Research Note

Changes in volatile flavor compounds in steam-dried *Allium hookeri* root

Hyun-Il Jun, Jae-Heon Yang¹, Ji Yeon Choi², Sung-Hyen Lee³, Geun-Seoup Song, Kyong Su Kim², and Young-Soo Kim*

Department of Food Science & Technology, Chonbuk National University, Jeonju, Jeonbuk 54896, Korea

¹Center for Healthcare Technology Development, Chonbuk National University, Jeonju, Jeonbuk 54896, Korea

²Department of Food and Nutrition, College of Natural Sciences, Chosun University, Gwangju 61452, Korea

³Functional Food & Nutrition Division, Department of Agro-food Resources, Rural Development Administration, Wanju, Jeonbuk 55365, Korea

Received April 20, 2016
Revised July 20, 2016
Accepted July 20, 2016
Published online October 31, 2016

*Corresponding Author
Tel: +82-63-270-2569
Fax: +82-63-270-2572
E-mail: ykim@jbnu.ac.kr

pISSN 1226-7708
eISSN 2092-6456

© KoSFoST and Springer 2016

Abstract This study was carried out to identify volatile flavor compounds in *Allium hookeri* root (AHR) and steam-dried AHR. The volatile compounds were extracted using a simultaneous steam distillation and extraction (SDE) method and identified by gas chromatography/mass spectrometry (GC/MS) analysis. Forty volatile compounds, present at a concentration of 76.10 mg/kg, were identified in AHR, with sulfur-containing compounds (96.8%) as the major volatile compounds. On the other hand, in two and four times steam-dried AHR, 34 volatile compounds present at 5.96 mg/kg and 28 compounds present at 4.23 mg/kg were identified, respectively. This two and four times steam-dried AHR respectively contained sulfur-containing compounds (64.1 and 37.4%) and aldehydes (19.3 and 45.4%) as the dominant compounds. The sulfur-containing compounds decreased, whereas the aldehydes increased relative to levels in AHR with increased steam-drying time. This is the first report on volatile flavor compounds in AHR and steam-dried AHR.

Keywords: *Allium hookeri* root, steam-drying process, volatile flavor compound, sulfur-containing compounds, aldehydes

Introduction

Allium hookeri (a member of the *Allium* genus) is primarily cultivated for traditional medicinal use in southeastern Asia (1). *A. hookeri* was recently introduced to South Korea, and *A. hookeri* root (AHR) has been used in spices for foods, such as salads, yogurt, and kimchi, due to its unique flavor derived from cysteine compounds, such as alliin, methiin, isoalliin, propiin, and allicin (2-4). Many members of the *Allium* genus, such as garlic, leek, onion, and welsh onion, are generally recognized as rich sources of bioactive sulfur and phenolic compounds (5,6). It has also been reported that AHR has various functional characteristics, including antioxidant, anti-inflammatory, and anti-diabetic effects (6-8).

The steam-drying process using high temperatures and/or pressure is a useful technique to ensure a safe, high-quality, and functional product due to the removal of water and the death of microorganisms (9,10). In a previous study, it was found that the steam-drying process could be used as an effective process to increase the antioxidant activity of AHR (11). The differences in antioxidant activities between AHR and steam-dried AHR result from changes in the chemical composition, including changes in phenolic compounds,

acids, sugars, browning products, and sulfur compounds, in AHR during repeated steam-drying (9-11). The contents and composition of flavor compounds are important factors related to the sensory characteristics of food during ripening, storage, and cooking (12).

There have been a few studies that have shown that thermally processed members of the *Allium* genus have lower volatile flavor compound contents than the original state (13,14). However, to the best of the author's knowledge, there is no published report on the contents or composition of volatile flavor compounds in AHR and steam-dried AHR. Therefore, the goal of this study was to investigate changes in volatile compounds in AHR during the steam-drying process.

Materials and Methods

Sample preparation including drying process Fresh AHR (200 kg) was purchased from a Hanam farm located at Sunchang-gun (Jeollabuk-do, Korea) in February 2015 and was hot air-dried for 12 h at 60°C after the removal of leaves. Hot air-dried AHRs (300 g) were steamed at 100°C for 4 h and then dried at 60°C for 8 h. These steam-

drying procedures were repeated two and four times, respectively. The final products were air-dried at 30°C for 24 h. Hot air-dried AHR was used as a control.

Steam-drying was performed using a steamer (HD-300; Hyundai total Co. Ltd., Gimpo, Korea) and an autoclave (BF-60AC; Biofree Co. Ltd., Bucheon, Korea). All AHRs were ground using a stainless roller (Shinpoong Eng. Ltd., Gwangju, Korea), passed through a 250 µm sieve. Vacuum-packed AHR powders were stored in a deep freezer at -20°C until use.

Chemicals Diethylether, *n*-heptadecane, *n*-pentane, and *n*-alkanes (C₇-C₄₀) were purchased from Sigma-Aldrich Co. (St. Louis, MO, USA). All other reagents were of analytical grade. Purified water was generated with a Milli Q water purification system (Millipore, Bedford, MA, USA).

Extraction and isolation of volatile compounds The volatile compounds present in AHR were extracted using a Likens-Nickerson-type apparatus (Kontes, Vineland, NJ, USA) for simultaneous steam distillation and extraction (SDE). Gas chromatography/mass spectrometry (GC/MS) was performed on a Agilent 7890 Series gas chromatograph directly coupled to an Agilent 7000 series mass spectrometer (Agilent Technologies, Santa Clara, CA, USA) in the EI (electron impact ionization) scan mode. Ground sample (70 g) was added to 1 L of purified water. The slurry was extracted using 45 mL of *n*-pentane/diethylether (1:1, v/v) mixture for 2 h under atmospheric pressure. The volatile compounds were extracted using a simultaneous steam distillation and extraction (SDE) apparatus of the Likens and Nikerson type, as modified by Schultz *et al.* (15,16). The extract was concentrated to 1 mL using a mild stream of nitrogen gas (99.99% purity). *n*-Heptadecane (5 mL) was added to the slurry as an internal standard for GC/MS analysis.

Identification and quantitative analysis of volatile compounds by GC/MS Volatile compounds were separated and identified using a GC/MS equipped with a ZB-5MS capillary column (60 m×0.25 mm i.d., 0.25 µm thickness; Phenomenex Inc., Torrance, CA, USA). The ionizing energy and ion source temperature of the mass selective detector were 70 eV and 220°C, respectively, with a scanning mass range from *m/z* 45 to 450. The oven temperature program was as follows: 40°C for 3 min, increase to 180°C at 2°C/min, increase to 200°C at 4°C/min, hold at this temperature for 10 min. The injector and detector temperatures were 250 and 300°C, respectively. Helium was used as the carrier gas at a constant flow rate of 1 mL/min and the sample was injection volume of 1 µL using a 1:20 split ratio.

Retention index was used as parameter for checking of a solute from chromatogram by comparing the retention time of standard *n*-alkanes (C₇-C₄₀) as external references. The separated peaks of the total ion chromatogram (TIC) were identified using a combination of our own mass spectra data; three mass spectrum libraries, including

FFNSC 2.0, NIST 9.0 and Wiley 8.0; a mass spectral data book (17,18); and the retention index of reference data (19). The content of volatile compounds in the sample was analyzed in duplicate and calculated using the following formula:

$$\text{Content (mg/kg)} = \frac{\text{Peak area of each compound in the sample}}{\text{Peak area of } n\text{-heptadecane} \times \text{Weight of sample (g)}} \times 1,000$$

Results and Discussion

Composition of volatile compounds in AHR The contents and functional groups of volatile compounds identified with GC/MS analysis are listed in Tables 1 and 2, respectively. The number and content of volatile compounds in AHR was 40 and 76.10 mg/kg, respectively. With respect to functional groups, the number and content of aldehydes, ethers, alcohols, esters, sulfur-containing compounds, and miscellaneous compounds were 7 and 0.69 mg/kg, 1 and 0.03 mg/kg, 1 and 0.20 mg/kg, 2 and 0.23 mg/kg, 25 and 73.64 mg/kg, and 4 and 1.31 mg/kg, respectively. Sulfur-containing compounds (96.8%) were the major volatile compounds. Allyl methyl trisulfide (20.1%), diallyl trisulfide (13.8%), isobutyl isothiocyanate (9.3%), dimethyl trisulfide (8.7%), methyl propyl trisulfide (6.5%), and dipropyl trisulfide (5.5%) were detected as the major sulfur-containing compounds.

Our results are similar to those in a previous report, where sulfur-containing compounds (95.1%), including diallyl trisulfide (36.6%), diallyl disulfide (35.8%), allyl methyl trisulfide (6.0%), methyl propyl trisulfide (3.6%), and allyl methyl disulfide (2.6%), were presented as the dominant volatile compounds in dried garlic (20). Lee *et al.* (21) reported that sulfur-containing compounds were the major volatile compounds in domestic onions, accounting for 62.6-80.3% of the total volatiles.

Changes in volatile compounds in AHR as a result of the steam-drying process The GC-MS chromatogram of volatile compounds in AHR and steam-dried AHR are shown in Fig. 1. The volatile compounds and peak intensities in AHR were clearly higher than those in steam-dried AHR. The number and content of volatile compounds in two and four times steam-dried AHR decreased from 6 to 12 and from 92.2 to 94.4% compared to those present in AHR, respectively. These data demonstrate that the number and amounts of volatile compounds decreased with increasing steam-dried cycle. In steam-dried AHR, sulfur-containing compounds and aldehydes were the dominant volatile compounds detected. When the two and four times steam-dried AHR were compared, sulfur-containing compounds (64.1 and 37.4%), including dimethyl trisulfide (20.8 and 12.3%), methyl propyl trisulfide (9.6 and 5.4%), and allyl methyl trisulfide (9.2 and 5.0%), were detected as the major volatile compounds, respectively. Aldehydes (19.3 and 45.4%), including furfural (11.2 and 31.9%), 3-methyl butanal (2.3 and 2.8%), and

Table 1. Contents of volatile compounds identified in AHR and steam-dried AHR

Peak	Retention index ¹⁾	Compound name	Molecular formula	Molecular weight	Identification method ²⁾	Content (mg/kg)		
						Control	2 times	4 times
1	580	3-Methylbutanal	C ₅ H ₁₀ O	86	MS, RI	0.07±0.00 ³⁾	0.14±0.00	0.12±0.00
2	603	2-Methylbutanal	C ₅ H ₁₀ O	86	MS, RI	- ⁴⁾	0.05±0.00	0.07±0.00
3	611	Dithiomethane	CH ₄ S ₂	80	MS, RI	0.18±0.00	-	-
4	694	Allyl methyl sulfide	C ₄ H ₈ S	88	MS, RI	0.12±0.00	-	-
5	724	1,1-Diethoxy-ethane	C ₆ H ₁₄ O ₂	118	MS, RI	0.03±0.00	0.03±0.00	-
6	740	Dimethyl disulfide	C ₂ H ₆ S ₂	94	MS, RI	1.11±0.00	0.18±0.00	0.12±0.00
7	758	Methyl propyl sulfide	C ₄ H ₁₀ S	90	MS, RI	0.06±0.00	0.03±0.00	-
8	780	2,3-Butanediol	C ₄ H ₁₀ O ₂	90	MS, RI	0.20±0.00	0.33±0.00	0.03±0.00
9	801	<i>n</i> -Hexanal	C ₆ H ₁₂ O	100	MS, RI	0.14±0.00	0.03±0.00	0.04±0.00
10	816	2-Ethoxy-3-chlorobutane	C ₆ H ₁₃ ClO	136	MS, RI	0.30±0.00	0.25±0.00	0.26±0.00
11	829	Furfural	C ₅ H ₄ O ₂	96	MS, RI	0.11±0.00	0.67±0.01	1.35±0.01
12	580	Furfuryl alcohol	C ₅ H ₆ O ₂	98	MS, RI	-	0.06±0.00	0.08±0.00
13	856	Diallyl sulfide	C ₆ H ₁₀ S	114	MS, RI	0.06±0.00	-	0.03±0.00
14	864	alpha-Angelicalactone	C ₅ H ₈ O ₂	98	MS, RI	-	0.02±0.00	0.06±0.00
15	871	Allyl isopropyl sulfide	C ₆ H ₁₂ S	116	MS, RI	0.08±0.00	-	0.03±0.00
16	903	2,4-Dimethyl thiophene	C ₆ H ₈ S	112	MS, RI	0.13±0.00	0.07±0.00	0.05±0.00
17	908	3-Methylthio propionaldehyde	C ₄ H ₈ OS	104	MS, RI	1.78±0.02	0.05±0.00	-
18	917	Methyl allyl disulfide	C ₄ H ₈ S ₂	120	MS, RI	3.55±0.08	0.09±0.00	0.08±0.00
19	929	(Z)-Propenyl methyl disulfide	C ₄ H ₈ S ₂	120	MS, RI	0.95±0.00	0.03±0.00	0.04±0.00
20	931	Methyl propyl disulfide	C ₄ H ₁₀ S ₂	122	MS, RI	0.84±0.00	0.07±0.00	0.05±0.00
21	938	(E)-Propenyl methyl disulfide	C ₄ H ₈ S ₂	120	MS, RI	1.86±0.00	0.06±0.00	-
22	961	5-Methyl furfural	C ₆ H ₆ O ₂	110	MS, RI	0.03±0.00	0.07±0.00	0.20±0.00
23	970	Dimethyl trisulfide	C ₂ H ₆ S ₃	126	MS, RI	6.62±0.03	1.24±0.02	0.52±0.00
24	976	<i>n</i> -Hexanoic acid	C ₆ H ₁₂ O ₂	116	MS, RI	-	-	-
25	990	2-Pentyl furan	C ₉ H ₁₄ O	138	MS, RI	0.04±0.00	-	-
26	1044	Benzeneacetaldehyde	C ₈ H ₈ O	120	MS, RI	0.08±0.00	0.16±0.00	0.11±0.00
27	1062	2-Acetyl pyrrole	C ₆ H ₇ NO	109	MS, RI	-	-	-
28	1081	Allyl disulfide	C ₆ H ₁₀ S ₂	146	MS, RI	3.75±0.01	-	-
29	1090	Butyl propenyl sulfide	C ₇ H ₁₄ S	130	MS, RI	0.24±0.01	-	-
30	1095	6-Methyl-4,5-dithia heptene	C ₆ H ₁₂ S ₂	148	MS, RI	2.93±0.01	0.04±0.00	-
31	1101	Diallyl disulfide	C ₆ H ₁₀ S ₂	146	MS, RI	2.54±0.04	-	-
32	1108	Dipropyl disulfide	C ₆ H ₁₄ S ₂	150	MS, RI	-	-	-
33	1128	Methyl methyl thiomethyl disulfide	C ₃ H ₈ S ₃	140	MS, RI	0.64±0.00	0.03±0.00	-
34	1143	Allyl methyl trisulfide	C ₄ H ₈ S ₃	152	MS, RI	15.26±0.11	0.55±0.01	0.21±0.00
35	1154	Methyl propyl trisulfide	C ₄ H ₁₀ S ₃	154	MS, RI	4.93±0.01	0.57±0.01	0.23±0.00
36	1158	s-Trithiane	C ₃ H ₆ S ₃	138	MS, RI	-	0.18±0.00	0.09±0.00
37	1218	Dimethyl tetrasulfide	C ₂ H ₆ S ₄	158	MS, RI	2.06±0.01	0.24±0.00	0.05±0.00
38	1265	Nonanoic acid	C ₉ H ₁₈ O ₂	158	MS, RI	-	-	-
39	1306	Diallyl trisulfide	C ₆ H ₁₀ S ₃	178	MS, RI	10.51±0.02	0.05±0.00	-
40	1312	4-Vinyl guaiacol	C ₉ H ₁₀ O ₂	150	MS, RI	0.51±0.00	0.08±0.00	0.03±0.00
41	1319	Isobutyl isothiocyanate	C ₅ H ₉ NS	115	MS, RI	7.04±0.07	0.17±0.00	0.05±0.00
42	1331	Dipropyl trisulfide	C ₆ H ₁₄ S ₃	182	MS, RI	4.19±0.11	0.17±0.00	0.04±0.00
43	1482	ar-Curcumene	C ₁₅ H ₂₂	202	MS, RI	-	-	-
44	1547	Diallyl tetrasulfide	C ₆ H ₁₀ S ₄	210	MS, RI	2.22±0.02	-	-
45	1613	Tetradecanal	C ₁₄ H ₂₈ O	212	MS, RI	0.15±0.00	0.03±0.00	0.03±0.00
46	1646	5-Methyl-2-octyl-3(2H)-furanone	C ₁₃ H ₂₂ O ₂	210	MS, RI	0.46±0.00	-	-
IS ⁵⁾	1700	<i>n</i> -Heptadecane	C ₁₇ H ₃₆	240	MS, RI	-	-	-
47	1714	Octadecanal	C ₁₈ H ₃₆ O	254	MS, RI	0.11±0.00	-	-
48	1860	Pentadecylic acid	C ₁₅ H ₃₀ O	242	MS, RI	-	-	-
49	1922	Methyl hexadecanoate	C ₁₇ H ₃₄ O ₂	270	MS, RI	-	0.03±0.00	-
50	1935	Hexadecanolact-16-one	C ₁₆ H ₃₀ O ₂	254	MS, RI	-	0.09±0.00	0.20±0.00
51	1922	Methyl palmitate	C ₁₇ H ₃₄ O ₂	270	MS, RI	0.11±0.00	-	-
52	1992	Ethyl palmitate	C ₁₈ H ₃₆ O ₂	284	MS, RI	0.12±0.00	0.10±0.00	0.07±0.00
Total						76.10±0.05	5.96±0.00	4.23±0.01

¹⁾Retention indices were determined using *n*-alkanes (C₇-C₄₀) as external references.²⁾MS and RI were determined volatile compounds by mass spectra and retention index, respectively.³⁾Values are mean±SD (*n*=2).⁴⁾Hyphen was indicated as not detected.⁵⁾IS was an internal standard.

Table 2. Functional groups of volatile compounds identified in AHR and steam-dried AHR

Functional group	Control		2 times		4 times	
	Peak number	Content (mg/kg)	Peak number	Content (mg/kg)	Peak number	Content (mg/kg)
Aldehyde	7	0.69±0.00 ¹⁾	7	1.15±0.01	7	1.92±0.01
Ether	1	0.03±0.00	1	0.03±0.00	-	-
Alcohol	1	0.20±0.00	2	0.39±0.00	2	0.11±0.00
Ester	2	0.23±0.00	3	0.15±0.00	2	0.13±0.00
Acid	- ²⁾	-	-	-	-	-
Sulfur-containing compound	25	73.64±0.05	18	3.82±0.01	14	1.58±0.00
Miscellaneous compound	4	1.31±0.00	3	0.42±0.00	3	0.50±0.00
Total	40	76.10±0.05	34	5.96±0.00	28	4.23±0.01

¹⁾Values are mean±SD (*n*=2).

²⁾Hyphen was indicated as not detected.

benzene acetaldehyde (2.7 and 2.6%), were the second most dominant types of volatile compounds. The two dominant volatile compounds decreased from 19.3- to 46.6-fold for sulfur-containing compounds as a result of the steam-drying process, whereas aldehydes increased

from 1.7- to 2.8-fold compared to those in AHR. These results indicate that steam drying is a good processing method to apply to AHR used in food manufacturing, because of the reduction in sulfur-containing compounds, which cause undesirable and spicy flavors,

Fig. 1. GC-MS chromatograms of the volatile compounds in steam-dried AHR. (A) Control, (B) 2 times, and (C) 4 times.

and the increase in aldehydes, such as furfural and 5-methyl furfural, which provide a sweet flavor (22,23). In addition, Woo *et al.* (24) reported that the sulfur-containing compounds found in garlic changed from di- or tri-sulfur compounds to mono-sulfur compounds upon thermal processing.

In conclusion, the steam-drying process of AHR resulted in important changes in sulfur-containing compounds and aldehydes among the volatiles. In addition, our results represent the first report of the comparison of the volatile compounds obtained from AHR and steam-dried AHR.

Acknowledgments This research was carried out with the support of the Cooperative Research Program for Agriculture & Technology Development (Project No. PJ01049002), Rural Development Administration, Republic of Korea.

Disclosure The authors declare no conflict of interest.

References

1. Ayam VS. *Allium hookeri*, Thw. Enum. A lesser known terrestrial perennial herb used as food and its ethnobotanical relevance in Manipur. Afr. J. Food Agric. Nutr. Dev. 11: 5389-5412 (2011)
2. You BR, Kim EG, Choi HJ, Kim HJ. Quality characteristics of kimchi with *Allium hookeri* root powder added. Korean J. Food Preserv. 20: 863-870 (2013)
3. Jun HI, Park SY, Jeong DY, Song GS, Kim YS. Quality properties of yogurt added with hot water concentrates from *Allium hookeri* root. J. Korean Soc. Food Sci. Nutr. 43: 1415-1422 (2014)
4. Rhyu DY, Park SH. Characterization of alkyl thiosulfinate in *Allium hookeri* root using HPLC-ESI-MS. J. Korean Soc. Appl. Biol. Chem. 56: 457-459 (2013)
5. Song HP, Shim SL, Jung IS, Kim DH, Kim KS. Analysis of volatile organosulfur compounds in Korean *Allium* species. Korean J. Food Preserv. 16: 923-937 (2009)
6. Park SY, Je JY, Ahn CB. Phenolic composition and hepatoprotective activities of *Allium hookeri* against hydrogen-peroxide-induced oxidative stress in cultured hepatocytes. J. Food Biochem. 40: online (2015)
7. Lee KW, Kim YS, Park PJ, Jeong JH. Comparison of effect of water and ethanolic extract from roots and leaves of *Allium hookeri*. J. Korean Soc. Food Sci. Nutr. 43: 1808-1816 (2014)
8. Kim NS, Choi BK, Lee SH, Jang HH, Kim JB, Kim HR, Kim DK, Kim YS, Yang JH, Kim HJ, Lee SH. Effects of *Allium hookeri* on glucose metabolism in type II diabetic mice. Kor. J. Pharmacogn. 46: 78-83 (2015)
9. Kim WY, Kim JM, Han SB, Lee SK, Kim ND, Park MK, Kim CK, Park JH. Steaming of ginseng at high temperature enhances biological activity. J. Nat. Prod. 63: 1702-1704 (2000)
10. Koh E, Jang OH, Hwang KH, An YN, Moon B. Effects of steaming and air-drying on ginsenoside composition of Korean ginseng (*Panax ginseng* CA Meyer). J. Food Process. Pres. 39: 207-213 (2015)
11. Jun HI, Jang HN, Yang JH, Song GS, Kim YS. Physicochemical properties and antioxidant activities of steam-dried *Allium hookeri* root. J. Korean Soc. Food Sci. Nutr. 44: 412-417 (2015)
12. Artacho R, Serrano MF, Lopez MD. Determination of organic sulphur compounds in garlic extracts by gas chromatography and mass spectrometry. Food Chem. 53: 91-93 (1995)
13. Kim YD, Seo JS, Kim KJ, Kim KM, Hur CK, Cho IK. Component analysis by different heat treatments of garlic (*Allium sativum* L.). Korean J. Food Preserv. 12: 161-165 (2005)
14. Jeong JY, Woo KS, Hwang IG, Yoon HS, Lee YR, Jeong HS. Effects of heat treatment and antioxidant activity of aroma on garlic harvested in different cultivation areas. J. Korean Soc. Food Sci. Nutr. 36: 1637-1642 (2007)
15. Nickerson GB, Likens ST. Gas chromatography evidence for the occurrence of hop oil components in beer. J. Chromatogr. A 21: 1-5 (1996)
16. Schultz TH, Flath RA, Mon TR, Enggling SB, Teranishi R. Isolation of volatile components from a model system. J. Agr. Food Chem. 25: 446-449 (1977)
17. Sadtler Research Laboratories. The saddler standard gas chromatography retention index library. Bio-Rad Laboratories, Philadelphia, PA, USA (1986)
18. Davies MW. Gas chromatographic retention indices of monoterpenes and sesquiterpenes on methyl silicone and Carbowax 20M phases. J. Chromatogr. A 503: 1-24 (1990)
19. Adams RP. Identification of essential oil components by gas chromatography and mass spectroscopy. Vol. I, Allured Publishing Corporation, Carol Stream, IL, USA. pp. 18-43 (1995)
20. Kim YS, Seoa HY, No KM, Shim SL, Yang SH, Park ER, Kim KS. Comparison of volatile organic components in fresh and freeze dried garlic. J. Korean Soc. Food Sci. Nutr. 34: 885-891 (2005)
21. Lee HY, Jeong EJ, Jeon SY, Cho MS, Cho WJ, Kim HD, Cha YJ. Comparison of volatile flavor compounds of domestic onions harvested in various regions. J. Korean Soc. Food Sci. Nutr. 37: 1609-1614 (2008)
22. Jeong YJ, Jeong EJ, Jeon SY, Cha YJ. Changes of volatile compounds in concentrated onion extracts (ONIWELL™) during storage. J. Life Sci. 20: 113-118 (2010)
23. Jeon SY, Baek JH, Jeong EJ, Cha YJ. Volatile flavor compounds in commercial black garlic extracts. J. Korean Soc. Food Sci. Nutr. 41: 116-122 (2012)
24. Woo KS, Yoon HS, Lee YR, Lee J, Kim DJ, Hong JT, Jeong HS. Characteristics and antioxidative activity of volatile compounds in heated garlic (*Allium sativum*). Food Sci. Biotechnol. 16: 822-827 (2007)