Available online at www.sciencedirect.com
ScienceDirect
Food Chemistry 106 (2008) 545–551
Food Chemistry
www.elsevier.com/locate/foodchem

Juice components and antioxidant capacity of citrus varieties cultivated in China

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Received 9 April 2007; received in revised form 5 June 2007; accepted 5 June 2007

Abstract

Juices from fifteen citrus varieties (seven mandarins, four sweet oranges, one lemon, one grapefruit, and two pummeloes) of China were investigated mainly on quality parameters, total carotenoid, phenolic compounds (total phenolics, flavanone glycosides (FGs), and phenolic acids), and antioxidant capacity (ferric reducing antioxidant power (FRAP) assay and 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay). Among the fifteen varieties, Bendizao had the highest content of total carotenoid (10.02 mg/L), Satsuma had the highest content of narirutin (288.12 mg/L), Yinzaocheng had the highest content of hesperidin (533.64 mg/L), and Huyou had the highest content of naringin (348.53 mg/L), neohesperidin (265.25 mg/L) and total FGs (746.08 mg/L). As for total phenolic acids, Liubencheng had the highest content (72.61 mg/L). Hybrid 439 achieved the highest AA content (631.25 mg/L), and the highest total phenolics (1555.49 mg/L) and the greatest inhibition of DPPH radical (61.62%). Hamlin had the highest ascorbic acid equivalent antioxidant capacity (AEAC: 899.31 mg/L) determined by FRAP assay. Correlation coefficients of AA, total phenolics (gallic acid equivalent), FRAP (AEAC), DPPH (I%), total FGs and total phenolic acids indicated that AA played a major role for the antioxidant capacity of citrus juices, and phenolics also played an important role, which may be mainly ascribed to FGs, whilst phenolic acids seemed to play a minimal role. Furthermore, Huyou and Hybrid 439 were considered two valuable varieties from the view of antioxidant capacity and nutrition.

Keywords: Citrus juices; Phenolic acids; Flavanone glycosides; Ascorbic acid; Antioxidant capacity

1. Introduction

Citrus fruits not only have their delicious flavors but also have their antioxidant capacity with health benefits (Morton, Caccetta, Puddey, & Croft, 2000; Pellegrini et al., 2003). It's well known that vitamin C and carotenoids are abundant in some citrus fruits (Dhuique-Mayer, Caris-Veyrat, Ollitrault, Curk, & Amiot, 2005), thus they are very beneficial to human health. In recent years, more attentions had been paid on phenolic compounds of citrus fruits, and some publications have suggested they might play an important role on the antioxidant capacity of citrus fruits (Gorinstein et al., 2004a; Rapisarda et al., 1999; Wang, Cao, & Prior, 1996). Dietary phenolic compounds of citrus fruits include flavonoids and phenolic acids (Balasundram, Sundram, & Samman, 2006). Generally, FGs dominate in citrus flavonoids, which were summarized recently by Peterson (Peterson et al., 2006a; Peterson et al., 2006b). Furthermore, narirutin, hesperidin, naringin and neohesperidin are the major FGs (Rouseff, Martin, & Youtsey, 1987). On the other hand, phenolic acids exist

Abbreviations: TSS, total soluble solids; TA, total acidity; AA, ascorbic acid; AEAC, ascorbic acid equivalent antioxidant capacity; HPLC–PDA, high-performance liquid chromatography–photodiode array detector; FGs, flavanone glycosides; FRAP, ferric reducing antioxidant power; DPPH, 2,2-diphenyl-1-picrylhydrazyl; GAE, gallic acid equivalent.

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doi:10.1016/j.foodchem.2007.06.046

largely in citrus fruits as bound forms, which mostly occur as hydroxycinnamics, such as caffeic, *p*-coumaric, ferulic and sinapic (Robbins, 2003). Several researches have focused on the quantification of phenolic acids of citrus fruits (Peleg, Naim, Rouseff, & Zehavi, 1991; Rapisarda, Pannuzzo, Romano, & Russo, 2003). Recently, some studies have investigated the antioxidant capacity of citrus fruits, and it was assumed that total antioxidant capacity of citrus fruits were mainly attributed to AA and phenolic compounds, though there were some divergences as to which compound was the major contributor (Arena, Fallico, & Maccarone, 2001; Caro, Piga, Vacca, & Agabbio, 2004; Gardner, White, McPhail, & Duthie, 2000; Rapisarda et al., 1999; Sun, Chu, Wu, & Liu, 2002; Wang et al., 1996; Yoo, Lee, Park, Lee, & Hwang, 2004).

In China, the total agricultural yield of citrus fruits consists of mandarins (55%), oranges (30%), pummelo (5%) and other varieties (10%) (Ye, 2005). Among the seven selected mandarins, Satsuma, Ponkan, and Bendizao are the most popular varieties cultivated in China. Furthermore, Huyou is a grapefruit originated from China (Xu, Ye, Chen, & Liu, 2007), and Hybrid 439 is a recent citrus tangor hybrid (*C. reticulata* × *C. sinensis*) which had never been reported on.

The consumption of processed citrus juices in China is increasing rapidly recently. However, not much work has been reported on the study of antioxidant capacity of citrus juice of China. The objective of this study was to analyze the antioxidant components and evaluate the antioxidant capacity of citrus juices from selected citrus fruits grown in China, which would be useful for the citrus processing industry of China.

2. Materials and methods

2.1. Materials

Fifteen typical citrus varieties cultivated in China were selected for this research, including seven varieties of mandarins, four kinds of sweet oranges, one lemon, one grapefruit, and two pummelo varieties (Table 1). The selected fifteen citrus varieties at mature stage were provided by Zhejiang Citrus Research Institute in Huangyan city, Zhejiang province. Citrus fruits samples were peeled and squeezed by hand and then juice yields were calculated. TSS and TA of citrus juices were measured according to the reference (Sánchez-Moreno, Plaza, De Ancos, & Cano, 2003), and total carotenoid were determined as the method of Wang (Wang, Chuang, & Ku, 2007), respectively.

2.2. Chemicals

Standards of protocatechuic, *p*-hydroxybenzoic, vanillic, sinapic, ferulic, caffeic, *p*-coumaric, narirutin, naringin, hesperidin, neohesperidin, TPTZ (2,4,6-tris (2-pyridyl)-*s*-triazine), 2,2-diphenyl-1-picrylhydrazyl radical (DPPH·), and Folin-Ciocalteu phenol reagent were purchased from Sigma. All other chemicals used were analytical grade.

2.3. Extraction of phenolics

One mL of citrus juice was extracted with 9 mL of 80% methanol for 30 min at room temperature. After centrifugation at 5000 rpm for 10 min, the supernatant was taken out for determination of total phenolics by Folin–Ciocalteu method, analysis of FGs was carried out by HPLC, and evaluation of antioxidant capacity by FRAP and DPPH assay.

2.4. FGs content determination

The contents of FGs (narirutin, naringin, hesperidin and neohesperidin) were determined by HPLC. 10 μL extract was injected into a HPLC system, and it was filtered through a millipore membrane (0.22 μm) before injection. The analysis utilized a Diamonsil C18 column (250 × 4.6 mm i.d.) using methanol: water: acetic acid (37:59:4) (v/v/v) as the mobile phase at a flow rate of 1.0 mL/min at 25 °C oven temperature, and the eluent was monitored at 283 nm for quantification of FGs. Identification of the FGs was accomplished by comparing the retention times of peaks in samples to those of FG standards. Calculation of FGs concentration (expressed as mg/L) was carried out by an external standard method using calibration curves.

2.5. Phenolic acids content determination

Phenolic acids were determined according to Nardini with some modifications (Nardini et al., 2002). Two milliliter citrus juice was firstly diluted to 5 mL with distilled water, and then it was treated by alkaline hydrolysis (5 mL of 4 M NaOH, containing 1% ascorbic acid and 10 mM EDTA) for 4 h under a nitrogen atmosphere at room temperature. After acidification to pH 2 using 6 M HCl, it was centrifuged at 5000 rpm for 10 min. Afterwards, phenolic acids were extracted from the hydrolysate 3 times with diethyl ether-ethyl acetate (1:l) (v/v) at a solvent to water phase ratio of 1:l. The ether-ethyl acetate extracts were dehydrated with anhydrous sodium sulfate, filtered, and evaporated to dryness under vacuum at 30 °C. The dry residues were dissolved into 5 mL methanol. Phenolic acids of HPLC analyses were carried out on an Alliance 2695 separations module (Waters) linked simultaneously to a PDA 2996 (Waters). The prepared phenolic acid solution was filtered through a millipore membrane (0.22 μm) before injection, and 20 μL was injected on the reversed phase column (250 × 4.6 mm i.d.). The column thermostat was set at 40 °C. Solvent A consisted of 4% acetic acid, and solvent B consisted of methanol (A:B = 20:80) at a flow rate of 1 mL/min, which was in accordance with Rao et al. (Rao & Muralikrishna, 2002) with minor modifications. After each run the column was washed with 100%

Table 1
Juice yield, TSS, TA, and TSS/TA ratio of citrus juices

Varieties	Common name	Species name	Juice yield (%)	TSS (%)[a]	TA (%)[b]	TSS/TA ratio
Wase-Satsuma	Mandarin	*C. unshiu* var. praecox Tanaka Satsuma	55.46	11.75	0.94	12.48
Satsuma	Mandarin	*C. unshiu* Marc.	52.87	13.08	1.06	12.35
Ponkan	Mandarin	*C. poonensis* Hort. ex Tanaka	52.13	12.00	1.29	9.33
Bendizao	Mandarin	*C. succosa* Hort. ex Tanaka	56.80	14.17	0.96	14.76
Manju	Mandarin	*C. tadiferax* Hort. ex Tanaka	60.74	10.42	1.07	9.75
Hybrid 439	Mandarin	*C. reticulata* × *C. sinensis*	42.85	14.92	1.87	8.00
Zhuhong	Mandarin	*C. erythrosa* Hort. ex Tanaka	48.09	11.58	0.94	12.30
Skaggs bonanza	Sweet orange	*C. sinensis* var. brasiliensis Tanaka	50.79	12.58	0.86	14.63
Hamlin	Sweet orange	*C. sinensis* Osbeck cv Hamlin	43.53	12.58	1.31	9.58
Liubencheng	Sweet orange	*C. sinensis* Osbeck cv Liubencheng	46.24	11.58	1.20	9.62
Yinzaocheng	Sweet orange	*C. sinensis* Osbeck cv Yinzaocheng	43.64	11.33	1.38	8.23
Lemon	Lemon	*C. limon* (L.) Burm.f	40.39	10.92	6.11	1.79
Huyou	Grapefruit	*C. paradisi* Macf. Changshanhuyou	40.04	10.58	1.53	6.92
Miyou	Pummelo	*C. grandis* (L.) Osbeck cv Miyou	27.50	11.92	0.70	17.09
Sijiyou	Pummelo	*C. grandis* (L.) Osbeck cv Sijiyou	26.95	10.33	0.72	14.44

[a] Total soluble solids.
[b] Total acidity.

methanol and equilibrated to initial conditions for 15 min. The PDA detector was set scanning range from 210 to 400 nm with resolution of 1.2 nm. Phenolic acids were identified by the retention time and the UV–Vis spectra of standards. Quantification of phenolic acids was carried out by an external standard method using calibration curves, and concentration of phenolic acids was expressed as mg/L.

2.6. AA content determination

AA was analyzed by using liquid chromatography on an RP-Phase with UV detection according to Leong and Shui (Leong & Shui, 2002) with some modifications. AA standard solution (400 μg/mL) was prepared. This was then diluted to give 40, 20, 10, 5 and 2.5 mg/L working standard solutions. 1 mL sample was extracted with 9 mL 0.1% oxalic acid for 3 min. Then the sample was immediately filtered through a millipore membrane (0.45 μm) before injection. The separation was performed on a Diamonsil C18 column (250 × 4.6 mm i.d.) using 0.1% (v/v) oxalic acid as the mobile phase at a flow rate of 1.0 mL/min at 25 °C oven temperature, and the eluent was monitored at 243 nm. The ascorbic acid contents were expressed here as mg/L.

2.7. Total phenolics determination

Total phenolics were determined by the Folin–Ciocalteu method (Singleton, Orthofer, & Lamuela-Raventos, 1999). Briefly, an aliquot (1 mL) of appropriately diluted 80% methanol extracts were added to a 25 mL volumetric flask filled with 9 mL distilled water. A reagent blank using ddH_2O was prepared. Folin–Ciocalteu phenol reagent (0.5 mL) was added to the mixture and shaken vigorously. After 5 min, 5 mL of 5% Na_2CO_3 solution was added with mixing. The solution was immediately diluted to 25 mL with distilled water and mixed thoroughly and then allowed to stand for 60 min before measurement, and the absorbance was measured at 750 nm versus the prepared blank. Total phenolics content of sample was expressed as mg/L of gallic acid equivalent (GAE).

2.8. Ferric reducing antioxidant power (FRAP) assay

The ferric reducing ability of each standard solution was measured according to a modified protocol developed by Benzie et al. (Benzie & Strain, 1996). To prepare the FRAP reagent, a mixture of 0.1 M acetate buffer (pH 3.6), 10 mM TPTZ, and 20 mM ferric chloride (10:1:1 v:v:v) was made. 0.1 mL extract was added to 1.9 mL reagent. Readings at the absorption maximum (593 nm) were taken using a Shimadzu UV–visible 2501 spectrophotometer, and the reaction was monitored for 10 min. AA solution was used to perform the calibration curves. Result was also expressed as AEAC mg/L.

2.9. DPPH free radical-scavenging assay

The DPPH free radical-scavenging activity of juices was measured using the method described by Gorinstein et al. (Gorinstein et al., 2004b). A 0.1 mM solution of DPPH in methanol was prepared. An aliquot of 0.2 mL of sample was added to 2.8 mL of this solution and kept in the dark for 30 min. The ability of scavenging the DPPH radical was calculated with the following equation:

$$\%\text{Inhibition} = [(A0 - A1)/A0] \times 100$$

Where A0 is the absorbance of the control, A1 is the absorbance in the presence of sample.

2.10. Statistics

All samples were prepared and analyzed in triplicate. To verify the statistical significance of all parameters, the values of means ± S.D. were calculated. To compare several groups, analysis of variance (ANOVA) was used. The Pearson correlation coefficient (R) and p-value were used to show correlations and their significance (SPSS for Windows, Release 11.5.0 (June 2002, SPSS Inc.)). Probability value of $p < 0.01$ was adopted as the criteria for significant differences.

3. Results and discussion

3.1. Juice yield, TSS, TA, and TSS/TA ratio

The quality parameters, including juice yield, TSS, TA, and TSS/TA ratio of citrus juices were shown in Table 1. Apparently, the values varied largely among citrus varieties, where Manju achieved the highest yield (60.74%), and Sijiyou had the lowest yield (26.96%). Hybrid 439 had the highest TSS value (14.92%), whereas Sijiyou had the lowest value (10.33%). TA value of lemon achieved the highest value (6.11%) followed by Hybrid 439 (1.87%), while Miyou had the lowest value (0.70%). The TSS/TA ratio was also an important parameter, related with quality characteristics of citrus fruits, where Miyou had the highest value of TSS/TA (17.09), and lemon had the lowest value (1.79). From the above data, significant differences between species and varieties were observed. Among the citrus varieties selected, the Hybrid 439 was a new variety, and more attention was given to it.

3.2. Contents of FGs and phenolic acids

Four major FGs (narirutin, naringin, hesperidin, neohesperidin) of citrus fruits were determined (Table 2). Hesperidin and narirutin were considered as major FGs in mandarin and orange juices, whereas naringin and neohesperidin were not detectable. For mandarin and orange juices, hesperidin content ranged from 304.46 mg/L (Zhuhong) to 533.64 mg/L (Yinzaocheng), and narirutin content ranged from 24.42 mg/L (Zhuhong) to 288.12 mg/L (Satsuma). Our results were comparable with several latest reports (Dhuique-Mayer et al., 2005; Peterson et al., 2006a; Peterson et al., 2006b; Vanamala, Reddivari, Yoo, Pike, & Patil, 2006). Only hesperidin was detected in lemon juice, while Huyou had all of the four FGs with the highest content of naringin (348.53 mg/L), neohesperidin (265.25 mg/L) and total FGs (746.08 mg/L). Narirutin was not detectable in Miyou juice, and narirutin and neohesperidin were not detectable in Sijiyou juice. Generally, mandarin, orange and grapefruit had higher content of FGs, while lemon and pummelo had lower content. Furthermore, as a grapefruit, Huyou had the highest content of total FGs (746.08 mg/L), amount to 359.48 mg/L as flavanone aglycones, which was higher than the average value (270 mg/kg as aglycones) of grapefruits reported by Peterson et al. (Peterson et al., 2006a), Therefore future study and more attention should be paid to this variety.

Seven phenolic acids which included four cinnamic acids: caffeic, p-coumaric, ferulic, and sinapic, and three benzoic acids: protocatechuic, p-hydroxybenzoic and vanillic were measured by HPLC–PDA. The results were shown in Table 3. Before hydrolysis, 1% ascorbic acid and 10 mM EDTA were added to avoid the degradation of phenolic acids under alkaline conditions (Nardini et al., 2002). Generally, ferulic dominated in the citrus juices, with the exception of Miyou and Sijiyou where sinapic (4.55 mg/L Miyou) and p-coumaric (8.79 mg/L Sijiyou) were the leading ones, respectively. Total phenolic acids ranged from 14.00 mg/L (Miyou) to 72.61 mg/L (Liubencheng). Generally, mandarin (except Manju) and orange had higher content of phenolic acids compared with grapefruits and pummelos. The results were lower to some extent when compared with the previous reports (Rapisarda, Carollo, Fallico, Tomaselli, & Maccarone, 1998; Rapisarda et al., 2003), which might be caused by the variety diversity.

Table 2
FGs contents of citrus juices (mg/L)

Fruit	Narirutin	Hesperidin	Naringin	Neohesperidin
Wase-Satsuma	169.45 ± 0.34[a]	337.44 ± 1.45	nd[b]	nd
Satsuma	288.12 ± 3.96	450.60 ± 2.89	nd	nd
Ponkan	42.63 ± 2.63	379.92 ± 7.01	nd	nd
Bendizao	42.44 ± 0.04	417.94 ± 10.25	nd	nd
Manju	43.70 ± 0.17	315.88 ± 3.46	nd	nd
Hybrid 439	119.80 ± 0.95	501.44 ± 6.73	nd	nd
Zhuhong	24.42 ± 0.01	304.46 ± 5.89	nd	nd
Skaggs bonanza	136.74 ± 0.91	427.76 ± 8.70	nd	nd
Hamlin	102.77 ± 2.10	489.64 ± 0.13	nd	nd
Liubencheng	89.49 ± 1.03	506.40 ± 10.52	nd	nd
Yinzaocheng	84.12 ± 0.84	533.64 ± 2.78	nd	nd
Lemon	nd	237.96 ± 0.12	nd	nd
Huyou	94.04 ± 0.88	38.26 ± 1.49	348.53 ± 0.36	265.25 ± 0.94
Miyou	nd	42.17 ± 1.27	108.52 ± 0.03	6.71 ± 0.97
Sijiyou	nd	21.81 ± 0.36	125.79 ± 0.80	nd

[a] Data presented are in means ± standard deviation ($n = 3$).
[b] Not detected.

Table 3
Phenolic acid contents of citrus juices (mg/L)

Fruit	Cinnamics				Benzoics			
	Caffeic	*p*-Coumaric	Ferulic	Sinapic	Protocatechuic	*p*-Hydroxybenzoic	Vanillic	Total
Wase-Satsuma	2.71 ± 0.00[a]	6.19 ± 0.00	36.49 ± 0.08	2.90 ± 0.02	0.86 ± 0.03	1.69 ± 0.01	3.40 ± 0.06	54.24 ± 0.15
Satsuma	2.74 ± 0.07	3.66 ± 0.08	40.07 ± 0.37	2.78 ± 0.04	0.71 ± 0.03	1.16 ± 0.03	2.71 ± 0.02	53.83 ± 0.60
Ponkan	5.24 ± 0.04	2.79 ± 0.07	26.07 ± 0.35	3.36 ± 0.05	0.57 ± 0.01	0.90 ± 0.02	0.94 ± 0.05	39.85 ± 0.57
Bendizao	5.39 ± 0.02	7.24 ± 0.05	45.00 ± 0.07	6.05 ± 0.07	0.55 ± 0.02	0.74 ± 0.04	0.69 ± 0.03	65.66 ± 0.30
Manju	2.54 ± 0.20	1.32 ± 0.11	18.11 ± 1.92	2.78 ± 0.31	0.55 ± 0.06	0.86 ± 0.02	0.94 ± 0.03	27.10 ± 2.66
Hybrid 439	5.50 ± 0.11	3.47 ± 0.03	16.53 ± 0.06	9.12 ± 0.20	0.82 ± 0.01	1.77 ± 0.07	3.65 ± 0.22	40.87 ± 0.30
Zhuhong	6.55 ± 0.11	3.06 ± 0.01	45.91 ± 0.21	4.39 ± 0.21	0.58 ± 0.03	1.01 ± 0.01	1.39 ± 0.05	62.90 ± 0.40
Skaggs bonanza	5.02 ± 0.12	8.15 ± 0.09	32.14 ± 0.15	5.09 ± 0.29	0.61 ± 0.02	1.04 ± 0.00	1.14 ± 0.00	53.19 ± 0.67
Hamlin	3.26 ± 0.02	6.17 ± 0.10	39.94 ± 0.82	7.88 ± 0.41	0.70 ± 0.03	0.99 ± 0.02	1.17 ± 0.01	60.10 ± 1.41
Liubencheng	5.68 ± 0.06	13.49 ± 0.18	43.20 ± 0.76	6.83 ± 0.07	1.02 ± 0.04	1.17 ± 0.01	1.21 ± 0.00	72.61 ± 0.96
Yinzaocheng	4.79 ± 0.15	9.17 ± 0.27	40.13 ± 1.20	6.24 ± 0.16	0.75 ± 0.35	0.87 ± 0.33	0.87 ± 0.63	62.82 ± 3.09
Lemon	2.07 ± 0.03	11.57 ± 0.08	35.77 ± 0.37	6.75 ± 0.15	0.72 ± 0.03	0.79 ± 0.00	0.85 ± 0.02	58.50 ± 0.68
Huyou	2.54 ± 0.06	2.60 ± 0.12	11.13 ± 0.38	3.88 ± 0.19	0.71 ± 0.06	1.07 ± 0.07	2.86 ± 0.20	24.79 ± 1.06
Miyou	2.02 ± 0.04	3.75 ± 0.09	1.63 ± 0.03	4.55 ± 0.14	0.76 ± 0.06	0.67 ± 0.04	0.63 ± 0.07	14.00 ± 0.35
Sijiyou	7.23 ± 0.01	8.79 ± 0.08	6.77 ± 0.05	3.77 ± 0.30	0.81 ± 0.02	0.81 ± 0.00	1.17 ± 0.00	29.35 ± 0.46

[a] Data presented are in means ± standard deviation ($n = 3$).

3.3. Content of total carotenoid, AA, total phenolics, and antioxidant capacity of citrus juices

Total carotenoid was determined by colorimetric method (expressed as β-carotene equivalent), and AA content was determined by HPLC, and total phenolics were measured by Folin–Ciocalteu method (GAE), and antioxidant capacity of citrus juice was evaluated by FRAP (AEAC) and DPPH assay (I%) (Table 4). Total carotenoid ranged from 0.06 mg/L (Yinzaocheng) to 10.02 mg/L (Bendizao). Generally, mandarin fruits had much higher content of total carotenoid than sweet oranges, lemon, grapefruit, and pummelos. It was reported that mandarin fruits had much higher content of beta-cryptoxanthin and vitamin A than oranges (Dhuique-Mayer et al., 2005; Melendez-Martinez, Vicario, & Heredia, 2007). Also, our result was comparable with other reports (Gardner et al., 2000; Wang et al., 2007), though there were some divergences due to different citrus varieties investigated. As for AA, mandarin juices had lower AA content when compared with orange juices except Hybrid 439, which was accordance with the other reports (Dhuique-Mayer et al., 2005; Rapisarda et al., 2003). It was interesting that Hybrid 439 achieved the highest AA content (631.25 mg/L) among the fifteen selected citrus juices. Furthermore, total phenolics and DPPH inhibitory of Hybrid 439 both achieved the highest value: 1555.49 mg/L and 61.62%, which suggested that Hybrid 439 is a valuable variety with high antioxidant capacity that may be beneficial to health. For FRAP assay, Hamlin had the highest value of 899.31 AEAC mg/L, while lemon had the lowest value of 307.43 AEAC mg/L. Contribution of AA to total antioxidant capacity was calculated, and it was found that AA contribution to total antioxidant capacity of citrus juices was more than 50% except Wase-Satsuma (48.12%). The results were in agreement with previous reports (Arena et al., 2001; Caro et al., 2004; Gardner

Table 4
Total carotenoid, AA contents, total phenolics, and antioxidant capacity of citrus juices

Fruit	Total carotenoid (mg/L, β-carotene equivalent)	AA (mg/L)	FRAP (AEAC, mg/L)	Contribution of AA (%)	Total phenolics (GAE, mg/L)	Inhibition of DPPH (%)
Wase-Satsuma	7.26 ± 0.06	218.83 ± 4.00[a]	454.72 ± 11.06	48.12	863.38 ± 12.40	26.31 ± 0.87
Satsuma	9.14 ± 0.11	326.80 ± 1.23	598.48 ± 14.79	54.61	1109.23 ± 10.33	33.65 ± 0.48
Ponkan	2.92 ± 0.20	282.68 ± 1.08	476.19 ± 19.31	59.36	830.32 ± 4.13	29.67 ± 0.33
Bendizao	10.02 ± 0.02	245.95 ± 0.99	482.98 ± 5.70	50.92	972.88 ± 35.12	25.39 ± 1.77
Manju	5.20 ± 0.44	234.74 ± 1.80	361.24 ± 9.06	64.98	774.54 ± 10.63	23.69 ± 0.54
Hybrid 439	6.36 ± 0.72	631.25 ± 5.51	875.93 ± 11.74	72.07	1555.49 ± 18.59	61.62 ± 0.71
Zhuhong	6.38 ± 0.18	337.20 ± 3.69	541.14 ± 6.59	62.31	1043.12 ± 22.73	36.75 ± 0.88
Skaggs bonanza	0.60 ± 0.04	539.34 ± 0.40	765.33 ± 7.47	70.47	1173.28 ± 20.66	50.92 ± 2.12
Hamlin	0.72 ± 0.00	623.79 ± 5.51	899.31 ± 12.61	69.36	1499.71 ± 16.53	60.24 ± 0.19
Liubencheng	0.16 ± 0.04	614.11 ± 3.96	886.26 ± 1.72	69.29	1462.52 ± 4.73	60.13 ± 0.51
Yinzaocheng	0.06 ± 0.02	474.71 ± 1.55	712.61 ± 10.63	66.62	1245.59 ± 12.33	47.82 ± 0.79
Lemon	0.08 ± 0.04	233.44 ± 2.52	307.43 ± 14.37	75.93	751.82 ± 13.34	24.50 ± 0.66
Huyou	0.14 ± 0.02	429.44 ± 1.00	617.50 ± 11.82	69.55	1241.46 ± 12.21	39.83 ± 2.20
Miyou	0.10 ± 0.02	390.57 ± 1.22	510.16 ± 3.99	76.56	863.38 ± 10.54	37.71 ± 1.07
Sijiyou	0.16 ± 0.00	314.19 ± 2.74	442.22 ± 3.31	71.05	801.40 ± 5.49	35.79 ± 0.95

[a] Data presented are in means ± standard deviation ($n = 3$).

Table 5
Correlation coefficients of AA, total phenolics (GAE), FRAP (AEAC), DPPH (I%), total FGs, and total phenolic acids ($n = 15$)

	Total phenolics	FRAP	DPPH	AA	Total FGs
FRAP	0.904*				
DPPH	0.845*	0.962*			
AA	0.841*	0.961*	0.992*		
Total FGs	0.659*	0.643*	0.459	0.489	
Total phenolic acids	0.472	0.336	0.227	0.185	0.341

* Correlation is significant at the 0.01 level (2-tailed).

et al., 2000; Yoo et al., 2004), which suggested AA, not phenolic compounds, was the major contributor of total antioxidant capacity of citrus juices. However, some studies suggested phenolic compounds dominated total antioxidant capacity of citrus fruits (Rapisarda et al., 1999; Sun et al., 2002; Wang et al., 1996). It seemed that some factors such as the different citrus variety, maturity, material preparation and analyzing methods might cause the divergence. Generally, orange had higher antioxidant capacity than other citrus varieties due to its higher AA content.

3.4. Correlation coefficients of AA, total phenolics (GAE), FRAP (AEAC), DPPH (I%), total FGs, and total phenolic acids

Correlation coefficients of AA, total phenolics (GAE), FRAP (AEAC), DPPH (I%), total FGs, and total phenolic acids were shown in Table 5. AA content correlated highly ($p < 0.01$) with total phenolics, FRAP (AEAC) and DPPH (I%), which meant that AA played a major role for the antioxidant capacity of citrus juices. Total FGs correlated highly ($p < 0.01$) with total phenolics and FRAP (AEAC), but correlation with DPPH (I%) was not significant, which indicated that FGs played a minor role for the antioxidant capacity of citrus juices. As FGs are the major phenolic compounds, they obviously present a high correlation with total phenolics. Correlation coefficients of total phenolic acids with FRAP (AEAC) and DPPH (I%) were not significant, which demonstrated that phenolic acids played a minimal role to the antioxidant capacity of citrus juices.

4. Conclusion

Based on the correlation coefficients of AA, total phenolics (GAE), FRAP (AEAC), DPPH (%), total FGs, and total phenolic acids, AA played a major role in the antioxidant capacity of citrus juices; phenolics also played an important role. Phenolic acids seemed to play a minimal role. When considering antioxidant capacity, orange would be more suitable for juice processing than other varieties due to their high content of AA. Hybrid 439 (tangor) achieved several highest values in our study, and Huyou (grapefruit) had the highest FGs content. These traits of Hybrid 439 and Huyou made them valuable from a nutritional and health benefits point of view. Therefore, Hybrid 439 and Huyou may be considered as excellent sources of phytochemicals with potential health benefits.

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