Aroma-Active Compounds in Kimchi during Fermentation

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During fermentation, volatile flavor compounds in Kimchi prepared with (FS) and without (C) fish sauce were analyzed by vacuum simultaneous steam distillation−solvent extraction/gas chromatography/mass spectrometry (V-SDE/GC/MS) and GC/olfactometry. On the basis of their high odor intensities (OI ≥ 3), eight sulfur-containing compounds having garlic-, garlic salt-, onion-, green onion-, and cooked cabbage-like odors and six unknowns with garlic-, onion-, and green onion-like odors were predominant in both FS and C during fermentation. The most intense odorants (OI ≥ 4.0) in Kimchi included dimethyl trisulfide, diallyl disulfide isomers, diallyl trisulfide, methylallyl disulfide, and an unknown (garlic salt- and/or mustard-like). In addition to these, other odorants (OI ≥ 3.5) such as 3-(methylthio)propanal (baked/boiled potato-like), (*E*,*Z*)-2,6-nonadienal (cucumber-like), phenylacetaldehyde (honeysuckle-like), linalool (floral- and/or flower-like), (*E*,*E*)-2,4-decadienal (fatty and/or sweet), 2,3-butanedione (buttery), unknown (meaty), unknown (apple sauce-like), and unknown (vitamin and/or cooked rice-like) may play important roles in formation of Kimchi flavor. Addition of fish sauce did not noticeably affect the aroma profile of Kimchi.

Keywords: *Kimchi; aroma-active compound; volatile flavor*

INTRODUCTION

Kimchi is a traditional Korean fermented vegetable product served at every meal along with cooked rice and other dishes (Mheen and Kwon, 1984). Chinese cabbage is the main ingredient of Kimchi. Other minor components include red pepper, garlic, ginger, and fish sauce. Many kinds of Kimchi are available depending on the raw materials and processing methods. The types and combinations of minor ingredients have been reported to be key for delicious Kimchi (Park, 1995; Lee and Lee, 1994; Lee et al., 1989).

Previous research has demonstrated that salt concentration and fermentation time and temperature are important factors affecting Kimchi quality (Park, 1995; Mheen and Kwon, 1984; Choi et al., 1990; Koo and Choi, 1990). It is generally accepted that an intial salt concentration of about 3% is optimum for high-quality Kimchi. Park (1995) reported that a fermentation period of 2−3 weeks at 2−7 °C was best with respect to the nutritional and taste quality of Kimchi. Choi et al. (1990) also reported that Kimchi made under these conditions (3% salt content and 4 °C) could be stored for more than 80 days without significant deterioration in quality. However, Park et al. (1994) concluded from a survey of Kimchi producers that fish sauce was the most important factor affecting Kimchi flavor quality.

Recently, the focus of studies on Kimchi has merged into optimization and standardization of processing methods for the purpose of producing Kimchi on an industrial scale. To achieve this goal, a better understanding of Kimchi flavor is needed. Limited research has been conducted on the volatile constituents of Kimchi (Heo et al., 1988; Ryu et al., 1984). Fish sauce, as a rich nutrient source, is known to play an important role in flavor formation in Kimchi (Park, 1995; Park et al., 1994). However, the role of this ingredient as well as others in formation of aroma-active compounds of Kimchi during fermentation has not been investigated. The objective of this study was to identify and compare aroma-active compounds in Kimchi made with and without fish sauce during 30 day fermentations at 5 °C.

MATERIALS AND METHODS

Materials. All materials (Table 1) for making Kimchi were obtained from Ducksung Food Co. (DFC, Changwon, South Korea). Brined Chinese cabbage was prepared using a commercial process at DFC as follows. Washed Chinese cabbage (≈60 kg) was submerged in 8% (w/v) salt for 12 h at 15 °C, followed by dewatering by pressing with a heavy stone (≈30 kg) for 1 h in a stainless steel sieve.

The yield of brined cabbage after dewatering was 73% (e.g. 44 kg). The salinity of the brined cabbage was 3.5% as determined by the Mohr method (AOAC, 1980). Pretreatment of the sample was as follows. Cabbage (100 g) was homogenized in a Waring blender. Five grams of the homogenized cabbage was suspended in 90 mL of distilled water, and the suspension was allowed to stand at ambient temperature for 1 h. The suspension was filtered (no. 40 filter paper, Whatman). The filter pad was washed several times, and the combined filtrate was brought to a volume of 100 mL. Duplicate salt determinations were made.

The other minor ingredients, including fish sauce [or 23% (w/v) brine for control], were blended to paste consistency before addition to Chinese cabbage. Care was taken to fully distribute the ingredients among the salted Chinese cabbage leaves by using a gloved hand. The final mixture was divided into 3 kg aliquots, which were placed in 5 L stainless steel containers (one for each treatment−time combination), covered with stainless steel lids, and stored for 30 days at 5 °C.

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Table 1. Composition[a] of Kimchi

material	C[b]	FS[b]
Chinese cabbage (brined)	86.1	86.1
red pepper (powder)	3.30	3.30
anchovy sauce	–	3.50
shrimp paste	–	0.40
garlic	1.40	1.40
ginger	0.25	0.25
green onion	0.50	0.50
leek	0.80	0.80
carrot	0.50	0.50
sea tangle (*Laminaria* sp.)	3.00	3.00
salt	0.21	0.21
sugar	0.04	0.04
brine (23% NaCl)	3.90	–
total	100.0	100.0

[a] Percent (w/v). [b] C = control, FS = fish sauce (anchovy sauce and shrimp paste) substituted for brine in control.

Proximate compositions (AOAC, 1980) of anchovy and shrimp paste used in this study were as follows: moisture, 67.6 and 61.7%, respectively; lipid, 1.0 and 2.7%, respectively; protein, 8.1 and 11.3%, respectively; ash, 22.3 and 27.9%, respectively; salinity, 22.7 and 27.0%, respectively; and amino nitrogen, 0.78 and 0.80 g % (w/w), respectively.

All standard compounds were purchased from Aldrich Chemical Co. (Milwaukee, WI) except 2-acetyl-1-pyrroline, which was from R. Buttery (USDA, ARS, WRRC, Albany, CA), and (*Z*)-4-heptenal, which was purchased from Alfa (Ward Hill, MA).

Vacuum Simultaneous Steam Distillation–Solvent Extraction (V-SDE). The procedure of Chung and Cadwallader (1994) for V-SDE was followed with some modifications. A homogenized (Waring blender for 30 s) Kimchi sample (350 g) and distilled water (1.15 L) were extracted for 2.5 h with redistilled diethyl ether (200 mL) under reduced pressure (26–28 in.Hg) in a modified SDE apparatus (catalog no. 523010-0000, Kontes, Vineland, NJ). The sample temperature was maintained at 60–65 °C during extraction. V-SDE extracts were kept at −20 °C overnight to facilitate water removal as ice crystals. The volume of each V-SDE extract was reduced to 10 mL under a gentle stream of nitrogen and dried over 2 g of anhydrous sodium sulfate, and then the volume was further reduced to 1 mL prior to analysis. Duplicate extractions were carried out for FS and C at each sampling time.

Gas Chromatography/Olfactometry (GC/O). The GC/O system consisted of an HP 5890 Series II gas chromatograph (Hewlett-Packard Co., Palo Alto, CA) equipped with a flame ionization detector (FID) and a sniffing port. On-column injection was employed to minimize destruction of thermally labile compounds, such as terpenes and sulfur-containing compounds (Block and Calvey, 1994). One microliter of each extract (9-fold diluted in redistilled diethyl ether from the original concentrated extract) was injected into a capillary column (DB-WAX, 30 m × 0.32 mm inside diameter × 0.25 μm film thickness; J&W Scientific, Folsom, CA). Effluent from the end of the GC column was split 1:1 between the FID and sniffing port. Further details of the procedure have been reported elsewhere (Chung and Cadwallader, 1994). The oven temperature was programmed from 40 to 200 °C at a rate of 6 °C/min with initial and final hold times of 5 and 30 min, respectively. FID and injector temperatures were 250 and 40 °C, respectively. Sniffing port and transfer line temperatures were maintained at 200 °C. The carrier gas was helium at a constant flow of 1.4 mL/min. GC/O was performed on one of each duplicate V-SDE extract by three trained panelists. Panelists were instructed to assign the odor properties and rate odor intensity of each compound using an eight-point scale (where 0 = no odor detected and 7 = very strong odor detected). Odor descriptions for each compound were assigned using a free choice vocabulary.

Gas Chromatography/Mass Spectrometry (GC/MS). One microliter of each V-SDE extract was injected (on-column) into an HP 5890 Series II GC/HP 5972 mass selective detector (MSD) (Hewlett-Packard Co.) equipped with a capillary column (DB-WAX, 60 m × 0.25 mm inside diameter × 0.25 μm film thickness; J&W Scientific Inc.). The oven temperature was programmed from 40 to 200 °C at 3 °C/min with initial and final hold times of 5 and 60 min, respectively. The carrier gas was helium at a constant flow of 0.96 mL/min. MSD conditions were as follows: capillary direct MS interface temperature, 280 °C; ion source temperature, 280 °C; ionization energy, 70 eV; mass range, 33–350 amu; scan rate, 2.2 scans/s; and electron multiplier voltage, 200 V above autotune. Duplicate analyses were performed on each V-SDE extract.

Compound Identification. Positive identifications were based on comparison of GC retention indices (RI) (van den Dool and Kratz, 1963), mass spectra, and aroma properties of unknowns with those of authentic standard compounds analyzed under identical experimental conditions. Tentative identifications were based on comparison with the Wiley 138k mass spectral database (John Wiley and Sons, Inc., 1990).

Statistical Analysis. Quantitative data were analyzed with analysis of variance (SAS Institute, Inc., 1995) to determine whether significant differences existed between FS and C at 0, 7, 15, and 30 d of fermetation and among fermentation periods within FS or C. Mean separation was done using the least significant difference (LSD) method. GC/O data were analyzed using a randomized complete block design with panelists serving as blocks. Mean separation was with the LSD method.

RESULTS AND DISCUSSION

A total of 160 volatile compounds were detected by GC/MS analysis of V-SDE extracts of Kimchi prepared with (FS) and without (C) added fish sauce (Table 2). One hundred fifty compounds were detected in C and 159 in FS. These included 23 sulfur-containing compounds, 23 aldehydes, 10 ketones, 36 alcohols, 24 terpenes, 6 isothiocyanates, 9 acids, 11 esters, 5 nitrogen-containing compounds, 6 aromatic compounds, and 7 miscellaneous compounds. A total of 77 aroma-active compounds, including 16 sulfur-containing compounds, 6 aldehydes, 2 ketones, 6 alcohols, 1 terpene, 1 nitrogen-containing compound, 1 isothiocyanate, 1 acid, and 43 unknowns, were detected by GC/O in FS and C (Table 3).

Among 23 sulfur-containing compounds detected, diallyl disulfide isomers, methylallyl disulfide, dimethyl trisulfide, and dimethyl disulfide were in highest abundance. Dimethyl trisulfide, diallyl disulfide isomer (no. 95), and diallyl trisulfide had the highest odor intensities in both FS and C throughout the fermentation period despite their gradual decrease in concentration. These compounds contributed strong cooked cabbage-, hot spicy- and/or fresh garlic-, and green onion-like odors and are characteristic of the overall aroma of Kimchi. Quantitative and GC/O data were comparable for many sulfur compounds (e.g. no. 5, 95, and 117). In general, odor intensities of most sulfur compounds decreased during fermentation. In particular, intensities of compounds 4, 13, 27, 65, and 117, having onion-, rotten onion-, garlic-, garlic salt-, and green onion-like odors, were low in both FS and C after 30 d of fermentation. The level of dimethyl trisulfide and dimethyl tetrasulfide decreased during fermentation in FS and C; however, the perceived odor intensity of dimethyl trisulfide remained constant throughout the fermention period.

The majority of sulfur-containing compounds detected in the present study may have originated from the *Allium* species used as ingredients in Kimchi, such as garlic (Yu et al., 1993, 1994a), green onion (Kuo and Ho, 1992), and leek (Block et al., 1992). These com-

Table 2. Changes in the Volatile Composition of Kimchi during Fermentation

			C[a]								FS[a]							
			day 0		day 7		day 15		day 30		day 0		day 7		day 15		day 30	
no.[a]	compound name by class	RI[b]	MAR[c]	SD[d]	MAR	SD	MAR	SD	MAR	SD	MAR	SD	MAR	SD	MAR	SD	MAR	SD
	S-containing compounds (23)																	
4	propanethiole	830	0.013	0.011	0.025	0.008	–	–	–	–	0.021	0.014	0.015	0.013	–	–	–	–
5	methylthiirane[e]	875	0.14	0.20	1.3	0.20	0.27	0.07	0.10	0.030	0.38	0.43	0.88	0.78	0.45	0.11	0.24	0.080
13	3-(methylthio)-1-propene[e]	948	0.11	0.030	0.045	0.078	0.013	0.002	0.004	0.003	0.13	0.010	0.022	0.022	0.007	0.003	0.002	0.002
24	*S*-methyl thioethanoate	1041	0.044	0.004	0.005	0.010	–	–	0.050	0.058	0.029	0.021	–	–	–	–	0.091	0.030
27	dimethyl disulfide	1065	2.8	0.50	0.26	0.020	2.5	0.40	0.39	0.060	2.6	1.2	0.62	0.18	0.80	0.21	0.36	0.17
32	allylpropyl sulfide[e]	1099	0.004	0.008	0.007	0.006	0.005	0.004	–	–	–	–	0.014	0.002	0.003	0.005	0.002	0.005
41	diallyl sulfide[e]	1143	0.12	0.020	0.19	0.030	0.19	0.010	0.18	0.010	0.072	0.019	0.29	0.010	0.19	0.010	0.27	0.070
59	methylpropyl disulfide	1226	0.15	0.040	0.061	0.035	0.29	0.020	0.096	0.006	0.13	0.010	0.043	0.014	0.16	0.050	0.088	0.029
65	methyl-(*Z*)-propenyl disulfide[e]	1261	0.20	0.020	0.043	0.016	0.065	0.005	0.019	0.008	0.18	0.050	0.055	0.026	0.052	0.011	0.027	0.006
67	methyl allyl disulfide	1281	5.3	1.1	2.1	0.20	5.3	0.50	2.1	0.10	5.1	0.90	3.2	0.60	3.7	0.80	2.0	0.60
69	methyl-(*E*)-propenyl disulfide[e]	1287	1.3	0.20	0.26	0.050	0.41	0.020	0.14	0.030	1.2	<0.1	0.40	0.14	0.28	0.050	–	–
81	dipropyl disulfide[e]	1377	0.15	0.050	0.054	0.006	0.104	0.012	0.046	0.033	0.18	0.08	0.027	0.002	0.026	0.018	0.026	0.016
82	dimethyl trisulfide	1379	3.5	0.70	0.50	0.050	1.2	<0.1	0.25	0.030	3.7	0.60	1.4	0.50	0.80	0.33	0.34	0.13
87	allylpropyl disulfide[e]	1428	0.36	0.090	0.35	0.10	0.30	0.07	0.30	0.020	0.29	0.10	0.36	0.15	0.32	0.10	0.21	0.040
88	(*E*)-propenylpropyl disulfide[e]	1435	0.083	0.019	0.052	0.015	0.047	0.004	0.006	0.011	0.080	0.018	0.052	0.018	0.026	0.009	0.012	0.015
91	3-(methylthio)propanal	1449	0.006	0.001	0.007	0.005	0.005	0.006	0.002	0.002	0.013	0.002	0.021	0.004	0.002	0.002	0.001	<0.001
94	dithio(1-propenyl) propionate[e]	1462	0.19	0.050	0.16	0.050	0.12	0.02	0.057	0.017	0.15	0.030	0.19	0.090	0.17	0.070	–	–
95	diallyl disulfide isomer[e]	1479	4.7	1.4	5.8	1.1	5.4	0.20	4.3	0.10	4.3	1.0	6.0	1.7	4.8	1.3	3.8	0.70
96	diallyl disulfide isomer[e]	1483	1.7	0.60	1.3	0.30	0.90	0.35	0.73	0.10	1.4	0.20	1.4	0.60	1.2	0.40	–	–
102	methylpropyl trisulfide[e]	1529	0.064	0.008	0.005	0.005	0.043	0.006	0.020	0.007	0.067	0.012	0.037	0.014	0.047	0.018	0.031	0.008
117	methyl(methylthio)methyl disulfide[e]	1662	0.19	0.030	0.051	0.014	0.083	0.048	0.034	0.015	0.15	0.020	0.081	0.035	0.037	0.007	0.026	0.011
131	dimethyl tetrasulfide[e]	1750	0.23	0.060	0.040	0.034	–	–	–	–	0.15	0.050	–	–	0.018	0.022	–	–
139	diallyl trisulfide[e]	1789	0.95	0.23	0.70	0.25	0.68	0.13	0.50	0.13	0.92	0.11	1.0	0.60	1.2	0.30	0.59	0.15
	aldehydes (23)																	
3	2-methylpropanal	810	–	–	–	–	0.007	0.002	0.016	0.004	–	–	–	–	0.013	0.006	0.025	0.010
9	2-methylbutanal	907	0.054	0.008	0.018	0.008	0.009	0.003	0.045	0.031	0.059	0.009	0.035	0.013	0.036	0.010	0.058	0.024
10	3-methylbutanal	911	0.093	0.013	0.030	0.009	0.022	0.003	0.039	0.006	0.10	<0.01	0.080	0.036	0.056	0.024	0.055	0.059
15	pentanal	971	0.033	0.004	0.029	0.019	0.026	0.033	0.074	0.12	0.035	0.010	0.062	0.008	0.065	0.061	0.075	0.15
22	(*E*)-2-butenal	1034	1.0	0.20	0.24	0.050	0.99	0.040	0.87	0.17	1.2	0.30	0.32	0.14	1.2	0.10	1.0	0.20
28	hexanal	1075	0.29	0.020	0.089	0.008	0.072	0.016	0.10	0.010	0.20	0.040	0.11	0.030	0.076	0.013	0.093	0.020
29	2-methyl-(*E*)-2-butenal	1088	0.065	0.021	0.027	0.006	0.012	0.009	0.005	0.004	0.078	0.012	0.053	0.008	0.005	0.005	–	–
39	(*E*)-2-pentenal	1125	0.035	0.013	0.008	0.010	–	–	0.051	0.044	0.031	0.006	0.030	0.005	–	–	0.022	0.044
49	heptanal	1181	0.038	0.012	0.031	0.011	0.023	0.003	0.041	0.010	0.033	0.005	0.031	0.016	0.021	0.003	0.028	0.010
56	(*E*)-2-hexenal	1214	0.92	0.82	0.25	0.010	0.15	0.010	0.083	0.013	0.50	0.29	0.27	0.020	0.24	0.11	0.074	0.016
75	(*E*)-2-heptenal	1320	0.051	0.007	0.021	0.004	0.029	0.004	0.039	0.018	0.046	0.005	0.037	0.017	0.039	0.003	0.044	0.033
84	nonanal	1390	0.084	0.032	0.062	0.012	0.048	0.005	0.087	0.015	0.059	0.010	0.050	0.016	0.034	<0.001	0.043	0.011
85	(*E*,*E*)-2,4-hexadienal	1398	–	–	–	–	0.011	0.010	0.038	0.012	–	–	–	–	0.047	0.011	0.026	0.007
93	2-furancarboxaldehyde	1458	0.048	0.054	0.040	0.027	0.029	0.014	0.005	0.003	0.092	0.021	0.082	0.033	0.032	0.009	0.13	0.02
97	(*E*,*E*)-2,4-heptadienal	1491	0.057	0.013	0.047	0.028	0.034	0.010	0.094	0.018	0.058	0.012	0.082	0.039	0.043	0.015	0.072	0.018
101	benzaldehyde	1522	0.052	0.042	0.024	0.028	0.012	0.012	0.014	0.024	0.025	0.011	0.076	0.040	0.006	0.002	0.006	0.003
106	(*E*,*Z*)-2,6-nonadienal	1580	–	–	0.011	0.009	0.014	0.008	0.048	0.012	–	–	0.012	0.004	0.011	0.013	0.032	0.017
111	β-cyclocitral[e]	1622	0.022	0.027	–	–	0.022	0.011	0.054	0.009	–	–	–	–	0.034	0.014	0.024	0.015
113	phenylacetaldehyde	1638	0.15	0.070	0.071	0.034	0.091	0.052	0.11	0.020	0.18	0.010	0.12	0.040	0.14	0.030	0.12	0.020
114	(*E*)-2-decenal	1642	–	–	–	–	–	–	0.030	0.002	–	–	–	–	–	–	0.021	0.012
120	(*Z*)-citral	1680	0.25	0.020	0.12	0.11	0.13	0.020	0.13	0.020	0.23	0.030	0.24	0.080	0.18	0.020	0.14	0.010
128	(*E*)-citral	1731	0.32	0.030	0.27	0.10	0.17	0.030	0.17	0.060	0.28	0.020	0.26	0.15	0.034	0.018	0.18	0.040
141	(*E*,*E*)-2,4-decadienal	1808	0.096	0.018	0.043	0.029	0.029	0.007	0.10	0.020	0.074	0.008	0.084	0.058	0.036	0.020	0.093	0.019
	ketones (10)																	
8	2-butanone	894	–	–	–	–	–	–	–	–	–	–	0.019	0.039	–	–	0.021	0.041
14	2,3-butanedione	965	0.074	0.008	0.083	0.016	0.14	0.002	0.52	0.21	0.083	0.016	0.17	0.03	0.40	0.13	1.2	0.70
25	2,3-pentanedione	1055	–	–	–	–	–	–	0.012	0.014	0.003	0.005	–	–	–	–	–	–
37	(*E*)-3-penten-2-one	1121	0.007	0.005	0.036	0.014	0.023	0.027	–	–	0.008	0.006	0.047	0.007	0.059	0.042	0.046	0.055

68	3-hydroxy-2-butanone	1282	0.19	0.050	0.18	0.02	0.040	0.021	0.14	0.060	0.11	0.06	0.14	0.010	0.048	0.031	0.42	0.12
77	6-methyl-5-hepten-2-one	1333	0.045	0.004	0.020	0.005	0.019	<0.001	0.028	0.003	0.040	0.007	0.031	0.009	0.022	0.012	0.019	0.005
99	1-(2-furanyl)ethanone[e]	1501	0.020	0.005	0.020	0.014	0.027	0.021	0.036	0.027	0.036	0.024	0.013	0.005	0.044	0.050	0.063	0.043
108	2-undecanone	1595	0.047	0.022	0.35	0.57	0.053	0.012	0.046	0.009	0.049	0.036	0.038	0.013	0.048	0.027	0.053	0.011
146	geranylactone	1852	0.10	0.020	0.078	0.024	0.095	0.037	0.14	0.030	0.093	0.017	0.098	0.055	0.11	0.040	0.11	0.020
150	β-ionone	1943	0.14	0.090	0.041	0.042	0.13	0.030	0.20	0.040	0.045	0.043	0.030	0.015	0.18	0.030	0.17	0.030
	alcohols (36)																	
11	ethanol	935	7.3	0.3	26.0	1.4	40.0	6.4	49.4	3.5	8.2	2.9	27.6	6.4	38.3	2.8	42.5	10.7
20	2-butanol	1027	0.005	0.005	0.013	0.008	0.005	0.010	0.010	0.021	0.007	0.008	0.031	0.022	0.005	0.010	0.082	0.099
23	propanol	1038	0.095	0.022	0.27	0.068	0.30	0.020	0.67	0.070	0.17	0.040	0.54	0.050	0.37	0.014	0.76	0.15
31	2-methyl-1-propanol	1098	0.005	0.010	0.033	0.022	0.055	0.008	1.8	0.10	0.005	0.010	0.040	0.016	0.19	0.15	2.8	1.3
34	3-pentanol	1108	–	–	0.003	0.003	0.001	0.003	0.005	0.006	–	–	0.004	0.005	0.006	0.004	0.023	0.007
35	allyl alcohol[e]	1109	0.061	0.005	0.062	0.012	0.020	0.013	0.039	0.044	0.060	0.019	0.083	0.007	0.056	0.018	0.10	0.080
42	butanol	1145	0.026	0.30	0.013	0.018	0.11	0.010	0.32	0.040	0.086	0.010	0.12	0.020	0.15	0.030	0.33	0.090
45	1-penten-3-ol	1160	0.27	0.22	0.15	0.030	0.099	0.039	0.42	0.13	0.20	0.020	0.26	0.08	0.16	0.040	0.30	0.20
46	3-buten-1-ol	1170	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.025	0.011
54	2-methyl-1-butanol	1208	–	–	0.014	0.022	0.055	0.040	0.42	0.18	–	–	–	–	0.10	0.044	1.7	1.0
55	3-methyl-1-butanol	1208	–	–	0.019	0.038	0.082	0.004	2.0	0.10	–	–	–	–	0.21	0.090	4.2	1.8
57	(E)-2-buten-1-ol[e]	1215	–	–	0.013	0.015	0.13	0.04	0.19	0.020	–	–	–	–	0.23	0.10	0.18	0.050
63	3-methyl-3-buten-1-ol	1247	–	–	0.005	0.004	0.002	0.004	0.026	0.004	–	–	0.006	0.005	0.012	0.004	0.094	0.043
64	pentanol	1248	0.085	0.022	0.048	0.021	0.048	0.001	0.14	0.020	0.13	0.050	0.14	0.040	0.051	0.002	0.11	0.030
70	4-penten-1-ol	1297	0.074	0.008	0.18	0.050	0.031	0.031	0.12	0.010	0.072	0.014	0.10	0.010	0.082	0.028	0.26	0.090
71	2-ethyl-1-butanol	1305	–	–	–	–	0.007	0.005	0.017	0.003	–	–	–	–	0.012	0.004	0.024	0.005
72	(Z)-2-penten-1-ol	1310	0.015	0.007	0.010	0.003	0.055	0.043	0.080	0.028	0.010	0.007	0.013	0.010	–	–	0.044	0.051
73	4-methyl-1-pentanol	1311	0.026	0.009	0.055	0.006	0.085	0.007	0.14	0.010	0.024	0.005	0.074	0.017	0.099	0.015	0.16	0.030
74	(E)-2-penten-1-ol	1317	0.23	0.15	0.14	0.010	0.072	0.025	0.27	0.050	0.17	0.010	0.22	0.030	0.11	0.030	0.22	0.13
80	hexanol	1350	0.10	0.03	0.045	0.006	0.062	0.006	0.21	0.020	0.069	0.005	0.066	0.007	0.085	0.010	0.16	0.030
83	(Z)-3-hexen-1-ol	1381	–	–	0.025	0.011	0.038	0.005	0.075	0.004	–	–	–	–	0.13	0.10	0.11	0.030
86	(E)-2-hexen-1-ol	1402	0.23	0.04	0.011	<0.001	0.011	0.007	0.019	0.008	0.10	0.030	0.016	0.004	0.024	0.002	0.021	0.007
89	1-octen-3-ol	1446	–	–	0.009	0.010	–	–	–	–	0.042	0.020	0.023	0.016	–	–	–	–
104	octanol	1555	0.084	0.035	0.060	0.031	0.039	0.017	0.063	0.013	0.063	0.014	0.058	0.030	0.038	0.006	0.035	0.012
110	(E)-2-octen-1-ol	1612	0.015	0.010	–	–	–	–	–	–	0.019	0.009	–	–	–	–	–	–
115	2-furanmethanol	1656	0.98	0.040	0.56	0.020	0.27	0.060	0.13	0.020	0.88	0.090	0.053	0.020	0.29	0.020	0.12	0.030
148	2-phenylethanol	1912	0.15	0.20	0.051	0.002	0.010	0.012	0.059	0.017	0.063	0.015	0.052	0.011	0.040	0.011	0.15	0.090
53	1,8-cineole	1207	0.16	0.020	0.17	0.070	0.14	0.050	0.12	0.070	0.14	0.020	0.17	0.040	0.23	0.010	0.16	0.030
100	camphor	1519	–	–	–	–	0.020	0.013	0.016	0.012	–	–	–	–	–	–	–	–
103	linalool	1540	0.056	0.067	–	–	0.070	0.014	0.11	0.020	0.054	0.057	0.069	0.039	0.077	0.048	0.11	0.020
122	α-terpineol	1697	0.089	0.021	0.072	0.019	0.17	0.050	0.14	0.030	0.11	0.050	0.071	0.020	0.14	0.020	0.16	0.020
123	borneol	1704	0.35	0.060	0.24	0.10	0.25	0.030	0.26	0.050	0.25	0.060	0.22	0.090	0.36	0.070	0.31	0.050
135	β-citronellol	1763	0.23	0.020	0.16	0.060	0.084	0.022	0.11	0.020	0.21	0.030	0.15	0.080	0.12	0.010	0.13	0.030
140	nerol	1798	0.12	0.010	0.059	0.027	0.050	0.026	0.059	0.020	0.10	0.010	0.067	0.037	0.075	0.010	0.069	0.040
144	geraniol	1845	0.54	0.080	0.33	0.070	0.17	0.010	0.19	0.060	0.48	0.020	0.28	0.070	0.14	0.080	0.24	0.050
151	nerolidol	2034	0.34	0.040	0.32	0.060	0.22	0.020	0.23	0.040	0.41	0.060	0.25	0.070	0.24	0.020	0.26	0.060
	terpenes (24)																	
17	tricyclene[e]	1002	0.032	0.003	0.018	0.006	0.013	0.001	0.015	0.007	0.030	0.002	0.025	<0.001	0.026	0.004	0.019	0.011
19	α-pinene	1014	0.35	0.040	0.31	0.090	0.18	0.040	0.16	0.050	0.35	0.020	0.35	0.060	0.30	0.040	0.23	0.050
26	camphene	1056	0.96	0.10	0.71	0.090	0.52	0.070	0.42	0.060	0.93	0.030	0.90	0.030	0.81	0.070	0.65	0.11
30	β-pinene	1094	0.037	0.007	0.019	0.007	0.015	0.005	0.012	0.002	0.022	0.015	0.037	0.019	0.018	0.006	0.016	0.002
33	sabinene	1108	0.031	0.002	0.030	0.032	0.012	0.004	0.005	0.006	0.032	0.004	0.030	0.003	0.011	0.014	–	–
43	β-myrcene[e]	1154	0.19	0.010	0.11	0.080	0.056	0.011	0.053	0.007	0.18	0.010	0.17	0.010	0.004	0.005	0.009	0.013
51	limonene	1195	0.28	0.030	0.20	0.060	0.15	0.020	0.13	0.020	0.25	0.020	0.26	0.030	0.21	0.030	0.17	0.040
52	β-phellandrene	1205	1.3	<0.1	1.1	0.20	0.36	0.14	0.44	0.040	1.3	0.10	1.2	0.10	–	–	0.20	0.24
61	γ-terpinene	1235	0.021	0.005	0.025	0.012	0.027	0.007	0.024	0.007	0.015	0.004	0.024	0.007	0.022	0.006	0.022	0.005
62	(E)-ocimene[e]	1241	0.070	0.011	0.045	0.005	0.042	0.011	0.031	0.003	0.014	0.028	0.021	0.042	–	–	–	–
98	α-copaene[e]	1496	0.079	0.027	0.033	0.017	0.060	0.040	0.065	0.034	0.053	0.009	0.041	0.018	0.090	0.039	0.059	0.044
109	caryophyllene[e]	1600	0.16	0.030	0.099	0.048	0.090	0.033	0.078	0.012	0.093	0.057	0.047	0.048	0.075	0.011	0.024	0.032
116	farnesene isomer[e]	1661	0.051	0.005	0.046	0.022	0.019	0.010	0.022	0.004	0.050	0.014	0.021	0.017	0.043	0.028	0.025	0.008
124	β-himachalene[e]	1713	0.18	0.020	0.16	0.080	0.047	0.061	0.068	0.006	0.14	0.020	0.094	0.054	0.047	0.005	–	–
125	α-zingiberene[e]	1722	2.8	0.80	2.3	0.60	0.63	0.67	0.35	0.060	2.2	0.30	1.3	0.30	0.046	0.006	–	–

Table 2 (Continued)

			C[a]								FS[a]							
			day 0		day 7		day 15		day 30		day 0		day 7		day 15		day 30	
no.[a]	compound name by class	RI[b]	MAR[c]	SD[d]	MAR	SD	MAR	SD	MAR	SD	MAR	SD	MAR	SD	MAR	SD	MAR	SD 127
126	γ-cadinene[e]	1722	0.093	0.11	0.053	0.062	0.064	0.043	0.10	0.010	0.17	0.020	0.11	0.050	0.16	0.020	0.12	0.020
127	β-bisabolene[e]	1727	0.74	0.12	0.55	0.17	0.47	0.10	0.47	0.090	0.59	0.03	0.42	0.18	0.66	0.04	0.48	0.10
129	5b*H*,7b,10a-selina-4(14),11-diene[e]	1733	0.25	0.03	0.18	0.07	0.11	0.03	0.11	0.020	0.21	0.02	0.15	0.08	0.14	0.02	0.10	0.020
130	farnesene isomer[e]	1746	0.66	0.08	0.47	0.16	0.29	0.11	0.27	0.050	0.52	0.03	0.35	0.17	0.034	0.067	0.10	0.12
133	farnesene isomer[e]	1758	0.088	0.013	0.073	0.035	0.029	0.008	0.030	0.010	0.076	0.013	0.063	0.041	0.021	0.014	0.025	0.008
134	δ-cadinene[e]	1760	0.053	0.005	0.022	0.005	0.051	0.039	0.041	0.006	0.041	0.009	0.029	0.007	0.038	0.005	0.036	0.009
136	β-sesquiphellandrene[e]	1771	1.1	0.20	0.90	0.28	0.41	0.22	0.49	0.080	0.91	0.060	0.63	0.28	0.052	0.007	0.16	0.15
137	ar-curcumene[e]	1773	0.36	0.02	0.24	0.04	0.20	0.04	0.26	0.050	0.32	0.030	0.22	0.080	0.37	0.020	0.27	0.060
143	germacrene B[e]	1836	0.090	0.004	0.075	0.025	0.052	0.024	0.049	0.010	0.084	0.010	0.072	0.034	0.030	0.007	0.035	0.012
	thiocyanates (6)																	
47	isopropyl isothiocyanate[e]	1177	0.062	0.026	0.015	0.0062	–	–	–	–	0.065	0.039	0.028	0.003	–	–	–	–
66	methyl thiocyanate[e]	1266	2.4	0.90	1.5	0.50	0.82	0.020	0.79	0.030	2.8	0.080	2.2	0.40	0.88	0.050	0.74	0.13
92	3-butenyl isothiocyanate[e]	1453	1.9	0.30	4.5	1.0	1.4	0.30	0.36	0.050	1.9	0.30	2.8	0.10	1.6	0.40	0.35	0.050
107	hexyl isothiocyanate[e]	1588	0.051	0.006	0.046	0.020	0.029	0.006	–	–	0.042	0.007	0.045	0.016	0.033	0.009	–	–
121	heptyl isothiocyanate[e]	1696	0.13	0.04	0.081	0.032	0.057	0.032	0.048	0.007	0.093	0.024	0.069	0.033	0.059	0.013	0.019	0.038
157	2-phenylethyl isothiocyanate[e]	2234	9.7	2.1	7.4	0.10	5.4	0.60	2.9	0.40	11.8	1.0	8.4	0.40	5.9	1.2	2.6	0.60
	acids (9)																	
90	acetic acid	1447	0.074	0.052	0.022	0.0267	0.334	0.316	6.3	0.70	0.039	0.029	0.042	0.013	2.0	0.70	5.4	1.5
105	isobutyric acid	1564	–	–	–	–	–	–	–	–	–	–	–	–	0.011	0.005	0.11	0.084
112	butanoic acid	1624	–	–	–	–	–	–	–	–	–	–	–	–	0.062	0.037	0.11	0.038
118	isovaleric acid	1667	–	–	–	–	–	–	–	–	–	–	–	–	0.039	0.010	0.14	0.03
145	hexanoic acid	1874	–	–	–	–	–	–	–	–	0.13	0.015	–	–	–	–	–	–
153	octanoic acid[e]	2061	–	–	–	–	–	–	0.074	0.026	–	–	–	–	0.060	0.012	0.14	0.074
154	isonicotinic acid[e]	2088	0.77	0.29	0.81	0.22	0.13	0.050	0.033	0.006	0.92	0.10	0.41	0.050	0.074	0.002	0.044	0.010
155	nonanoic acid[e]	2166	–	–	–	–	0.031	0.020	0.078	0.023	–	–	–	–	0.051	0.010	0.096	0.016
159	decanoic acid[e]	2268	–	–	–	–	–	–	–	–	–	–	–	–	0.071	0.018	0.10	0.010
	esters (11)																	
6	ethyl acetate	880	1.4	0.60	0.92	0.30	0.34	0.11	0.47	0.10	1.7	0.30	1.1	0.30	0.97	0.090	0.84	0.24
44	ethyl 2-butenoate[e]	1158	–	–	0.001	0.003	0.014	0.010	0.008	0.005	–	–	–	–	0.009	0.002	0.004	0.005
50	methyl hexanoate	1181	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.015	0.006
60	ethyl hexanoate	1228	–	–	–	–	–	–	0.029	0.003	–	–	0.008	0.009	0.010	0.004	0.12	0.040
79	2-methylpropyl hexanoate[e]	1347	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.003	0.007
132	geranyl acetate[e]	1753	0.094	0.009	0.058	0.039	–	–	–	–	0.078	0.006	0.27	0.46	0.008	0.009	–	–
138	methyl 2-hydroxybenzoate[e]	1778	0.039	0.004	0.042	0.038	0.066	0.020	0.099	0.017	–	–	–	–	0.12	0.030	0.10	0.030
142	2-phenylethyl acetate	1816	–	–	–	–	–	–	0.137	0.035	–	–	–	–	–	–	0.27	0.080
156	methyl hexadecanoate[e]	2210	–	–	0.058	0.091	0.017	0.003	0.30	0.31	–	–	–	–	0.16	0.27	0.31	0.20
158	ethyl hexadecanoate[e]	2246	–	–	0.21	0.030	0.26	0.14	0.35	0.040	–	–	0.19	0.010	0.24	0.090	0.39	0.16
160	diethyl 1,2-benzenedicarboxylate[e]	2366	0.086	0.089	0.37	0.13	0.077	0.073	0.10	0.060	0.24	0.040	0.21	0.05	0.091	0.027	0.11	0.10
	N-containing compounds (5)																	
76	2,6-dimethylpyrazine	1327	0.022	0.004	0.002	0.005	–	–	–	–	0.020	0.002	0.003	0.005	–	–	–	–
119	3,5-dimethyl-1*H*-pyrazole[e]	1675	–	–	–	–	–	–	–	–	–	–	0.056	0.032	0.037	0.015	0.046	0.021
78	pentanedinitrile[e]	1343	1.7	0.20	1.6	0.30	0.70	0.080	0.53	0.040	1.9	0.40	2.0	0.10	0.82	0.030	0.64	0.15
149	phenylacetonitrile[e]	1927	0.031	0.014	0.010	0.003	0.004	0.005	–	–	0.028	0.007	0.014	0.006	–	–	–	–
152	benzenepropanenitrile[e]	2041	2.1	0.80	1.7	0.10	0.95	0.12	0.34	0.080	2.9	0.30	1.9	0.40	0.70	0.16	0.47	0.090
	aromatic compounds (6)																	
21	toluene	1033	0.93	0.23	0.11	0.020	0.15	0.060	0.17	0.020	0.33	0.11	0.20	0.040	0.19	0.020	0.16	0.030
36	ethylbenzene	1118	0.007	0.005	0.004	0.005	0.25	0.020	0.11	0.080	0.007	0.010	0.006	0.005	0.26	0.030	0.12	0.050
38	*p*-xylene	1125	0.011	0.002	–	–	0.072	0.023	0.063	0.022	0.006	0.007	–	–	0.050	0.011	0.11	0.13
40	*m*-xylene	1136	0.022	0.005	0.021	0.006	0.14	0.03	0.13	0.03	0.021	0.003	0.031	0.011	0.16	0.028	0.15	0.11
48	*o*-xylene	1177	–	–	0.002	0.003	0.072	0.007	0.064	0.003	0.010	0.012	0.003	0.006	0.076	0.008	0.11	0.030

147	1-methylnaphthalene	1891	0.022	0.007	–	–	–	–	–	–	–	–	–	–	0.016	0.006	0.017	0.015
	miscellaneous compounds (7)																	
1	ethoxybutane[e]	780	–	–	–	–	1.4	0.10	0.63	0.26	–	–	–	–	1.3	0.10	0.49	0.16
2	octane	800	0.085	0.12	0.038	0.011	0.010	0.011	0.003	0.005	0.025	0.009	0.030	0.017	–	–	–	–
7	nonane	894	0.11	0.14	–	–	–	–	–	0.041	0.010	0.008	0.016	–	–	–	–	12
12	2-ethylfuran	945	0.029	0.008	0.003	0.005	0.003	0.005	0.002	0.002	0.027	0.10	0.006	0.003	0.004	0.004	–	–
16	decane	993	0.11	0.17	0.026	0.019	0.016	0.006	0.010	0.007	0.028	0.001	0.019	0.007	0.016	0.003	0.020	0.009
18	chloroform	1013	0.43	0.10	0.34	0.050	1.0	0.1	0.97	0.48	0.47	0.020	0.46	0.14	1.1	0.10	0.68	0.25
58	2-pentylfuran	1224	0.091	0.005	0.031	0.016	0.018	0.009	0.021	0.012	0.072	0.011	0.065	0.013	0.020	0.003	0.027	0.005

[a] For C and FS, refer to Table 1. [b] Retention index on DB-WAX (60 m length × 0.25 mm inside diameter × 0.25 μm film thickness) column. [c] Percent mean area ratio. [d] Standard deviation of mean area ratio from two V-SDE extractions and two injections of each extract. Calculated by dividing the peak area by the total area of all peaks. [e] Compound tentatively identified by MS data only.

pounds may play predominant roles in the characteristic flavor of Kimchi with their garlic-, cooked cabbage-, onion-, and green onion-like odors. Yu et al. (1994b) reported that allicin, the major flavor compound of garlic, was readily degraded to allyl alcohol and cysteine during heating and that decomposition of cysteine gave rise to methyl sulfides, thiazoles, thrithiolanes, and cyclic sulfur-containing compounds. The majority of the sulfur-containing compounds detected in this study were methyl sulfides. Despite our efforts to maintain a moderate temperature (<65 °C) during V-SDE, it is possible that some of these compounds were artifacts of our isolation method.

There were many unidentified compounds having odor properties reminescent of sulfur compounds (e.g., RI = 1177, 1555, 1576, 1585, 1593, 1603, 1676, 1724, 1836, 1881, 1927, 1949, 1998, 2030, 2036, and 2098). Most had low odor intensities, except for the hot rubber- and wild onion-like (RI = 1177), garlic salt- and mustard-like (RI = 1576), sweet, meaty, and garlic-like (RI = 1836), phenolic, piney, and green garlic-like (RI =1949), and stale, garlic-, and wild green onion-like (RI = 1998) odorants. 3-(Methylthio)propanal and dithio(1-propenyl) propionate, described as baked/boiled potato and roasted and nutty potato-like, respectively, had distinctly different odor properties compared with other sulfur compounds. 3-(Methylthio)propanal may have been formed via Strecker degradation of methionine (Forss, 1979).

With the exception of (*E*)-2-butenal, (*E*)-2-hexenal, (*E*)-citral, (*Z*)-citral, phenylacetaldehyde, 3-methylbutanal, and (*E*,*E*)-2,4-decadienal, aldehydes were found in low abundance in FS and C (Table 2). Among the aldehydes, (*E*,*Z*)-2,6-nonadienal, phenylacetaldehyde, and (*E*,*E*)-2,4-decadienal had the highest odor intensities in both FS and C throughout the fermentation period, followed by 3-methylbutanal. These compounds might contribute to the overall flavor of Kimchi because of their low odor threshold values (t), e.g., (*E*,*E*)-2,4-decadienal ($t = 0.03$ ppb in water; Buttery et al., 1988), (*E*,*Z*)-2,6-nonadienal ($t = 0.1$ ppb; Milo and Grosch, 1993), 3-methylbutanal ($t = 0.4$ ppb; Guth and Grosch, 1993), and phenylacetaldehyde ($t = 4$ ppb; Buttery et al., 1988). (*E*,*E*)-2,4-Decadienal and (*E*,*Z*)-2,6-nonadienal were reported as major aroma compounds in cabbage (Buttery et al., 1976). (*E*,*Z*)-2,6-Nonadienal, having a cucumber-like odor, can be derived from omega-3 fatty acids (Josephson et al., 1984) and is readily converted to (*Z*)-4-heptenal through the retro-aldol degradation reaction (Josephson and Lindsay, 1987). (*Z*)-4-Heptenal (rancid and fishy) was detected in both FS and C by GC/O at low odor intensities. Park (1995) reported that linoleic and linolenic acids composed 44–60% of the total free fatty acids in Kimchi. 3-Methylbutanal (dark chocolate-like), detected at low odor intensities in both FS and C, may have originated from Strecker or microbiological degradation of amino acids (Collin et al., 1993). The citral isomers identified in both FS and C are major volatile constituents of ginger (Wu and Yang, 1994), an ingredient of Kimchi, and are readily degraded into 6-methyl-5-hepten-2-one by heating (Chen and Ho, 1989).

Two terpene derivatives (geranylacetone and β-ionone) were found in high abundance among 10 ketones detected. These compounds contribute fruity odors in plants (Kawakami and Kobayashi, 1991; Takeoka et al., 1990). However, these compounds were not detected by

Table 3. Mean Odor Intensities of Aroma-Active Compounds in Kimchi during Fermentation[a]

no.[b]	RI[c]	compound	methods of identification	C[d] day 0	C[d] day 7	C[d] day 15	C[d] day 30	FS[d] day 0	FS[d] day 7	FS[d] day 15	FS[d] day 30	odor description[e]
4	833	propanethiol	MS	0.67 (1.03)^{f,g}	0.67 (1.03)^{g}	0.33 (0.52)^{g}	0.00 (0.0)^{g}	0.67 (1.03)^{GH}	2.33 (1.97)^{G}	0.83 (0.98)^{GH}	0.00 (0.0)^{H}	onion, green onion
5	869	methylthiirane	MS	2.67 (1.03)^{g}	5.17 (0.98)^{h}	2.33 (1.03)^{g}	2.50 (2.26)^{g}	2.00 (0.89)^{H}	4.50 (1.38)^{G}	4.33 (1.37)^{G}	3.17 (0.75)^{GH}	fresh-cut garlic
10	911	3-methylbutanal	MS, RI, odor	1.67 (1.03)^{gh}	2.67 (1.03)^{g}	0.00 (0.0)^{h}	0.67 (0.52)^{h}	0.83 (0.75)^{G}	1.50 (1.64)^{G}	1.33 (1.37)^{G}	1.50 (0.55)^{G}	dark chocolate, malty
11	930	ethanol	MS, RI, odor	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.67 (1.03)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	1.17 (1.33)^{G}	ethanol, sweet
13	943	3-(methylthio)-1-propene	MS	0.67 (1.03)^{gh}	0.33 (0.52)^{gh,*}	1.83 (1.47)^{g}	0.00 (0.0)^{h}	1.83 (1.47)^{G}	1.83 (0.75)^{G,*}	3.00 (2.00)^{G}	1.00 (1.10)^{G}	meaty, garlic, onion
14	963	2,3-butanedione	MS, RI, odor	1.17 (0.41)^{g}	1.50 (0.84)^{g}	2.83 (1.33)^{gh}	4.33 (1.03)^{h}	1.00 (0.00)^{I}	2.17 (1.17)^{HI}	3.50 (1.64)^{GH}	4.00 (0.89)^{G}	buttery, cream cheese
19	1008	α-pinene	MS, RI, odor	0.33 (0.52)^{g}	0.33 (0.52)^{g}	0.67 (0.52)^{g}	0.67 (1.03)^{g}	0.67 (0.52)^{GH}	0.00 (0.0)^{H}	1.00 (0.89)^{GH}	1.67 (0.52)^{G}	plastic bottle, piney
	1027	unknown		0.00 (0.0)^{g}	0.33 (0.52)^{g}	0.67 (1.03)^{g}	0.00 (0.0)^{g}	0.67 (0.52)^{G}	1.50 (1.22)^{G}	1.33 (0.52)^{G}	0.33 (0.52)^{G}	fruity
23	1038	propanol	MS, RI, odor	1.17 (0.98)^{g}	1.33 (1.37)^{g}	2.00 (1.10)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{G}	1.00 (0.00)^{G}	1.00 (0.00)^{G}	2.17 (2.04)^{G}	sweet, fruity
	1054	unknown		0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g,*}	0.00 (0.0)^{H}	0.67 (1.03)^{GH}	0.67 (0.52)^{GH}	1.67 (0.52)^{G,*}	sweet, ester
27	1058	dimethyl disulfide	MS, RI, odor	2.00 (0.63)^{g}	0.00 (0.0)^{h}	1.00 (1.55)^{gh}	0.00 (0.0)^{h}	0.67 (1.03)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	sour, sulfury, rotten onion
28	1068	hexanal	MS, RI, odor	0.33 (0.52)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.33 (0.52)^{G}	0.00 (0.0)^{G}	green
	1075	unknown		0.00 (0.0)^{g}	1.00 (0.89)^{g}	0.67 (1.03)^{g}	0.83 (0.75)^{g}	0.67 (0.52)^{GH}	0.00 (0.0)^{H}	1.83 (0.98)^{G}	0.67 (1.03)^{GH}	sour, onion, rubber
	1084	unknown		0.83 (0.75)^{g}	0.50 (0.84)^{g}	0.33 (0.52)^{g}	1.17 (1.83)^{g}	0.67 (0.52)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.67 (1.03)^{G}	plastic, sour
	1128	unknown		0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.17 (0.41)^{g}	0.67 (1.03)^{g}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	grassy, hexanal
	1177	unknown		3.00 (0.63)^{g}	3.00 (0.89)^{g}	2.17 (0.98)^{h}	1.67 (0.52)^{h}	3.17 (1.47)^{G}	2.83 (0.41)^{GH}	1.50 (0.55)^{GH}	1.67 (0.52)^{H}	hot rubber, wild onion
53	1195	1,8-cineole	MS, RI, odor	0.67 (1.03)^{g}	0.00 (0.0)^{g}	1.00 (1.55)^{g}	1.00 (1.55)^{g}	0.67 (1.03)^{G}	0.67 (1.03)^{G}	0.00 (0.0)^{G}	1.00 (1.10)^{G}	camphorous, menthol
55	1200	3-methyl-1-butanol	MS, RI, odor	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	2.83 (0.75)^{h}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	3.67 (3.01)^{G}	chocolate
59	1218	methylpropyl disulfide	MS, RI, odor	1.00 (1.55)^{g}	0.00 (0.0)^{g}	1.00 (1.55)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{G}	0.33 (0.52)^{G}	0.67 (1.03)^{G}	0.00 (0.0)^{G}	garlic, sour
	1229	(*Z*)-4-Heptenal	RI, odor	0.33 (0.52)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	1.33 (2.07)^{g}	0.00 (0.0)^{G}	0.33 (0.52)^{G}	0.33 (0.52)^{G}	0.00 (0.0)^{G}	rancid, fishy
	1243	unknown		0.67 (1.03)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g,*}	2.17 (0.98)^{h}	4.00 (1.10)^{GH}	1.33 (2.16)^{I}	4.67 (1.03)^{G,*}	2.17 (0.98)^{HI}	soil, rubbery, plant root
65	1250	methyl-(*Z*)-propenyl disulfide	MS	2.33 (1.51)^{gh}	1.33 (1.37)^{hi}	3.33 (1.03)^{g,*}	0.00 (0.0)^{i}	0.00 (0.0)^{H}	1.67 (1.21)^{G}	0.00 (0.0)^{H,*}	0.00 (0.0)^{H}	garlic
67	1266	methylallyl disulfide	MS	4.67 (1.37)^{g}	4.00 (1.55)^{gh}	3.67 (1.21)^{gh}	3.00 (1.10)^{h}	4.17 (0.98)^{G}	3.17 (2.23)^{GH}	3.83 (2.23)^{G}	1.67 (0.82)^{H}	garlic salt
	1283	1-octen-3-one	RI, odor	3.17 (2.56)^{g}	0.00 (0.0)^{h}	2.33 (1.97)^{gh}	2.33 (1.86)^{gh}	2.17 (1.83)^{G}	0.00 (0.0)^{G}	1.83 (1.72)^{G}	0.67 (1.03)^{G}	mushroom, earthy
	1319	2-acetyl-1-pyrroline	RI, odor	5.00 (1.10)^{g}	4.00 (1.26)^{g}	0.00 (0.0)^{h}	0.00 (0.0)^{h}	5.17 (0.75)^{G}	4.83 (0.98)^{G}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	popcorn
82	1365	dimethyl trisulfide	MS, RI, odor	5.50 (0.84)^{g}	5.50 (0.55)^{g}	4.83 (0.75)^{g}	4.83 (0.41)^{g}	5.50 (0.55)^{G}	4.50 (1.38)^{G}	4.83 (1.47)^{G}	4.67 (1.03)^{G}	cooked/rotten cabbage
90	1434	acetic acid	MS, RI, odor	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	2.17 (1.83)^{h}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	1.33 (2.07)^{G}	1.50 (2.35)^{G}	vinegar
91	1436	3-(methylthio)propanal	MS, RI, odor	4.17 (3.25)^{g}	4.00 (3.10)^{g}	3.50 (2.95)^{g}	3.17 (2.56)^{g}	3.67 (2.88)^{G}	4.00 (3.10)^{G}	3.83 (2.99)^{G}	3.67 (2.88)^{G}	baked/boiled potato
94	1448	dithio(1-propenyl) propionate	MS	4.00 (1.10)^{g}	1.33 (2.16)^{g}	3.00 (2.37)^{g}	0.00 (0.0)^{g}	2.67 (2.16)^{G}	2.50 (1.76)^{G}	3.17 (2.48)^{G}	1.00 (1.67)^{G}	roasted/nutty potato
95	1466	diallyl disulfide isomer	MS	4.50 (1.38)^{g}	5.33 (0.82)^{g,*}	4.67 (1.21)^{g}	4.67 (1.51)^{g}	4.50 (1.52)^{GH}	4.00 (1.10)^{GH,*}	5.33 (0.82)^{G}	3.33 (1.75)^{H}	fresh garlic, hot spicy
96	1470	diallyl disulfide isomer	MS	3.00 (2.37)^{g}	4.50 (1.22)^{g}	0.00 (0.0)^{h}	0.00 (0.0)^{h}	4.33 (1.51)^{G}	1.33 (1.03)^{G}	2.83 (2.23)^{G}	1.67 (1.86)^{G}	green onion
	1485	unknown		4.83 (1.17)^{g}	4.17 (1.17)^{g}	4.83 (0.75)^{g}	4.83 (0.98)^{g}	5.17 (0.75)^{GH}	4.83 (0.98)^{GH}	5.67 (0.82)^{G}	4.17 (0.75)^{H}	meaty, wonton soup
	1510	unknown		4.67 (1.37)^{g}	5.50 (0.55)^{g,*}	4.50 (1.64)^{g}	4.67 (1.21)^{g}	5.17 (0.98)^{G}	4.33 (1.03)^{G,*}	4.67 (1.03)^{G}	4.50 (0.55)^{G}	spicy, tree root, floral
102	1519	methylpropyl trisulfide	MS	2.00 (1.79)^{g}	2.67 (2.07)^{g}	2.33 (2.25)^{g}	2.83 (1.83)^{g}	1.83 (1.47)^{GH}	0.67 (1.03)^{I}	2.67 (1.03)^{G}	1.67 (1.37)^{H}	bitter, stale, pungent, spicy
103	1532	linalool	MS, RI, odor	4.50 (0.84)^{g}	3.83 (1.33)^{g}	3.67 (0.52)^{g}	3.83 (0.98)^{g}	3.17 (1.17)^{G}	2.83 (0.98)^{G}	4.17 (1.17)^{G}	3.17 (1.17)^{G}	floral, spicy, flowers
	1555	unknown		0.67 (1.03)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.33 (0.52)^{G}	0.67 (1.03)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	nutty, garlic
106	1570	(*E*,*Z*)-2,6-nonadienal	MS, RI, odor	2.33 (2.25)^{g}	3.33 (1.51)^{gh}	3.00 (2.37)^{gh}	4.17 (1.47)^{h}	3.67 (0.52)^{G}	3.83 (1.17)^{G}	3.00 (0.89)^{G}	3.00 (1.10)^{G}	cucumber
	1576	unknown		5.17 (1.33)^{g}	5.50 (0.84)^{g}	4.83 (0.41)^{g}	3.00 (2.37)^{g}	5.33 (0.82)^{G}	4.83 (1.17)^{G}	4.50 (1.38)^{G}	2.33 (1.37)^{H}	garlic salt, mustard
	1585	unknown		1.33 (2.07)^{g}	0.67 (1.03)^{g}	1.00 (1.55)^{g}	0.00 (0.0)^{g}	1.83 (2.04)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	garlic salt, rancid fish
	1593	unknown		1.00 (1.55)^{g}	0.00 (0.0)^{g}	1.00 (1.55)^{g}	0.00 (0.0)^{g}	1.33 (2.07)^{G}	1.00 (1.10)^{G}	0.00 (0.0)^{G}	0.50 (0.84)^{G}	garlic salt
	1603	unknown		2.33 (1.86)^{g}	1.67 (1.37)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.67 (1.03)^{G}	0.00 (0.0)^{G}	garlic salt
113	1626	phenylacetaldehyde	MS, RI, odor	3.83 (1.47)^{g}	3.33 (1.03)^{g}	2.83 (0.75)^{g}	1.00 (1.55)^{h}	4.00 (1.41)^{G}	3.17 (1.83)^{G}	3.33 (1.37)^{G}	2.50 (1.76)^{G}	floral, spicy, honeysuckle
117	1650	methyl(methylthio)-methyl disulfide	MS	2.33 (2.58)^{g}	2.33 (1.51)^{g}	3.17 (1.47)^{g}	1.00 (0.89)^{g}	2.83 (0.41)^{G}	1.00 (1.55)^{HI}	2.00 (1.55)^{GH}	0.00 (0.0)^{I}	green onion, sulfury, rubbery
	1657	unknown		2.83 (2.32)^{g}	3.33 (2.66)^{g}	5.00 (0.63)^{g}	4.33 (0.82)^{g}	4.00 (1.67)^{G}	3.67 (1.03)^{G}	4.83 (0.98)^{G}	4.00 (1.67)^{G}	nutty, vitamin, cooked rice
	1676	unknown		1.67 (1.37)^{g}	0.00 (0.0)^{g}	1.33 (1.37)^{g}	1.33 (1.37)^{g}	1.33 (2.07)^{G}	0.50 (0.84)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	garlic, pungent, stale
	1681	unknown		2.67 (2.25)^{g}	1.33 (1.03)^{g}	2.83 (2.32)^{g}	2.83 (0.75)^{g}	2.00 (1.67)^{GH}	0.67 (1.03)^{H}	2.50 (1.05)^{G}	2.17 (1.33)^{G}	fatty, chicken broth (dienal)
	1700	unknown		1.33 (1.37)^{g}	1.67 (1.37)^{g}	3.00 (0.89)^{g}	1.83 (0.75)^{g}	3.33 (1.03)^{GH}	2.00 (0.89)^{H}	4.00 (1.67)^{G}	0.00 (0.0)^{I}	sweet, sour, fatty, planty
	1712	unknown		1.33 (2.07)^{g}	0.00 (0.0)^{g}	1.33 (2.07)^{g}	1.17 (0.98)^{g}	2.00 (1.79)^{G}	1.00 (1.55)^{G}	2.00 (1.79)^{G}	1.00 (1.10)^{G}	savory, saffron, hay
	1724	unknown		0.00 (0.0)^{g}	1.33 (1.03)^{g}	1.33 (2.07)^{g}	2.17 (0.75)^{g}	1.33 (2.07)^{G}	1.83 (1.83)^{G}	1.67 (1.86)^{G}	1.50 (1.38)^{G}	rancid, roasted garlic
131	1742	dimethyl tetrasulfide	MS	2.00 (1.10)^{g}	0.67 (1.03)^{gh}	0.00 (0.0)^{h}	0.00 (0.0)^{h}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	roasted garlic
	1754	unknown		2.00 (1.55)^{g}	1.00 (1.55)^{g}	0.83 (1.33)^{g}	2.33 (0.82)^{g}	0.67 (1.03)^{G}	2.33 (0.52)^{G}	2.67 (2.25)^{G}	0.50 (1.22)^{G}	fatty, melon
139	1775	diallyl trisulfide	MS	5.33 (1.51)^{g}	4.00 (1.10)^{gh}	3.00 (2.00)^{h,*}	3.83 (0.75)^{gh}	4.00 (1.67)^{GH}	3.17 (1.60)^{GH}	4.17 (1.47)^{G,*}	3.00 (1.26)^{H}	green onion
	1781	unknown		0.00 (0.0)^{g}	0.00 (0.0)^{g}	3.50 (0.84)^{h,*}	0.00 (0.0)^{g}	1.00 (0.89)^{G}	0.00 (0.0)^{G}	0.33 (0.82)^{G,*}	0.00 (0.0)^{G}	sweet, candy
141	1797	(*E*,*E*)-2,4-decadienal	MS, RI, odor	3.00 (2.37)^{g}	3.50 (0.84)^{g}	3.17 (2.48)^{g}	3.17 (2.14)^{g}	2.87 (2.23)^{G}	2.00 (1.67)^{G}	2.33 (1.86)^{G}	2.50 (2.07)^{G}	fatty, sweet (dienal)

	1810	unknown		3.83 (0.98)^{g}	4.17 (0.98)^{g}	3.83 (1.83)^{g}	3.67 (2.16)^{g}	3.67 (1.51)^{G}	3.83 (1.17)^{G}	2.50 (1.38)^{H}	3.33 (1.03)^{G}	apple sauce, cooked apple
	1817	unknown		0.00 (0.0)^{g}	0.00 (0.0)^{g}	2.00 (2.37)^{g}	0.00 (0.0)^{g}	3.50 (1.87)^{G}	0.67 (1.03)^{H}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	smoky, sweet, meaty
	1836	unknown		3.00 (0.89)^{g}	2.17 (2.04)^{g}	1.83 (1.83)^{g}	2.50 (1.38)^{g}	3.33 (2.58)^{G}	1.83 (1.60)^{G}	2.50 (2.07)^{G}	4.00 (0.63)^{G}	garlic, sweet, meaty
	1845	unknown		2.00 (1.79)^{g}	2.67 (0.52)^{g}	2.33 (0.52)^{g}	3.00 (0.89)^{g}	0.00 (0.0)^{I}	1.33 (1.21)^{H}	2.83 (0.41)^{G}	3.33 (0.52)^{G}	smoky
	1852	unknown		1.67 (2.58)^{g}	0.67 (1.03)^{g}	1.33 (2.07)^{g}	0.00 (0.0)^{g}	3.17 (1.60)^{G}	2.67 (2.25)^{GH}	0.00 (0.0)^{H}	1.67 (2.58)^{GH}	onion, mushroom, phenolic
	1858	unknown		2.67 (2.25)^{g}	1.33 (2.07)^{g}	1.67 (2.58)^{g}	2.83 (2.32)^{g}	2.00 (1.79)^{G}	0.00 (0.0)^{G}	0.67 (1.03)^{G}	0.00 (0.0)^{G}	fatty, stale (dienal)
	1872	unknown		1.67 (2.58)^{g}	1.00 (1.55)^{g}	1.33 (2.07)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	fatty, stale, meaty
	1881	unknown		0.67 (1.03)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	1.00 (1.55)^{G}	0.00 (0.0)^{G}	garlic, onion
148	1908	2-phenylethanol	MS, RI, odor	3.17 (1.83)^{g,*}	0.67 (0.52)^{g}	3.17 (2.48)^{g}	2.00 (2.37)^{g}	2.17 (1.72)^{G,*}	1.67 (2.58)^{G}	2.33 (1.86)^{G}	1.83 (2.86)^{G}	floral, pine sap, rosy
	1927	unknown		0.00 (0.0)^{g}	2.33 (1.97)^{h}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	1.33 (1.03)^{G}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	garlic, stale
	1949	unknown		3.33 (0.82)^{g}	2.50 (2.17)^{g}	4.00 (1.26)^{g}	2.67 (1.21)^{g}	2.50 (1.22)^{G}	1.83 (0.75)^{G}	2.50 (1.22)^{G}	2.67 (1.37)^{G}	phenolic, piney, green garlic
	1967	unknown		1.67 (1.37)^{gh}	0.00 (0.0)^{h}	2.33 (1.51)^{g}	2.00 (0.00)^{g}	2.83 (2.48)^{G}	2.17 (1.17)^{G}	0.67 (1.03)^{G}	1.67 (1.86)^{G}	fatty, meaty (dienal)
	1998	unknown		2.00 (1.67)^{g,*}	2.50 (0.55)^{g}	3.67 (1.21)^{g}	4.33 (1.51)^{g}	3.50 (1.22)^{GH,*}	1.33 (1.03)^{H}	4.83 (0.75)^{G}	2.17 (1.72)^{H}	garlic, wild green onion, stale
	2030	unknown		1.00 (1.55)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.67 (1.03)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	meaty, garlic
	2036	unknown		1.83 (1.47)^{g}	1.00 (0.89)^{g}	2.00 (1.79)^{g}	0.33 (0.52)^{g}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	garlic
	2098	unknown		0.00 (0.0)^{g}	0.33 (0.52)^{g}	2.00 (1.10)^{g}	1.50 (1.22)^{g}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	0.50 (0.84)^{G}	garlic, floral
	2106	unknown		0.00 (0.0)^{g}	0.00 (0.0)^{g}	2.00 (0.89)^{h}	0.00 (0.0)^{g}	0.00 (0.0)^{G}	0.00 (0.0)^{G}	1.33 (1.03)^{G}	0.67 (1.03)^{G}	sweetish, phenolic
	2140	unknown		0.00 (0.0)^{g}	1.33 (1.03)^{gh}	1.67 (0.52)^{h,*}	1.67 (0.52)^{h,*}	0.00 (0.0)^{G}	0.67 (1.03)^{G}	0.00 (0.0)^{G,*}	0.00 (0.0)^{G,*}	grapes, rancid, oily
	2148	unknown		2.50 (0.84)^{g,*}	1.67 (1.51)^{gh}	1.00 (0.89)^{h}	0.83 (0.75)^{h}	3.33 (1.37)^{G,*}	2.33 (1.97)^{G}	0.33 (0.52)^{H}	0.33 (0.52)^{H}	meaty, sweet, cloves
	2171	unknown		0.00 (0.0)^{g}	1.00 (1.55)^{g}	1.33 (1.03)^{g}	0.00 (0.0)^{g}	2.00 (1.55)^{G}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	smoky, phenolic, spicy
	2219	unknown		2.50 (0.84)^{gh}	2.17 (1.72)^{gh}	2.67 (1.03)^{g}	0.00 (0.0)^{h}	3.33 (1.03)^{G}	1.83 (1.83)^{G}	1.67 (1.51)^{G}	1.67 (1.37)^{G}	meaty, grape, naphthalene
157	2234	2-phenylethyl isothiocyanate	MS	1.67 (1.37)^{g}	1.00 (1.55)^{g}	0.67 (1.03)^{g}	1.00 (0.89)^{g}	2.00 (1.55)^{G}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	grape, floral, musty, raddish
	2336	unknown		2.33 (2.25)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	0.00 (0.0)^{g}	2.00 (1.79)^{G}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	0.00 (0.0)^{H}	ginger root, meaty

[a] Mean odor intensity from three replications. [b] Numbers correspond to those in Table 2. [c] Retention index on DB-WAX (30 m length × 0.32 mm inside diameter × 0.25 mm film thickness) column. [d] For C and FS, refer to Table 1. [e] Odor description as perceived by panelists during GC/O. [f] Numbers in parentheses represent standard deviations. [ghi]Means having different superscripts in each row under C are significantly different ($p < 0.05$). [GHI]Means having different superscripts in each row under FS are significantly different ($p < 0.05$). *Means at given time for C and FS are significantly different ($p < 0.05$).

GC/O, although they have low threshold values of 60 and 0.007 ppb in water, respectively (Buttery et al., 1971). Only two ketones, 2,3-butanedione and 1-octen-3-one, were detected during GC/O. The odor intensity of 2,3-butanedione (buttery and cheese-like) increased with fermentation time in both FS and C, while that of 1-octen-3-one (mushroom and earthy) decreased.

The alcohols ethanol, propanol, 1-penten-3-ol, 3-methyl-1-butanol, and 2-furanmethanol and four terpene alcohols (borneol, β-citronellol, geraniol, and nerolidol) were in high abundance in both samples during fermentation. In particular, levels of ethanol sharply increased during fermentation and composed more than 40% of the total volatile compounds in both samples after 30 days. Nevertheless, all of the alcohols detected in GC/O, except for linalool and 2-phenylethanol, had low odor intensities in FS and C throughout the fermentation. This may be because most alcohols have high threshold values (Buttery et al., 1988; Takeoka et al., 1990). Linalool, having a low threshold ($t = 6$ ppb; Takeoka et al., 1990), contributed a floral, spicy, and flower-like odor throughout the fermentation period. The odor intensity of 2-phenylethanol (floral and rosy) remained constant in FS and C during fermentation. Terpene alcohols detected in Kimchi may have been derived from nonvolatile terpenoid glycosides through the action of enzymes, acid, and/or heat (Chen and Ho, 1989).

Among 24 terpenes detected, 6 such as α-zingiberene, β-phellandrene, β-sesquiphellandrene, camphene, β-bisabolene, and farnesene isomer (no. 130) were found in high abundance at days 0 and 7; however, levels of these compounds decreased markedly after 30 days in both samples. Chen and Ho (1989) reported that α-zingiberene and β-sesquiphellandrene are readily converted to ar-curcumene by oxidative degradation. These sesquiterpenes may not be important in the characteristic flavor of Kimchi because of their relatively high threshold values (Takeoka et al., 1990; Buttery et al., 1988), especially when compared with the sulfur-containing compounds. α-Pinene (plastic bottle and piney) was the only terpene detected by GC/O and had low odor intensities in both FS and C.

Three thiocyanates, 2-phenylethyl- and 3-butenyl isothiocyanate and methyl thiocyanate, were detected in high abundance in both samples at day 0 and then gradually decreased during fermentation. These compounds, with mustard oil, pungency, hot-like odors, were reported as major components affecting the characteristic flavor of Chinese cabbage (Daxenbichler et al., 1979), cabbage, broccoli, and cauliflower (VanEtten et al., 1976; Buttery et al., 1976). However, 2-phenylethyl isothiocyanate (floral, musty, and raddish) was the only compound in this group detected by GC/O and was at low odor intensities in C throughout the fermentation period, while it was present in FC at day 0 only. Buttery et al. (1976) reported that 2-phenylethyl isothiocyanate was an important component of cabbage aroma, and its odor threshold was 6 ppb in water. Hashimoto et al. (1982) also reported that glucosinolate (thioglucoside) in cabbage leaves is degraded by myrosinase to yield three main types of products, isothiocyanates, thiocyanates, and nitriles.

Nine acids were identified in FS and 4 in C during fermentation. Low-molecular weight fatty acids from C4 to C6 were detected in FS only. These compounds, having rancid, pungent, and cheesey odors, depending on their concentration, may be formed either from lipid oxidation or via bacterial degradation of amino acids (Dougan and Howard, 1975; Sanceda et al., 1992). Ryu et al. (1984) reported that levels of volatile organic acids, such as acetic, propionic, butyric, valeric, caproic, and heptanoic, increased with the fermentation period of Kimchi. Acetic acid (vinegar-like) was only detected by GC/O after day 15.

2-Acethyl-1-pyrroline (popcorn-like) was detected with high odor intensities until day 7 in both C and FS but was not detected after day 15. This compound can be formed from the reaction of 2-oxopropanal with either proline or ornithine (Schieberle, 1990). 2-Acetyl-1-pyrroline is a character-impact odorant in many foods, including cooked crab meat (Chung and Cadwallader, 1994), cooked spiny lobster (Cadwallader et al., 1995), and aromatic rice (Buttery et al., 1983).

Among the unidentified compounds detected in GC/O, four compounds (RI = 1485, 1510, 1657, and 1810) had high odor intensities in both FS and C. These compounds were described as meaty (RI = 1485), spicy and floral (RI = 1510), nutty and vitamin-like (RI = 1657), and apple sauce- and cooked apple-like (RI = 1810). Two additional unidentified compounds (RI = 1858 and 1872), having fatty and stale odors, were found at higher intensities in C than in FS.

On the basis of the odor intensities of compounds detected by GC/O, sulfur-containing compounds may play important roles in formation of Kimchi flavor. These include many unidentified compounds having garlic- and green onion-like odors. There was no difference in the intensities and numbers of aroma-active compounds between C and FS during fermentation. It was, therefore, concluded that addition of fish sauce had little or no impact on the formation of aroma-active compounds in Kimchi during fermentation. It is possible that fish sauce only has a noticeable effect on the taste quality of Kimchi. Additional studies involving sensory evaluation and/or the monitoring of levels of taste-active compounds in Kimchi during fermentation are needed to determine if fish sauce actually impacts the flavor of Kimchi.

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