Feasibility of using kimchi by-products as a source of functional ingredients

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Abstract Baechu and radish are the major by-products generated from kimchi factories. Because vegetable and fruit by-products have abundant functional ingredients, the availability of them as a source of bioactive compounds is gaining attention. The objective of this study was to determine the feasibility of using kimchi by-products as sources of functional ingredients. For this purpose, 13 by-product samples were collected from different kimchi factories and analyzed for their sugar contents, total dietary fiber (TDF), antioxidant capacity, water holding capacity (WHC), viscosity, and specific gravity. The dietary fiber contents in kimchi by-product cabbage powder and radish powder were 27.37–49.54 and 30.19–62.81 %, respectively. TDF, WHC, and antioxidant capacities of kimchi by-products were equally as high as those of other by-products that are reused in industry. These results suggested that kimchi by-products have the potential as a new agro-industrial by-product that could be recycled as valuable sources of dietary fibers.

Keywords Antioxidant capacity · Baechu · Kimchi by-products · Radish · Total dietary fiber

Introduction

Baechu (Brassica campestris L. ssp. pekinensis) and radish (Raphanus sativus L. var. sativus) are the most popular vegetables used for preparing the traditional Korean fermented food “kimchi.” Baechu is grown and consumed in large quantities in Korea (Jung et al. 2009). It contains various nutritional compounds, including vitamins (A, B1, and C), calcium, β-carotene, and dietary fiber, as well as bioactive compounds such as glucosinolates (Wennberg et al. 2006). Radish also contains many nutritional benefits, being rich in vitamin C, dietary fiber, pectin, and minerals as well as digestive enzymes such as amylase (Park et al. 2009). Therefore, it is considered not only as a vegetable crop but also as an important source of essential compounds for human nutrition (Hong and Kim 2013).

The total annual production of Baechu and radish in Korea is about 2,500,000 and 1,300,000 ton, respectively, and is usually consumed as kimchi (MAFRA 2001). Kimchi is gaining popularity in many countries, and the production of Baechu has consequently been stimulated (Kim et al. 2010). In Korea, demand for the mass production of kimchi has been increasing owing to the expansion of the catering industry, and a large amount of by-products is generated from kimchi manufacturing factories (Kafle et al. 2012). Usually, 12.9–25.2 and 12.5–33.3 % of the original amount of whole Baechu and radish, respectively, are generated as by-products, which is a significant amount of waste that can cause a negative effect on the environment (Liu et al. 2012). Baechu by-products are mainly the outer leaves and core. Seong et al. (2016) reported that Baechu outer leaves had a higher antioxidant content and activity than the inner leaves. The by-products of Baechu are produced during harvest, transport to markets, and processing (Choi and Park 2003).
Many by-products of the agricultural food processing industry could be used as a source of functional ingredients and nutrients (Parwa et al. 2008). For example, paprika leaves, by-products of paprika farm, have antioxidant, antimicrobial, and tyrosinase-inhibiting activities and contain higher amounts of tocopherol and lutein than the paprika fruit itself (Kang et al. 2016). According to Mahro and Timm (2007), the availability of vegetable by-products as a source of bioactive compounds is gaining attention in related research fields. In addition, the use of agro-industrial by-products to produce functional ingredients can subsequently improve the economic value of such by-products. Therefore, there is a need to analyze the nutritional composition of by-products and their potential for use (Domínguez-Perles et al. 2010).

For manufacturing kimchi, *Baechu* and radish need to be cut, salted, dewatered and desalted, and fermented after mixing with spices (Fig. 1). Especially, by-products are generated mainly from the trimming process. In this study, we tried to determine the feasibility of using by-products from kimchi as a source of bioactive compounds. For this purpose, we screened the sugar contents, dietary fiber contents, water holding capacity (WHC), viscosity, specific gravity, and antioxidant activity of 13 by-products of kimchi collected from kimchi processing factories in Korea.

**Materials and methods**

**Materials**

The TDF assay kit (K-TDFR) was purchased from Megazyme International (Wicklow, Ireland). D-(-)-Fructose, sucrose, D-(+)-glucose, ascorbic acid, Folin–Ciocalteu reagent, and DPPH were procured from Sigma-Aldrich Co. (St. Louis, MO, USA), and gallic acid was obtained from Kanto Chemical Co., Ltd. (Tokyo, Japan). All other chemicals were purchased from Thermo Fisher Scientific (Springfield, NJ, USA).

**Sample collection and preparation**

Kimchi by-products of *Baechu* (*Brassica campestris* L. spp. *pekinensis*) and radish (*Raphanus sativus* L. var. *sativus*) were procured from kimchi factories in 13 different areas of Korea [Gangwon (three factories: A, B, C), Gyeonggi (three factories: D, E, J), Chungbuk (four factories: F, H, I, K), and Chungcheongnamdo (four factories: M, N, O, P)]. These by-products were collected from 13 different areas of Korea. The by-products were collected at the time of kimchi processing and stored at -20°C until analysis.

![Flow chart for processing of kimchi](image-url)

Fig. 1 Flow chart for processing of kimchi. *KBCP* Kimchi by-product cabbage powder, *KBCP-1* KBCP generated after the trimming and cutting stage, *KBCP-2* KBCP generated after the salting and washing stage, *KBCP-3* KBCP generated after the dewatering and desalting stage. *KBRP* Kimchi by-product radish powder, *KBRP-1* KBRP generated after the peeling and cutting stage, *KBRP-2* KBRP generated after the salting and washing stage, *KBRP-3* KBRP generated after the dewatering stage.
factories: G, F, H, I), Chungnam (two factory: L, K), and Gyeongnam (one factory: M)). Samples were collected from three different stages of kimchi processing [trimming/peeling and cutting (stage 1), salting or washing (stage 2), and dewatering and desalting (stage 3)] (Fig. 1). The samples were freeze-dried (PVTFD10R; ilShinBioBase, Gyeonggi-do, Korea) and ground and then passed through a 50-mesh sieve to obtain the powders, which were then sealed in plastic bags and stored at −20 °C until analysis.

**Sugar contents of kimchi by-products**

The sugar composition of the kimchi by-products was measured according to the method of Wilson and Work (1981) with some modifications. Two grams of the freeze-dried powder was dissolved in distilled water (25 mL) and 25 mL of acetonitrile was added. For extraction, the solutions were mixed using a sonicator (JAC-5020; KODO Ltd, Gyeonggi-do, Korea) for 30 min at 45–50 °C. After sonication, the sample was centrifuged at 7041×g for 10 min at 4 °C and the supernatant was then filtered through a 0.45-μm syringe filter. The sugar contents were measured using an analytical high-performance liquid chromatography system (1525 pump with 2707 auto sampler, and 2489 UV detector; Waters, Milford, MA, USA) equipped with a polymer-based amino column (Asahipak NH2P-50 4E, 250 × 4.6 mm; inner diameter 5 μm; Shodex, Kawasaki, Japan). A 10-μL injection sample was used for the analysis. Acetonitrile in water (75:25) was used as the mobile phase at a flow rate of 1.0 mL/min. Based on a standard curve (50, 100, 150, 200, and 250 ppm), the concentrations of sucrose, glucose, and fructose were calculated as g sugar/100 g dry weight.

**Dietary fiber contents of kimchi by-products**

The insoluble and soluble dietary fiber contents were assayed according to AOAC Official Method 991.43 (Lee et al. 1992). In brief, about 1 g of the dried powder was mixed with 40 mL of 0.05 M MES-Tris buffer (pH 8.2), following which 50 μL of α-amylase was added and hydrolysis was allowed to occur in a 100 °C shaking water bath for 30 min. Then, the sample was digested with 100 μL of protease in a 60 °C shaking water bath for 30 min. After cooling, 5 mL of 0.561N HCl was added to adjust the pH to 4.3–4.7. Then, 200 mL of amylglucosidase was added and the sample was incubated at 60 °C for 30 min. The sample was filtered through a Celite layer in a crucible and washed with 3 mL of distilled water. Fifteen milliliters of 78 % ethanol was added to the mixture of filtrate and wash water to precipitate the SDF. The remaining sample was rinsed with 15 mL of 78 % ethanol (two times), 15 mL of 95 % ethanol (two times), and 10 mL of 95 % acetone (two times), and then weighed after drying at 105 °C for 24 h. The IDF and SDF residues were corrected by analyzing the protein by the Kjeldahl method and the ash contents by incinerating the sample at 550 °C. The TDF content was calculated as the sum of IDF and SDF.

**Water holding capacity, viscosity, and specific gravity of kimchi by-products**

The WHC was determined by Andercon’s method (1982) with slight modifications. The freeze-dried powder (0.5 g) was hydrated in 20 mL of distilled water and equilibrated by holding at room temperature for 24 h. Then, the sample was centrifuged at 7041×g for 20 min and the residue was dried at 105 °C until a constant weight was measured. The WHC was calculated using the following equation:

\[
\text{WHC (g/g)} = \frac{\text{residue fresh weight (g)} - \text{residue dried weight (g)}}{\text{residue dried weight (g)}}.
\]

The specific gravity of the sample was determined by the method of AACC 10-15 (2000), whereas the viscosity in distilled water (10 % w/v) was measured using a viscometer (LVDV-E; Brookfield AMETEK, Middleboro, MA, USA).

**Antioxidant properties of kimchi by-products**

The DPPH radical scavenging activity of the kimchi by-products was determined according to the method of Brand-Williams et al. (1995), with minor modifications. The freeze-dried samples were extracted with 80 % ethanol for 24 h at 37 °C and centrifuged at 7041×g for 10 min at 4 °C. One milliliter of supernatant (sample solution) was mixed with 3 mL of an ethanolic solution of DPPH (0.1 mM, 80 %) and incubated at 37 °C for 20 min. The absorbance of the mixture was read at 517 nm on a microplate reader (Eon; BioTek Ltd, Winooski, VT, USA).

The total phenolic content of the kimchi by-products was determined according to the method of Kim et al. (2014). Samples (0.5 g) were sonicated in 80 % methanol for 10 min, and the supernatant was collected by centrifugation at 7041×g for 10 min in a centrifuge (Labogene 2236R; Hamil SME, Anyang, Korea) at 4 °C. Twenty microliters of supernatant (sample solution) and 100 μL of 2N Folin-Ciocalteu phenol reagent were mixed for 3 min and then 80 μL of sodium carbonate solution was added. The mixture was incubated at 37 °C for 1 h, after which the absorbance was measured at 750 nm. The results are expressed as mg gallic acid equivalents/100 g of dry weight.
The ABTS radical scavenging activity was measured according to the method of Hiranvarachat et al. (2013), with slight modifications. In brief, the freeze-dried powder was extracted with 80% ethanol for 24 h at 37°C, after which the solution was centrifuged at 7041 g for 10 min at 4°C. The supernatant was collected and evaporated to dryness, and the precipitate was dissolved in dimethyl sulfoxide solution. A stock solution of 7 mM ABTS and 2.45 mM K$_2$S$_2$O$_8$ (at a ratio of 2:1) was prepared and kept in the dark at room temperature for 16 h. The stock solution was diluted with 99.9% ethanol to an absorbance of 0.70 (± 0.04) at 734 nm, and 90 µL of this ABTS+ solution was added to 10 µL of sample solution in a microplate. After 10 min at room temperature, the absorbance was measured at 734 nm using a microplate reader (Eon).

**Statistical analysis**

Quantitative data are expressed as the mean ± standard deviation of triplicate measurements. Data were analyzed with one-way analyses of variance and Duncan’s multiple-range test (p < 0.05), using SAS version 8.0 for Windows (SAS Institute Inc., Cary, NC, USA).

**Results and discussion**

**Sugar contents of kimchi by-products**

The fructose, glucose, and sucrose in kimchi by-product cabbage powder (KBCP) and kimchi by-product radish powder (KBRP) after various processing stages were determined and quantified. The results are shown in Table 1. The fructose and glucose contents of KBCP were 6.12–12.87 g/100 g dry weight and 5.29–17.67 g/100 g dry weight, respectively, and sucrose was not detected in most of the samples. According to Kim et al. (2000), sucrose was not detected from several Baechu varieties (Golden House, Golden Spring, Alpine Summer, and Summer Best), which was similar to our results. While the glucose content was higher than fructose in the leaves, the opposite was true in the stems (Kim et al. 2000). In this study, the glucose-to-fructose ratio was different in the

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**Table 1** Sugar contents (g/100 g dry weight) of kimchi by-products

| By-products | Processing | Sample | Fructose | Glucose | Sucrose | Total sugar |
|-------------|------------|--------|----------|---------|---------|-------------|
| KBCP        | Con1       | 9.99 ± 0.23b | 11.68 ± 0.28b | ND      | 21.67 ± 0.51c |
|             | A-1        | 9.04 ± 0.12c | 6.35 ± 0.11f | ND      | 15.39 ± 0.21bc |
|             | D-1        | 12.50 ± 0.26a | 17.67 ± 0.48a | 2.92 ± 0.26a | 33.14 ± 0.75a |
|             | E-1        | 12.87 ± 1.61a | 10.63 ± 0.29c | ND      | 23.50 ± 1.80b |
|             | G-1        | 7.03 ± 0.47d | 4.10 ± 0.23b | ND      | 11.13 ± 0.70b |
|             |            |         |          |         |         |             |
|             | A-2        | ND      | 5.29 ± 0.36f | ND      | 5.29 ± 0.36f |
|             | B-2        | 10.23 ± 0.30b | 8.39 ± 0.32d | ND      | 18.62 ± 0.62d |
|             | F-2        | 12.25 ± 0.38a | 8.54 ± 0.21d | ND      | 20.79 ± 0.58d |
|             | G-2        | 8.31 ± 0.39c | 5.70 ± 0.17g | ND      | 14.01 ± 0.54d |
|             |            |         |          |         |         |             |
|             | A-3        | 8.17 ± 0.06c | 6.19 ± 0.15g | ND      | 14.36 ± 0.17f |
|             | B-3        | 10.08 ± 1.10b | 6.57 ± 0.11hf | ND      | 16.65 ± 1.21c |
|             | C-3        | 10.04 ± 0.13b | 5.73 ± 0.06g | ND      | 15.77 ± 0.15f |
|             | E-3        | 6.14 ± 0.05d | 6.08 ± 0.21f | ND      | 12.22 ± 0.24ai |
|             | F-3        | 8.06 ± 0.08c | 8.82 ± 0.07d | ND      | 16.88 ± 1.03f |
|             | H-3        | 6.12 ± 0.70d | 7.00 ± 0.77e | ND      | 13.12 ± 1.47b |
|             | I-3        | 6.15 ± 0.10d | 6.10 ± 0.12g | ND      | 12.25 ± 0.28hi |
|             |            |         |          |         |         |             |
| KBRP        | Con2       | 26.86 ± 0.77a | 28.36 ± 0.85a | 2.48 ± 0.11b | 57.70 ± 1.72a |
|             | J-1        | 11.18 ± 0.20a | 15.14 ± 0.69c | 2.99 ± 0.04a | 29.31 ± 0.39a |
|             | K-1        | 7.50 ± 0.17d | 6.98 ± 0.07d | 0.75 ± 0.09d | 15.23 ± 0.28d |
|             | L-2        | 13.72 ± 0.37b | 19.07 ± 0.48b | 1.59 ± 0.08e | 34.38 ± 0.78b |

Values are expressed as the mean ± standard deviation of three measurements

A–L: collected from different factories in Korea

1–3: stage of kimchi processing

Con1 Baechu as control, Con2 radish as control, KBCP kimchi by-product Baechu powder, KBRP kimchi by-product radish powder, ND not determined.
different processing stages, likely as a result of the different leaf-to-stem ratios discarded at each processing step. In the case of KBRP, although sucrose was detected in all the samples, fructose and glucose were still the major sugars. Overall, the sugar contents of KBRP were higher than those of KBCP. Lee et al. (1970) reported similar results, in that the total sugar contents of radish were higher than those of Baechu. The total sugar contents of KBCP were significantly reduced during kimchi processing ($p < 0.05$). A previous study showed that during the salting process, pectin is hydrolyzed by pectin-degrading enzymes, causing the breakdown of cell walls and resulting in the loss of vitamin C, total sugars, glucosinolates, and free amino acids of the cabbage fibers (Hwang 2010). Therefore, the salting and washing process likely caused the loss of total sugars during kimchi processing.

### Dietary fiber contents of kimchi by-products

Table 2 shows the insoluble dietary fiber (IDF), soluble dietary fiber (SDF), and total dietary fiber (TDF) contents of the kimchi by-product powders. Jongaroontaprangsee et al. (2007) reported that the outer leaves of cabbage contained 41–43 % of TDF (dry basis). Many by-products have been reported to be valuable TDF sources, with fiber contents ranging from 30 to 75 %; for example, banana (31.8 %) (Rodrı´guez-Ambriz et al. 2008), guava (49.42 %) (Jiménez-Escrig et al. 2001), lemon peel (60.1–68.3 g/100 g dry mass) (Figuerola et al. 2005), red grape pomace (74.5 %) (Llibera and Caˇnˇekkas 2007), and Mexican lime peel (70.4 %) (Ubando-Rivera et al. 2005). Our results showed that KBCP (20.34–49.54 %) and KBRP (22.88–62.81 %) had high TDF contents and could be considered as good sources of dietary fiber. KBCP and KBRP also contained a high amount of IDF as the major dietary fiber. Insoluble fibers have important roles in human health, helping to increase fecal bulk, decrease cholesterol levels and intestinal transit, and improve blood glucose levels (Liu et al. 2012). Jongaroontaprangsee et al. (2007) reported that the IDF content of white cabbage varied depending on the cultivar and plant portion used for analysis. According to Wennberg et al. (2006), the SDF

| By-products | Processing | Sample | IDF  | SDF  | TDF   |
|-------------|------------|--------|------|------|-------|
| KBCP        | Trimming and cutting | Con1 | 32.69 ± 2.34° | 0.71 ± 0.03° | 32.90 ± 2.13bcd |
|             | A-1        | 40.44 ± 0.68bc | 0.78 ± 0.03cde | 41.22 ± 0.65abc |
|             | D-1        | 31.86 ± 1.40° | 1.45 ± 0.82bc | 33.31 ± 1.48bcd |
|             | E-1        | 34.58 ± 0.28de | 0.27 ± 0.05de | 34.86 ± 0.42bde |
|             | F-1        | 37.03 ± 1.61ed | 0.17 ± 0.19de | 37.19 ± 1.22bcd |
|             | Salting and washing | A-2 | 26.44 ± 1.10f | 0.93 ± 0.05de | 27.37 ± 1.11ed |
|             | B-2        | 26.78 ± 2.17f | 1.04 ± 0.17de | 27.83 ± 2.05ed |
|             | F-2        | 41.72 ± 0.08h | 0.71 ± 0.53a | 42.43 ± 0.58ab |
|             | G-2        | 23.57 ± 0.56  | 0.82 ± 0.61cde | 24.39 ± 0.86e |
|             | Dwatering and desalting | A-3 | 39.39 ± 1.70bc | 0.71 ± 0.03cde | 40.09 ± 1.69abc |
|             | B-3        | 35.13 ± 1.39de | 2.27 ± 0.73ab | 37.40 ± 1.22bcd |
|             | C-3        | 49.27 ± 1.41bc | 0.72 ± 0.07cde | 49.54 ± 1.40a |
|             | E-3        | 46.99 ± 2.33a  | 0.75 ± 0.11cde | 47.74 ± 2.28a |
|             | F-3        | 37.49 ± 3.02ed | 2.91 ± 1.23e | 40.40 ± 4.20abc |
|             | H-3        | 19.87 ± 1.62a  | 0.47 ± 0.63cde | 20.34 ± 2.15e |
|             | I-3        | 48.35 ± 3.68a  | 0.12 ± 0.73c | 48.46 ± 3.46a |
|             | KBRP       | Con2 | 21.72 ± 2.92c | 1.16 ± 0.78a | 22.88 ± 3.54b |
|             | Peeling and cutting | J-1 | 62.58 ± 2.48g  | 0.24 ± 0.24c | 62.81 ± 2.69a |
|             | K-1        | 47.93 ± 3.12c  | 0.73 ± 0.55b | 48.66 ± 3.33a |
|             | Salting or washing | L-2 | 30.01 ± 4.75d  | 0.18 ± 0.25c | 30.19 ± 4.60b |
|             | Dwatering | M-3 | 58.32 ± 2.21b  | 0.37 ± 0.31c | 58.68 ± 1.95a |

Values are expressed as the mean ± standard deviation of three measurements

* A different letter in the same column indicates statistical difference ($p < 0.05$)

A–M: collected from different factories in Korea

1–3: stage of kimchi processing

Con1 Baechu as control, Con2 radish as control, KBCP kimchi by-product Baechu powder, KBRP kimchi by-product radish powder, IDF insoluble dietary fiber, SDF soluble dietary fiber, TDF total dietary fiber
and IDF contents of two cultivars of white cabbage (Heckla and Predikant) were in the range of 17.7–20.0 and 4.7–6.2 % (dry basis), respectively. Based on the results of this study, the TDF and IDF contents in the kimchi by-products from all the factories were equally as high as those of various fruit and vegetable by-products which have been used as valuable sources of dietary fiber.

**Water holding capacity, viscosity, and specific gravity of kimchi by-products**

The WHC, viscosity, and specific gravity of the kimchi by-products are shown in Table 3. Vegetable fibers have various functional properties, including WHC, viscosity, swelling index, and gel formation, depending on their IDF-to-SDF ratio, particle size, and vegetable sources (Figuerola et al. 2005; Femenia et al. 1997).

The WHC of KBCP (5.71–12.70 g/g) was on average lower than that of KBRP (7.35–15.12 g/g). Generally, the WHC of the kimchi by-products increased \( (p < 0.05) \) after each processing step, likely as a result of the damaged fiber matrix and the collapse of the fiber pore structure during processing (Jongaroontaprangsee et al. 2007). Larrauri (1999) reported that washing increased the WHC of the fiber in orange peel by removing the sugars within the fiber. Our results were compatible with those of Jongaroontaprangsee et al. (2007) who reported WHCs of 6.2–18.2 g/g from cabbages. A high WHC is important for the gel formation and texture stability of processed foods such as jams and yogurts. Therefore, it seemed that dietary fibers in kimchi by-products have potentials for industrial application as a fiber source.

The viscosity of KBCP ranged from 655.00 to 1120.67 cP and that of KBRP was between 758.00 and 1190.00 cP. The specific gravity values of the kimchi by-products were lower than that of the control.

**Antioxidant properties of kimchi by-products**

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, total polyphenol contents, and 2,2’-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assay...
results are shown in Table 4. KBCP and KBRP had DHHP radical scavenging activity values of 16.72–40.16 and 13.44–41.11 %, respectively. According to Seong et al. (2016), cabbage outer leaves had the strongest DPPH radical scavenging activity when compared with the other leaf parts. By-products of lime peel (35 %), coffee (60 %), and artichoke leaves (40 %) were also reported to have DPPH radical scavenging activities similar to the results of this study (Yuan et al. 2012).

The total polyphenol contents in KBCP ranged from 96.76 to 217.24 mg gallic acid equivalents (GAE)/100 g, whereas that of KBRP ranged from 85.72 to 180.93 mg GAE/100 g. By-products of fruits and vegetables, such as pomegranate peels (294 mg GAE/100 g), broccoli leaves (135.64 mg GAE/100 g), and Baechu outer leaves (148.81–347.46 mg GAE/100 g), were reported to contain higher amounts of polyphenols than the edible parts (Garau et al. 2007; Mahro and Timm 2007; Seong et al. 2016). Hakkinen and Törönen (2000) reported that during processing and storage of berry, each phenolic compound showed different decomposition rates.

The ABTS radical scavenging activity of KBCP and KBRP was 26.75–88.16 and 58.00–75.03 %, respectively. Overall, all the antioxidant properties, including DPPH and ABTS radical scavenging activities and total phenolic content of the KBCP and KBRP samples, were maintained throughout kimchi processing.

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References

AACC (2000) Approved method of American Association of Cereal Chemists. The American Association of Cereal Chemists, Houston

Table 4 Antioxidant properties and contents of kimchi by-products

| By-products            | Processing     | Sample | DPPH radical scavenging activity (%) | ABTS radical scavenging activity (%) | Total polyphenol contents (mg GAE/100 g) |
|------------------------|----------------|--------|--------------------------------------|--------------------------------------|------------------------------------------|
| KBCP                   | Con1           |        | 32.49 ± 1.93b                        | 80.85 ± 0.79bc                      | 140.46 ± 1.25ad                          |
| Trimming and cutting   | A-1            | 32.64 ± 2.96b                        | 52.94 ± 1.85j                       | 96.76 ± 2.22k                          |
|                        | D-1            | 25.12 ± 3.54abf                      | 61.36 ± 1.97i                       | 114.24 ± 2.45fg                        |
|                        | E-1            | 13.29 ± 0.73b                        | 78.41 ± 2.57c                       | 111.74 ± 1.80eg                        |
|                        | G-1            | 26.83 ± 3.61abf                      | 82.24 ± 1.48b                       | 142.93 ± 0.98c                         |
| Salting and washing    | A-2            | 18.15 ± 1.34abf                      | 49.05 ± 1.60j                       | 94.58 ± 1.83k                          |
|                        | B-2            | 20.26 ± 1.79afg                      | 70.55 ± 2.40ef                      | 115.02 ± 1.31f                         |
|                        | F-2            | 28.48 ± 1.69abcdef                   | 23.20 ± 1.75f                       | 108.92 ± 2.93bi                        |
|                        | G-2            | 20.08 ± 2.71afg                      | 72.68 ± 1.46af                       | 138.35 ± 2.45d                         |
| Dewatering and desalting | A-3          | 16.83 ± 1.10abf                      | 26.75 ± 1.93k                       | 100.81 ± 1.03j                         |
|                        | B-3            | 25.78 ± 4.81ac                      | 75.24 ± 1.51d                       | 85.72 ± 0.35f                          |
|                        | C-3            | 17.56 ± 2.20abf                      | 87.41 ± 2.31a                       | 102.09 ± 2.08d                         |
|                        | E-3            | 17.20 ± 0.44abf                      | 62.26 ± 1.34i                       | 106.79 ± 0.09f                         |
|                        | F-3            | 16.72 ± 2.24abf                      | 69.32 ± 1.64fg                      | 101.87 ± 2.75f                         |
|                        | H-3            | 16.76 ± 2.93abf                      | 67.09 ± 0.95fh                      | 122.04 ± 1.66c                         |
|                        | I-3            | 40.16 ± 5.81a                        | 64.44 ± 1.85hi                      | 106.66 ± 1.33j                         |
|                        | KBRP           | Con2       | 12.49 ± 1.40abf                      | 75.03 ± 2.13b                        | 102.80 ± 1.21c                          |
|                        | Peeling and cutting | J-1   | 15.63 ± 1.32abf                      | 60.89 ± 0.90c                        | 135.66 ± 2.01b                         |
|                        | K-1            | 14.09 ± 2.03abf                      | 65.02 ± 2.65b                       | 180.93 ± 0.50a                         |
|                        | Salting or washing | L-2  | 13.44 ± 1.86abf                      | 72.06 ± 0.97b                        | 85.72 ± 1.03d                          |
|                        | Dewatering     | M-3          | 17.74 ± 3.41b                        | 84.23 ± 1.37a                        | 103.49 ± 1.23c                         |

Values are expressed as the mean ± standard deviation of three measurements. The total polyphenol contents are expressed in gallic acid equivalents (GAE)

a–l A different letter in the same column indicates statistical difference (p < 0.05)

A–M: collected from different factories in Korea

1–3: stage of kimchi processing

Con1 Baechu as control, Con2 radish as control, KBCP kimchi by-product Baechu powder, KBRP kimchi by-product radish powder, DPPH 2,2-diphenyl-1-picrylhydrazyl, ABTS 2,2’-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)
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