Effects of different drying methods on physicochemical properties, volatile profile, and sensory characteristics of kimchi powder

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Abstract The effects of five different drying conditions on kimchi powder quality were determined by comparatively analyzing their physicochemical characteristics, volatile profile, and sensory evaluations. The moisture content of the kimchi powder obtained by each method was < 10%, and the yield after drying differed among methods ranging from 9.50 to 10.38% ($p < 0.05$). Electronic nose and tongue analyses demonstrated significant differences ($p < 0.05$) between samples based on the drying temperature. The particle size distribution did not differ considerably between drying methods, except for the ground kimchi ($p < 0.05$). The sensory evaluation test revealed that the flavor and taste were rated the highest for the kimchi powder prepared using HADHT. Therefore, hot-air drying at a high temperature was the most effective method for kimchi powder production owing to have a good flavor and taste and the shorter drying time.

Keywords Kimchi · Drying · Volatile profile · Sensory evaluation

Introduction

Kimchi is a traditional Korean food prepared with vegetables such as cabbage and radishes, and spices such as garlic and red pepper powder. The unique taste and nutritional value of kimchi is attributable to lactic acid fermentation by lactic acid bacteria such as *Leuconostoc* (Ku et al., 2005), *Lactobacillus*, and *Weissella* species. Kimchi contains various free amino acids (such as lysine, tryptophan, leucine, and tyrosine) (Cho et al., 1979; Jung et al., 2014; Tamang et al., 2016), organic acids (such as lactic acid, pyroglutamic acid, and succinic acid), saccharides, ethanol, methyl ethyl ketone, and acetaldehyde, which impart a unique flavor during fermentation (Kim et al., 2017). Recently, kimchi was categorized under the Codex Alimentarius (Codex, 2001) and Korea has been designated as its country of origin. Furthermore, kimchi has been ranked as one of the world's healthiest foods, along with natto from Japan, olive oil from Spain, Greek yogurt, and lentils from India (Tamang et al., 2016). Its popularity is expected to increase with the rising global interest in Korean food. The global popularization of kimchi requires its development and merchandising as a commercial product (Jung et al., 2014).

To enhance the vitality of the Korean kimchi industry, it is essential to develop products that satisfy the sense of taste of people worldwide by standardization, diversification, and industrialization. These developments would highlight the potential global economic value of kimchi. Since kimchi is expected to be highly valuable as a seasoning that can impart flavor to other foods (Chamber et al., 2012), the possibility of developing kimchi powder as a raw material was evaluated.

Recently, kimchi powder has been developed as an ingredient and seasoning for foods such as snacks, noodles,

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seafood buns, fermented sausages, and breakfast sausages (Park et al., 2016). Drying of kimchi powder is mainly aimed at reducing the moisture to extend the shelf life. The major challenge during dehydration of kimchi powder is to reduce the energy consumption and the water content of the material to the desired level without substantial loss of color, appearance, flavor, taste, and chemical components (Park et al., 2016).

To extend shelf life and to use as a food ingredient, kimchi is dehydrated by various methods such as freeze drying, hot air drying, and vacuum drying (Park et al., 2016; Seo et al., 2013). Hot air drying involves a continuously flowing hot stream of air to remove the surface moisture of kimchi while freeze drying reduces the surrounding pressure to allow the frozen water in the material to directly sublimate from the solid to gas phase after freezing the product at low temperature (Park et al., 2016). Finally, vacuum drying is used to dry heat-sensitive products (Lewicki, 2006).

However, few studies have investigated the characteristics of kimchi powder obtained using different drying methods. This study investigated the effects of five drying methods on the production of kimchi powder and established the optimal drying conditions based on the yield, volatile compounds, and sensory evaluation.

Materials and methods

Kimchi powder preparation

Kimchi was purchased from Yaksunwon Inc. (Sejong, Korea) and matured in a cold-storage room (4 °C) until the samples reached pH 4.4–4.6 and 0.6%–0.8% acidity. The mature kimchi was ground using a blender, and then dried using the five drying methods to establish the optimum conditions to produce kimchi powder. The ground kimchi samples (Sample A) were moistened to ensure they had the same moisture content before drying in all experiments, except for the sensory evaluation. The five kimchi powder sample prepared using: B, freeze drying (FD); C, decompression drying (DD) at high temperature (DDHT); D, hot-air drying at high temperature (HADHT); E, DD at low temperature (DDLTL); and F, HAD at low temperature (HADLT). The five drying methods evaluated were: freeze-drying (FD, FDT-8632; Operon, Gimpo, Korea), decompression drying (DD) at high and low temperatures (DDHT and DDLTL, 60 ± 1 and 35 ± 1 °C, respectively; SMED-0.3, Hansung, Gimje, Korea), and hot-air drying (HAD) at high and low temperatures (HADHT and HADLT, 60 ± 1 and 35 ± 1 °C, respectively; GN10; Hanil GNCO, Jangseong, Korea). After drying, the kimchi was ground using a blender and stored at − 20 °C. The pH

of the kimchi was measured by placing an electrode (phgl bl14; SI Analytics, Mainz, Germany) into the filtrate. The titratable acidity was calculated using the Association of Official Analytical Chemists (AOAC, 1990) analysis method; 10 mL of the filtrate was titrated with 0.1 N sodium hydroxide (NaOH) until the pH reached 8.3.

Measurement of drying yield, moisture content, and restoration rate

The drying yield was calculated based on the drying time and method by measuring the pre-drying and post-drying weight of the sample. The moisture content was measured using an infrared moisture sensor (MB45; Ohaus, Parsippany, NJ, USA). The restoration rate was measured to investigate the effects of each drying method by dividing the samples into kimchi powder, stem, and leaves. For each sample, 30 g was analyzed, and each dish was subsequently dried using a different drying method. After drying, the weight loss from each dish was made up with distilled water, each dish was incubated for 24 h at 4 °C, and then the restoration rate was measured for each sample.

Analysis of particle size distribution

Powder samples with particle sizes ranging from 0.017 mm to 2000 mm can be suspended in solution, and the amount of sample needed depends on the size and concentration of the particles. Particle size distribution was examined using a laser diffraction particle size analyzer (LS 13 320, Beckman Coulter, Inc., Brea, CA, USA) with distilled water as the dispersion solvent.

Color analysis

The Commission Internationale de l'Eclairage (International Commission on Illumination)-LAB (CIE-Lab) color values of the kimchi powder samples were acquired 10 times using the CR-300 Chroma Meter (Konica Minolta, Tokyo, Japan). Color changes were recorded before and after drying. The standard white panel was adjusted before measuring the chromaticity (lightness [*L*] = 92.0; redness [*a*] = − 0.84; and yellowness [*b*] = 3.75).

Gas chromatography-mass spectrometry (GC/MS)

Volatile compounds were measured using a gas chromatography-mass selective detector (GC/MSD, 7890B/5977A Hewlett-Packard Co., Palo Alto, CA, USA). The sample (1.0 g of ground kimchi or 0.5 g of kimchi powder) was measured in a headspace vial (20 mL, 22.5 mm × 75.7 mm), 2 mL distilled water was added with stirring, and then the sample was analyzed. Each sample was

extracted following equilibration for 30 min at 80 °C using a Headspace Autosampler (Agilent 7694E Headspace Sampler, Santa Clara, CA, USA). A DB-5 ms column (Agilent J&W GC column, 30 m × 0.25 mm; film thickness, 0.25 µm) was used for GC/mass spectrometry (MS). High-purity helium (flow rate, 1 mL/min) was used as the carrier gas, the injector temperature was 200 °C, and the oven temperature was between 30 °C (5 min) and 280 °C (5 min) with a temperature rate change of 10 °C/min. The peaks were analyzed using the National Institute of Standard and Technology (NIST) Library (Mass Spectral Library, version 4.5, NIST08, Gaithersburg, MD, USA).

Electronic and electronic tongue and sensory evaluation

To analyze the content of aromatic compounds, a GC-type electronic nose (Heracles II; Alpha MOS, Toulouse, France) was used. Aromatic compounds were detected in each sample using a flame ionization detector (FID) with MXT-5 and MXT-1701 (10 m length × 180 µm diameter) as the column. Distilled water (2 mL) was added to the sample (1 g ground kimchi or 0.5 g kimchi powder) in a 20-mL headspace vial for the analysis. The samples were incubated for 15 min at 60 °C, followed by shaking at 500 rpm, and the gas was then injected using the headspace method. To analyze the taste, an electronic tongue was used (Astree 2, Alpha MOS). The samples were diluted 1000×, filtered (No. 10, Hyundai Micro Co., Ltd., Seoul, Korea), and then 25 mL was placed in a glass container and analyzed using an automatic sample measuring instrument. The electronic tongue consisted of a module with seven sensors (Sensor Array #5, produced by Alpha MOS, in Toulouse, France), which did not measure each chemical component but rather sensed the total taste and subsequently transformed the sensors' sensitivity to the taste score ranging from 0 to 12. The mean ($\bar{X}$) and standard deviation ($\hat{\sigma}$) of the score of every sensor were calculated. Based on the $\bar{X}$ value of the repeated data sensory score of each sample, the normal distribution value was computed using the formula below:

$$X' = \frac{|\bar{X} - m|}{\sigma}$$

With those X' 's, the relative taste scores are shown and taken advantages. The sample estimation was repeated three times. After analyzing one sample, the sensors were rinsed. The statistical analysis was performed using the Alpha MOS software (AlphaSoft version 14.1, Alpha MOS, Toulouse, France).

The effects of five different drying conditions on kimchi powder quality were determined by comparatively analyzing their sensory evaluations. To investigate the sensory

properties of the kimchi powder, appearance, flavor and taste were evaluated. The commercial kimchi stew powder was used as positive control (PC). A panel of 15 experienced judges from the World Institute of Kimchi was recruited for sensory evaluation (Herbert et al., 2012; Hootman, 1992; Meilgaard et al. 2015). For 3 days, once a day, the 15-member panel assessed the following sensory characteristics of the kimchi using the 7-point Likert scale: overall quality, appearance, flavor, and taste. Scores were marked on a seven-point hedonic scale (1 = dislike very much, 2 = dislike moderately, 3 = dislike very little, 4 = neither like nor dislike, 5 = like a little, 6 = like moderately, 7 = like very much) (Meilgaard et al., 1999). Panelists were served 10 g portions of each kimchi powder sample in coded 50 ml disposable white paper cups with the cover. The samples were coded with three-digit random numbers and presented to the panel. To avoid the effects of residual taste on other kimchi powder samples, water and boiled rice were provided to the evaluators. The judges rinsed with water to cleanse their palates between sample tasting.

Statistics

All experiments were replicated three times, and the statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) v 19.0 (IBM, Armonk, NY, USA). A one-way analysis of variance (ANOVA) was conducted to test the significance of differences between groups. Duncan's multiple range test was used to determine significant differences between mean values ($p < 0.05$). Principal component analysis (PCA) and correlation analysis were conducted using XLSTAT 2016 (Addinsoft, Paris, France).

Results and discussion

Analysis of yield, moisture content, and restoration rate after drying

There are three primary drying methods, each with its advantages and disadvantages: FD, HAD, and DD. FD has a high restoration rate and causes minimal changes in nutrition and color, but is an expensive process. HAD is more affordable, but the restoration rate is low, and there are changes in the color and nutritional value. DD has a higher restoration rate and produces a better-quality product than that of HAD, and costs less than FD. In this study, we attempted to identify a method suitable for kimchi powder production by investigating the physico-chemical properties and sensory characteristics of kimchi dried using five drying methods. Kimchi maturity can be

categorized into three stages based on the acidity: pre-, optimum-, and over-mature at titratable acidity levels of < 0.3%, 0.3–0.8%, and 0.8–1.0%, respectively (Cho and Lee, 1979; Ku et al., 2005; Seo et al., 2013). The samples were dried until they reached optimum maturity, and 10% moisture content was considered acceptable for the dried kimchi as this is the moisture content of commercial kimchi powder. The drying time, drying yield, and moisture content of the kimchi powder for each drying method are shown in Fig. 1. The estimated moisture content of the kimchi powder after drying varied from 8.79 to 9.56% depending on the method. These differences were attributed to differences in the drying method, time, and temperature (Kim et al., 2007). Therefore, in this study, kimchi powder produced by all five drying methods satisfied the standard commercial requirements. FD had the longest drying time, followed by DDLT/HADLT and DDHT/HADHT. The drying times for DDLT/HADLT and DDHT/HADHT were 36, and 60 h shorter than those for FD were, respectively. Drying yields showed the greatest change between 0 and 3 h at a high temperature, whereas the greatest change at a low temperature was observed between 0 and 6 h. After this point, a gradual decrease in the rate of change of drying yields was observed. In contrast, the drying yield obtained by FD showed a constant decrease. These findings suggest that the DDHT and HADHT processes substantially changed the product weight, as the moisture content decreased rapidly during drying at high temperatures (Choi et al., 1987). Additionally, based on the

drying yield obtained for different drying times, HADHT and DDHT were the most efficient drying methods.

The restoration rate is the ability of a powder in a solution to absorb moisture and return to its original state and is an important consideration when manufacturing secondary products made of kimchi. The rate of restoration strongly affects quality during the manufacture of instant food products. Table 1 shows the restoration rate for each drying method. The highest restoration rate was observed with HADHT (94.36%), whereas FD, which is widely known for its high restoration rate, showed a restoration rate of 94.00%. The powder samples exhibited minimal differences in the restoration rate among the different drying methods, which were all > 92%. Because the differences were minimal, the most economically feasible method could be chosen. The dried stems and leaves showed a lower restoration rate than that of the kimchi powder. Kimchi flakes obtained by FD had the highest restoration rate (83.28%) for dried stems and the second highest for dried leaves (91.31%). The restoration rate for the stems was higher when the samples were dried at a high temperature than when it was dried at a low temperature, whereas the opposite result was observed for the leaves. These findings show that HADHT and FD were the most suitable methods for producing kimchi powder as a seasoning ingredient.

Analysis of particle size distribution

The particle size analyzer measured the size distribution of particles suspended in a dry powder form using the principle of light scattering, which is one of the most widely used techniques for measuring particle size distribution. As summarized in Table 1, the mean particle sizes before and after drying were 941.53 and 698.28–787.25 μm , respectively. No significant difference in particle size was found among the drying methods, except for the ground kimchi. The particle size has a considerable effect on conjunction strength and moisture absorption, as well as manufacturability parameters such as viscosity and texture (Jozinovic et al., 2012). A higher water content results in larger particle size owing to the effects on particle surfaces during the grinding process (Ko et al., 2003). The effects of differences in the particle size of kimchi powder require further study of the effect of the final moisture content and grinding method.

Measurement of color differences

Changes in color were expressed using the L , a , and b values of the Hunter color system, which is commonly used to quantify color changes after product drying and processing. The L , a , and b values are shown for the kimchi

Fig. 1 Drying yield and moisture content of kimchi powder under various drying conditions. ● Ground kimchi, ○ kimchi powder obtained by FD, ▼ kimchi powder obtained by DDHT, △ kimchi powder obtained by HADHT, ■ kimchi powder obtained by DDLT, □ kimchi powder obtained by HADLT; Solid line, drying yield; dashed line, moisture content. FD, freeze drying; DDHT, decompression drying (DD) at high temperature ($60 \pm 1^\circ\text{C}$); D, HADHT, hot-air drying (HAD) at high temperature ($60 \pm 1^\circ\text{C}$), DDLT, DD at low temperature ($35 \pm 1^\circ\text{C}$); HADLT, HAD at low temperature ($35 \pm 1^\circ\text{C}$)

Table 1 Summary of drying parameters and physicochemical characteristics of kimchi powder prepared using different drying methods

Variable		A	B	C	D	E	F
Drying parameters	Drying method	–	–	–	–	–	–
	Drying temperature (°C)	–	–	–	–	–	–
	Drying duration (h)	–	–	–	–	–	–
Physicochemical characteristics	Total drying duration (h)	–	–	–	–	–	–
	Drying yield (%)	–	–	–	–	–	–
	Moisture content (%)	84.70 ± 0.48 ^a	8.79 ± 0.86 ^b	9.50 ± 0.21 ^a	9.99 ± 0.81 ^a	9.99 ± 0.05 ^a	10.38 ± 0.22 ^a
	Restoration rate (%)	–	84.00 ± 0.30 ^{ab}	92.64 ± 0.73 ^c	94.36 ± 0.49 ^a	93.28 ± 0.43 ^{bc}	93.39 ± 0.65 ^{bce}
	Powder (%)	–	83.28 ± 0.44 ^a	69.71 ± 0.45 ^c	78.03 ± 1.67 ^b	63.05 ± 1.81 ^d	64.46 ± 3.84 ^d
	Stem (%)	–	91.31 ± 0.17 ^a	81.65 ± 4.14 ^b	82.60 ± 2.70 ^b	90.47 ± 0.42 ^a	92.21 ± 2.00 ^a
	Leaf (%)	–	165.50 ± 4.27 ^b	128.04 ± 23.60 ^b	144.09 ± 36.06 ^b	167.04 ± 32.57 ^b	123.78 ± 27.05 ^b
	Particle size (μm)	274.98 ± 53.61 ^a	–	–	–	–	–
	Diameter at 10%	644.22 ± 83.78 ^a	369.26 ± 11.58 ^b	317.10 ± 49.43 ^b	363.22 ± 89.11 ^b	422.43 ± 86.53 ^b	301.24 ± 53.83 ^b
	Diameter at 25%	967.03 ± 142.30 ^a	755.72 ± 24.05 ^{ab}	646.07 ± 89.11 ^b	722.10 ± 224.06 ^b	776.63 ± 53.54 ^{ab}	655.65 ± 112.82 ^b
Color differences	Diameter at 50%	1272.29 ± 175.57 ^a	1139.90 ± 13.66 ^a	1042.28 ± 47.58 ^a	1059.50 ± 253.69 ^a	1133.03 ± 38.23 ^a	1036.65 ± 140.02 ^a
	Diameter at 75%	1525.48 ± 116.84 ^a	1446.57 ± 32.93 ^a	1362.57 ± 105.05 ^a	1363.09 ± 220.32 ^a	1418.45 ± 78.34 ^a	1379.62 ± 120.20 ^a
	Diameter at 90%	941.53 ± 101.96 ^a	777.61 ± 1.15 ^b	699.28 ± 34.32 ^b	735.00 ± 158.50 ^b	787.25 ± 42.01 ^{ab}	698.28 ± 82.70 ^b
	Mean diameter	42.69 ± 0.31 ^d	48.61 ± 0.30 ^a	44.34 ± 0.45 ^b	43.50 ± 0.05 ^c	41.69 ± 0.05 ^f	42.05 ± 0.31 ^e
	L	22.16 ± 0.43 ^c	23.88 ± 0.22 ^a	22.11 ± 0.32 ^c	22.75 ± 0.08 ^b	23.68 ± 0.15 ^a	22.73 ± 0.13 ^b
	A	22.59 ± 0.50 ^b	24.72 ± 0.12 ^a	22.23 ± 0.39 ^c	21.88 ± 0.02 ^d	20.87 ± 0.07 ^f	21.28 ± 0.05 ^e
	B	–	–	–	–	–	–
	–	–	–	–	–	–	–
	–	–	–	–	–	–	–
	–	–	–	–	–	–	–

^aGround kimchi; kimchi powder prepared using^bFreeze drying (FD)^cDecompression drying (DD) at high temperature, 60 ± 1 °C (DDHT)^dHot-air drying at high temperature, 60 ± 1 °C (HADHT)^eDD at low temperature, 35 ± 1 °C (DDLTL)^fHAD at low temperature, 35 ± 1 °C (HADLT)Means (± standard deviation) indicated by different letters in each row are significantly different according to Duncan's multiple range test ($p < 0.05$)

Table 2 Volatile compounds present in kimchi powder identified using gas chromatography-mass spectrometry (GC/MS)

No.	R.T.	Compounds	Peak area (%) ^g					
			A	B	C	D	E	F
1	3.33	Ethyl acetate	0.94 ± 0.31	–	–	–	–	–
2	4.29	Butanol, 3-methyl-	–	5.20 ± 0.61 ^{cd}	29.34 ± 0.94 ^b	48.22 ± 8.43 ^a	4.26 ± 3.17 ^{cd}	8.87 ± 2.21 ^c
3	4.87	Sulfide, allyl methyl	0.89 ± 0.13 ^b	4.65 ± 1.07 ^a	0.99 ± 0.19 ^b	1.16 ± 0.30 ^b	1.21 ± 0.15 ^b	1.63 ± 0.12 ^b
4	6.39	Disulfide, dimethyl	7.66 ± 0.36 ^b	9.89 ± 0.86 ^a	4.10 ± 0.16 ^d	6.03 ± 0.30 ^c	3.10 ± 0.36 ^e	2.77 ± 0.22 ^e
5	7.06	1-(5-Bicyclo[2.2.1]heptyl)ethylamine	2.36 ± 0.53 ^b	4.54 ± 0.90 ^a	1.73 ± 0.32 ^a	–	–	–
6	8.08	Hexanal	0.76 ± 0.18 ^d	10.87 ± 0.45 ^a	3.13 ± 0.20 ^b	1.62 ± 0.46 ^c	2.14 ± 0.51 ^c	3.29 ± 0.18 ^b
7	9.49	1-Propene, 3,3'-thiobis-	3.06 ± 0.05 ^a	3.82 ± 0.25 ^{ab}	1.75 ± 0.30 ^{ab}	1.57 ± 0.38 ^{ab}	1.27 ± 0.54 ^b	1.30 ± 0.12 ^b
8	10.50	Heptanal	–	0.57 ± 0.06 ^a	0.44 ± 0.03 ^b	–	0.48 ± 0.06 ^{ab}	0.47 ± 0.06 ^{ab}
9	10.77	Disulfide, methyl 1-propenyl	22.25 ± 0.51 ^a	8.97 ± 0.23 ^d	7.25 ± 0.29 ^e	7.04 ± 1.16 ^e	12.80 ± 0.58 ^b	11.37 ± 0.35 ^c
10	11.25	1,3-Dithiane	2.86 ± 0.00 ^d	0.42 ± 0.01 ^f	4.75 ± 0.09 ^c	1.24 ± 0.24 ^e	8.08 ± 0.34 ^a	7.28 ± 0.23 ^b
11	11.89	Dimethyl trisulfide	1.17 ± 0.04 ^c	3.27 ± 0.16 ^b	3.37 ± 0.06 ^b	4.32 ± 0.79 ^a	1.42 ± 0.03 ^c	1.56 ± 0.15 ^c
12	12.10	1-Butene, 4-isothiocyanato-	9.39 ± 0.03 ^b	14.23 ± 0.26 ^a	6.53 ± 0.34 ^c	3.59 ± 1.17 ^d	6.17 ± 0.34 ^c	6.51 ± 0.57 ^c
13	13.95	Diallyl disulfide	34.81 ± 0.68 ^b	29.52 ± 0.20 ^c	24.03 ± 0.37 ^d	16.04 ± 2.78 ^e	37.51 ± 1.30 ^a	34.95 ± 0.38 ^b
14	14.20	Benzenemethanamine, alpha-2,5,7-octatrienyl-N-propyl-	6.25 ± 0.07 ^b	1.44 ± 0.01 ^e	4.92 ± 0.13 ^c	3.73 ± 0.61 ^d	8.73 ± 0.63 ^a	8.28 ± 0.13 ^a
15	14.30	Diallyl disulfide	3.17 ± 0.01 ^b	1.35 ± 0.04 ^d	2.94 ± 0.05 ^b	2.08 ± 0.36 ^c	4.417 ± 0.22 ^a	4.58 ± 0.08 ^a
16	14.44	Disulfide, dipropyl	4.03 ± 0.12 ^b	0.64 ± 0.12 ^e	2.60 ± 0.09 ^c	2.08 ± 0.41 ^d	5.07 ± 0.51 ^a	4.53 ± 0.09 ^b
17	14.72	Diallyl disulfide	0.40 ± 0.01 ^e	0.61 ± 0.03 ^e	2.12 ± 0.04 ^c	1.29 ± 0.25 ^d	3.29 ± 0.23 ^a	2.61 ± 0.09 ^b

^aGround kimchi; kimchi powder prepared using kimchi powder prepared using^bFreeze drying (FD)^cDecompression drying (DD) at high temperature, 60 ± 1 °C (DDHT)^dHot-air drying at high temperature, 60 ± 1 °C (HADHT)^eDD at low temperature, 35 ± 1 °C (DDL T)^fHAD at low temperature, 35 ± 1 °C (HADLT)^gMeans (± standard deviation) indicated by different letters in each column are significantly different according to Duncan's multiple range test ($p < 0.05$) Peak Area (%) = $\frac{\text{Peak area of each compound}}{\text{Total peak area of all compounds}} \times 100$

Fig. 2 Principal component analysis (PCA) plot of kimchi powder based on drying method, using an electronic nose. A Ground kimchi; kimchi powder prepared using: B, freeze drying (FD); C, decompression drying (DD) at high temperature, $60 \pm 1^\circ\text{C}$ (DDHT); D, hot-air drying at high temperature, $60 \pm 1^\circ\text{C}$ (HADHT); E, DD at low temperature, $35 \pm 1^\circ\text{C}$ (DDLTL); and F, HAD at low temperature, $35 \pm 1^\circ\text{C}$ (HADLT)

powder samples prepared using the five drying methods (Table 1). The *L* values were 48.61, 44.34, 43.5, 42.05, and 41.69 for FD, DDHT, HADHT, DDLT, and HADLT, respectively with substantial differences between each method, except for ground kimchi. The comparison of the *a* values showed that FD had the highest value of 23.88, whereas the *b* value differed slightly among the different drying methods. Kimchi powder prepared using FD showed the greatest color change, because the red pepper powder was bleached by the oxygen present in the air, which produced the light colored kimchi powder. Red pepper, which is a common ingredient in kimchi, contains capsanthin, β -carotene, and chlorophyll. Both capsanthin and β -carotene are carotenoid antioxidants whose main compounds contribute to the red and yellowish-crimson colors of kimchi, whereas chlorophyll contributes a green color. During the drying process, greenish-brown pheophytin and brown pheophorbide are produced from these compounds, which explains the increase in *a* and *b* values.

Analysis of volatile compounds using GC/MS

The volatile compound contents before and after processing and drying are summarized in Table 2. Based on the GC/MS analyses, sulfides, organic acids, and alcohols were identified as the volatile compounds in kimchi. The characteristic smell of kimchi is attributed to the fermentation of ingredients such as garlic, ginger, onion, and spring onion (Ko et al., 2011). Kimchi also contains various volatile compounds as reported by Ko and Lee (2003) who

identified the presence of highly volatile compounds such as diallyl disulfide and methyl propenyl disulfide from garlic and dimethyl disulfide from onion (Ko et al., 2003). Diallyl disulfide is a typical irritant flavor component found in plants of the *Allium* genus, which includes garlic and onion (Jeon et al., 2012). When the tissue is destroyed, alliin is decomposed to allicin and pyruvic acid by alliinase. Allicin is further decomposed to diallyl disulfide, which interacts with pyruvic acid to produce complex sulfur compounds and carbonyl compounds. Methyl-propenyl disulfide is a strong odorant found in plants such as garlic and leek (Cho et al., 2012). The characteristic aroma of kimchi or kimchi powder manufactured at a high temperature is produced by the interactions between aldehydes, acids, alcohols, and compounds in the kimchi. In particular, 3-methylbutanal, an aldehyde compound, is formed when vegetables or plants are heated to a high temperature. It is commonly found in semi-fermented tea, which contains much higher concentrations of 3-methylbutanal than green tea does (Choi, 2001). Similarly, 2-methylbutanal is produced when garlic is heated at a high temperature (Woo et al., 2007). Consistent with the findings of Hong et al. (2016), the present results show that the characteristic smell of kimchi could be attributed to volatile compounds in the raw ingredients such as garlic and onion, and the products of fermentation by lactic acid bacteria (Hong et al., 2016).

Electronic nose analysis

The electronic nose is an analytical instrument used for the rapid detection and differentiation of various types of gaseous samples (Wisniewska et al., 2016). Chemical sensors are exposed to a gas mixture to generate a characteristic odor profile, which is the so-called “fingerprint” (Dymerski et al., 2011). This enables comprehensive comparisons between given and reference samples. Figure 2 shows the differences in aromatic patterns based on the drying conditions. For the chromatogram obtained using the GC-type electronic nose, the peak with the highest difference between processing groups was selected, and a PCA was performed based on the peak area, followed by the calculation of the rate of contribution to the aromatic pattern. The major volatile compounds identified using the electronic nose and in the GC/MS analyses were dimethyl sulfide and carbon sulfide, which are both sulfides. Therefore, the results are reliable since the GC/MS, and electronic nose showed consistent results. Moreover, the concentrations of dimethyl sulfide and 3-methylbutanal increased during the drying process (data not shown). This increase was attributed to the loss of water during the drying process, resulting in the release of aromatic compounds and considerable improvement in the flavor relative

Fig. 3 Analysis of kimchi powder using an electronic tongue. (A) Principal component analysis (PCA) plot, (B) Changes in organoleptic characteristics, (C) Changes of intensity scale in organoleptic characteristics. A, ground kimchi; kimchi powder prepared using: B, freeze drying (FD); C, decompression drying (DD) at high temperature, $60 \pm 1^\circ\text{C}$ (DDHT); D, hot-air drying at high temperature, $60 \pm 1^\circ\text{C}$ (HADHT); E, DD at low temperature,

$35 \pm 1^\circ\text{C}$ (DDLTL); and F, HAD at low temperature, $35 \pm 1^\circ\text{C}$ (HADLT). SRS, sensor for sourness, astringency, and bitterness; GPS, sensor for standard; STS, sensor for saltiness, spiciness, and metallic; UMS, sensor for umami, saltiness, and astringency; SPS, sensor for standard; SWS, sensor for sweetness and sourness; BRS, sensor for bitterness and astringency

to that of kimchi before drying. The PCA showed that the main components 1 and 2 (F1, x-axis, and F2, y-axis) contributed to 43.48 and 21.31% of the variation, respectively. These components accounted for 64.79% of the total variation observed. The electronic nose analysis demonstrated that kimchi before drying could be distinguished from kimchi powder based on smell. The kimchi powder prepared using FD was different from that prepared using DDHT, HADHT, DDLT, and HADLT; however, the latter four samples did not differ strongly from each other.

Electronic tongue analysis

The electronic tongue is an instrument for rapidly screening the taste attributes of different compounds (Latha and Lakshmi, 2012). Chemical compounds responsible for taste are detected by human taste receptors, and the seven sensors in the electronic instruments generate electric signals as potentiometric variation. The PCA showed that the main components 1 and 2 accounted for 75.27 and 20.21%

of the variation, respectively (Fig. 3A). These components accounted for 95.47% of the total variation observed. The electronic tongue analysis demonstrated that kimchi before drying could be distinguished from kimchi powder based on taste. The kimchi powder prepared using FD differed from that prepared using DDHT, HADHT, DDLT, and HADLT; however, samples dried at the same temperature did not differ substantially. The taste was clearly affected by the drying method. The taste values were converted into scores, which are summarized in Fig. 3B. Sour, sweet, and bitter tastes showed the strongest intensity for ground kimchi, and kimchi powder prepared using HADLT and DDLT (in order of intensity). The most intense salty taste was perceived in the kimchi powder prepared using HADLT, HADHT, and DDLT, whereas the most intense umami taste was associated with the kimchi powder prepared using HADLT, DDLT, and ground kimchi. In particular, the sour, salty, and umami flavors were substantially different between samples, and the sour taste was strongest in the kimchi powder prepared using FD.

Furthermore, the intensity was not greatly affected by the drying temperature (Fig. 3C). Ground kimchi showed a considerably lower intensity of saltiness than the other samples did; the salty taste of the kimchi powder increased as water was evaporated during the drying process. Therefore, differences in drying conditions during the manufacture of kimchi powder resulted in differences in sweet, salty, and umami tastes, but not in sweetness or bitterness.

Sensory evaluation

Table 3 presents the sensory characteristics of kimchi powder for each drying method. The appearance, flavor, and taste of the positive control (PC) compared to the kimchi powder were evaluated by trained panelists.

There was no major difference in appearance among the kimchi powder prepared using the different methods, except for the powder prepared using FD and the positive control ($p < 0.05$). Based on the sensory evaluation results, the flavor and taste of the kimchi powder prepared using HADHT were different from those prepared using FD, DDHT, DDLT, and HADLT ($p < 0.05$). These results were reliable because the electronic nose and electronic tongue showed consistent results. As shown in Table 3, Figs. 2, and 3, the flavor and taste were rated the highest for the kimchi powder prepared using HADHT and lowest for the positive control (commercial kimchi stew powder). Therefore, HADHT was considered the optimal drying method for kimchi manufacture, that would enable the

production of kimchi powder as a seasoning for various food products.

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Table 3 Sensory evaluation for kimchi powder using different drying methods

Code	Appearance	Flavour	Taste
PC	2.47 ± 1.08 ^c	2.50 ± 1.41 ^b	1.97 ± 1.26 ^c
B	4.41 ± 1.34 ^b	4.47 ± 1.22 ^a	4.56 ± 1.08 ^{ab}
C	5.44 ± 1.09 ^a	4.75 ± 1.12 ^a	4.53 ± 1.26 ^{ab}
D	5.53 ± 0.88 ^a	5.06 ± 1.08 ^a	4.97 ± 1.26 ^a
E	5.34 ± 1.00 ^a	4.47 ± 1.16 ^a	4.63 ± 1.13 ^{ab}
F	5.06 ± 1.29 ^a	4.69 ± 1.16 ^a	4.25 ± 1.37 ^b

PC; positive control (commercial kimchi stew powder), kimchi powder prepared using

^bFreeze drying (FD)

^cDecompression drying (DD) at high temperature, 60 ± 1 °C (DDHT)

^dHot-air drying at high temperature, 60 ± 1 °C (HADHT)

^eDD at low temperature, 35 ± 1 °C (DDLTL)

^fHAD at low temperature, 35 ± 1 °C (HADLT)

Means (± standard deviation) indicated by different letters in the column are significantly different according to Duncan's multiple range test ($p < 0.05$)

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