Among the volatile organic compounds of *H. cordata*s, the terpenes are a large constituent. The changes in the contents of terpenes are shown in Figure 8.

When looking at the bioactivity of terpenoids, Kang *et al.* (50) reported that the growths of nine Grame negative bacteria were inhibited obviously when treated with and fraction including 2-undecanone, β-myrcene, β-ocimene, decanol and houttuynum, and fraction including decanal,

endobornylacetate, fenchene and decanoic acid, respectively.

Also, No mutagenicity was detected in the two assays with or without metabolic activation. From these results, the safety of the *H. cordata* irradiated with gamma-rays at practical dose could be revealed in further tests of genotoxicity in vivo, chronic and reproductive toxicity (56).

The relative percentages of 2-Undecanone and houttuynum, the characteristic compounds of *H. cordata*, were similar in all the irradiation dose samples. As a result, allmost all the compounds did not show significant changes after irradiation. However, in the *H. cordata* sample irradiatied at 5 kGy (517.32 mg/kg), their total amount was larger than in the other samples. All compounds showed an incerasing pattern from the control to the 5 kGy sample, and there after decreased up to the 20 kGy dose.

Table 11. Comparison of volatile organic compounds identified in unirradiated and irradiated H. cordatas at 1, 3, 5, 10 and 20 kGy

(unit : mg/kg)

Peak No.	R.T.[1)]	R.I.[2)]	Compound name	Irradiation dose (kGy)					
				0	1	3	5	10	20
1	7.745	878	Ethyl acetate	14.56	15.32	13.61	10.67	12.46	16.83
2	11.664	1021	*α*-Pinene	4.83	4.50	4.43	6.33	5.01	3.89
3	13.417	1065	Camphene	-	1.88	1.11	2.36	0.99	0.62
4	14.083	1080	Hexanal	-	0.61	0.75	1.23	0.60	0.54
5	15.256	1105	*β*-Pinene	8.44	5.89	6.48	9.56	8.18	5.59
6	17.815	1162	*β*-Myrcene	7.22	15.94	18.36	23.33	4.59	9.91
7	19.53	1195	Limonene	1.34	1.49	1.72	2.16	1.19	1.07
8	20.472	1215	[*E*]-2-Hexenal	2.37	1.90	2.70	3.53	1.22	1.92
9	21.042	1227	2-Pentylfuran	0.35	0.47	0.60	0.71	0.39	0.48
10	21.21	1231	[*Z*]-*β*-Ocimene	0.89	2.71	3.62	3.17	0.81	1.90
11	21.83	1244	*γ*-Terpinene	0.79	0.80	1.26	1.61	0.53	0.64
12	22.367	1255	2,6-Dimethylpyridine	1.20	0.22	0.53	0.82	0.43	0.46
13	23.008	1268	*ρ*-Cymene	0.79	0.75	1.01	1.02	0.45	0.72
14	23.942	1286	Octanal	0.18	0.23	0.24	0.21	0.22	0.27
15	24.497	1296	5-Butylnonane	0.63	0.50	0.72	1.07	0.55	0.70
I.S[3)]	25.231	1311	Butyl benzen	-	-	-	-	-	-
16	28.135	1368	3,4-Dimethyl-2,4,6-octatriene	0.51	1.40	1.63	1.92	0.26	0.79
17	29.1	1386	2-Nonanone	0.25	0.31	0.32	0.32	0.19	0.15
18	29.322	1390	Nonanal	1.70	2.66	2.91	3.96	1.99	2.23
19	29.6	1395	5-Butyldecane	0.88	1.26	1.35	2.27	0.76	1.06
20	29.906	1401	2-Butoxyethanol	0.25	1.24	1.80	1.78	0.32	0.61
21	30.563	1414	Perillen	0.52	0.98	1.17	0.84	0.44	0.67
22	31.706	1438	4,8-Dimethylundecane	-	0.34	0.45	0.46	0.31	0.44
23	32.096	1445	Acetic acid	1.95	1.60	2.38	1.02	2.81	2.40
24	32.325	1450	1-Octen-3-ol	0.20	0.23	0.22	0.29	0.14	0.40

[1)]Retention time, [2)]Retention index, [3)]Internal standard.

Table 11. Continued

(unit : mg/kg)

Peak No.	R.T.[1)]	R.I.[2)]	Compound name	Irradiation dose (kGy)					
				0	1	3	5	10	20
25	32.724	1457	(*E*)-2-Octenal	0.32	0.37	0.40	0.58	0.17	0.23
26	32.912	1461	Furfural	2.45	1.39	1.49	1.75	1.30	1.43
27	33.366	1470	*p*-Menthone	4.99	3.54	3.65	3.87	4.27	3.67
28	34.89	1498	*α*-Copaene	3.36	2.68	2.32	2.66	2.60	2.53
29	35.069	1501	Decanal	6.51	17.91	14.29	20.38	7.99	9.28
30	36.363	1524	Benzaldehyde	3.66	2.32	3.26	3.09	2.96	3.18
31	37.643	1547	Linalool	0.82	0.91	0.97	1.42	0.34	0.68
32	38.028	1553	(*Z*)-*p*-2-Menthen-1-ol	0.37	0.65	0.81	1.53	0.41	0.55
33	38.711	1565	Menthyl acetate	0.49	0.42	0.71	1.11	0.81	0.53
34	39.084	1571	5-Methylfurfural	0.46	0.34	0.44	0.63	0.49	0.46
35	39.81	1583	Bornyl acetate	7.23	11.86	11.68	15.40	9.24	7.92
36	40.71	1597	2-Undecanone	12.54	20.88	19.65	21.35	19.21	13.90
37	40.804	1598	(*E*)-*β*-Caryophyllene	5.03	4.51	4.47	5.22	2.25	4.53
38	41.006	1602	4-Terpineol	3.40	4.91	5.23	7.04	3.78	3.99
39	42.029	1621	*β*-Cyclocitral	0.61	0.47	0.53	0.99	0.41	0.61
40	42.882	1637	*γ*-Elemene	3.12	3.27	3.14	5.78	3.06	2.71
41	43.136	1641	Menthol	13.75	9.42	9.19	16.61	15.96	11.71
42	43.595	1649	Pulegone	2.97	2.69	2.59	2.53	3.90	2.62
43	44.128	1659	Nonanol	7.22	13.14	13.97	24.77	8.17	8.52
44	44.365	1663	Terpinyl acetate	0.32	0.63	0.65	3.06	0.76	0.36
45	44.515	1666	Estragole	0.39	0.26	-	-	0.32	-
46	44.797	1671	*α*-Humulene	0.96	1.16	0.99	1.02	1.18	0.84
47	46.255	1695	*α*-Terpineol	0.44	0.41	0.43	1.21	0.48	0.83
48	46.593	1701	Borneol	2.09	2.75	2.90	2.72	2.54	2.29
49	46.845	1706	Dodecanal	2.40	1.91	5.95	7.52	3.67	3.35
50	47.844	1723	*α*-Guaiene	1.46	2.13	2.20	3.02	1.38	1.76

[1)]Retention time, [2)]Retention index

Table 11. Continued

(unit : mg/kg)

Peak No.	R.T.[1)]	R.I.[2)]	Compound name	Irradiation dose (kGy)					
				0	1	3	5	10	20
51	48.107	1727	Piperitone	2.34	2.08	1.91	3.02	2.94	1.90
52	49.365	1749	Geranyl acetate	2.14	6.47	7.06	12.82	2.73	3.97
53	49.583	1752	δ-Cadinene	2.12	1.60	1.36	2.54	1.67	1.43
54	49.858	1757	Decanol	1.44	2.22	2.37	2.65	1.73	1.81
55	50.412	1766	α-Curcumene	0.64	0.51	0.58	1.29	0.62	0.55
56	51.915	1790	Butyrophenone	0.77	0.88	0.95	1.11	1.08	0.77
57	52.839	1804	Houttuynum	2.36	3.55	3.54	3.61	3.57	2.94
58	53.758	1817	β-Damascenone	1.10	0.86	1.25	1.32	1.34	1.22
59	54.529	1827	Calamenene	1.68	1.59	1.37	3.16	1.38	1.23
60	55.574	1841	(E)-Geraniol	1.11	1.72	1.82	3.01	1.23	0.95
61	57.047	1861	Undecanol	3.65	5.90	6.64	8.72	4.84	5.05
62	57.438	1866	Safrole	0.53	0.60	0.61	0.88	0.47	0.46
63	57.755	1870	Benzyl alcohol	0.82	1.05	1.45	2.52	0.80	0.84
64	60.541	1906	Phenethyl alcohol	1.78	4.63	3.08	5.06	1.96	1.61
65	61.469	1921	Citronellyl valerate	2.26	2.96	2.69	4.94	2.23	2.03
66	65.629	1986	Caryophyllene oxide	15.13	19.88	22.77	26.70	20.18	18.85
67	66.76	2003	Perilla alcohol	0.77	1.24	1.23	2.09	0.90	0.84
68	66.949	2006	Methyleugenol	1.30	1.62	1.56	2.34	1.66	1.46
69	67.955	2023	γ-Nonalacton	0.51	0.98	1.12	1.21	1.08	1.03
70	68.411	2030	Cinnamaldehyde	3.50	4.20	4.12	5.09	3.94	3.29
71	68.625	2034	Nerolidol	0.48	0.56	0.69	1.03	0.76	0.56
72	70.326	2062	Tridecanol	0.80	1.69	1.77	3.07	1.65	1.52
73	73.183	2112	Hexahydrofarnesyl acetone	42.28	41.37	40.56	44.56	41.85	54.22
74	73.437	2119	1,2-Epoxyoctadecane	0.62	1.05	1.11	2.47	0.76	0.56
75	73.853	2131	γ-Decalactone	1.67	2.66	2.63	2.72	2.22	2.51

[1)]Retention time, [2)]Retention index

Table 11. Continued

(unit : mg/kg)

Peak No.	*R.T.*[1)]	*R.I.*[2)]	*Compound name*	*Irradiation dose (kGy)*					
				0	*1*	*3*	*5*	*10*	*20*
76	75.622	2179	Patchouli alcohol	2.79	3.17	3.46	6.22	4.03	3.48
77	76.997	2214	Methyl Hexadecanoate	0.86	1.72	1.41	2.21	1.67	1.50
78	78.845	2257	Myristicin	1.13	0.92	0.99	1.83	1.11	1.02
79	79.213	2265	Decanoic acid	18.02	20.44	21.36	17.39	19.43	17.82
80	79.443	2271	Pentadecanol	1.15	1.58	2.11	3.10	1.80	1.76
81	83.948	2362	Undecanoic acid	3.21	4.02	4.21	3.57	4.35	3.76
82	87.01	2425	1H-Indole	2.62	2.66	3.12	2.18	3.61	2.73
83	88.788	2465	Dodecanoic acid	26.74	34.37	30.20	28.27	32.67	28.80
84	93.327	2569	Octadecanol	15.01	25.61	21.44	22.35	21.39	24.53
85	93.458	2572	Tridecanoic acid	0.18	-	-	-	-	-
86	94.615	2598	Phytol	29.42	41.41	43.32	46.38	40.68	36.32
Total				*330.12*	*421.94*	*427.20*	*517.32*	*376.80*	*376.12*

[1)]Retention time, [2)]Retention index

Table 12. Relative content of functional groups in identified volatile organic compounds in unirradiated and irradiated H. cordata at 1, 3, 5, 10 and 20 kGy

Functional groups	0		1		3		5		10		20	
	C[1)]	mg/kg	C	mg/kg	C	mg/kg	C	mg/kg	C	mg/kg	C	mg/kg
Acids	5	50.09	4	60.44	4	58.16	4	50.25	4	59.26	4	52.78
Alcohols	21	87.77	21	124.44	21	124.91	21	163.58	21	113.92	21	108.85
Aldehydes	12	26.52	13	37.86	13	40.62	13	52.57	13	28.52	13	29.73
Esters	7	27.86	7	39.39	7	37.81	7	50.21	7	29.91	7	33.13
Ethers	3	2.82	3	2.80	2	2.55	2	4.17	3	3.09	2	2.48
Hydrocarbons	18	44.68	20	54.92	20	58.59	20	79.94	20	37.76	20	42.93
Ketones	10	69.42	10	76.24	10	74.65	10	82.01	10	78.07	10	82.00
N-Compounds	2	3.82	2	2.89	2	3.65	2	3.00	2	4.04	2	3.19
Miscellaneous	5	17.14	5	22.97	5	26.26	5	31.60	5	22.24	5	21.03
Total	*83*	*330.12*	*85*	*421.94*	*84*	*427.20*	*84*	*517.32*	*85*	*376.80*	*84*	*376.13*

[1)]Number of Compounds.

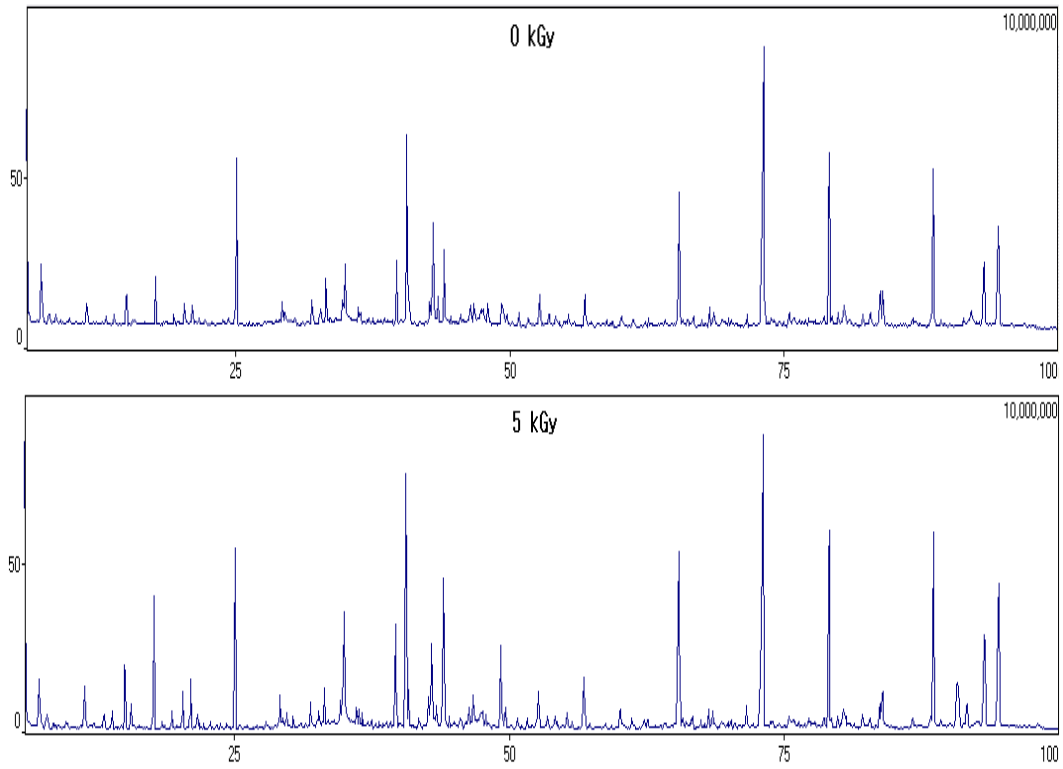

Figure 6. GC/MS total ion chromatograms of the volatile organic compounds in unirradiated and irradiated H. cordatas at 5 kGy.

Table 13. Relative content of terpenes in identified volatile organic compounds in unirradiated and irradiated H. cordata at 1, 3, 5, 10 and 20 kGy

Terpenes	0		1		3		5		10		20	
	C[1)]	mg/kg	C	mg/kg	C	mg/kg	C	mg/kg	C	mg/kg	C	mg/kg
Monoterpenes	32	82.61	33	112.84	32	115.22	32	161.40	33	89.69	32	85.99
Sesquiterpenes	13	81.32	13	85.39	13	86.62	13	108.15	13	83.16	13	94.73
Diterpenes	1	29.42	1	41.41	1	43.32	1	46.38	1	40.68	1	36.32
Total	***46***	***193.35***	***47***	***239.64***	***46***	***245.16***	***46***	***315.92***	***47***	***213.52***	***46***	***217.03***

[1)]Number of Compounds.

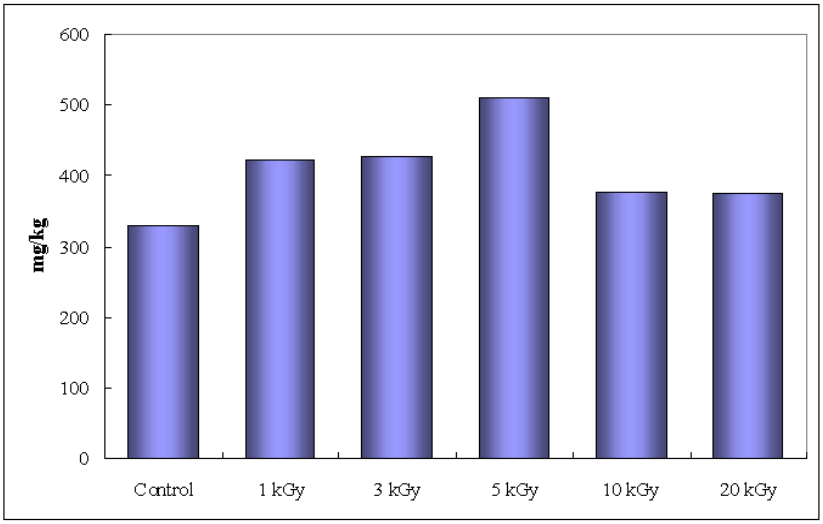

Figure 7. Effect of total content in unirradiated and irradiated H. cordata.

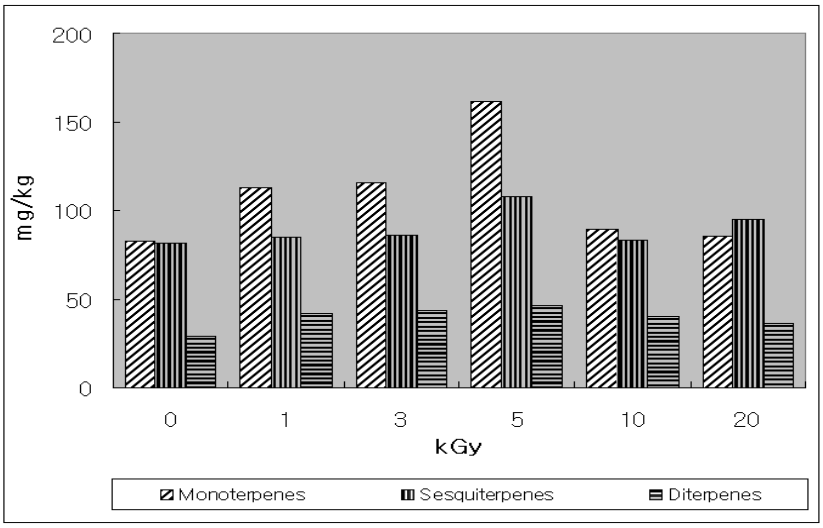

Figure 8. Effect of terpenoid contents in unirradiated and irradiated H. cordata.

CONCLUSION

This study was performed to examine the effect of γ-irradiation on the volatile organic compounds in *Houttuynia cordata* Thunb.. Volatile compounds from *H. cordata* samples were extracted using an SDE apparatus, and analyzed by GC/MS. Total components of 83, 85, 84, 84, 85 and 84 were detected in the control and the 1, 3, 5, 10 and 20 kGy irradiation doses, respectively. The major functional groups in the volatile organic compounds of *H. cordata* were alcohols and ketones. The profile of volatile organic compounds was same in unirradiated and irradiated samples. And, hexahydrofarnesyl acetone, phytol, decanoic acid, dodecanoic acid, octadecanol, caryophyllene oxide, 2-undecanone and menthol were detected as dominant compounds. Also houttuynum, which is characteristic compound of *H. cordata* was analyzed as low amount. The total contents of volatile compounds was increased after irradiation, and the level of irradiated sample at 5 kGy was more greater than other irradiated samples. However, the tendency was not significant with irradiation doses. Consequently, irradiation may be an effective sanitation process with energy and extraction efficiency, as well as desirable aspects for components, which will prove beneficial for *H. cordata*.

요 약

본 연구에서는 현재 우리나라에서 그 소비량이 증가하고 있고, 여러 가지 효능이 확인되고 있는 한약재 중의 하나인 어성초의 휘발성 유기성분을 각 선량별로 방사선 조사된 어성초와 비교하였다. n-Pentane과 diethylether 혼합용매를 추출용매로 사용하여 연속증류추출장치로 추출하고 이를 GC/MS로 사용하여 분석・확인하였다. 비 조사 시료에서 확인된 성분은 83종, 1, 3, 5, 10 및 20 kGy의 선량으로 방사선 조사된 어성초에서 확인된 성분은 85, 84, 84, 85 그리고 84종이 확인되었다. 전체적인 관능기별 함량으로는 alcohol류와 ketone류가 두드러지는 경향을 보여 어성초의 주요 휘발성 유기화합물에 크게 영향을 미치는 것으로 판단되었다. 어성초의 대표적인 휘발성 유기화합물로는 hexahydrofarnesyl acetone, phytol, decanoic acid, dodecanoic acid, octadecanol, caryophyllene oxide, 2-undecanone 및 menthol 등이었다. 특히 houttuynum은 그 함량이 다른 주요화합물보다 상대적으로 낮게 확인되었으나, 어성초의 특징적인 비린내 성분을 부여하는 화합물로 확인되었다. 또한, 어성초의 주요 생리활성 성분 이라고 할 수 있고, 항균, 항진균, 항생물, 항염증 및 항종양등의 여러 가지 효능이 입증되고 있는 terpene류의 상대적인 함량도 크게 확인되었다. 조사 선량에 따른 함량의 변화는 거의 모든 시료에서 비슷하였으나 5 kGy로 조사된 시료에서 상대적으로 많은 함량의 증가를 보였다. 따라서, 어성초의 위생화 처리 효과, 에너지 효율 및 유용성분의 추출효율을 고려할 때 최대 적정 조사선량은 5 kGy가 적절할 것으로 사료된다. 본 연구의 결과는 한약재에 대한 방사선 조사에 영향을 보여주고 있으며, 한약재의 위생화 방안과 현재 활발히 진행되고 있는 방사선 조사식품에 대한 여러 연구들에 대한 기초 자료로 활용될 수 있을 것으로 판단된다.

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감사의 글

받기만 했을 뿐 감사의 말들에 인색했던 제가 이 기회를 빌어 지금껏 저에게 도움을 주셨던, 그리고 곁에서 힘이 되어 준 많은 분들께 진심으로 고개 숙여 감사드립니다.

부족한 저를 학문의 길로 이끌어 주시고, 학문뿐만 아니라 인생을 가르쳐주시며 엄한 질타와 때론 부드러운 칭찬으로 지도해 주신 김경수 지도교수님께 머리 숙여 깊이 감사드립니다. 많은 학문적 가르침을 주시고, 바쁘신 가운데에서도 성심껏 논문을 심사하여 주신 장해춘 교수님, 귀중한 시간을 내어 많이 부족한 논문에 여러 조언과 가르침을 주신 변명우 박사님께 깊은 감사를 드립니다. 그리고 학부때나 지금이나 변함없이 좋은 가르침을 주신 이명렬 교수님, 노희경 교수님, 김복희 교수님 그리고 새로 부임하신 이소정 교수님, 마지막으로 지금은 정년하신 서화중 교수님께도 깊은 감사를 드립니다.

항상 같이 지내며, 같이 즐거움을 느끼고, 때론 같이 힘들어해서 이제는 떨어져 지내는 걸 생각해 볼 수도 없는 실험실 식구들인 혜영이 누나, 동기 준형이와 기미, 동생이지만 실험실 선배인 수형, 성례 그리고 묵묵히 뒷받침이 되어준 원이형, 학부생들이지만 벌써부터 실험실의 모든 뒤처리를 도맡아 하는 민석이, 인민이 에게 감사의 말을 전합니다. 공부를 하는 중에도 학업의 중요성을 더욱 깨닫게 해주시고, 실험실 밖의 지식을 전해주시며 든든한 조언자가 되어주시는 홍철희 선생님, 정양모 선생님, 김관수 선생님, 한규재 선생님, 김왕근 선생님, 정찬희 선생님, 전삼녀 선생님 그리고 은령이 누나, 정민 누나, 지금은 멀리 미국에 있지만 항상 격려해주고, 도와주었던 현파 누나, 그리고 비록 같은 실험실은 아니지만 항상 선배로서 조언과 충고를 아끼지 않는 호준이형 에게도 감사의 마음을 전합니다. 지금껏 같이 있었지만 지금은 졸업하고 고향으로 돌아간 나의 친구 Rajendra 보고 싶습니다.

언제나 변함없는 우정으로 늘 곁에 있어준 현진, 인진, 상훈, 민준, 지훈, 희석, 광중이 고맙다. 너희들이 있어서 난 항상 행복하다. 그리고 학부 때부터 같이 지내온 예쁜 동생들 지혜, 현경, 형덕이 에게도 고마움을 전합니다.

마지막으로 평생 같이 지내오면서 언제나 건강하고, 인정받는 사람이 되기를 바라시는 할머니(건강하세요), 언제나 저한테 손해만 보시고 아직까지 모든걸 주기만 하시는 아버지, 어머니, 동생을 위해 아낌없는 도움을 주는 근철이형, 근석이형, 또한 묵묵히 지켜봐 주신 여러 친지들에게 말로다 할 수 없는 고마움을 전합니다.

2007년 6월

유 근 영

저작물 이용 허락서

학 과	식품영양학과	학 번	20067034	과 정	석사
성 명	한글: 유 근 영 한문 : 柳 根 榮 영문 : Ryu, Keun-Young				
주 소	광주 광역시 북구 우산동 491				
연락처	E-MAIL : zetryu@hanmail.net				
논문제목	영문 : Effect of Gamma-Irradiation on the Volatile Effective Components of *Houttuynia cordata* Thunb.				

본인이 저작한 위의 저작물에 대하여 다음과 같은 조건아래 조선대학교가 저작물을 이용할 수 있도록 허락하고 동의합니다.

- 다 음 -

1. 저작물의 DB구축 및 인터넷을 포함한 정보통신망에의 공개를 위한 저작물의 복제, 기억장치에의 저장, 전송 등을 허락함
2. 위의 목적을 위하여 필요한 범위 내에서의 편집·형식상의 변경을 허락함. 다만, 저작물의 내용변경은 금지함.
3. 배포·전송된 저작물의 영리적 목적을 위한 복제, 저장, 전송 등은 금지함.
4. 저작물에 대한 이용기간은 5년으로 하고, 기간종료 3개월 이내에 별도의 의사 표시가 없을 경우에는 저작물의 이용기간을 계속 연장함.
5. 해당 저작물의 저작권을 타인에게 양도하거나 또는 출판을 허락을 하였을 경우에는 1개월 이내에 대학에 이를 통보함.
6. 조선대학교는 저작물의 이용허락 이후 해당 저작물로 인하여 발생하는 타인에 의한 권리 침해에 대하여 일체의 법적 책임을 지지 않음
7. 소속대학의 협정기관에 저작물의 제공 및 인터넷 등 정보통신망을 이용한 저작물의 전송·출력을 허락함.

동의여부 : 동의(0) 조건부 동의( ) 반대( )

2007년 8 월

저작자: 유 근 영 (서명 또는 인)

조선대학교 총장 귀하