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Phytochemicals and antioxidant activity in four varieties of head cabbages commonly consumed in China

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Abstract

Head cabbage (*Brassica oleracea var. capitata*) is a cruciferous leafy vegetable consumed commonly in China. It has been suggested that diets rich in cabbages play an important role in disease prevention. The phytochemicals as well as antioxidant activity of four typical varieties of head cabbages in China were systematically investigated. Sinapic acid was the most abundant phenolic acid in all samples followed by iso-ferulic acid. Most phenolic acids in red head cabbage were significantly higher than in other head cabbages. The 5-CH_3-H_4 folate contents in all samples were much higher than folate. Conical head cabbage contained the highest amount of folic acids while red head cabbage had the lowest. Cyanidin was the only anthocyanidins found in red head cabbage with the content of 44.52 mg 100 g^{-1} fresh weight (fw). Total isothiocyanates in flat head cabbage was significantly higher than other head cabbages. Red head cabbage had the significant the highest level of total phenolics and flavonoids with the values of 153.94 mg gallic acid equivalents·100 g^{-1} and 51.32 mg rutin equivalents·100 g^{-1}, respectively, while flat head cabbage had the lowest level. Red head cabbage exhibited the highest antioxidant activity as measured by 1, 1-diphenyl-2-picryl-hydrazyl (DPPH) and 2, 2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) radical scavenging and ferric ion reducing antioxidant power (FRAP) assays with the values of 69.82, 87.23% and 0.53, respectively. The study suggests that different varieties of head cabbages have different nutritional advantages, and provides useful information to recommend the right head cabbages for consumers.

Keywords: Head cabbage, Phytochemical, Antioxidant activity, Phenolic acid, Folic acid

Practical application

This study provides a meaningful reference for consumers to choose the right head cabbages. Different consumers need different nutrients based on their physical condition. The study substantiated that the different varieties of head cabbages have their own nutritional advantages and it is useful for recommending the right head cabbages for different consumers. It is also useful for farmers to plant the head cabbages with high contents of phytochemicals and antioxidant activity. Among the varieties of head cabbages, red head cabbage had the highest contents of phenolic acids, anthocyanins, total phenolics and flavonoids, as well as the highest antioxidant activity; conical head cabbage contained the highest amount of folic acids; flat head cabbage had the highest level of total isothiocyanates from precursor compounds.

Introduction

Cabbages have proven to be beneficial for health by numerous epidemiological and clinical studies (Podsędek 2007; Cartea and Velasco 2008). High intake of cabbages for consumers could reduce the risk of degenerative diseases, age-related chronic illnesses (Kris-Etherton et al. 2002) and several types of cancer (Wang et al. 2004; Björkman et al. 2011). The presence of vitamins, provitamins, such as folic acids, and a wide variety of phenolic substances and organo-sulfur compounds are considered to be contributory factors (Khanam et al. 2012; Cartea and Velasco 2008). Phenolic substances are correlated with the antioxidant activity in many studies (Leja et al. 2010), cabbages have also proved to

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have higher antioxidant activity than many other vegetables such as capsicum, carrot, cucumber, gourd and so on (Isabelle et al. 2010).

There are many reports about the phenolic substances and antioxidant activity of cabbage, many of them have focused on the Chinese cabbage or the red cabbage (Ahmadiani et al. 2014). Seong et al. (2016) studied the antioxidant capacities and polyphenolics of Chinese cabbage leaves, Watanabe et al. (2011) investigated the polyphenol content and antioxidant activity of orange-colored Chinese cabbage. Mizgier et al. (2016) reported the characterization of phenolic compounds and antioxidant properties of red cabbage. Leja et al. (2010) found phenolic compounds as the major antioxidant in red cabbage. Nonetheless, the systematic analysis of phytochemicals in cabbages and the comparisons between the different cabbage varieties were limited.

Head cabbage (*Brassica oleracea var. capitata*) considered to be originated from China, has been cultivated for a long period (King and Zhang 1996). They play an important role in the diet in Asian countries, especially in China. The production of cabbages and other brassicas were more than 33.88 million tons in China in 2016, it is almost 20% of total vegetable production according to the Food and Agriculture Organization of the United Nations. The head cabbage commonly consumed in China can be classified into four groups based on the shape and color: red head cabbage (*Brassica oleracea var. capitata f, rubra*), conical head cabbage (*Brassica oleracea var. capitata f, acuta*), ball head (round head) cabbage (*Brassica oleracea var. capitata f, alba*), and flat head (drum head) cabbage (*Brassica oleracea var. capitata f, linn*).

The present study selected four varieties of head cabbage mentioned above and investigated the phytochemicals and antioxidant activity. The total polyphenol content, total flavonoid content, phenolic acids, folic acids, and total isothiocyanates were determined to clarify the phytochemical profiles. The antioxidant activity were evaluated using DPPH, ABTS and FRAP assays based on their simplicity and widespread application (de Camargo et al. 2019). The findings of this research will improve the understanding of nutrition of head cabbages for food nutritionists and consumers.

Materials and methods

Reagents

The standards of phenolic acids, cyaniding 3-glucoside, folic acids and rutin, 1, 1-diphenyl-2-picryl-hydrazyl (DPPH), 2, 2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) and 2, 4, 6-tris (2-pyridyl)-S-triazine (TPTZ) of analytical grade were obtained from Sigma-Aldrich Co. (St. Louis, MO, USA). Formic acid, hydrochloric acid, benzenedithiol, dichloromethane, ferric chloride and Folin–Ciocalteu's phenol reagent were purchased from Sinopharm Chemical Reagent Co. (Shanghai, China). Methanol and acetonitrile of high performance liquid chromatography (HPLC) grade were from Anpel Laboratory Technologies Inc. (Shanghai, China). Water was purified in a Milli-Q water purification system (Millipore, Burlington, MA, USA).

Instruments

Phenolic acids were determined by Agilent 1200 Series HPLC (Agilent, CA, USA) and Agilent 6410A triple quadrupole mass spectrometer coupled with Agilent G1948B Electrospray Ionization (ESI) (Agilent, Santa Clara, CA, USA). Agilent 6410 Quantitative Analysis data processing software was used to employ the data. Folic acids and total isothiocyanates were determined by Agilent 1200 Series HPLC equipped with diode-array detector (Agilent, Santa Clara, CA, USA). The absorbance was recorded by Alpha-1506 ultraviolet and visible spectrophotometer for the determination of total anthocyanins, phenolics, flavonoids and antioxidant activity (Puyuan, Shanghai, China).

Plant materials and sampling

Four varieties of head cabbages were purchased from local farm in Jiangsu province, which were major cabbage producing areas. The cabbages were transported under cooling conditions. When arrived at the lab, the cabbages were cleaned and cut into small pieces, frozen in liquid nitrogen and stored at − 80 °C until use. Sixty-four samples were collected to get results more representative.

Phenolic acids determination

The sample preparation for determination of free and bound phenolic acids was conducted according to the methods of Zhang et al. (2019). Two grams samples were extracted by 20 mL of 80% methanol aqueous solution containing 0.2% vitamin C. After vortex oscillation for 10 s, the samples were ultrasonicated for 30 min at room temperature and then centrifuged at 8000×g for 5 min in a high-speed refrigerated centrifuge. The supernatant was moved to a 50 mL volumetric flask. After repeating extraction, two supernatants were mixed. Before analysis, the volume of the combined supernatants was adjusted to 50 mL by adding water and passed through a 0.22 μm microporous membrane for free phenolic acids determination. The extraction after centrifugation in above was moved to a 150 mL conical flask, treated with 20 mL of 4 M aqueous NaOH, and then purged with N_2. The mixed solution was hydrolyzed at 40 °C for 2 h in a gas bath with shaking and protection from light. The pH value was adjusted to 2 by adding 4M HCl. The mixture was shaken with 20 mL of n-hexane at room temperature for 20 min to remove the n-hexane layer. Ethyl acetate (2 × 20 mL) was used to

extract the aqueous layer, and the mixed extracts were concentrated to nearly dry on a rotary evaporator at 35 °C under reduced pressure. Before analysis, the residue was dissolved in 10 mL of 50% methanol/water and passed through a 0.22 μm microporous membrane for bound phenolic acids determination.

The phenolic acids were determined by liquid chromatography and electrospray ionization mass spectrometry (HPLC-ESI-MS/MS) on the basis of the method described by Oniszczuk and Olech (2016) with slight modifications. Phenolic acids were separated on XDB C_{18} (4.6 mm × 150 mm, 5 μm) at 25 °C. The eluent was consisted of solvent A (water containing 0.1% formic acid) and solvent B (methanol containing 0.1% formic acid). The gradient elution program was as follows: 0–1 min, solvent B from 0 to 5%; 2–4 min, solvent B from 5 to 20%; 8–9.5 min, solvent B from 20 to 70%; 11.5–15 min, solvent B from 70 to 5%. The flow rate was 400 μL·min^{-1}. Mass spectrometer equipped with an ESI and a triple quadrupole-ion trap mass analyzer. The ESI interface was operated in the negative-ion mode.

Folic acids determination

Folic acids including 5-CH_3-H_4 folate (C20H25N7O6, MW 459.46) and folate (C19H19N7O6, MW 441.40) were extracted and analysed following the method from Shohag et al. (2012) with slight modification. Five gram sample was freeze-dried and placed in a 50 mL centrifuge tube with 25 mL 0.1 mol·L^{-1} phosphate buffer adding to it, then blew by nitrogen for 15 s and capped to protect the folic acids. The centrifuge tube was put into water bath at 90 °C for 10 min, then cooled rapidly on ice and centrifuged at the speed of 26,900 g for 5 min. After filtration through a 0.2 μm membrane, the solution was kept in brown bottle and determined by liquid chromatography. The separation was performed on a column of Zorbax SB-C_{18} (4.6 × 150 mm, 5 μm) with 25 °C of column temperature. The flow rate was 0.4 mL/min, and the injection volume was 20 μL. The gradient elution process was started at 6% acetonitrile + 94% phosphate buffer and maintained for 5 min, then adjusted to 25% acetonitrile + 75% phosphate buffer in 25 min and maintained for 2 min. The detection wavelength was 285 nm.

Anthocyanidins determination

Anthocyanidins including cyanidin, delphinidin, pelargonidin, paeonidin, malvidin and petunidin were determined by liquid chromatography (LC). Samples were placed in high-speed freezing grinder and grinded with liquid nitrogen for 1 min. Five grams crushed samples was added with 20 mL ethanol-water solution (V/V, 3:2) containing of 3 mol/L HCl and extracted by ultrasonic for 40 min, then centrifuged at 26900 g for 2 min. The upper layer was was hydrolyzed in boiling water bath for 1 h, then cooled immediately and filtered by 0.45 μm microporous membrane for LC determination. The chromatographic column is Agilent ZORBAX SB-C18 (150 mm × 4.6 mm, 5.0 μm), column temperature is 35 °C, the wavelength of UV detector is 525 nm. The eluent was consisted of solvent A (water containing 0.1% formic acid) and solvent B (acetonitrile containing 0.1% formic acid). The gradient elution program was as follows: 0–10 min, solvent B from 0 to 20%; 10–20 min, solvent B from 20 to 80%; 20–30 min, solvent B from 80 to 0%. The flow rate was 800 μL·min^{-1}.

Total isothiocyanates determination

Total isothiocyanates were determined following the method of Totušek et al. (2011) with modifications. Two grams grounded sample were added with 10 mL deionized water and left to hydrolyze for 3 h in 40 °C water bath. 0.5 mL hydrolysis product were added with 5 mL methanol, 4 mL of 0.2 mol·L^{-1} sodium borate and 1 mL of 7 mmol·L^{-1} benzenedithiol and kept in 65 °C water bath for 1 h. The reagent was extracted with 5 mL of dichloromethane and then the upper fraction collected. The procedure was repeated three times. The dichloromethane fractions were combined and filtered through 0.2 μm membrane. The total isothiocyanates content was measured using HPLC. The chromatographic system consisted of XDB C_{18} (4.6 mm × 150 mm, 5 μm) operated isocratically with 70% methanol in water at a flow rate of 1.0 mL·min^{-1} for 10 min. The eluates were monitored with a UV detector at 365 nm. A standard curve was generated from measurements using varying amounts of sulforaphane (SF) to estimate the amount of isothiocyanates in test samples.

Total phenolics determination

Total phenolic content was determined using the Folin-Ciocalteau reagent according to previous published procedures (Cai et al. 2004). Data were expressed as milligram gallic acid equivalents (GAE) per gram of fresh weight.

Total flavonoids determination

Total flavonoid content was measured by a previous method (Seong et al. 2016). The results were expressed as milligram rutin equivalents (RE) per gram of fresh weight.

Antioxidant activity determination

Sample preparation

The head cabbage samples were ground to powder using high speed grinding machine. 100 mL of 75% ethanol was mixed with 2 g sample and refluxed for 30 min. Then the mixture was cooled to room temperature, the

clear supernatant was got through filtration. The supernatant was stored at 4 °C and used within 24 h.

DPPH radical scavenging assay

The DPPH radical scavenging activity was measured using the method described by Borneo et al. (2009) with slight modifications. 3 mL of 0.003% ethanol solution of DPPH was mixed with 0.5 mL extracts and incubated in dark at room temperature for 30 min. The absorbance was measured at 517 nm. The percentage of DPPH radical inhibition was calculated as follows:

$$\text{Inhibition of DPPH radical}\,(\%) = [(A_{control} - A_1)/A_{control}] \times 100$$

where $A_{control}$ is the absorbance of the DPPH solution, and A_1 is the absorbance of the mixture of DPPH solution and cabbage extract.

ABTS radical scavenging assay

The ABTS radical scavenging activity was carried out according to Liang et al. (2015). 7 mmol·L^{-1} ABTS stock solution was reacted with 2.45 mmol·L^{-1} potassium persulfate to produce the ABTS radical cation. The mixture was stand in the dark for 16 h. 80% ethanol was used to dilute the ABTS radical cation solution to the absorbance of 0.700 ± 0.02 at 734 nm. 0.5 mL extracts was mixed thoroughly with 2 mL ABTS radical cation solution (absorbance of 0.700 ± 0.02) and stood at room temperature for 6 min. Then the UV spectrophotometer was used immediately to record the absorbance at 734 nm. The inhibition percentage of ABTS radical was calculated according to the formula:

$$\text{Inhibition of ABTS radical}\,(\%) = (1 - A_1/A_{control}) \times 100$$

where $A_{control}$ is the absorbance of the control solution (containing only ABTS), and A_1 is the absorbance in the presence of the cabbage extracts.

Ferric ion reducing antioxidant power (FRAP) assay

The FRAP assay was performed using the method described by Benzie and Strain (1996). FRAP reagent were consisted of 0.3 mol·L^{-1} acetate buffer (pH 3.6), 20 mmol·L^{-1} $FeCl_3$ solution and 10 mmol·L^{-1} TPTZ solution in 40 mmol·L^{-1} HCl in proportions of 10: 1: 1 (v/v/v). The reagent was warmed to 37 °C in water bath. 200 μL FRAP reagent mixed with 5 μL sample was incubated at 37 °C for 10 min. UV spectrophotometer was used to measure the absorbance at 593 nm. All the solutions were prepared before using.

Statistical analysis

Microsoft Excel was used to perform the statistical analysis. The data were expressed as means of replicate± standard deviation. There were 18 samples for red head cabbage and ball head cabbage, respectively, 12 samples for conical head cabbage and 16 samples for flat hand cabbage. If the difference level of $p<0.05$, it was considered significant.

Results and discussion

Phenolic acids in cabbages

The contents of phenolic acids are the sum of free and insoluble-bound phenolic acids and shown in Table 1. Gallic acid, 3, 5-dihydroxy-benzoic acid, chlorogenic acid, caffeic acid, sinapic acid, ferulic acid, iso-ferulic acid and *p*-coumaric acid are added together and expressed as sum of phenolic acids.

The results in Table 1 revealed that sinapic acid was the most abundant phenolic acid in all samples ranged from 635.90 to 12,736.82 μg·g^{-1} fw, followed by iso-ferulic acid ranged from 415.63 to 3482.20 μg·g^{-1} fw, then 3, 5-dihydroxy-benzoic acid and ferulic acid in red head cabbage, ferulic acid and 3, 5-dihydroxy-benzoic acid in other head cabbages. Most phenolic acids except *p*-coumaric acid and chlorogenic acid in red head cabbage were significantly higher than in other head cabbages, especially for 3, 5-dihydroxy-benzoic acid, caffeic acid, ferulic acid and sinapic acid, which represent 10 to 40-fold difference between red and other head cabbages. Sum of phenolic acids in red head cabbage was of 19,124.60 μg·g^{-1} fw and significantly higher than other head cabbages. Phenolic acids were no significant differences among flat, ball and conical head cabbages except chlorogenic acid.

There have been several researches about the composition of phenolic acids in Brassica species, but in *Brassica oleracea* var. capitate groups were limited. Mizgier et al. (2016) identified 21 hydroxycinnamic acid derivatives rather than hydroxylbenzoic acids in red cabbage extract which mainly include *p*-coumaric, ferulic and sinapic acids or their hydrated forms. *p*-coumaric, ferulic and sinapic acids were also found in our study with hydroxylbenzoic acids including gallic acid and 3, 5-dihydroxy-benzoic acid. According to the report of Velasco et al. (2011), sinapic acid was presented in higher quantities in *B. napus* than in *B. oleracea* crops. Mattila and Hellström (2007) determined the contents of phenolic acids in many vegetables consumed in Finland and found sinapic acid was the dominating phenolic acid in Brassica vegetables with the content almost 10-fold higher in red head cabbage than in ball head cabbage. This finding is in agreement with our studies.

Table 1 The contents of phenolic acids in cabbage samples

Cabbages	Moisture content (%)	Phenolic acids (μg·g^{-1} fw)								
		Gallic acid	3, 5-Dihydroxy-benzoic acid	Chlorogenic acid	Caffeic acid	Sinapic acid	Ferulic acid	Iso-ferulic acid	*p*-Coumaric acid	Sum of phenolic acids
Red head cabbage *B. o. var. capitata f, rubra*	91.79 ± 0.77^{a}	0.90 ± 0.28 ^{a}	1417.78 ± 251.35 ^{a}	2.45 ± 1.34 ^{a}	98.78 ± 26.99 ^{a}	12,736.82 ± 2373.25 ^{a}	1378.08 ± 169.05 ^{a}	3482.20 ± 264.87 ^{a}	7.59 ± 2.51 ^{a}	19,124.60 ± 2618.45 ^{a}
Flat head cabbage *B. o. var. capitata f, linn*	92.08 ± 0.65^{a}	0.24 ± 0.15 ^{b}	44.21 ± 8.25 ^{b}	4.39 ± 2.01 ^{a}	4.67 ± 1.32 ^{b}	787.15 ± 271.62 ^{b}	75.02 ± 18.75 ^{b}	512.32 ± 164.23 ^{b}	21.79 ± 1.23 ^{b}	1449.73 ± 328.24 ^{b}
Ball head cabbage *B. o. var. capitata f, alba*	92.49 ± 0.59^{a}	0.07 ± 0.05 ^{b}	43.99 ± 6.30 ^{b}	2.51 ± 1.77 ^{a}	4.04 ± 1.05 ^{b}	976.45 ± 276.12 ^{b}	88.18 ± 12.47 ^{b}	478.72 ± 90.82 ^{b}	17.86 ± 8.08 ^{ab}	1611.80 ± 346.64 ^{b}
Conical head cabbage *B. o. var. capitata f, acuta*	92.76 ± 0.86^{a}	0.16 ± 0.06 ^{b}	42.84 ± 15.18 ^{b}	0.09 ± 0.08 ^{b}	2.45 ± 1.24 ^{b}	635.90 ± 47.64 ^{b}	88.15 ± 12.80 ^{b}	415.63 ± 177.23 ^{b}	22.72 ± 8.52 ^{b}	1207.92 ± 71.23 ^{b}

Data expressed as means ± standard deviation. Different letters in each column mean significant differences ($p < 0.05$)

Folic acids in cabbages

Folic acids in different forms are present in a wide range of food, especially in leafy vegetables (Devi et al. 2008). The contents of 5-CH_3-H_4 folate ($C_{20}H_{25}N_7O_6$, MW459.46) and folate ($C_{19}H_{19}N_7O_6$, MW441.40) which have been proved to be the predominant folate classes in leafy vegetables were determined and presented in Table 2. The 5-CH_3-H_4 folate contents in cabbages were all much higher than folate. Conical head cabbage was possessed of the highest 5-CH_3-H_4 folate and folate content which were 80.44 and 41.37 μg·100 g^{-1} fw, respectively. Meanwhile, red head cabbage was possessed of the lowest 5-CH_3-H_4 folate and folate content which were 63.13 and 29.41 μg·100 g^{-1} fw, respectively. Folic acids in conical head cabbage were significantly higher than in red head cabbage. The contents of sum of folic acids ranged from 93.54 to 121.84 μg·100 g^{-1} in all cabbages.

According to the report of Shohag et al. (2012), 5-CH_3-H_4 folate was the major individual vitamer found in cabbage using monoenzyme treatment, which was in line with our study. Holasová et al. (2008) found there was 16 μg·100 g^{-1} fw 5-CH_3-H_4 folate in white cabbage using trienzyme method. Devi et al. (2008) have reported that the total folates in Chinese cabbage (Brassica chinensis.) were 81 μg·100 g^{-1} fw. The study of Iwatani et al. (2003) showed the total folate was 68 μg·100 g^{-1} fw in cabbage by microbiological assay. In general, the folic acids values obtained from the current study were higher than the folic acid values reported in the literature. The probable reason for this is not only the variation in variety, season, and climate (Devi et al. 2008), but the differences in analytical procedures (Hefni et al. 2010). There were so many cabbage varieties planted and consumed in China, four varieties in *Brassica oleracea var. capitata* group were analyzed in the present study. The results indicate that cabbages in green color are better sources of total folates than in red color.

Anthocyanidins, isothiocyanates, phenolics and flavonoids in cabbages

Besides of phenolic acids and folic acids, anthocyanidins, isothiocyanates, phenolics and flavonoids in cabbages were also analyzed and presented in Table 3. Cyanidin was the only anthocyanidins found in red head cabbage with the content of 44.52 mg 100 g^{-1} fw. It is in accordance with the results of Wieslaw et al. (2013).

Total isothiocyanates of 7.07 mg SF·100 g^{-1} in flat head cabbage was significantly higher in other three varieties of cabbages. There were no significant differences in the contents of total isothiocyanates among the red head, ball head and conical head cabbage. Tang et al. (2013) investigated the total isothiocyanate yield from raw cruciferous vegetables consumed in the United States and found a wide range from 0.5 to 77.9 μmol·100 g^{-1} (0.089 to 13.81 mg SF·100 g^{-1}) of total isothiocyanates was observed across the cabbages which may be attributed to genetic and environmental factors. The different varieties of cabbage samples in present study were collected at the same season and the same place. The contents of total anthocyanins in cabbages were in the range of the study of Tang et al. (2013).

Red head cabbage had the significant highest level of total phenolics (153.94 mg GAE·100 g^{-1}) and flat head cabbage had the lowest level (86.64 mg GAE·100 g^{-1}). There were no significant difference between ball head and conical head cabbages. Isabelle et al. (2010) analyzed the total phenolic contents of common vegetables in Singapore and found they varied widely across different vegetables even different cabbages. The highest content of total phenolics (186 mg GAE·100 g^{-1}) was found in red cabbage among many varieties of cabbages. Podsędek et al. (2006) reported that red cabbage had the highest total phenolics of 171.36 compared with white cabbage and savoy cabbage. The results of the present study are generally in agreement with previous reports.

The content of total flavonoids in red head cabbage (51.32 mg RE·100 g^{-1}) was significantly higher than

Table 2 The contents of folic acids in cabbage samples

Cabbages	Folic acids (μg·100 g^{-1} fw)		
	5-CH_3-H_4 folate	Folate	Sum of folic acids
Red head cabbage *B. o. var. capitata f, rubra*	63.13 ± 5.63 ^{b}	29.41 ± 6.70 ^{b}	93.54 ± 5.44 ^{b}
Flat head cabbage *B. o. var. capitata f, linn*	64.60 ± 15.51 ^{ab}	40.26 ± 7.07 ^{a}	103.85 ± 12.23 ^{ab}
Ball head cabbage *B. o. var. capitata f, alba*	72.30 ± 6.50 ^{ab}	39.72 ± 4.19 ^{a}	112.02 ± 4.97 ^{a}
Conical head cabbage *B. o. var. capitata f, acuta*	80.44 ± 4.97 ^{a}	41.37 ± 8.27 ^{a}	121.84 ± 9.78 ^{a}

Data expressed as means ± standard deviation. Different letters in each column mean significant differences ($p < 0.05$)

Table 3 The contents of anthocyanidins, isothiocyanates, phenolics and flavonoids in cabbages

Cabbages	Cyanidin (mg 100 g^{-1} fw)	Total isothiocyanates (mg SF·100 g^{-1})	Total phenolics (mg GAE·100 g^{-1})	Total flavonoids (mg RE·100 g^{-1})
Red head cabbage *B. o. var. capitata f, rubra*	44.52 ± 5.16 [a]	2.36 ± 0.66 [b]	153.94 ± 5.24[a]	51.32 ± 3.48 [a]
Flat head cabbage *B. o. var. capitata f, linn*	n.d	7.07 ± 1.42 [a]	86.64 ± 11.64 [c]	9.45 ± 0.42 [c]
Ball head cabbage *B. o. var. capitata f, alba*	n.d	3.67 ± 0.95 [b]	125.54 ± 16.86 [b]	15.26 ± 2.09 [b]
Conical head cabbage *B. o. var. capitata f, acuta*	n.d	3.23 ± 1.49 [b]	119.34 ± 2.34 [b]	16.48 ± 1.78 [b]

Data expressed as means ± standard deviation. n.d means not detected. Different letters in each column mean significant differences ($p < 0.05$)

other three varieties of cabbages. Flat head cabbage had the lowest level of total flavonoids (9.45 mg RE·100 g^{-1}). There were no significant differences between ball head and conical head cabbage. Leja et al. (2010) showed that the total flavonoids were in the range of 38.6 to 41.4 mg quercetin·100 g^{-1} fw in red cabbage and 4.4 to 6.9 mg quercetin·100 g^{-1} fw in white cabbage. The results in the report of Leja et al. (2010) were lower than the present study. It may be not only due to the different varieties of cabbages used in the study but also the different equivalents used in the results.

Antioxidant activity of head cabbages

The antioxidant activity including DPPH and ABTS radical scavenging and FRAP are shown in Table 4. DPPH• is a stable nitrogen-centered free radical and has been used widely for the determination of antioxidant activity. Red head cabbage was exhibited the highest antioxidant capacities measured by the DPPH and ABTS radical scavenging and FRAP assays with the values of 69.82, 87.23% and 0.53, respectively. The antioxidant activity of flat head, ball head and conical head cabbage were significantly lower than red head cabbage and no significant differences among themselves.

Total phenolic acids in cabbages were significantly correlated with DPPH and ABTS radical scavenging activity and FRAP with the R^2 of 0.979, 0.996, and 0.971, respectively ($P < 0.05$). The correlation between total flavonoids and antioxidant activity were also significant with the R^2 of 0.905, 0.954, and 0.952, respectively ($P < 0.05$). The correlation between total phenolics and antioxidant activity were relatively low with the R^2 of 0.479, 0.561,and 0.688, respectively($P > 0.05$). The results revealed that total phenolic acids and total flavonoids strongly contributed to the antioxidant activity of head cabbages.

On account of the different modifications of antioxidant assay and different expressions of results even in the same antioxidant assays, it was hard to compare the values of antioxidant activity from different studies. The relative antioxidant activity among the varieties of cabbages can be obtained although there were limited researches on it. Isabelle et al. (2010) compared the hydrophilic oxygen radical absorbance capacity of cabbages including *B. o. var. capitata L. (F. rubra)* and *B. o. var. capitata L.* and found the capacity of the former was much higher than the latter. Podsędek et al. (2006) evaluated the antioxidant capacity of red and white cabbages by ABTS and DPPH radical scavenging assays and found the capacity of red cabbage were much higher than white cabbage in both assays. These findings are in line with our study.

Oxidative/nitrosative stress (overproduction of free radicals) during hyper-cholesterolemia is a major root cause for the pathophysiology of atherosclerosis and other related cardiovascular diseases (Lahera et al. 2007). The importance of dietary phenolic antioxidants in counteracting cardiovascular diseases is well recognized

Table 4 Antioxidant activity of head cabbages

Cabbages	DPPH (Inhibition %)	ABTS (Inhibition %)	FRAP (Absorbance)
Red head cabbage *B. o. var. capitata f, rubra*	69.82 ± 0.63 [a]	87.23 ± 2.75 [a]	0.53 ± 0.07 [a]
Flat head cabbage *B. o. var. capitata f, linn*	47.76 ± 1.23 [b]	28.65 ± 1.87 [b]	0.24 ± 0.02 [b]
Ball head cabbage *B. o. var. capitata f, alba*	44.56 ± 0.57 [b]	24.36 ± 1.05 [b]	0.29 ± 0.02 [b]
Conical head cabbage *B. o. var. capitata f, acuta*	43.25 ± 0.83 [b]	25.48 ± 2.03 [b]	0.23 ± 0.04 [b]

Data expressed as means ± standard deviation. Different letters in each column mean significant differences ($p < 0.05$)

(Chiu et al. 2018). For this reason, the intake of red head cabbage is very good for human health.

Conclusion

This study substantiated that the different varieties of head cabbages have different nutritional advantages and it is useful for recommending the right head cabbages for different consumers. Among the varieties of head cabbages, red head cabbage had the highest contents of phenolic acids, anthocyanins, total phenolics and flavonoids, as well as the highest antioxidant activity; conical head cabbage was possessed of the highest content of folic acids; flat head cabbage had the highest level of total isothiocyanates. The contents of phytochemicals in head cabbages were also influenced by cultivation methods and agronomic factors. There is need to address the relation between cabbage nutrition and planting in future studies.

Abbreviations

ABTS: 2, 2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt; DPPH: 1, 1-diphenyl-2-picryl-hydrazyl; ESI: Electrospray ionization; FRAP: Ferric ion reducing antioxidant power assays; fw: Fresh weight; GAE: Gallic acid equivalents; HPLC: High performance liquid chromatography; MS: Mass spectrometry; MW: Molecular weight; RE: Rutin equivalents; SF: Sulforaphane; TPTZ: 2, 4, 6-tris (2-pyridyl)-S-triazine

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Authors' contributions

YLia designed the experiments, analyzed the data of the experiments and drafted the manuscript. YLiu collected the data. LZ helped to collect the data. XL helped to design the experiments. All authors read and approved the final manuscript.

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Availability of data and materials

Please contact author for data requests.

Ethics approval and consent to participate

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Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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