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Bioactive compounds and antioxidant activity in three types of Korean watery kimchi

Hyosun Park[1], Suna Kim[2], Jaecheol Kim[3], KyeongJin Lee[1] and BoKyung Moon[1*]

Abstract

Watery kimchi is a traditional fermented food served with its soup. In this study, we collected 21 samples of *yeolmu mul* kimchi (YMK), *dongchimi* (DC), and *nabak* kimchi (NK), respectively, which are the most popular watery kimchi in Korea. A composite sample of each watery kimchi was prepared for estimation of their bioactive compounds and antioxidant activities. Of the three kimchi types, YMK had the highest total carotenoid content (63.78 ± 4.88 mg/100 g, of which lutein, capsanthin, and β-carotene were the main carotenoids), and DC had the lowest (3.50 ± 0.12 mg/100 g). YMK also had the highest contents of chlorophyll (250.1 ± 3.91 mg/100 g), ascorbic acid (447.16 ± 8.95 mg/100 g), and capsaicinoids (2.51 ± 0.09 mg/100 g) compared to DC and NK. The lactic acid content was highest in NK (582.72 ± 29.10 mg/100 g). Moreover, YMK showed significantly higher antioxidant activity (ABTS and DPPH) than DC and NK ($p < 0.05$). Chlorophyll and antioxidant activity showed a strong positive correlation ($p < 0.01$). The results of this study highlighted watery kimchi as a potentially valuable source of bioactive compounds, and the carotenoids and capsaicinoids were affected by the supporting ingredients used in watery kimchi. Furthermore, watery kimchi provides 4.11% of the recommended daily intake of vitamin A according to the 2020 Korean dietary reference intakes.

Keywords Watery kimchi, Carotenoids, Chlorophylls, Capsaicinoids, Antioxidant activity

Introduction

Kimchi is a Korean traditional fermented dish that has gained popularity on a global scale due to its health benefits. *Mul* (watery) kimchi is a type of Korean kimchi distinct from regular kimchi in several ways; unlike regular kimchi, which is typically consumed as a side dish, watery kimchi is prepared with added water or brine solution during the fermentation process and is usually consumed as a soup. It also has a less salty and pungent taste compared to its regular counterpart. The fermentation period for watery kimchi is shorter than that of regular kimchi because of the higher proportion of soup with lower salt content (2 ~ 4%) [1], and its unique flavor and aroma are due to the organic acids and fermentation products.

According to the Korea National Health and Nutrition Examination Survey (KNHANES, 2016–2020), the average daily intake of watery kimchi (127.79 ± 13.39 g/day) exceeds that of *baechu* kimchi (80.28 ± 2.96 g/day; >70% of kimchi present in the Korean market), indicating the popularity of watery kimchi among people of all ages in Korea. Furthermore, the salt–water base of watery kimchi is used as a soup base for Korean cold noodles, a popular summertime dish [2].

The main ingredient of watery kimchi can vary, but it is typically cabbage or radish. Three representative types of Korean watery kimchi are *yeolmu mul* kimchi (YMK), *dongchimi* (DC), and *nabak* kimchi (NK),

*Correspondence:
BoKyung Moon
bkmoon@cau.ac.kr
[1] Department of Food and Nutrition, College of Biotechnology and Natural Resources, Chung-Ang University, 72-1, Nae-ri, Daedeok-myeon, Anseong-si, Gyeonggi-do 456-756, Republic of Korea
[2] Division of Human Ecology, College of Natural Science, Korea National Open University, Seoul, Republic of Korea
[3] School of Bio-health Convergence, Health & Wellness College, Sungshin Women's University, Seoul, Republic of Korea

with the main ingredient being Korean white radish (*Raphanus raphanistrum* subsp. *sativus)* and its leaves (Table 1). YMK is traditionally consumed during the summer. *Yeolmu* (young summer radish), the main ingredient of YMK, imparts a refreshing taste and texture to the dish. In addition to *yeolmu*, YMK typically contains secondary ingredients, such as green onion, garlic, ginger, red pepper, red pepper powder, and starchy paste [1]. DC is primarily consumed during the winter. Its main ingredient is radish, which is combined with side ingredients, such as garlic, ginger, fresh red pepper, green onion, and pear, to create a unique flavor and texture [3]. NK is typically consumed during seasons when DC is unavailable [4]. NK has its own distinctive taste, and its main ingredient is sliced radish or napa cabbage. Other ingredients typically include green onion, fresh red pepper, garlic, ginger, and red pepper powder [5].

During the lactic acid fermentation process, lactic acid bacteria (LAB) produce various metabolites that, along with the secondary metabolites derived from the various vegetables used in the preparation of kimchi, contribute to kimchi's distinctive flavor and health benefits. These metabolites, such as carotenoids, chlorophyll, ascorbic acid, and capsaicinoids, have anticancer, antioxidant, anti-aging, anti-obesity, and immune-boosting effects, among other health-promoting effects [6]. Therefore, watery kimchi can be a good source of various bioactive compounds. However, studies concerning the health benefits and bioactive compounds in kimchi have mainly focused on regular kimchi, which has no soup. Therefore, an analysis of the bioactive compounds and antioxidative effects of watery kimchi is warranted.

Carotenoids and chlorophylls, the main bioactive substances in the main and side ingredients used in preparing kimchi, cannot be synthesized in the body and must be consumed in food. Carotenoids are fat-soluble pigments that are biosynthesized in plants and some microorganisms, and they can have yellow, orange, and red colors depending on the type of carotenoid [7]. Common dietary carotenoids include neoxanthin, capsorubin, violaxanthin, capsaicin, antheraxanthin, lutein, zeaxanthin, β-cryptoxanthin, α-carotene, β-carotene, and lycopene [7, 8]. The red pigments capsaicin and capsorubin account for 30–70% of the carotenoids in red peppers, which are used as an ingredient in kimchi [9].

Chlorophylls are abundant in watery kimchi because of the green vegetables used. Chlorophylls are lipophilic derivatives mostly composed of chlorophyll-*a* and -*b* (Chl-*a* and Chl-*b*) that can have antioxidant, antimutagenic, metabolic enzyme regulatory activity in vitro, and cancer-preventive effects [10].

Capsaicinoids, responsible for the spiciness of peppers (*Capsicum*), are synthesized in the plumule epidermal cells of the peppers [11]. More than ten different capsaicinoid structures have been identified in chili peppers, including capsaicin (8-methyl-*N*-vanillyl-6-nonenamide) and dihydrocapsaicin (8-methyl-*N*-vanillylnonanamide) [11]. Capsaicin is suggested to have various physiological activities, such as antioxidant, anti-inflammatory, anticancer, anti-obesity, analgesic, and cardioprotective effects [12].

In this study, we collected three types of watery kimchi from 21 markets in the 10 largest cities in Korea. We analyzed the carotenoid, chlorophyll, capsaicinoid, lactic acid, and ascorbic acid contents in composite samples of those watery kimchi and measured their antioxidant activity to determine the functional potential of commercially available watery kimchi. We also estimated the functional ingredients consumed from each kimchi based on the KNHANES.

Materials and methods

Chemicals

HPLC-grade solvents, including acetonitrile, dichloromethane, formic acid, and methanol, were purchased from J.T. Baker (Phillipsburg, NJ, USA). Methanol and acetone for extraction were purchased from Junsei Chemical Co. Ltd. (Saitama, Japan). Neoxanthin, capsorubin, capsanthin, antheraxanthin, zeaxanthin, lutein, α-cryptoxanthin, β-cryptoxanthin, α-carotene, and β-carotene were procured from CaroteNature (Lupsingen, Switzerland). Other chemicals were bought from Sigma-Aldrich Co. (St. Louis, MO, USA).

Table 1 Classification of three kinds of watery kimchi with main vegetable species

Samples	Main vegetables		Main edible parts
	Scientific name	Common name	
Yeolmu mul kimchi (YMK)	*Raphanus raphanistrum* subsp. *sativus*	Young summer radish	Leaf
Dongchimi (DC)		Korean radish	Root
Nabak kimchi (NK)		Korean radish	Root

Preparation of watery kimchi samples

The three types of watery kimchi (YMK, DC, and NK) were selected based on the consumption rate of foods in Korea; In this study, the most consumed watery kimchi was selected by identifying representative foods based on average amounts and frequency of intake using the KNHANES database [13]. YMK, DC, and NK were purchased from 21 supermarkets (E, L, H, and N supermarkets) with a high sales ranking in each of the 10 largest cities in Korea (Seoul, Daejeon, Daegu, Busan, Ulsan, Changwon, Cheongju, Suwon, Incheon, and Gwangju). These cities have a population of over 1 million inhabitants. Each watery kimchi was purchased by choosing the best-selling products at the mart. Each watery kimchi from 21 supermarkets was pooled in equal amounts (by mixing solid and soup in a 1:1 ratio) to make a representative sample that was then freeze-dried (FD8512, Ilshin Co., Dongducheon, Korea) at −70 °C for 24 h. The freeze-dried samples were pulverized using a blender (Hanil Co., Bucheon, Korea) and stored at −20 °C until extraction.

Extraction and analysis of carotenoids

Carotenoids were identified and quantified by a previous method with a slight modification [7]. An accelerated solvent extraction (ASE) 150 system (Dionex, Sunnyvale, CA, USA) was used for extraction. The freeze-dried sample (1 g) was mixed with Dionex ASE Prep diatomaceous earth (ASE Prep DE) in a 22 mL stainless steel cell (Dionex). The cell was pressurized and purged with nitrogen for 60 s. Extraction was performed using acetone as the extraction solvent with six static cycles of 3 min at 100 °C and 1500 psi. The extract was concentrated under nitrogen using a TurboVap LV evaporator (Biotage, Uppsala, Sweden) at 60 °C.

The concentrated extract was dissolved in 3 mL acetone for saponification, then 3 mL methanol and 1 mL of a 30% (w/v) potassium hydroxide solution were added, and the mixture was left undisturbed for 150 min at room temperature in the dark. To collect the lipophilic phase, 25 mL of diethyl ether was added to the mixture in a separating funnel. The diethyl ether layer was collected and repeatedly washed with distilled water to remove the hydrophilic phase. The residual distilled water in the diethyl ether layer was then removed using 2 mL each of sodium chloride (10%, w/v) and sodium sulfate (2%, w/v) solutions. Before analysis, the final diethyl ether layer was collected, concentrated using the TurboVap LV evaporator (Biotage), and dissolved in 3 mL acetone. It was then filtered using a 0.2 µm polyvinylidene fluoride (PVDF) syringe filter (Millex-HV, Millipore, Billerica, MA, USA).

Carotenoids were analyzed using an ACQUITY UPLC H-Class system (Waters, Milford, MA, USA) equipped with an ACQUITY UPLC HSS T3 column (2.1 mm × 100 mm, 1.8 µm; Waters) set to 35 ℃, and the detection wavelength set to 450 nm. The mobile phase consisted of acetonitrile/methanol/dichloromethane (65:25:10, v/v/v) (A) and distilled water (B) at a flow rate of 0.5 mL/min, with the following gradient: 0–6.5 min, 30% B; 6.5–7 min, 30–25% B; 7–11 min, 25% B; 11–11.5 min, 25–30% B; 11.5–17 min, 30% B; 17–17.5 min, 30–0% B; 17.5–27.5 min, 0% B; 27.5–28 min, 0–30% B; and 28–30 min, 30% B. The injection volume was 1.0 µL.

Extraction and analysis of chlorophylls

Chl-*a* and Chl-*b* were identified by the method of a previous study with a slight modification [14]. The freeze-dried watery kimchi powder (0.5 g) was mixed with 10 mL of 0.2 M Tris-HCl (pH 8.0)/acetone (10:90, v/v) and vortexed for 10 s. Then, it was centrifuged at 1500×*g* for 10 min at 20 °C using a centrifuge (2236R, Gyrozen Co., Daejeon, Korea), and the supernatant was filtered using a 0.45 µm PVDF syringe filter. Chlorophylls were analyzed using a Waters e2695 HPLC system with a ZORBAX Eclipse XDB-C18 column (4.6 mm × 250 mm, 5 µm; Agilent Technologies, Santa Clara, CA, USA). The mobile phase was composed of 1 M ammonium acetate/methanol (20:80, v/v) (A) and acetone/methanol (20:80, v/v) (B) at a flow rate of 1.2 mL/min, with the following gradient: 0–15 min, 0–100% B; 15–25 min, 100% B; 25–28 min, 100–0% B; and 28–30 min, 0% B. The column temperature, detection wavelength, and injection volume were 35 °C, 665 nm, and 10 µL, respectively.

Extraction and analysis of capsaicinoids

Capsaicinoids (capsaicin and dihydrocapsaicin) were identified by a previous method with a slight modification [15]. One gram of sample was extracted with acetonitrile (5 mL) for 24 h at 4 °C. The supernatant was collected by centrifugation at 2700×*g* for 10 min at 20 °C and analyzed using a Waters e2695 HPLC system equipped with a ZORBAX Eclipse XDB-C18 column (4.6 mm × 250 mm, 5 µm; Agilent Technologies). The mobile phase was composed of acetonitrile (A) and distilled water (B) at a flow rate of 1.0 mL/min, with the following gradient: 0–21 min, 40% B; 21–23 min, 40–10% B; 23–27 min, 10–40% B; and 27–33 min, 40% B. The column temperature, detection wavelength, and injection volume were 35 °C, 280 nm, and 10 µL, respectively.

Extraction and analysis of lactic acid

Lactic acid was identified by a previous method with a slight modification [16]. For lactic acid extraction, freeze-dried watery kimchi powder (100 mg) was mixed with distilled water (10 mL), vortexed for 1 min, and extracted at room temperature for 60 min. The mixture was vortexed for 1 min and centrifuged at 2000×*g* for 10 min at 20 °C. The supernatant was filtered through a 0.22 μm syringe filter and analyzed using an ACQUITY UPLC H-Class system (Waters) equipped with an ACQUITY UPLC HSS T3 column (2.1 mm × 100 mm, 1.8 μm; Waters). The mobile phase was composed of 0.1% formic acid in distilled water (A) and 0.1% formic acid in acetonitrile (B) at the ratio of 98:2 (v/v)_at a flow rate of 0.3 mL/min. The column temperature, detection wavelength, and injection volume were 40 °C, 210 nm, and 1 μL, respectively.

Extraction and analysis of ascorbic acid

Ascorbic acid was measured by the method listed in the Korean Food Standards Codex with a slight modification [17]. The freeze-dried watery kimchi powder (0.5 g) was extracted with 5% metaphosphoric acid (7.5 mL) at 4 °C for 20 min and centrifuged at 1500×*g* for 10 min at 4 °C. The supernatant was filtered through a 0.45 μm PVDF syringe filter and analyzed using a Waters e2695 HPLC system equipped with a ZORBAX Eclipse XDB-C18 column (4.6 mm × 250 mm, 5 μm; Agilent Technologies). The mobile phase was 50 mM potassium phosphate in acetonitrile (60:40, v/v) at a flow rate of 1 mL/min. The column temperature, detection wavelength, and injection volume were 40 °C, 254 nm, and 10 μL, respectively.

Antioxidant activities

Antioxidant activities of the watery kimchi extracts were measured using the 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging assays. Methanol (80%, 10 mL) was mixed with freeze-dried watery kimchi powder (1 g) and mixed using a sonicator (8510, Branson, Danbury, CT, USA) for 1 h. The supernatant was collected by centrifugation of the mixture at 2700×g for 5 min at 20 °C and was concentrated under nitrogen using the TurboVap LV evaporator (Biotage) at 60 °C. After concentration, the dried extract was dissolved in 80% methanol and used as a stock solution (200 mg/mL).

The ABTS free radical scavenging activity was measured by a previous method with a slight modification [18]. ABTS solution was prepared by mixing 7 mM ABTS solution and 2.45 mM potassium persulfate solution (1:1, v/v) and activated by incubation at room temperature for 24 h in the dark. Before use, the ABTS free radical solution was diluted with ethanol to obtain an absorbance of 0.7 ± 0.02 at 734 nm. The extract (3 μL) was mixed with 297 μL of the diluted ABTS free radical solution and kept for 5 min in the dark. The absorbance was measured at 734 nm using a microplate reader (CLARIOstar, BMG Labtech, Ortenberg, Germany). The results were expressed as ABTS radical scavenging activity (%).

The DPPH free radical scavenging activity was evaluated by a previous method with a slight modification [19]. The extract (20 μL) was reacted with 180 μL of 0.1 mM DPPH methanolic solution and kept at room temperature in the dark for 30 min. The absorbance was measured at 517 nm using the CLARIOstar microplate reader (BMG Labtech). The results were expressed as DPPH radical scavenging activity (%).

Statistical analysis

All experiments were conducted in triplicate. The results were expressed as mean ± standard deviation. Data were compared by one-way analysis of variance (ANOVA), followed by Duncan's multiple range test ($p < 0.05$). The correlation between pairs of variables was evaluated by Pearson's correlation coefficient. Statistical analysis was performed using the SPSS 26.0 software (SPSS, Inc., Chicago, IL, USA).

Results and discussion

Carotenoids and chlorophylls

Carotenoids and chlorophylls in watery kimchi were analyzed. Chromatograms of carotenoids and chlorophylls are shown in Additional file 1: Figs. S1 and S2. Nine different carotenoids were identified in YMK and NK and six in DC (Table 2). The total carotenoid content was

Table 2 Carotenoid and chlorophyll contents in watery kimchi (unit: mg/100 g dry weight)

Bioactives	YMK	DC	NK
Neoxanthin	2.34 ± 0.31^{a}	ND	0.07 ± 0.006^{b}
Capsorubin	1.72 ± 0.07^{a}	0.09 ± 0.002^{c}	0.43 ± 0.03^{b}
Capsanthin	11.89 ± 0.57^{a}	ND	3.05 ± 0.005^{b}
Antheraxanthin	0.52 ± 0.02^{a}	ND	0.41 ± 0.01^{b}
Zeaxanthin	7.59 ± 0.47^{a}	0.90 ± 0.02^{b}	1.11 ± 0.07^{b}
Lutein	24.52 ± 2.66^{a}	1.44 ± 0.07^{b}	0.85 ± 0.03^{b}
α-Cryptoxanthin	ND	ND	ND
β-Cryptoxanthin	0.98 ± 0.07^{a}	0.13 ± 0.003^{c}	0.29 ± 0.026^{b}
α-Carotene	2.62 ± 0.15^{a}	0.20 ± 0.01^{c}	0.62 ± 0.06^{b}
β-Carotene	11.51 ± 0.83^{a}	0.73 ± 0.02^{b}	1.02 ± 0.08b
Total carotenoids	63.78 ± 4.88^{a}	3.50 ± 0.12^{c}	7.63 ± 0.68^{b}
Chl-*a*	156.77 ± 2.65^{a}	5.22 ± 0.07^{b}	2.52 ± 0.02^{b}
Chl-*b*	93.33 ± 1.26^{a}	5.52 ± 0.27^{b}	1.57 ± 0.01^{c}
Chl-*a*/Chl-*b*	1.68 ± 0.006^{a}	0.95 ± 0.061^{c}	1.61 ± 0.008^{b}
Total Chl	250.1 ± 3.91^{a}	10.74 ± 0.21^{b}	4.09 ± 0.03^{c}

Values are means ± standard deviations ($n = 3$). Different superscripts within the same rows indicate significant differences ($p < 0.05$; one-way ANOVA and Duncan's multiple range test)

YMK, *yeolmu mul* kimchi; DC, *dongchimi*; NK, *nabak* kimchi; ND, not detected; Chl, chlorophyll highest in YMK, followed by NK and DC, due to differences in the kinds and edible parts of vegetables and seasonings used in their preparation. Generally, regular kimchi, napa cabbage kimchi, *kkakdugi* (diced radish kimchi), *yeolmu* kimchi, and *oi-sobagi* (cucumber kimchi) contain plenty of lutein and β-carotene [20], and the main supporting vegetables and seasonings are composed of capsanthin as the main red pigment in red pepper, besides other pigments, such as capsorubin, lutein, zeaxanthin, α-carotene, and β-carotene [21].

Although all watery kimchi are made with the same radish species, YMK uses radish leaves and a small amount of radish root, and DC and NK use sliced radish root with a few radish leaves as the main ingredient. In a previous study, we showed that the lutein content in leafy kimchi was higher than that in radish kimchi [21]. In YMK, the lutein content (24.52 ± 2.66 mg/100 g) was about double that of β-carotene and capsanthin, respectively (Table 2), and accounted for 38% of the total carotenoids. Similarly, *yeolmu* kimchi was reported to contain more lutein (984.4 μg/100 g fresh weight) than β-carotene (530.4 μg/100 g fresh weight) [20]. Capsanthin constituted 39.97% of the total carotenoid content in NK. It is reported that commercially consumed NK uses small amounts of red pepper powder or fresh red pepper, and no capsanthin was detected in DC, which contained no red pepper powder [5].

Of the nine carotenoids detected in the study, the provitamin A carotenoids β-carotene, α-carotene, and cryptoxanthin can be converted into vitamin A in the intestine [22]. Therefore, kimchi is a good dietary source of vitamin A. When retinol and carotenoids were converted to micrograms of retinol activity equivalents (RAE), YMK had a higher vitamin A content (65.44 RAE/100 g) compared to NK (3.69 μg RAE/100 g) and DC (2.83 RAE/100 g) [23]. According to the KNHANES (2016–2020), the average daily intake of YMK, NK, and DC was 138.54 ± 6.60, 131.19 ± 9.81. and 113.62 ± 8.84, g/day, respectively. Based on these calculations, it can be inferred that individuals consuming the three types of watery kimchi can obtain a daily intake of 92.74 μg RAE of vitamin A. This amount corresponds to 4.11% of the recommended daily intake of vitamin A (800 μg RAE/day for adult males) based on the 2020 Korean dietary reference intakes [24].

Chl-*a* and Chl-*b* concentrations were highest in YMK ($p < 0.05$) compared to DC and NK (Table 2). Among the watery kimchi, YMK also contained the highest ratio of Chl-*a* to Chl-*b*. This ratio is usually 3:1 in vegetables; in this study, however, the highest chlorophyll ratio was 1.68:1. This is consistent with experimental results that chlorophyll is degraded by organic acids produced during fermentation, which is related to changes in the pH of the brine. In *yeolmu* kimchi, the chlorophyll content decreased continuously during the fermentation period [25], and Chl-*b* is much more stable in acidic conditions compared to Chl-*a* [26].

Lactic acid and ascorbic acid

The contents of lactic acid and ascorbic acid in the three types of watery kimchi are shown in Table 3. It is known that the predominant microorganisms in kimchi are *Leuconostoc mesenteroide*s in the middle stage and *Lactobacillus plantarum* in the late stages during fermentation [27]. These two microorganisms are LAB that convert carbohydrates into organic acids and produce metabolites possessing strong antioxidant and antibacterial activities [6]. However, these two LAB have different acid tolerance and organic acid profiles. *Leu. mesenteroides*, a heterofermentative lactic acid bacterium, grows until pH 5.4 ~ 7.5 and produces various organic acids, while *Lac. plantarum*, a homofermentative lactic acid bacterium, grows until pH 4.6 ~ 4.8 and produces only lactic acid [27]. In DC, *Leuconostoc* spp. became dominant within only 3 days and remained until 100 days during fermentation [28]. This persistence of heterofermentative *Leuconostoc* spp. in watery kimchi likely contributes to the unique sour taste, distinct in cabbage kimchi, by producing various organic acids. In this study, DC had the highest lactic acid content, followed by NK and YMK (Table 3). These differences might be related to the main ingredients, seasonings, as well as fermentation stage.

The type of vegetables, seasonings, and fermentation conditions can also influence the ascorbic acid (vitamin C) content in kimchi. Fluctuation of ascorbic acid levels in kimchi during fermentation has been related to the enzymes present in the plant tissues or in the kimchi liquid [29]. Pectin in kimchi can be degraded by polygalacturonase, and increased galacturonic acid can be used as substrates for the biosynthesis of vitamin C [29]. In the present study, YMK had a higher content of ascorbic acid compared to DC and NK (Table 3). According to the ninth revision of the Korean Food Composition Table [30], the ascorbic acid content in YMK, NK, and DC is 3.88, 3.50, and 2.33 mg/100 g,

Table 3 Lactic acid and ascorbic acid contents in watery kimchi (unit: mg/100 g dry weight)

Compounds	YMK	DC	NK
Lactic acid	311.07 ± 24.43^{b}	579.60 ± 30.89^{a}	582.72 ± 29.10^{a}
Ascorbic acid	447.16 ± 8.95^{a}	237.09 ± 4.11^{c}	301.36 ± 10.27^{b}

Values are means ± standard deviations ($n = 3$). Different superscripts within the same rows indicate significant differences ($p < 0.05$; one-way ANOVA and Duncan's multiple range test)

YMK, *yeolmu mul* kimchi; DC, *dongchimi*; NK, *nabak* kimchi respectively. Considering that the moisture content of watery kimchi is more than 90%, the results of this study are consistent with those published by the Rural Development Administration [30]. Jeong et al. noted that the water base of kimchi retained more ascorbic acid than the kimchi itself during fermentation [29]. In this context, watery kimchi, especially YMK, might be an excellent source of ascorbic acid.

Capsaicinoids

Watery kimchi was analyzed for the capsaicinoids capsaicin and dihydrocapsaicin (Table 4). Chromatograms of capsaicinoids are shown in Additional file 1: Fig. S3. As shown in the table, the capsaicin content differed significantly among the samples ($p < 0.05$), whereas the dihydrocapsaicin content was comparable between NK and DC. The highest total capsaicinoid content was found in YMK, followed by DC and NK ($p < 0.05$). Capsaicinoids are the pungent flavor components in the *Capsicum* genus. Red pepper is added in different forms as a side ingredient with different shape. Red pepper powder and decorative shredded red pepper are used in YMK and NK, and fermented pickled peppers are used in DC. It was reported that the capsaicin/dihydrocapsaicin ratio of dried chili pepper ranged from 1.47 to 3.06 [31], and that of red pepper powder was 1.26 to 2.23 [32]. Lower values (0.93 ~ 1.58) in watery kimchi analyzed in this study might be explained by the lactic acid produced during fermentation and the form of red pepper added. Ye et al. noted that the spiciness of chili peppers decreased during the fermentation period due to a decrease in the contents of capsaicin and dihydrocapsaicin [33]. DC had the highest ratio of capsaicin/dihydrocapsaicin in the current study, which was thought to be due to its higher retention of capsaicin because red peppers were added as whole fermented pickled peppers, whereas capsaicin in YMK and NK was derived from red pepper powder and broken down easily.

Table 4 Capsaicinoid content in watery kimchi (unit: mg/100 g dry weight)

Capsaicinoids	YMK	DC	NK
Capsaicin (CAP)	1.39 ± 0.03^a	0.63 ± 0.01^b	0.41 ± 0.01^c
Dihydrocapsaicin (DHCAP)	1.13 ± 0.09^a	0.40 ± 0.003^b	0.44 ± 0.02^b
Total capsaicinoids	2.51 ± 0.09^a	1.04 ± 0.01^b	0.84 ± 0.02^c
CAP/DHCAP	1.23 ± 0.11^b	1.58 ± 0.01^a	0.93 ± 0.04^c

Values are means ± standard deviations ($n = 3$). Different superscripts within the same rows indicate significant differences ($p < 0.05$; one-way ANOVA and Duncan's multiple range test). YMK, *yeolmu mul* kimchi; DC, *dongchimi*; NK, *nabak* kimchi

Antioxidant activities

The ABTS and DPPH radical scavenging activities of YMK, DC, and NK are shown in Fig. 1. The ABTS radical scavenging activity of watery kimchi increased in a concentration-dependent manner with increasing concentration of the sample extracts (10, 25, and 50 mg/mL). Among the watery kimchi, YMK had the highest ABTS radical scavenging activity (50 mg/mL, $p < 0.05$). The DPPH radical scavenging activity of watery kimchi showed a concentration-dependent increase for all samples except for YMK at 50 mg/mL. When the extract concentration was 50 mg/mL, the DPPH radical scavenging capacity of YMK (75.42 ± 1.13%) was significantly the highest among the watery kimchi samples ($p < 0.05$). The DPPH radical scavenging activity of *Yulmoo* kimchi, which was a different type of kimchi made from *Yulmoo*, ranged from 50 to 60% at the first day of fermentation and showed a slight increase until 20th day of fermentation in all samples. After 20 days of fermentation, the scavenging activity decreased in all samples [34]. Kim et al. [35] reported that the DPPH radical scavenging activity of winter radishes was different depending on the varieties of them. The difference was attributed to the varying levels of phenolic compounds, such as polyphenols and flavonoids, depending on the cultivar [35]. Therefore, the antioxidative activity of commercially available watery kimchi seemed to be affected by main ingredients and their cultivars as well as fermentation periods. Further research is necessory to investigate the change of antioxidative activity of watery kimchi in relation to the fermentation stages.

Correlation analysis between watery kimchi

The correlation analysis results between the composition (carotenoids, chlorophylls, capsaicinoids, and ascorbic acid) and the antioxidant capacity of YMK, DC, NK at a concentration of 25 mg/mL are shown in Fig. 2. The ABTS radical scavenging activity showed positive correlations with neoxanthin, zeaxanthin, lutein, β-carotene, total capsaicinoids, Chl-*a*, Chl-*b*, and total chlorophyll ($p < 0.05$). The DPPH radical scavenging activity showed positive correlations with neoxanthin, zeaxanthin, lutein, β-carotene, total carotenoids, dihydrocapsaicin, total capsaicinoids, Chl-*a*, Chl-*b*, and total chlorophyll. Hwang et al. reported that the contents of chlorophyll and carotenoids were highly positively correlated with the ABTS and DPPH radical scavenging activity in napa cabbage [36]. A study of cultigens of *Brassica oleracea*, a *Brassicaceae* species, also reported a high correlation ($p < 0.0001$) between carotenoid and chlorophyll [37], which was similar to the results of this study. Specifically, this study found a strong positive correlation ($p < 0.01$)

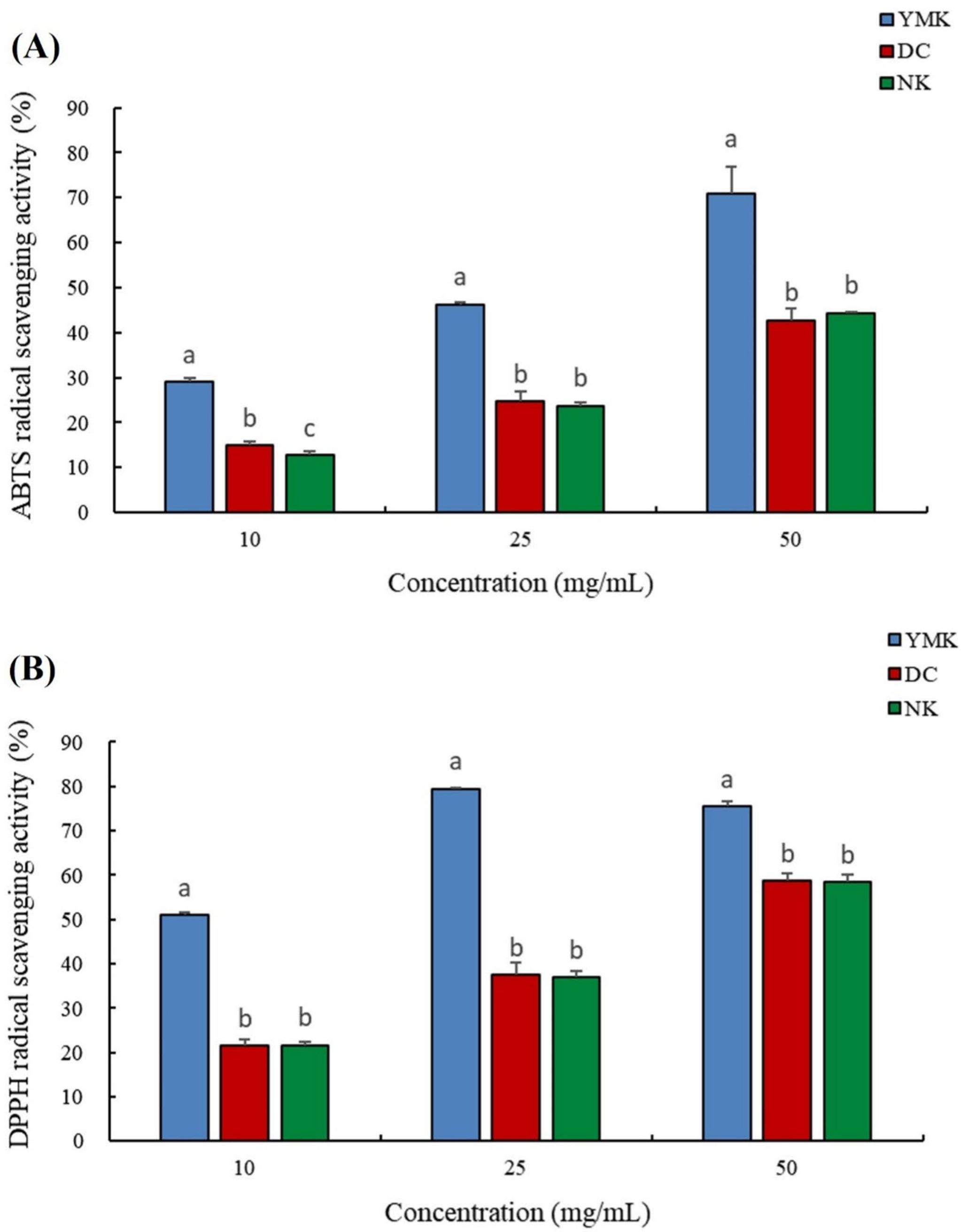

Fig. 1 Antioxidant activity analysis of watery kimchi **A** ABTS and **B** DPPH radical scavenging activities. Values are means ± standard deviations ($n = 3$). Different superscripts within the same concentration indicate significant differences ($p < 0.05$; one-way ANOVA and Duncan's multiple range test). YMK, *yeolmu mul* kimchi; DC, *dongchimi*; NK, *nabak* kimchi; ND, not detected

between chlorophyll and antioxidant activity. Among the carotenoids analyzed in this study, neoxanthin, zeaxanthin, lutein, and β-carotene were positively correlated ($p < 0.05$) with antioxidant activity.

Kimchi cabbage and radish, which are the primary vegetables used in kimchi, are cruciferous vegetables that contain carotenoids, chlorophyll, ascorbic acid, and antioxidants such as glucosinolate and sulforaphane [21, 38]. In our previous report [39], we analyzed six types of glucosinolates (glucoraphanin, glucoraphenin, glucoerucin, glucoraphasatin, glucobrassicin, and 4-Methoxyglucobrassicin) and three types of breakdown products (indole-3-carboxaldehyde, sulforaphane, and ascorbigen) in watery kimchi (YMK, DC, and NK).

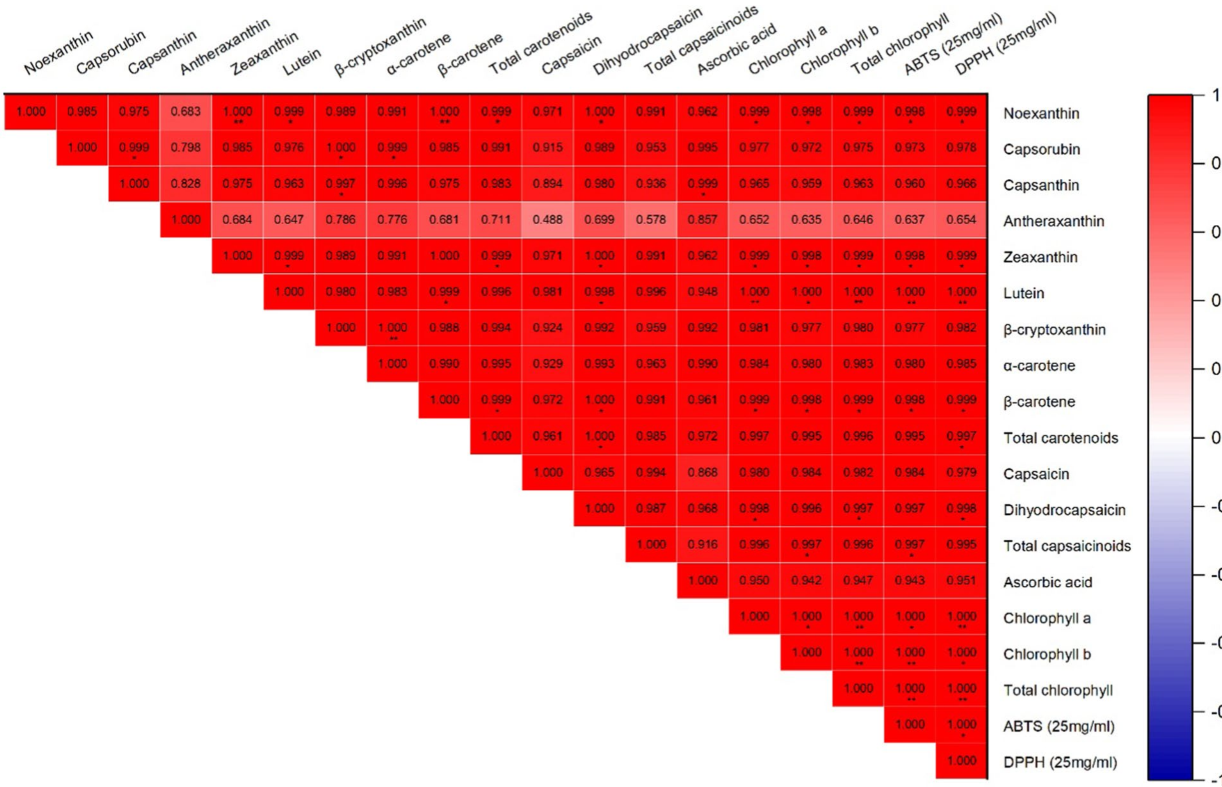

Fig. 2 Correlation between bioactive compounds and antioxidant activities of watery kimchi (* and ** indicate the significant levels at 0.05 and 0.01, respectively)

Watery kimchi, made with radish as the main vegetable, showed a higher glucoraphasatin content compared to other glucosinolates and ascorbigen was the most abundant breakdown products of glucosinolate in the three types of watery kimchi [39]. In this study, three types of watery kimchi showed the total carotenoids and ascorbic acid in the following order: YMK, NK, and DC. The chlorophyll analysis revealed that both chlorophyll a and b were detected in all watery kimchi, and the chlorophyll content was highest in YMK and lowest in NK. Kim et al. [39] reported that YMK showed the highest results in their analysis of ascorbigen. Unlike other types of watery kimchi, YMK is made using radish leaves instead of radish roots. These results suggest that YMK possesses excellent antioxidant properties. This study was the first to provide information on the analysis of carotenoids in watery kimchi. It also provided data on chlorophyll, capsaicinoid, ascorbic acid content, and antioxidant activity. Among watery kimchi, YMK has excellent carotenoid, chlorophyll, capsaicinoid, ascorbic acid content, and antioxidant activity. Therefore, it is recommended to increase the utilization of YMK in order to improve the intake of functional ingredients.

Abbreviations

Chl-*a* chlorophyll-*a*
Chl-*b* chlorophyll-*b*
DC *dongchimi*
NK *nabak* kimchi
YMK *yeolmu mul* kimchi

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13765-023-00855-6.

Additional file 1: Figure S1. Chromatograms of standard carotenoid mixtures (A) and *yeolmu mul* kimchi (B). (1) Neoxanthin, (2) capsorubin, (3) violaxanthin, (4) capsanthin, (5) anteraxanthin, (6) zeaxanthin, (7) lutein, (8) α-cryptoxanthin, (9) β-cryptoxanthin, (10) α-carotene, and (11) β-carotene. **Figure S2.** Chromatograms of standard chlorophylls mixtures (A) and *yeolmu mul* kimchi (B). (1) Chlorophyll-*b*,and (2) chlorophyll-*a*. **Figure S3.** Chromatograms of standard capsaicinoid and capsinoid mixtures (A) and *yeolmu mul* kimchi (B). (1) Capsaicin, (2) dihydrocapsaicin, (3) capsiate, and (4) dihydrocapsiate.

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Author contributions

HP Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review and editing. perform the analysis. SK Data curation, Writing – original draft. JK Formal analysis. KJL Writing – review and editing. BKM

Conceptualization, Methodology, Investigation, Writing – original draft, Supervision. All authors read and approved the final manuscript.

Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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