Antioxidants and Antioxidant Capacity in Leafy, Stem, and Fruit Vegetables Including 50 Species

Lijuan Zhan*, Yadan Ma, Cuicui Zhang, Linjie Li, Lingyun Pang, Xianqing Huang

College of Food Science and Technology, Henan Agricultural University, Zhengzhou, China

**E-mail: ljzhan@hotmail.com (Corresponding author)*

Abstract: Epidemiological studies have confirmed that high intake of fruits and vegetables is associated with low incidence of many kinds of diseases, which are hypothesized to be owing to antioxidants in fruits and vegetables. In this study, three types (leafy, stem, fruit) vegetables including 50 species were systematically evaluated for their antioxidant capacity (AC) and antioxidants including total phenolic compound (TPC), total flavonoids (TF), and L-ascorbic acid (LAA). Results showed that vegetables types had no significant effects on antioxidants. Vegetables with vivid color like purple cabbage, purple dolichos lablab, purple cowpea, red pepper, yellow pepper, lotus root, and ginger ranked high in their antioxidants (TPC 32.76-117.63 mg gallic acid/g FW, TF 25.78-152.96 mg rutin/100g FW, LAA 69.11-165.44 mg/100g FW) and AC (FRAP 69.38-109.13 μmol Fe^{2+}/100gFW, ABTS 2.19-3.75 μmol Trolox/gFW). Relatively, crown daisy, endive, celery stem, and cucumber had low antioxidants (TPC 2.66-6.29 mg gallic acid/g FW, TF 10.37-37.56 mg rutin/100g FW, LAA 14.64-39.44 mg/100g FW) and AC (FRAP 1.99-10.81 μmol Fe^{2+}/100gFW, ABTS 0.39-0.68 μmol Trolox/gFW). TPC and LAA had strong positive correlations with AC regardless of vegetable types, while TF was positively related to AC only in leafy vegetables. The result would be valuable for both epidemiological research and dietary guidelines as these vegetables are affordable and widely available.

Keywords: Ascorbic acid; Correlation; Fresh produce; Phenolic compound

1. Introduction

Epidemiological studies have confirmed that high intake of fruits and vegetables is associated with low incidence of many kinds of diseases [1]. These beneficial effects are hypothesized to be owing, at least in part, to antioxidants in fruits and vegetables [2]. The natural antioxidants in fresh fruits and vegetables include vitamins, carotenoids, and phenolic compounds [3]. Both the World Health Organization (WHO) and Food and Agricultural Organization (FAO) recommend a minimum of 400g of fruit and vegetable per day for the prevention of some diseases such as heart disease, cancer, diabetes and obesity [4]. Therefore, it is necessary to establish a comprehensive database on antioxidant and antioxidant capacity in fruits and vegetables, which would offer valuable reference not only for epidemiological research but also for dietary guidelines. In view of this, data on antioxidants and antioxidant capacity have been widely collected from fruits and vegetables produced in different countries and/or regions including Spain [5], Italy [6], Singapore [7], France [8], and Colombia [9].

China is the major vegetable producing country in the world. The average production of fresh vegetables in China is more than 150 million tonnes in past ten years, ranking first in the world [10-11]. China exports vegetables to more than 190 countries and regions, mainly concentrated in East Asia and Southeast Asia countries, followed by the European Union, North America, and Russia [12]. In addition, vegetables are also primary food component in Chinese diets and the consumption of vegetables per capita will be expected to rise up to 166 kilograms in 2023 from 149 kilograms in 2013, with an average annual growth rate of about 1.1% [11]. Thus, a comprehensive evaluation on antioxidants and antioxidant capacity in fresh vegetables grown in China is necessary and urgent. Deng et al. [13]. assayed the antioxidant capacities and phenolic contents in vegetables commonly consumed in China Nevertheless, according to our knowledge, information on the antioxidant capacity (AC) and main individual antioxidants including total phenolic compounds (TPC), total flavonoids (TF), and L-ascorbic acid (LAA) in different types of vegetables commonly grown in China is incomplete and lacking. To establish and/or supplement antioxidant databases of vegetables grown in China, the aim of this study is systematically to assay AC and antioxidants including TPC, TF, and LAA in leafy, fruit, and stem vegetables grown in China. The correlation between antioxidants and AC were also analyzed.

2. Materials and methods

Three types vegetables including 17 leafy vegetables, 10 stem vegetables, and 23 fruit vegetables (Table 1) were chosen according to their availability and economic importance. These samples were grown three times in open filed at Maozhuang farm (Zhengzhou, Henan province, China) and collected at commercial maturity from 2014 to 2017 depending on harvesting season of each crop. In detail, asparagus lettuce, chive, cilantro, Garlic, garlic chive, pakchoi, water spinach, green onion, onion, cucumber, eggplant (purple), fruit cucumber, sponge gourd, summer squash, sweet melon, tomato, watermelon, and white gourd were harvested on 15 Jun 2014, 20 Jun 2015, and 10 Jun 2017, respectively. Baby cabbage, bok choy, celery, crown daisy, endive, leaf-used lettuce, lettuce, and garlic shoot were harvested on 11 April 2014, 23 April 2015, and 10 April 2016, respectively. Blanched garlic leaves and Chinese cabbage were harvested on 1 February 2014, 12 February 2015, and 20 January 2016, respectively. Cabbage (green), cabbage (purple), ginger, lotus root, potato, okra (green), and sweet corn were harvested on 10 October 2014, 20 October 2015, and 20 October 2015, respectively. Bitter gourd, bell pepper (red), bell pepper (yellow), bell pepper (green), cherry tomato, cowpea (purple), dolichos lablab (purple), French beans, garden pea, hot pepper, pepper, and pumpkin were harvested on 11 July 2014, 22 July 2016, and 2 August 2017, respectively. For each sampling day, vegetables were harvested by hand and transported to laboratory within one day. Any vegetable with physical damage or injury caused by insects and fungal infection was discarded. About 1 kg vegetables for each sample were prepared and stored at 10 °C in a refrigerate chamber overnight for further extraction and analysis.

Table 1 Vegetable selected and test parts.

Vegetable type	Common name	Scientific name	Test part
Leafy vegetable	Asparagus lettuce	Lactuca sativa L.var. angustanaIrish	Leaf
	Baby cabbage	Brassica rapa pekinensis.sp	Leaf
	Blanched garlic leaves	Allium sativum L.	Leaf
	Bok choy	Brassica rapa subsp.chinensis	Leaf
	Cabbage (green)	Brassica oleracea var. capitata	Leaf
	Cabbage (purple)	Brassica oleracea var. capitata	Leaf
	Celery	Apium graveolens L.	Leaf
	Chinese cabbage	Brassica rapa Pekinensis	Leaf
	Chive	Allium ascalonicum L.	Leaf
	Cilantro	Coriandrum sativum L.	Leaf
	Crown daisy	Chrysanthemum coronarium L.	Leaf
	Endive	Cichorium endivia L.	Leaf
	Garlic chive	Allium tuberosum Rottl. Ex Spreng.	Leaf
	Leaf-used lettuce	Lactuca sativa var longifoliaf. Lam	Leaf
	Lettuce	Lactuca sativa L.	Leaf
	Pakchoi	Brassica rapa L.Chinensis .L.	Leaf
	Water spinach	Ipomoea ylindr Forssk.	Leaf
Stem vegetable	Asparagus lettuce	Lactuca sativa L.var. angustanaIrish	Stem
	Blanched garlic leaves	Allium sativum L.	Stem
	Celery	Apium graveolens L.	Stem
	Garlic	Allium sativum L.	Stem
	Garlic shoot	Allium sativum L.	Stem
	Ginger	Zingiber officinale	Stem
	Green onion	Allium fistulosum L.var. giganteum Makion	Stem
	Lotus root	Nelumbo nucifera G.	Stem
	Onion	Allium fistulosum	Stem
	Potato	olanum tuberosum L.	Stem
Fruit vegetable	Bitter gourd	Momordica charantia L.	Stem
	Bell pepper (red)	Capsicum annuum var. grossum	Stem
	Bell pepper (yellow)	Capsicum annuum var. grossum	Fruit
	Bell pepper (green)	Capsicum annuum var. grossum	Fruit
	Cherry tomato	Lycopersicon esculentum Mill	Fruit
	Cowpea (purple)	Vigna unguiculata (Linn.) Walp	Fruit
	Cucumber	Cucumis sativus var. sativus	Fruit
	Dolichos lablab (purple)	Lablab purpureus (Linn.)Sweet	Fruit
	Eggplant (purple)	Solanum melongena L.	Fruit
	French beans	Phaseolus vulgaris Linn	Fruit
	Garden pea	Pisum sativum Linn	Fruit
	Hot pepper	Capsicum annuum L.var. conoides	Fruit

Okra (Green)	Abelmoschus esculentus (Linn.)Moench	Fruit
Pepper	Capsicum annuum L. var. annuum	Fruit
Pumpkin	Cucurbita moschata (Duch. Ex Lam.) Duch. Ex Poiret	Fruit
Fruit cucumber	Cucumis sativus var. sativus	Fruit
Sponge gourd	Luffa ylindrical (L.) Roem	Fruit
Summer squash	Cucurbita pepo L.	Fruit
Sweet corn	Zea mays L.	Fruit
Sweet melon	Cucumis melo L.	Fruit
Tomato	Lycopersicon esculentum Mill.	Fruit
Watermelon	Citrullus lanatus (Thunb.) Matsum. Et Nakai	Fruit
White gourd	Benincasa hispida (Thunb.) Cogn.var. hispida	Fruit

2.1 Total polyphenol assay

For each sample, 100 g fresh tissue was homogenized with 200 ml pure methanol and the homogenates were centrifuged at 15,000 × g at 4 °C for 20 min. The supernatant obtained was collected for TPC, TF, and AC measurement. Total phenol content assay was carried out according to Folin-Ciocalteu procedure [14] with slight modification. Briefly, 200 µl aliquot of extract was added in 1000 µl of Folin-Ciocalteu reagent. After standing for 3 min, the mixture was added 800 µl of 7.5% sodium carbonate/water (w/v) and incubated at 20 ºC for 30 min. The absorbance at 760 nm wavelength was read and the result was expressed as milligram gallic acid per 100 gram of fresh weight (mg gallic acid/100g FW).

2.2 Total flavonoid content assay

Flavonoid content was assayed according to modified aluminum chloride colorimetric method [15]. For each assay, 0.5 ml methanol extract was mixed with 1.5 ml of methanol, 0.1 ml of 10% aluminum chloride, 0.1 ml of 1 M potassium acetate, and 2.8 ml of distilled water. After incubation for 30 min at room temperature, the absorbance of the reaction mixture was measured at 420 nm wavelength. Rutin standard solution from 40 to 200 mg/L was used to make the calibration curve. Total flavonoid content was expressed as mg rutin equivalents per 100 g fresh weight (mg rutin /100g FW).

2.3 Total ascorbic acid content assay

Total AA was determined based on methodology of Kampfenkel et al. [16] with slight modification. A 50 g of material was ground in 100 ml 6% of freezing trichloroacetic acid/water (w/v). The homogenate was centrifuged at 15,000 × g at 4 ºC for 10 min and the resultant supernatant was immediately used for the total AA analysis. The results were expressed as mg L-ascorbic acid per 100 g fresh weight (mg /100g FW) based on the calibrations that were compared with standard curves produced by freshly prepared L-ascorbic acid.

2.4 Antioxidant capacity assay

The AC value was test using two methodologies of both FRAP (ferric reducing antioxidant power) [17] and $ABTS^{\bullet+}$ (2, 2-azinobis (3-ethyl-benzothiazoline-6-sulfonic acid)) [18]. In FRAP procedure, the FRAP working solution was freshly prepared by mixing 300 mM sodium acetate-acetic buffer (pH 3.6), 20 mM $FeCl_3$, and 10 mM 2,4,6-tripyridyl-s-stiazine (10:1:1, v/v). For each measurement, 150 µL aliquot of methanol extract was mixed with 2850 µL of FRAP working solution. The mixture was kept at 20 ºC for 4 min and the absorbance was measured at 593 nm wavelength. The result was expressed as micromole of ferrous ion per gram of fresh weight (µmol Fe^{2+}/g FW) according to standard curve produced by the fresh ammonium ferrous sulfate solution. The $ABTS^{\bullet+}$ stock solution was freshly prepared by mixing 7 mmol/L $ABTS^{\bullet+}$ and 2.45 mmol/L potassium persulfate in equal quantities (v/v) and allowing them to react for 15 h at room temperature in the dark. For each assay, 150 µL of the methanol extract was mixed with 2850 µL $ABTS^{\bullet+}$ working solution. The mixture stood for 6 min at room temperature in darkness before the absorbance was taken at 734 nm wavelength. The results were expressed as micromole Trolox equivalents per gram fresh weight (µmol TE/g FW) based on standard curve that was linear between 20 and 400 µM Trolox.

2.5 Statistical analysis

The data were analyzed using SPSS (version 13.0) and the results were expressed as the means ± SD. One-way ANOVA followed by Duncan test at 0.05 confidence level was used to identify significant differences. The Pearson correlation analyses between variables were done using bivariate analysis of variance. The correlation and significance were expressed as correlation coefficient (R) and P-value, respectively.

3. Results

3.1 Antioxidants and antioxidant capacity in leafy vegetables

TPC content in leafy vegetables ranged from as high as 117.63 mg gallic acid/100g FW in purple cabbage to as low as 6.04 mg gallic acid/100g FW in endive, with the difference of nearly 20-fold. Following purple cabbage, garlic chive and blanched garlic leaves contained 47.34 and 41.12 mg gallic acid/100g FW TPC content, respectively. Relatively, chive, crown daisy, and endive contained low TPC that was less than 10 mg gallic acid/100g FW (Table 2). Similar to TPC, the highest TF was also recorded in purple cabbage with value of 152.96 mg rutin/100g FW, followed by. garlic chive, celery leaf, and cilantro that possessed over than 100 mg rutin/100g FW TF, respectively. Vegetables, like cabbage, Chinese cabbage, blanched garlic leaves, and baby cabbage in decreasing order, had low TF values, being less than 10 mg rutin/100g FW. Regard to LAA, all leafy vegetables selected possessed more than 10 mg/100g FW LAA content. Vegetables containing more than 50 mg/100g FW LAA content were ranked as follows: purple cabbage > water spinach > blanched garlic leaves >pakchoi > baby cabbage > garlic chive > lettuce, with values being 169.44, 91.23, 74.69, 69.13, 63.15, 61.49, 51.99 mg/100g FW, respectively (Table 2).

As expected, purple cabbage possessed the highest AC values of 109.13 μmol Fe^{2+}/100gFW and 3.75 1.78 μmol Trolox/gFW assayed by FRAP and ABTS methods, respectively, followed by garlic chive and blanched garlic leaves (Table 2). Among all tested leafy vegetables, endive possessed the lowest AC value of 3.41μmolFe^{2+}/100g FW and 0.37μmol Trolox/g FW assayed by FRAP and ABTS methods, respectively (Table 2). In addition, AC in leafy vegetables displayed a close relationship with TPC (R=0.873 and 0.743, $P<0.001$), TF (R=0.657and 0.503, $P<0.005$), and LAA (R=0.792 and 0.622, $P<0.001$), respectively, regardless of assay methods (Table 3). This indicated all antioxidants significantly contributed to AC values, of which TPC was the main contributor, followed by LAA and TF according to correlation coefficient.

Table 2 Antioxidants and antioxidant capacity in leafy vegetables.

Vegetables	TP content (mg gallic acid/100g FW)	Flavonoids content (mg rutin/100g FW)	L-ascorbic acid content (mg/100 gFW)	FRAP (μmolFe^{2+}/100gFW)	ABTS (μmol Trolox/gFW)
Asparagus lettuce	35.01±0.65d	82.7±2.45d	39.55±2.74h	35.95±0.24d	3.20±0.05b
Baby cabbage	26.82±0.92f	4.74±1.03i	63.15±5.03de	27.81±2.36f	2.80±0.22c
Blanched garlic	41.12±0.30c	6.56±0.27i	74.69±0.28c	49.32±7.03c	2.01±0.04d
Bok choy	16.52±0.94hi	35.85±4.81f	29.85±2.48i	10.51±1.04jk	1.08±0.06f
Cabbage	26.15±1.74f	9.18±1.50i	22.04±5.08j	15.05±0.13hi	1.52±0.00e
Cabbage (purple)	117.63±2.82a	152.96±4.15a	165.44±9.23a	109.13±0.35a	3.75±0.02a
Celery	17.83±2.21gh	139.90±14.69b	46.65±2.10fgh	27.51±1.31f	0.89±0.08fg
Chinese cabbage	11.00±1.25j	7.36±3.55i	40.64±5.65h	6.90±0.26l k	0.80±0.29g
Chive	9.25±0.00j	81.41±0.00d	42.00±0.00gh	23.83±0.46g	2.03±0.05d
Cilantro	25.22±0.36f	101.40±5.55c	42.58±1.78gh	16.18±2.26hi	1.90±0.07d
Crown daisy	6.29±0.08k	11.18±3.03hi	39.44±3.17h	7.28±0.09kl	0.39±0.06h
Endive	6.04±1.39k	17.60±0.58h	14.81±0.43k	3.41±0.16m	0.37±0.01h
Garlic chive	47.34±1.37 b	142.39±3.44b	61.49±2.74e	86.35±1.47b	3.29±0.34b
Leaf-used lettuce	14.73±0.58i	27.68±4.87g	48.07±2.47fg	31.66±0.50e	1.60±0.14e
Lettuce	19.55±1.68g	55.70±2.22e	51.99±0.16f	17.54±0.88h	0.75±0.09g
Pakchoi	31.55±3.75 e	36.64±1.97f	69.13±5.66cd	12.81±0.24ij	1.89±0.13d
Water spinach	19.50±0.900g	51.55±5.70e	91.23±3.64b	35.92±1.71d	1.93±0.06d
Significance	0.000	0.000	0.000	0.000	0.000

3.2 Antioxidants and antioxidant capacity in stem vegetables

Similar to leafy vegetables, antioxidants in stem vegetables also varied in very large range. In detail, the TPC ranged from 77.94 mg gallic acid/100g FW in lotus root to 3.18 mg gallic acid/100g FW in celery stem. TF content varied widely ranging from 134.92 mg rutin/100g FW in onion to 5.82 mg rutin/100g FW in blanched garlic leaf. Following onion, garlic shoot and ginger had statistically same TF values about 58 mg rutin/100g FW. With regard to LAA, lotus root had extremely high LAA content of 150.25 mg/100 gFW, followed closely by ginger with value of 140.97 mg/100 gFW. Asparagus lettuce, celery, and green onion had low LAA content with value being less than 20 mg/100g FW (Table 4).

AC values in stem vegetables ranged from 103.48 to 1.99 μmol Fe^{2+}/100gFW, and 3.74 to 0.68 μmol

Trolox/gFW assayed by FRAP and ABTS methods, respectively. The highest AC values appeared in ginger and lotus root, the lowest appeared in celery stem (Table 4). Strong positive correlations between TPC and AC (R=0.853 and 0.879, P<*0.001*), LAA and AC (R=0.936 and 0.902, P<*0.001*) were found (Table 3). While TF content was not related to AC values (Table 3).

Table 3. The Pearson correlation analyses between antioxidants and antioxidant capacity in leafy, stem, and fruit vegetables.

Vegetable types	Variables		N	Correlation coefficient (R)	*P-value* (2-tailed)
Leafy vegetables	AC (FRAP)	TPC	51	0.873**	0.000
		TF	51	0.657**	0.000
		LAA	51	0.792**	0.000
	AC (ABTS)	TPC	51	0.743**	0.000
		TF	51	0.503**	0.003
		LAA	51	0.662**	0.000
		AC (FRAP)	51	0.793**	0.000
Stem vegetables	AC (FRAP)	TPC	30	0.853**	0.000
		TF	30	ns	0.167
		LAA	30	0.936**	0.000
	AC (ABTS)	TPC	30	0.879**	0.000
		TF	30	ns	0.077
		LAA	30	0.902**	0.000
		AC (FRAP)	30	0.920**	0.000
Fruit vegetables	AC (FRAP)	TPC	69	0.709**	0.000
		TF	69	ns[a]	0.278
		LAA	69	0.816**	0.000
	AC (ABTS)	TPC	69	0.714**	0.000
		TF	69	ns	0.623
		LAA	69	0.770**	0.000
		AC (FRAP)	69	0.861**	0.000

** Correlation is significant at the 0.01 level (2-tailed). N =number of replicates, ns means no significance

Table 4 Antioxidants and antioxidant capacity of stem vegetables.

Vegetables	TP content (mg gallic acid/100g FW)	Flavonoids content (mg rutin/100g FW)	L-ascorbic acid content (mg/100 gFW)	FRAP (μmolFe^{2+}/100gFW)	ABTS (μmol Trolox/gFW
Asparagus lettuce	11.89±0.63ef	12.77±1.11ef	14.45±2.28e	12.95±0.98e	1.55±0.26e
Blanched garlic	34.43±0.25c	5.82±1.67g	40.24±8.82d	13.23±0.72e	2.14±0.15c
Celery	3.18±0.84f	10.37±2.68fg	17.64±2.12e	1.99±0.22f	0.68±0.05g
Garlic	50.67±11.47b	37.72±1.40c	61.54±8.40c	25.74±1.69d	1.98±0.12cd
Garlic shoot	21.16±0.79de	58.43±3.00b	31.76±1.68d	34.62±0.37c	1.89±0.16d
Ginger	76.79±11.85a	58.93±5.88b	140.97±5.38b	103.48±0.80a	3.68±0.00a
Green onion	14.47±0.84e	18.54±2.53e	19.31±2.59e	24.60±1.70d	1.28±0.03f
Lotus root	77.94±1.62a	16.24±1.23ef	150.25±7.26a	103.39±0.45a	3.74±0.00a
Onion	20.07±0.74de	134.92±7.35a	39.15±2.44d	45.16±11.62b	2.61±0.03b
Potato	25.88±1.24cd	31.50±2.50d	36.93±3.01d	28.60±1.00cd	1.57±0.12e
Significance	0.000	0.000	0.000	0.000	0.000

3.3 Antioxidants and antioxidant capacity in fruit vegetables

TPC in fruit vegetables varied widely ranging from 87.69 to 2.66 mg gallic acid/100g FW with difference of nearly 33-fold. Purple cowpea possessed the highest TPC, followed by hot pepper, purple dolichos lablab, and pepper. While fruit vegetables like fruit cucumber, white gourd, watermelon, summer squash, sweet melon, and cucumber had low TPC (<10 mg gallic acid/100g FW) (Table 5). Like TPC, TF in fruit vegetables also varied largely ranging. Purple dolichos lablab had as high as 150.70mg rutin/100g FW TF, followed by sponge gourd with value of 114.67 mg rutin/100g FW. The species like sweet corn, summer squash, watermelon, sweet melon, and tomato had low TF (<10 mg rutin/100g FW) in decreasing order (Table 5). All fruit vegetables tested possessed more than 10 mg /100g FW LAA content with exception of summer squash with 6.68 mg /100g FW LAA. Yellow bell pepper, purple cowpea, and red bell pepper had high LAA content with values of 133.19, 117.79, and 104.20 mg /100g FW, respectively (Table 5).

AC in fruit vegetables ranged largely regardless of assay methods. Interesting, species from *Capsicum annuum L.* Like pepper, yellow bell pepper, red bell pepper, and hot pepper contained high AC values. In addition, purple cowpea, and purple dolichos lablab recorded high AC values (Table 5). Similar to stem vegetables, in fruit vegetables, strong positive relationships were found between TPC and AC (R=0.709 and 0.714, P<0.001), LAA and AC (R=0.816 and 0.770, P<0.001) (Table 3). No significant correlation was observed between AC and TF in fruit vegetables (Table 3).

Table 5 Antioxidants and antioxidant capacity in fruit vegetables

Vegetables	TP content (mg gallic acid/100g FW)	Flavonoids content (mg rutin/100g FW)	L-ascorbic acid content (mg/100 gFW)	FRAP (µmol Fe^{2+}/100gFW)	ABTS (µmol Trolox/gFW)
Bitter gourd	26.29±0.76e	60.20±1.41d	46.60±6.85g	30.84±0.11h	0.31±0.05lm
Bell pepper (red)	37.87±7.71cd	55.21±1.10d	104.20±13.92c	100.20±0.12a	3.75±0.04a
Bell pepper (yellow)	32.76±5.99de	52.39±8.42d	133.19±0.85a	100.37±0.13a	3.73±0.02a
Bell pepper (green)	18.06±2.67f	79.37±1.91c	29.70±2.25h	64.52±0.39d	2.88±0.09d
Cherry tomato	33.38±2.12de	81.02±4.75c	48.85±1.86g	39.63±13.88fg	3.19±0.21c
Cowpea (purple)	87.69±2.40a	25.78±0.88e	117.79±1.37b	91.06±2.56b	3.50±0.06b
Cucumber	2.66±0.94h	23.56±0.55e	25.93±3.49hi	10.81±0.51jk	0.41±0.02l
Dolichos lablab (purple)	46.71±3.21b	150.70±9.21a	69.11±0.65ef	69.38±4.28cd	2.19±0.01g
Eggplant	17.67±1.74f	54.21±2.59d	22.54±4.10hij	16.64±0.76j	1.35±0.06i
French beans	38.02±4.10cd	63.21±5.72d	61.16±7.42f	39.44±1.58fg	2.73±0.05e
Garden pea	26.85±2.70e	31.95±8.78e	47.77±2.97g	25.16±1.52i	1.15±0.11j
Hot pepper	52.04±12.57b	53.41±0.16d	64.89±11.93ef	72.78±2.22c	3.17±0.06c
Okra (Green)	11.89±0.63ef	12.77±1.11ef	14.45±2.28e	12.95±0.98e	1.55±0.26e
Pepper	45.09±6.71bc	25.70±0.72e	82.67±1.69d	100.28±0.13a	3.69±0.03a
Pumpin	12.88±0.75fgh	86.19±4.34c	18.43±1.45ij	8.24±0.44k	0.20±0.04m
Fruit cucumber	9.91±2.37gh	62.93±34.17d	24.37±5.84hi	12.19±1.06jk	0.17±0.10m
Sponge gourd	32.87±1.80de	114.67±7.65b	79.61±2.86d	30.36±0.13hi	1.48±0.07i
Summer squash	6.67±0.15gh	7.90±0.57f	6.68±0.74k	8.08±0.50k	0.16±0.03m
Sweet corn	36.74±3.58d	9.12±0.98f	69.44±4.15ef	37.54±0.33g	2.51±0.04f
Sweet melon	4.52±0.86h	4.85±0.61f	26.72±2.69hi	24.85±0.99i	1.18±0.14j
Tomato	13.13±1.37fg	4.36±1.11f	20.77±1.71hij	43.99±2.38f	1.91±0.06h
Watermelon	6.72±1.68gh	5.45±1.70f	22.04±6.23hij	10.80±0.62jk	1.34±0.25i
White gourd	9.23±0.55gh	57.34±1.97d	13.48±0.32jk	33.91±1.92gh	0.62±0.03k
Significance	0.000	0.000	0.000	0.000	0.000

4. Discussion

Current study showed vegetable type had no significant effects on antioxidants (Table 5). This is maybe attributed to high standard deviation that came from the large range values of antioxidants in each type of vegetable. For example, TPC content in leafy type vegetables ranged from 117.63 mg gallic acid/100g FW in purple cabbage to 6.04 mg gallic acid/100g FW in endive, with the differences of nearly 20-fold (Table 2). Compared to leafy vegetable, fruit vegetables showed significantly higher ($P<0.05$) AC values assayed using FRAP method (please see Appendix data), indicating antioxidants in fruit vegetables possess strong oxidant reducing power. In addition, the vegetables with vivid color like purple cabbage, purple dolichos lablab, purple cowpea, red pepper, and yellow pepper ranked high in their antioxidants and AC (Table 2, 5). This result was in agreement with finding that brightly colored vegetables tended to contain high antioxidants [7] due to the vivid tissue having more pigments involved in the antioxidant reaction [19].

The AC of the plant extract largely depends on both the composition of the extract and the test system. It can be influenced by a large number of factors, thus more than one type assay methods are recommended to provide a reliable picture of the AC taking into account the various mechanisms of antioxidant action [20]. In the present study, the AC were assayed by both FRAP and ABTS methodologies. The FRAP assay can be applied to both aqueous and alcohol extracts of plants. It is based on the principle of reduction of Fe^{3+} complex to Fe^{2+} by antioxidants of samples at low pH value [17]. ABTS is widely used to screen antioxidant activity of fruits and vegetables because the long wavelength absorption maximum at 734 nm eliminates color interference in plant extracts [21]. In this study, AC values assayed by FRAP were strongly correlated to those assayed by ABTS regardless of vegetable types (Table 3), implicating the antioxidants in selected vegetables possess the ability of both reducing oxidants (ferric ions) and scavenging free radicals ($ABTS^{\bullet+}$). It is worth mentioning that some vegetables such as bitter gourd and fruit cucumber possessed relatively high oxidant reducing activities, but low radical scavenging activities (Table 5). On the contrary, vegetables like celery had relatively low oxidant reducing activities, but high radical scavenging activities (Table 4). These differences might be resulted from the different antioxidant characteristic of antioxidants they contain.

It is hard to clarify which antioxidants in fresh vegetables are responsible for the observed total AC because a large number of phytochemicals that might be considered to contribute to AC [22]. To explore the influence of the antioxidant constituents on antioxidant capacity in fresh vegetables, the correlation between the main antioxidants and AC was analyzed. The TPC and LAA appeared to be responsible for AC values as strong positive correlation between TP and AC, LAA and AC were obtained regardless of vegetable types (Table 3). This is in agreement to conclusion that vitamin C and total phenolic compounds were the main contributors to AC in fruits and vegetables [13,22];. Furthermore, TPC in the lipophilic fraction contributes more AC than the hydrophilic fraction [13].

Table 5 Effects of vegetable types on antioxidants and antioxidant capacity

Vegetable type	Number of repetitions	TP content (mg gallic acid/100g FW)	Flavonoids content (mg rutin/100g FW)	L-ascorbic acid content (mg/100 g FW)	FRAP (μmolFe^{2+}/100gFW)	ABTS (μmol Trolox/gFW)
Leaf vegetable	51	27.74±25.49a	56.75±50.37a	55.46±33.63a	30.42±27.91b	1.78±1.01a
Stem vegetable	30	33.65±25.87a	38.52±37.59a	55. 22±48.06a	39.38±34.73ab	2.11±0.96a
Fruit vegetable	69	27.94±20.07a	50.55±50.55a	52.61±34.61a	44.59±30.92a	1.96±1.29a
Significance		0.475	0.173	0.903	0.047	0.420

5. Conclusions

Summarily, vegetable types had no significant influences on antioxidants as their values varied in very large range. Vegetables with vivid color like purple cabbage, purple dolichos lablab, purple cowpea, red pepper, yellow pepper, lotus root, and ginger ranked high in their antioxidants and AC, which supported the dietary recommendation that encourages consumption a variety of vegetables every day, especially the brightly colored ones. Positive correlations between TPC, LAA and AC values regardless of vegetables types. Overall, the data from this study would be valuable for epidemiological research and dietary guidelines of promoting public health benefits as these vegetables are affordable and widely available in China.

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethics requirements

This article does not contain any studies with human participants or animals performed by any of the authors.

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