



Research Article

Vitamin contents and antioxidant characteristics of red and gold *kimchi* cabbages (*Brassica rapa*. L. ssp. *pekinensis*)

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Abstract *Kimchi* cabbage is widely consumed in Korea, with the popularity of this pickled vegetable dish growing internationally due to its health benefits. In this study, the physical (size, color), functional (antioxidant activity, total polyphenol, and flavonoid content), and nutritional (water- and fat-soluble vitamins) characteristics of two new *kimchi* cabbage varieties, namely red and gold *kimchi* cabbages (RKC and GKC, respectively), were analyzed and compared with those of the common *kimchi* cabbage (CKC). There were no significant differences in the thickness or length of the three *kimchi* cabbages, although RKC had the narrowest outer leaves among the three varieties (11.94 cm). Regarding chromaticity, yellowness was highest in GKC (29.86), whereas redness was highest in RKC (9.31). Furthermore, RKC had the highest recorded vitamin B₆ and B₉ (1,288.5 µg/100 g and 776.7 µg dietary folate equivalent/100 g, respectively). On the other hand, the fat-soluble vitamins vitamin A (β-carotene) and K (Phylloquinone) were both highest in GKC (907.1 µg/100 g and 712.2 µg/100 g, respectively). Generally, all *kimchi* cabbage samples contained high levels of vitamin E (1.8-4.9 mg α-tocopherol equivalent/100 g). RKC attained the highest antioxidant activity and total polyphenol and total flavonoid contents among the three *kimchi* cabbages. These results show that gold and red *kimchi* cabbage can be used as raw materials in the food-processing industry.



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Keywords antioxidant activity, chromaticity, *kimchi* cabbage, nutrient, variety

1. Introduction

Recently, customer demand for information on the vitamin content and functionality of food has increased due to the high correlation between vitamin intake and health (Awuchi, 2020). In Korea, the nutritional information of specific foods can be found in the food nutrient database developed and maintained by the Rural Development Administration, the Ministry of Food and Drug Safety, and the National Institute of Fisheries Science. Data shown on the website were verified by different government agencies in Korea that prioritized the most highly-consumed and health-related foods in the country. However, most of the information on the nutritional components of food is only focused on the macronutrients, while information on micronutrients such as vitamins is very limited.

Kimchi cabbage (*Brassica rapa*. L. ssp. *pekinensis*) is a leafy biennial vegetable belonging to Brassicaceae family. It is among the most widely consumed vegetables in Korea. As of December 2022, the total cultivation area of *kimchi* cabbage in Korea is 13,953 ha, with a production of approximately 1,352 thousand tons, representing 9,692 kg of production per 10 ha (KOSIS, 2022). *Kimchi* cabbage can be classified into spring, highland, autumn, and winter *kimchi* cabbage based on its growing season. It can be further classified according to its shape or form: spherical, semi-spherical and incompletely spherical. One of the optimal conditions for the growth and development of *kimchi* cabbage is a cool environment, which promotes a spherical shape (Ku et al., 2014; Lee et al., 2013).

Kimchi cabbage contains functional substances, such as flavonoids, carotenoids, phenolic acids, sterols, alkaloids, and glucosinolates (Hounsoume et al., 2008). In addition, *kimchi* cabbage is rich in various minerals and vitamins, including fiber and calcium. Owing to its nutrient content, it is an essential food for Koreans during winter (Gantumar et al., 2013), and is growing in popularity internationally as a dietary component for health-conscious individuals.

Vitamins perform various metabolic functions in the human body and can be ingested in μg or mg levels. However, since our bodies cannot synthesize the required daily intake, vitamins can be supplemented through the diet (Awuchi, 2019). In Korea, *kimchi* cabbage is mainly used to prepare *kimchi*, an integral component of the Korean diet. Because of the nature of every meal consumed, the frequency of consumption is very high. The total vitamin level ingested in *kimchi* cabbage is a very important for evaluating vitamin intake level in Koreans.

Kimchi cabbage shows substantial variability in

its genetics and morphological characteristics, which are important for breeding to improve particular characteristic traits (Balkaya et al., 2005; Bhandari et al., 2021; Kibar et al., 2016). Generally, light yellow *kimchi* cabbages have been widely used for many years. However, genetic variations have recently been introduced to improve the size, nutrient content, and organoleptic characteristics of large varieties. Examples of these improvements includes the development of red and gold *kimchi* cabbages, which are high in nutrients and currently cultivated in the Haenam region in Korea (Lee et al., 2019; Park et al., 2019; Yang, 2018). But, almost no data available on their nutritional and functional properties. To increase the use of these new varieties in preserved *kimchi* products, analyzing their nutritional value is an essential step.

In this study, the morphological characteristics, antioxidant capacity, and major water- and fat-soluble vitamin content of gold and red *kimchi* cabbage produced in Haenam were analyzed. This was done to determine the nutritional content for food processing purposes and to prepare a scientific basis for future research.

2. Materials and methods

2.1. Materials and reagents

Vitamin B₆ standard pyridoxine, pyridoxal, and pyridoxamine; vitamin B₉ standard folic acid; vitamin E standard α -, β -, γ -, δ -tocopherol; and vitamin K standard phyloquinone were all purchased from Sigma-Aldrich Co. (St. Louis, MO, USA). Standard β -carotene for vitamin A analysis was purchased from FUJIFILM Wako Pure Chemical Co. (Osaka, Japan). The strain used for B₉ analysis was *Lactobacillus casei* subsp. *rhamnosus* (ATCC 7469) was purchased from the American Type Culture

Collection (ATCC; Manassas, VA, USA). All other reagents used were of high grade and HPLC grade or higher.

2.2. Sample preparation

The red *kimchi* cabbage (RKC) used in this experiment consisted of a variety of cabbages derived from red lettuce and common cabbage. On the other hand, gold *kimchi* cabbage (GKC) is a variety derived from common *kimchi* cabbage (CKC) and tomato. RKC and GKC harvested during the fall season were obtained from Haenam-SungJin *kimchi* (Haenam, Korea). CKC was purchased from a local market (Suncheon, Korea).

Kimchi cabbages (n=5) were prepared by removing all the inedible parts of the cabbage and cutting them into eight equal parts before washing them with clean water. After draining the water, the *kimchi* cabbage was sliced and then lyophilized at -70°C using a freeze dryer (Il-Shin Freeze Dryer Series, Il-Shinbiobase Co. Ltd., Yangju, Korea). It was then pulverized using a food processor (HMF-3250S; Hanil Science Industrial Co., Gwangju, Korea) and mixed homogeneously. The powdered samples were vacuum-packed and stored at room temperature until further analysis. The moisture content of all *kimchi* cabbages was approximately 92%, and there was no significant difference between the varieties.

2.3. Size measurement

To measure the size of *kimchi* cabbages, five medium-sized *kimchi* cabbages were randomly selected per variety. For size measurements, two to three layers of outer leaves were removed, as they are part of the inedible portion. The thickness and length of the *kimchi* cabbage heads were measured (n=5 per variety). The width of the removed outer

leaves was also measured (n=5 per variety). The length and thickness of each cabbage head, and the width of the outer leaves, were measured using the International System of Units (SI), and these are expressed as average values.

2.4. Chromaticity measurement

The lyophilized samples were powdered and mixed homogeneously. A powder sample was used for chromaticity measurement, which were taken using a colorimeter (CR-200; Minolta Co., Osaka, Japan). Before measurement, the meter was calibrated using a standard white plate ($L=97.06$, $a=-0.15$, and $b=+1.94$). All powder samples were measured five times, and the average values were obtained and expressed as L^* (lightness), a^* (redness), and b^* (yellowness).

2.5. Vitamin B₆ content analysis (HPLC-FLD)

For the extraction and analysis of vitamin B₆, the method of Islam et al. (2022) was used. The powder sample (2.0 g) was weighed into a round-bottom flask, and 20 mL of 10 mM ammonium formate (0.1% formic acid) solution was added and mixed. Extraction was performed at 40°C for 30 min using an ultrasonic extractor (Cole-Parmer 8893; Chicago, IL, USA). The extract was cooled to room temperature (20°C). Centrifugation (MF-550; Hanil Science Industrial Co., Gwangju, Korea) was performed at 0°C for 15 min at $252 \times g$ (gravity). The supernatant was transferred to a 50 mL volumetric flask. This process was repeated twice in total. Then, A 10 mM ammonium formate (0.1% formic acid) solution was used to be filled of the flask. The gastric extract (1.6 mL) was transferred to a microtube. After centrifugation (SUPR30K, Hanil Science Industrial Co.), the supernatant was filtered using a $0.45 \mu\text{m}$ membrane filter (cellulose acetate, Advantec®),

DISMIC®-13CP, Osaka, Japan). The filtrate was analyzed using an HPLC system equipped with a fluorescence detector (FLD, Agilent, Santa Clara, CA, USA). The mobile phase conditions are listed in Table 1. The column used was Imtakt Scherzo SW-C₁₈ (150×4.6 mm, 3 μm; Shiseido, Kyoto, Japan). The detection wavelength was at Exλ=290 nm and Emλ=396 nm. The injection volume was 20 μL, the flow rate was 0.7 mL/min, and the column oven temperature was set at 35°C.

2.6. Vitamin B₉ content analysis (trienzyme extraction-microplate assay)

Vitamin B₉ extraction and analysis were conducted using the method described by Chun et al. (2006). A 1.0 g powder sample was weighed into a 250 mL wide-neck Erlenmeyer flask. 20 mL of sodium phosphate buffer (pH 7.8) and 30 mL of distilled water were sequentially added. After a hot water treatment at 100°C for 15 min in a constant temperature water bath (WB-20M, Jeio Tech, Daejeon, Korea), it was cooled to room temperature. 1 mL of protease (2 mg/mL) and 10 mL of sodium phosphate buffer (pH 7.8) were added. Reacted for 3 h in a 37°C shaking incubator. To deactivate the protease, it was placed first in a water bath at 100°C for 10 min and cooled to room temperature. 1 mL of α-amylase (20 mg/mL) and 0.5 mL of toluene

were added to the culture medium and allowed to react for 2 h in a 37°C shaking incubator. Then, 4 mL of folate conjugate solution (5 mg/mL in sodium phosphate buffer, pH 7.8) was added to the culture medium and incubated for up to 16 h in a 37°C shaking incubator. To deactivate the enzyme, the sample was treated in a hot water bath for 10 min. The extract was adjusted to pH 4.5 using an HCl solution. The extracted solution (100 mL) was filtered through Whatman No. 1 filter papers (GE Healthcare, Little Chalfont, UK). The filtrate was used as the extract for the *L. casei* assay.

On the day of the assay, *L. casei* grown on solid medium was inoculated into a vitamin B₉-deficient medium (folic acid *L. casei* medium : *Lactobacillus* broth = 1:1, v/v). It was used after incubating at 37°C for approximately 6 h. The assay medium used in the microbiological assay of vitamin B₉ was prepared by mixing 15 mL of folic acid *L. casei* medium, 75 μL of *L. casei*, and 150 μL of ascorbic acid (0.1 g/mL). Then, 150 μL of the sample extract was added to a 96-well plate and serially diluted. Then, 150 μL of assay medium was added to each well and incubated at 37°C for 20 h. *Lactobacillus casei* growth was measured at an absorbance of 595 nm using a microplate reader (Eon; BioTek Instruments, Winooski, VT, USA). The vitamin B₉ content was calculated from the growth rate of *L. casei* using the microbial growth response curve for the standard solution. Gen5 data analysis software (version 2.04; Biotek Instruments) of the microplate reader was used to construct the calibration curve. The vitamin B₉ content was expressed as the dietary folate equivalents (DFE) as follows.

$$\text{DFE} = \mu\text{g of natural food folate} + (1.7 \times \mu\text{g folic acid})$$

Table 1. A gradient condition of HPLC mobile phases for vitamin B₉ analysis

Time (min)	Mobil phase A (10 mM ammonium formate, 0.1% formic acid) (%)	Mobil phase B (methanol) (%)
0	100	0
14	90	10
20	90	10
21	100	0
30	100	0

2.7. β -Carotene content analysis (HPLC-PDA)

β -Carotene extraction and analysis were performed as described by using the method of Moon et al. (2019). A 2.0 g powder sample was weighed into a glass extraction tube. Next, 10 mL of 6% pyrogallol ethanol solution was added. The samples were sonicated (Cole-Parmer 8893) for 10 min for homogeneous mixing. Next, 8 mL of a 60% KOH solution was added to the extraction tube. After mixing, nitrogen was injected into the top of the extraction tube to replace the air. An air condenser was attached to the nitrogen-purged extraction pipe. Saponification was performed at 75°C and 100 rpm for 1 h in a shaking water bath (HB-205SW, Hanbaek Scientific Co., Bucheon, Korea). After cooling, 20 mL of 2% NaCl solution was added to the saponification solution to terminate the reaction. 15 mL of an extraction solvent [hexane:ethyl acetate=85:15 (v/v), 0.01% 2,6-di-tert-butyl-4-methylphenol (BHT)] was then added to the saponification solution. After mixing for 2 min, the mixture was allowed to stand in the dark to separate the supernatant. Anhydrous sodium sulfate was added to the glass tube to remove moisture. The supernatant, from which the fat-soluble components were extracted, was passed through a glass tube. Only the supernatant from which water was removed was collected in a 50 mL volumetric flask. This process was repeated a total of three times. The collected supernatant was added and filled to 50 mL using an extraction solvent. This was mixed well and used as an extract for analysis.

The gastric extract (10 mL) was placed in a test tube. After volatilizing the solvent with nitrogen, it was re-dissolved in 1 mL of solvent [ethanol:chloroform=4:1 (v/v)]. Next, it was filtered with a 0.45 μ m membrane filter (cellulose acetate, Advantec, DISMIC-13CP). The filtrate was analyzed using an

HPLC equipped with a photodiode array detector (PDA, Shimadzu, Kyoto, Japan). The mobile phase conditions are listed in Table 2. The column used for the analysis was a Vydac 201TP C₁₈ (4.6×250 mm, 5 μ m; GRACE, Santa Clara, CA, USA), with detection at 452 nm. The injection volume was 20 μ L, the flow rate was 1 mL/min, and the column oven temperature was set at 30°C.

2.8. Vitamin E content analysis (HPLC-FLD)

Vitamin E content was analyzed using the method described by Moon et al. (2019). Saponification was performed in the same manner as the β -carotene extraction method. First, 2 mL of the extract was precisely extracted. The solvent was volatilized with nitrogen. The solution was then re-dissolved in hexane (1 mL) before the extract was filtered through a 0.45 μ m membrane filter (cellulose acetate, Advantec, DISMIC-13CP). The filtrate was analyzed for all eight homologs of vitamin E [α , β , γ , δ -Tocopherol (T), α , β , γ , δ -tocotrienol (T₃)] using an HPLC equipped with FLD (Shimadzu). For the mobile phase, n-hexane containing 0.6% isopropanol was used. The column used for analysis was LiChrospher Diol 100 (250×4 mm, 5 μ m; Merck, Darmstadt, Germany). Wavelengths were at Ex λ =285 nm and Em λ =325 nm. The injection

Table 2. A gradient condition of HPLC mobile phases for β -carotene analysis

Time (min)	Mobil phase A ¹⁾ (%)	Mobil phase B ²⁾ (%)
0	75	25
8	75	25
50	10	90
55	10	90
57	75	25
65	75	25

¹⁾Methanol:buthanol:water=89.5:10.0:0.5 (v/v/v).

²⁾Methanol:buthanol:water=60:10:30 (v/v/v).

volume was set to 20 μL and the flow rate was set to 1 mL/min. For vitamin E content, α -tocopherol equivalent (α -TE), a unit representing activity, was used, and was calculated using the following equation.

$$\begin{aligned} &\alpha\text{-TE (mg/100 g)} \\ &= (\alpha\text{-T} \times 1.0) + (\beta\text{-T} \times 0.5) + (\gamma\text{-T} \times 0.1) + \\ &\quad (\delta\text{-T} \times 0.01) + (\alpha\text{-T}_3 \times 0.3) + (\beta\text{-T}_3 \times 0.05) \end{aligned}$$

2.9. Vitamin K content analysis (HPLC-FLD)

For vitamin K extraction and analysis, the methods described by Jakob and Elmadfa (1996) and Leenheer et al. (1992) were partially modified. A 1.0 g powder sample was weighed into a 25 mL wide-neck flask. Fifteen milliliters of dichloromethane:methanol=2:1 (v/v) were added. The mixture was sealed and ultrasonically extracted (Cole-Parmer 8893) for 1 h. To remove water, anhydrous sodium sulfate was placed on filter paper, and the extract was filtered. Methanol was used for washing and regular use. Four milliliters of the extract were placed in a test tube. The extract was nitrogen-concentrated and re-dissolved in 2 mL of hexane. Methanol:water [5 mL, 9:1 (v/v)] and 2 mL of the re-dissolved extract were added to a 15 mL conical tube. To wash off the residual concentrate, 3 mL of methanol:water=9:1 (v/v) was added to the test tube. After washing, the samples were placed in conical tubes. The mixture was centrifuged for 5 min at 718 $\times g$. The supernatant (1 mL) was placed in a test tube. The solvent was completely volatilized using nitrogen before being redissolved in methanol (1 mL) and filtered through a 0.45 μm membrane filter (cellulose acetate, Advantec, DISMIC-13CP). The filtrate was analyzed using an HPLC equipped with an FLD (Agilent Technologies) and a solvent delivery pump (Agilent Technologies). The mobile phase

consisted of methanol:dichloromethane=9:1 (v/v), 10 mM/L zinc chloride, and 3 mM/L sodium acetate, and 5 mM/L acetic acid were added and mixed. The column used was a ZORBAX Eclipse XDB-C₁₈ column (4.6 \times 150 mm, 5 μm ; Agilent) and a post column filled with zinc powder. The wavelength was at $\text{Ex}\lambda = 243$ nm and $\text{Em}\lambda = 430$ nm, the injection volume was 20 μL , the flow rate was 1.0 mL/min, and the temperature was set at 35°C.

2.10. Antioxidant activity assays

The DPPH radical scavenging activity was measured by partially modifying the method described by Blois (1958). First, a 2.0 g powder sample was weighed and 20 mL 70% ethanol was added. Sonication (Cole-Parmer 8893) was performed at 40°C for 30 min. After extraction, the samples were filtered through Whatman No. 1 filter paper (GE Healthcare). Then, 60 μL of the filtrate was mixed with 240 μL of 0.2 mM DPPH solution. After reacting for 30 min in the dark, the absorbance was measured at 517 nm. The DPPH radical scavenging activity was calculated by substituting the absorbance of the sample into a standard curve for each concentration. Gallic acid (Sigma-Aldrich Co.) was used as the standard. DPPH radical-scavenging activity was expressed as μg gallic acid equivalent (GAE)/g.

The ABTS radical scavenging activity was measured by partially modifying the method described by Arts (2004). First, a 2.0 g powder sample was weighed and 20 mL 70% ethanol was added. Sonication (Cole-Parmer 8893) was performed at 40°C for 30 min. After extraction, the samples were filtered through Whatman No. 1 filter paper (GE Healthcare). ABTS reagent (7 mM ABTS reagent) was measured at 734 nm as the standard. It was then diluted to an absorbance value was 0.70 ± 0.02 . After mixing

15 μL of the filtrate and 285 μL of the diluted ABTS solution and reacting in the dark for 7 min, the absorbance at 734 nm was measured. The ABTS radical scavenging activity was calculated by substituting the measured absorbance into the calibration curve for each concentration. L-Ascorbic acid (Junsei Chemical Co., Ltd., Tokyo, Japan) was used as the standard. The ABTS radical scavenging activity was expressed as mg ascorbic acid equivalent (AAE)/g.

2.11. Analysis of total polyphenol and total flavonoid contents

The total polyphenol content was determined using the method described by Singleton et al. (1999), with some modifications. First, a 2.0 g powder sample was weighed and 20 mL 70% ethanol was added. Sonication (Cole-Parmer 8893) was performed at 40°C for 30 min. After extraction, the samples were filtered through Whatman No. 1 filter paper (GE Healthcare). First, 1 mL of a 2% Na_2CO_3 solution was added to 50 μL of the filtrate and allowed to stand for 3 min. After adding 50 μL of 50% Folin-Ciocalteu reagent, the mixture was allowed to stand for 30 min. The absorbance was measured at 750 nm. The total polyphenol content was calculated by substituting the absorbance of the sample into a calibration curve for each concentration. Gallic acid was used as the standard. The total polyphenol content was expressed as mg GAE/g.

The total flavonoid content was determined using the method described by Zhishen et al. (1999), with some modifications. First, 2.0 g of the powder sample was weighed and 20 mL 70% ethanol was added. Sonication (Cole-Parmer 8893) was performed at 40°C for 30 min. After extraction, the samples were filtered through Whatman No. 1 filter paper (GE Healthcare). Subsequently, 400 μL of 70%

ethanol and 30 μL of 5% NaNO_2 were mixed with 100 μL of filtrate. After 30 s, the reaction proceeded in a dark room for 5 min. The sample mixture was put into 30 μL of 10% $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ and left for 5 min. Subsequently, 200 μL of 1 M NaOH and 200 μL of DDW were added. The absorbance values were measured at 420 nm. Total flavonoid content was calculated by substituting the absorbance of the sample into a calibration curve for each concentration. Quercetin (Sigma-Aldrich Co.) was used as the standard. The total flavonoid content was expressed as μg quercetin equivalent (QE)/g.

2.12. Statistical analysis

For the statistical analysis, the mean and standard deviation of each measured parameter were calculated using SPSS (Statistics Package for the Social Sciences ver. 22.0 for Windows, SPSS Inc., Chicago, IL, USA). Significant differences between samples were verified using one-way ANOVA at a significance level of $p < 0.05$. When significant, a post-hoc test was performed using Duncan's multiple range test at a confidence level of 95%.

3. Results and discussion

3.1. Size and color

Fig. 1 shows the appearance of the three types of *kimchi* cabbage, CKC, GKC, and RKC. The details of the width, length, and thickness are listed in Table 3. There were no significant differences in the thickness and lengths of the three types of *kimchi* cabbages. However, the widths of the RKC was 11.94 cm, the smallest value ($p < 0.05$).

The chromaticity of each variety of freeze-dried *kimchi* cabbage is presented in Table 4. Lyophilized homogeneous *kimchi* cabbage powder was used as the sample. Based on these results, CKC (91.95)

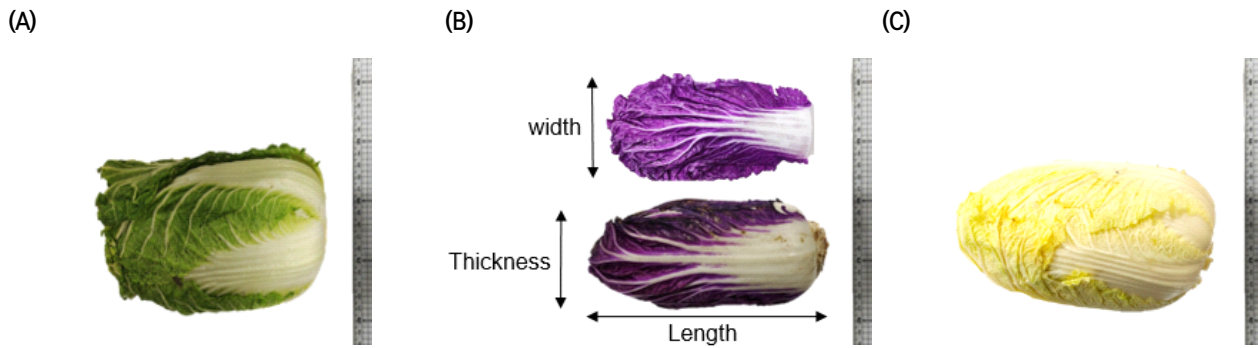


Fig. 1. Three kinds of *kimchi* cabbages (*Brassica rapa*, L. ssp. *pekinensis*). (A), common *kimchi* cabbage; (B), red *kimchi* cabbage; (C), gold *kimchi* cabbage.

Table 3. Morphological characteristics of *kimchi* cabbages (*Brassica rapa*, L. ssp. *pekinensis*)

Samples ¹⁾	Width (cm)	Length (cm)	Thickness (cm)
CKC	17.42±1.73 ^{a2)}	25.82±0.43 ^a	19.28±1.40 ^a
GKC	16.33±1.44 ^a	25.07±2.54 ^a	18.67±2.25 ^a
RKC	16.76±0.83 ^a	26.76±3.08 ^a	11.94±0.90 ^b

¹⁾CKC, common *kimchi* cabbage; GKC, gold *kimchi* cabbage; RKC, red *kimchi* cabbage.

²⁾Means (n=5, in triplicates) with different superscript small letters in the same column for the different types of *kimchi* cabbages are significantly different at p<0.05.

Table 4. Chromaticity of *kimchi* cabbages (*Brassica rapa*, L. ssp. *pekinensis*)

Samples ¹⁾	Chromaticity ²⁾		
	L	a	b
CKC	91.95±0.03 ^{a3)}	-7.55±0.02 ^c	20.34±0.03 ^b
GKC	87.04±0.03 ^b	0.22±0.02 ^b	29.86±0.05 ^a
RKC	63.99±0.04 ^c	9.31±0.02 ^a	-5.03±0.02 ^c

¹⁾CKC, common *kimchi* cabbage; GKC, gold *kimchi* cabbage; RKC, red *kimchi* cabbage.

²⁾L, lightness; a, redness; b, yellowness.

³⁾Means with different superscript small letters in the same column for the different types of *kimchi* cabbages are significantly different at p<0.05.

attained the highest value for lightness (L^a), RKC (9.31) for redness (a^a), and GKC (29.86) for yellowness (b^b). In purple cauliflower, anthocyanin accumulation is not limited to the outer cell layer (Chaves-Silva et al., 2018; Chiu and Li, 2012). It also occurs in the central region of the inflorescence meristem, near the vascular bundle, which explains its fairly high anthocyanin content. According to previous studies, RKC exhibits a high redness

because of its high anthocyanin content. In GKC, carotenoids may be responsible for its high yellowness. Various colors, from yellow to red to orange, depend on the conjugated double bonds and various functional groups present in the food. Moreover, color intensity is influenced by the esterification of carotenoids and fatty acids (Khoo et al., 2011), which may be the case for GKC, which had the highest yellowness value.

3.2. Content of major water-soluble vitamins (vitamin B₆ and B₉)

Table 5 lists the major water-soluble vitamins present in the three *kimchi* cabbage varieties. All results are presented on a dry weight basis (moisture content 92%). Vitamin B₆ (pyridoxine, pyridoxal, and pyridoxamine) is a cofactor in approximately 150 reactions regulating the metabolism of glucose, lipids, amino acids, DNA, and neurotransmitters (Mascolo and Verni, 2020). The vitamin B₆ content of the three varieties of *kimchi* cabbage was highest in the RKC (1,288.53 µg/100 g), followed by GKC (1,086.88 µg/100 g), and CKC (874.29 µg/100 g). Among the vitamin B₆ vitamers, pyridoxal was detected the most, ranging between 670.19–896.25 µg/100 g. Pyridoxal accounted for approximately 70–77% of the total vitamin B₆. Additionally, pyridoxamine ranged from 28.95–65.02 µg/100 g, which had the lowest composition ratio of about 3–6% of the total vitamin B₆. CKC contained the lowest levels of all three vitamers (pyridoxine, pyridoxal, and pyridoxamine). Therefore, the vitamin B₆ contents of RKC and GKC were 1.24 and 1.47 times higher than that of CKC, respectively.

Vitamin B₉ (folic acid) plays an important role as a coenzyme in several single-carbon transfer reactions and in the synthesis of DNA, RNA, and protein components (Ruggeri et al., 1999). It is also

involved in the prevention of cardiovascular diseases, growth, development, and reproduction. Particularly, pregnant women should consume twice the amount of vitamin B₉ to prevent deformities caused by neural tube defects. This has led to the United States mandating the use of folic acid fortified wheat flour (Bertuzzi et al., 2019). The lowest vitamin B₉ levels were attained by CKC, at 429.32 µg DFE/100 g flour. In contrast, RKC (776.70 µg DFE/100 g) and GKC (690.65 µg DFE/100 g) had 1.81 and 1.61 times higher vitamin B₉ levels. In a preliminary study, the moisture content of the three *kimchi* cabbage varieties was 92%. Based on this value, it can be assumed that fresh CKC, RKC, and GKC contain approximately 33.26 µg DFE/100 g, 62.14 µg DFE/100 g, and 55.25 µg DFE/100 g, respectively. The results of this study are similar to the reported folic acid content of CKC (34 µg DFE/100 g) (MFDS, 2023). For comparison, spinach is a good source of folic acid, which contains 170 µg DFE/100 g (MFDS, 2023). The assumed folic acid content of the freshly improved *kimchi* cabbage varieties was approximately 1/3 of the folic acid content of spinach, but 1.87 and 1.66 higher than the levels in CKC, respectively. Pan et al. (2019) compared the vitamin B₉ content of different sweet potato varieties, finding that varieties with darker yellow- and orange-colored flesh show significantly higher values than those

Table 5. Vitamin B₆ and B₉ contents of *kimchi* cabbages (*Brassica rapa*, L. ssp. *pekinensis*) (dry weight basis)

Samples ¹⁾	Vitamin B ₆ contents (µg/100 g)				Vitamin B ₉ contents (µg DFE/100 g)
	Pyridoxine	Pyridoxal	Pyridoxamine	Total vitamin B ₆ ³⁾	Total vitamin B ₉ ⁴⁾
CKC	175.15±1.56 ^{c2)}	670.19±3.69 ^c	28.95±0.99 ^c	874.29±4.66 ^c	429.32±11.02 ^c
GKC	261.92±2.32 ^b	759.93±3.35 ^b	65.02±1.31 ^a	1,086.88±5.14 ^b	690.65±26.29 ^b
RKC	346.49±4.86 ^a	896.23±3.16 ^a	45.81±0.93 ^b	1,288.53±6.13 ^a	776.70±25.84 ^a

¹⁾CKC, common *kimchi* cabbage; GKC, gold *kimchi* cabbage; RKC, red *kimchi* cabbage.

²⁾Means with different superscript small letters in the same column for the different types of *kimchi* cabbages are significantly different at p<0.05.

³⁾The total vitamin B₆ content is sum of the pyridoxine, pyridoxal, and pyridoxamine contents.

⁴⁾The total vitamin B₉ content is expressed as dietary folate equivalents (DFE). DFE = µg of natural food folate + (1.7 × µg folic acid).

with light flesh.

3.3. Content of fat-soluble vitamins (vitamin A, E and K)

Table 6 shows the fat-soluble vitamin content of the three *kimchi* cabbage varieties. Vitamin A is mainly present in the form of retinols in animal foods and in the form of β -carotenoids in plant foods (Underwood and Arthur, 1996). β -carotene is a precursor of carotenoids and is converted to vitamin A when ingested. In this study, the β -carotene content of *kimchi* cabbage was analyzed and expressed as the vitamin A content. The highest values were attained in GKC (907.12 $\mu\text{g}/100\text{ g}$), which was approximately 3.2 times higher than that of CKC (279.76 $\mu\text{g}/100\text{ g}$). On the other hand, the β -carotene content of RKC (157.87 $\mu\text{g}/100\text{ g}$) was lower than that of CKC. Ruiz et al. (2005) reported a strong correlation between color values and total carotenoid content. At least 1,000.86% higher β -carotene content was observed in orange apricot flesh cultivars with higher yellowness than in white apricot flesh cultivars. It has been proven that the β -carotene content can vary depending on the color of fruits and vegetables. Seong et al. (2018) reported differences in the content of carotenoid components in each part of *kimchi* cabbage, being highest in the

outer, middle, and inner leaves and a strong correlation with beta-carotene contents. Even in the same *kimchi* cabbage, the colors of the outer and inner leaves were different, resulting in different β -carotene values.

Vitamin E collectively refers to tocopherols or tocotrienols. The eight isomers are divided into α -, β -, γ -, and δ -tocopherols and tocotrienols according to the position and number of methyl groups (Kamal-Eldin and Appelqvist, 1996). In this study, the vitamin E homologs δ -T, β -T₃, γ -T₃, and δ -T₃ were not detected in any of the three *kimchi* cabbage varieties, whereas α -T was confirmed to exist as the major form of vitamin E. The β -T and γ -T showed high contents in the decreasing order of CKC, RKC, and GKC. On the other hand, α -T was highest in the order of RKC (3.74 mg/100 g), CKC (3.14 mg/100 g), and GKC (1.34 mg/100 g). On the contrary, GKC (0.04 mg/100 g) had the highest α -T₃. Furthermore, the α -TE was calculated by considering the *in vivo* biological activity of the vitamin E homologs. Results showed that CKC obtained 4.9 mg α -TE/100 g (highest), while GKC attained 1.8 mg α -TE/100 g (lowest), making the α -TE of CKC three times higher compared to GKC. Vitamin E is mainly present in plant cell membranes.

Table 6. Vitamin A, E and K contents of *kimchi* cabbages (*Brassica rapa*, L. ssp. *pekinensis*) (dry weight basis)

Samples ¹⁾	Vitamin A ($\mu\text{g}/100\text{ g}$)	Vitamin E (mg/100 g)								Vitamin K ($\mu\text{g}/100\text{ g}$)	
	β -Carotene	α -T ²⁾	β -T	γ -T	δ -T	α -T ₃ ³⁾	β -T ₃	γ -T ₃	δ -T ₃	α -TE ⁴⁾	Phylloquinone
CKC	279.76±16.13 ^{b5)}	3.14±0.14 ^b	3.47±0.20 ^a	0.24±0.01 ^a	- ⁶⁾	0.03±0.00 ^b	-	-	-	4.9 ^a	283.10±42.14 ^b
GKC	907.12±22.60 ^a	1.34±0.01 ^c	0.90±0.01 ^c	0.08±0.00 ^c	-	0.04±0.00 ^a	-	-	-	1.8 ^c	712.17±3.05 ^a
RKC	157.87±8.66 ^c	3.74±0.11 ^a	1.70±0.03 ^b	0.13±0.00 ^b	-	0.03±0.00 ^b	-	-	-	4.6 ^b	155.51±12.21 ^c

¹⁾CKC, common *kimchi* cabbage; GKC, gold *kimchi* cabbage; RKC, red *kimchi* cabbage.

²⁾T, tocopherol.

³⁾T₃, tocotrienol.

⁴⁾Vitamin E activity is expressed as mg α -tocopherol equivalent (α -TE)/100 g. α -TE = (α -T × 1.0) + (β -T × 0.5) + (γ -T × 0.1) + (δ -T × 0.01) + (α -T₃ × 0.3) + (β -T₃ × 0.05).

⁵⁾Means with different superscript small letters in the same column for the different type *kimchi* cabbages are significantly different at p<0.05.

⁶⁾-, not detected.

It is also an antioxidant that prevents the peroxidation of fatty acids, lowers cholesterol, and prevents chronic diseases such as cardiovascular diseases (Hill, 1998). According to the 2020 Dietary Reference Intake for Koreans, the required intake of vitamin E for adult males is 12 mg α -TE, and the upper limit of intake is 540 mg α -TE (KDRIs, 2020). Koreans frequently eat *kimchi* cabbage, which means that consuming the three varieties of *kimchi* cabbage can achieve sufficient intake. In this study, we proved that three varieties of *kimchi* cabbage are sources of vitamin E.

Vitamin K is a fat-soluble vitamin that regulates the synthesis of sphingolipids, which are important for cellular events such as proliferation, differentiation, senescence, and cell-cell interactions (Ferland, 2012). In nature, vitamin K exists in two forms, K₁ (phylloquinone) and K₂ (menaquinone) (Booth, 2009). The main sources of phylloquinone are dark-green leafy vegetables and vegetable oils, including canola, soybeans, and olives (Booth and Suttie, 1998) whereas menaquinone is produced by microorganisms. This vitamin is present in trace amounts in meat and fermented foods. The phylloquinone content in this study showed a significant difference according to the variety of *kimchi* cabbage. Phylloquinone content was highest in GKC (712.17 μ g/100 g), followed by CKC (283.10 μ g/100 g) and RKC (155.51 μ g/100 g). Moreover, GKC levels were 2.5 times higher value than those of CKC, which can be attributed to the occurrence of phylloquinone in green leafy vegetables. Phylloquinone serves as an essential electron carrier in photosynthesis and as an electron acceptor for protein disulfide bond formation (Basset et al., 2017). Its biosynthesis occurs in the inner membrane of chloroplasts (Schultz et al., 1981). Morelli et al. (2022) reported that the exposure of leaves to strong light promoted carotenoid

accumulation and accelerated the yellowish color transition in chloroplasts. Thus, the vitamin K content was consistent with the yellowness value.

3.4. Antioxidant properties

Table 7 shows the antioxidant activity, total polyphenol, and total flavonoid content of the three *kimchi* cabbage cultivars. There was no significant difference on the antioxidant activity (DPPH and ABTS radical-scavenging activities) of GKC and CKC. However, RKC exhibits significantly enhanced antioxidant properties. The DPPH radical scavenging activity of RKC was 7,249.26 μ g GAE/g, and the ABTS radical scavenging activity was 99.00 mg AEE/g. These values show that RKC has approximately 12 times higher DPPH radical scavenging activity and approximately 25 times higher ABTS radical scavenging activity than CKC. RKC had the highest total polyphenol (70.35 mg GAE/g) and flavonoid content (16.92 μ g QE/g), which was 3.3 and 7.7 times higher than CKC, respectively. Additionally, the total polyphenol content (18.53 mg GAE/g) and total flavonoid content (1.33 μ g QE/g) of GKC were significantly lower than CKC ($p < 0.05$). However, there was little numerical difference. The rankings of total flavonoid and total polyphenol contents by variety were similar. Shin et al. (2014) reported that flavonoids exhibit similar trends in their content distribution characteristics because they are phenolic compounds.

The damage caused by free radicals and reactive oxygen species (ROS) in the body is associated with neurodegenerative disorders and cancer. To prevent this, the consumption of fruits and vegetables rich in polyphenols and flavonoids is recommended (Floyd, 1999; Goodwin and Brodwick, 1995; Youdim and Joseph, 2001). In particular, *kimchi* cabbage contains abundant antioxidant flavonols, such as

Table 7. Antioxidant properties of *kimchi* cabbages (*Brassica rapa*. L. ssp. *pekinensis*) (dry weight basis)

Samples ¹⁾	Antioxidant activities		Antioxidant components	
	DPPH radical scavenging activity ($\mu\text{g GAE}^2/\text{g}$)	ABTS radical scavenging activity ($\text{mg AEE}^3/\text{g}$)	Total polyphenol content ($\text{mg GAE}/\text{g}$)	Total flavonoid content ($\mu\text{g QE}^4/\text{g}$)
CKC	621.66 \pm 16.67 ^{b5)}	3.99 \pm 0.09 ^b	21.44 \pm 0.33 ^b	2.19 \pm 0.04 ^b
GKC	811.59 \pm 5.33 ^b	3.35 \pm 0.05 ^b	18.53 \pm 0.30 ^c	1.33 \pm 0.29 ^c
RKC	7,249.26 \pm 211.03 ^a	99.00 \pm 0.16 ^a	70.35 \pm 1.24 ^a	16.92 \pm 0.29 ^a

¹⁾CKC, common *kimchi* cabbage; GKC, gold *kimchi* cabbage; RKC, red *kimchi* cabbage.

²⁾GAE, gallic acid equivalent.

³⁾AEE, ascorbic acid equivalent.

⁴⁾QE, quercetin equivalent.

⁵⁾Means with different superscript small letters in the same column for the different types of *kimchi* cabbages are significantly different at $p < 0.05$.

hydroxy-benzoic acid, hydroxy-cinnamic acid, kaempferol, and quercetin (Ku et al., 2007). Seong et al. (2016) measured the antioxidant activity and content of *kimchi* cabbage by dividing it into outer, middle, and inner leaves. Based on these results, outer leaves had the highest antioxidant properties, followed by the middle and inner leaves. This confirmed that antioxidant content is related to antioxidant activity. Naturally occurring pigments, such as anthocyanins, chlorophyll, and carotenoids, are antioxidant components involved in the leaf coloration of vegetables (Cai et al., 2003; Escribano et al., 1998). The color of the leaves of the RKC cultivar analyzed in this study were reddish-purple. This is thought to have contributed greatly to the increase in its antioxidant capacity, because it contains higher amounts of anthocyanin pigments.

4. Summary

In this study, the physical (size and color), functional (antioxidant activity and total polyphenol and flavonoid contents), and nutritional (water- and fat-soluble vitamins) characteristics of GKC and RKC were analyzed and compared to CKC. There were no significant differences in physical properties based on the thickness and length of the three

kimchi cabbages, although the outer leaves of RKC were significantly narrower than those of CKC and GKC. However, significant differences in functional and nutritional properties among the three varieties of *kimchi* cabbages were observed ($p < 0.05$). RKC which appears to be purple was found to have higher water-soluble vitamin contents (B_6 and B_9), DPPH and ABTS radical scavenging activities, and total polyphenol and flavonoid contents compared to CKC and GKC. In contrast, GKC appearing in yellow color was higher in fat-soluble vitamins, A and K, than the other varieties. Overall, red- and yellow-colored *kimchi* cabbages (RKC and GKC, respectively) were observed to contain higher water- and fat-soluble vitamins and antioxidant activities than CKC. *Kimchi* cabbage is primarily used in the *kimchi* industry. However, given that the colored *kimchi* cabbages has higher nutrient contents, this could have a great potential to be used in various food products in the future. These data analyzed by the National Reference Standard Center (National Food Composition Data Center) would be used to update the National Food Composition Table. This center performs analyses, method verification, and quality control to establish a national food and nutritional component database. In the future, if profile data such as polyphenols, flavonoids,

anthocyanins, and carotenoids of colored-*kimchi* cabbages are established, health functionalities of colored *kimchi* cabbages could be more extensively evaluated.

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Conflict of interests

The authors declare no potential conflicts of interest.

Author contributions

Methodology: Lee KH, Hong WH. Formal analysis: Lee KH, Oh S, Hong WH. Validation: Lee KH, Hong WH. Writing - original draft: Lee KH. Writing - review & editing: Lee KH, Chun J.

Ethics approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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