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Effects of genotype and treatment on the antioxidant activity of sweet potato in Taiwan

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Abstract

Six genotypes of sweet potato commercially available in Taiwan, including TNG57, TNG66, TNG68, TYY1, RP and WP, were used as samples in this study of the effects of steaming and kneading with pre-steaming treatments on the antioxidant components and antioxidant properties of methanolic extracts. Steam treatment increased the total phenols contents of all genotypes (2–13 times), flavonoids content of RP (1.3 times) and anthocyanins contents of RP and WP (5–6 times). Steam treatment also increased the reducing power and scavenging DPPH radical effect of sweet potato flours. For the methanolic extracts of steamed and kneaded flours, reducing powers were 0.02–1.70 at 5.0 mg ml^{-1} and the scavenging effects on DPPH radicals were 19–92% at 2.5 mg ml^{-1}. Both showed the order of RP > WP > TYY1 and TNG66 > TNG57 and TNG68. However, the chelating effect of the six genotypes at 1.0 mg ml^{-1} ranged from 50% to 73%. Contents of total phenols, flavonoids, and anthocyanins of sweet potato flours were significantly positively correlated with the reducing power and scavenging DPPH radical effects. After steaming and kneading treatments, RP showed the highest increase in the contents of total phenols, flavonoids and anthocyanins among the six genotypes studied.

Keywords: Sweet potato; Genotype; Steaming; Kneading; Antioxidant property

1. Introduction

Cancer and Cardiovascular diseases are ranked as the first two leading causes of death in many developed countries (DOH, 2004; Doll & Peto, 1981). Unhealthy dietary habits, living habits and exposure to dangerous chemicals in the environment could lead to the production of more free radicals. Oxidative damage caused by free radicals may be related to cancer, atherosclerosis, diabetes, arthritis and other aging diseases (Halliwell & Gutteridge, 1999). Antioxidants can be used to help the human body to reduce oxidative damage.

In recent years, there has been a global trend toward the use of natural phytochemical, as antioxidants and functional ingredients, which are present in natural resources such as vegetables, fruits, oilseeds and herbs, (Elliott, 1999; Kaur & Kapoor, 2001; Larson, 1988; Namiki, 1990). Sweet potato (*Ipomoea batatas* L.) is the sixth most important food crop in the world according to data from the food and agriculture organization. In Taiwan, the total production of sweet potato harvested in 2003 was 199,800 metric ton, ranking first in the coarse grains (COA, 2004). Sweet potato had intermediate antioxidant activity among 43 vegetables (Tsushida, Suzuki, & Kurogi, 1994). The purple-fleshed sweet potato genotypes have antioxidant activity, radical-scavenging activity (Oki et al., 2002), antimutagenicity (Konczak-Islam, Yoshimoto, De, Terahara, & Yamakawa, 2003; Yoshimoto, Okuno, Kumagai,

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Yoshinaga, & Yamakawa, 1999) and have been shown to reduce liver injury induced by carbon tetrachloride (Suda et al., 1997).

The conventional concept indicated that processed vegetables have lower nutritional values than their respective fresh commodities because of vitamin C loss in the process (Burge & Fraile, 1995; Rao, Lee, Katz, & Cooley, 1981). However, studies have demonstrated that thermal processing may increase the antioxidant activity of tomatoes (Dewanto, Wu, Adom, & Liu, 2002a) and sweet corn (Dewanto, Wu, & Liu, 2002b). Sweet potato paste is common used as the filling of waxy rice balls, bread, steamed bread, etc., in Taiwan. Sweet potato paste is traditionally produced by kneading the steamed sweet potato tuber with sugar and oil/butter. It is not clear whether the steaming and/or kneading treatments will enhance the antioxidant properties of sweet potato or not. Therefore, the objective of this study was to evaluate the effect of steaming and kneading processing on the antioxidant activity of sweet potato tubers from six genotypes popular in Taiwan by assessing contents of total phenols, flavonoids, anthocyanins and vitamin C and antioxidant properties of the raw, steamed and kneaded sweet potato.

2. Materials and methods

2.1. Materials

Six genotypes of sweet potato grown in Taiwan were used in this study. Tainung 57 (TNG57) and Tainung 66 (TNG66) were from Chiayi Agricultural Experiment Station, Tao-Yuan 1 (TYY1) was from Taoyuan District Agricultural Research and Extension Station, and red peeled Yu-Zai (RP), white peeled Yu-Zai (WP) and Tainung 68 (TNG68) were from Hualien District Agricultural Research and Extension Station. All reagents were of analytical grade.

2.2. Preparation of sweet potato flour

2.2.1. Raw sweet potato flour

The whole tuber was cleaned, peeled and sliced to small cubes ($1 \times 1 \times 1$ cm^3). The cubes of sweet potato were freeze-dried and ground and sieved to pass through a 100 mesh. The raw sweet potato flour was then packed in plastic bags and stored at 4 °C until used.

2.2.2. Steamed sweet potato flour

The cleaned sweet potato tubers were cut into small cubes ($3 \times 3 \times 3$ cm^3) with peels. After steaming for 40 min, the cooked cubes were packed in a plastic bag and cooled with flowing tap water for 40 min. The flesh was then removed from peel by hand, freeze-dried, ground and sieved to pass through a 100 mesh. The steamed sweet potato flour was also kept at 4 °C until used.

2.2.3. Kneaded sweet potato flour

The steamed sweet potato cubes from the above process were kneaded in a tabletop mixer (Model K5SS, Kitchen Aid, USA) at 120 rpm for 10 min. The paste was freeze-dried, ground and sieved, and the kneaded sweet potato flour was stored at 4 °C until used.

2.3. Preparation of sweet potato extracts

The raw, steamed and kneaded flours of sweet potato (0.75–1.85 g) were treated with 80% methanol (15 ml) in a rotary mixer (RT01C, Kansin, Taiwan) at a 45 °C angle and 150 rpm for 10 min, and the mixture was centrifuged at 1600*g* for 15 min. The residue was then extracted again with an additional 10 ml 80% methanol as described above. The combined supernatant was filtered through Whatman No. 4 filter paper, diluted to 25 ml and kept at 4 °C before analysis. The yields of extracts were determined by drying in a vacuum dryer.

2.4. Determination of antioxidant components

2.4.1. Total phenols

Total phenols were determined according to the method of Taga, Miller, and Pratt (1984). Each extract in methanol (0.2 ml) was mixed with 1.0 ml of Folin–Ciocalteau's reagent and 0.8 ml of saturated sodium carbonate solution (7.5%). After 30 min standing, the absorbance was read at 765 nm against a blank in a spectrophotometer (Spectronic Helios Alpha, Unicam, UK). Content of phenols was calculated on the basis of the calibration curves of gallic acid, and was expressed as mg gallic acid per 100 g dry matter.

2.4.2. Flavonoids

Content of flavonoids was measured according to the $AlCl_3$ method (Quettier-Deleu et al., 2000). Each extract in methanol (0.5 ml) was mixed with 1.0 ml of 2% methanolic $AlCl_3 \cdot 6H_2O$, and the absorbance was measured 10 min later at 430 nm. Content of flavonoids was calculated on the basis of the calibration curves of quercetin, and was expressed as mg quercetin per 100 g dry matter.

2.4.3. Anthocyanins

Content of anthocyanins was determined by following the procedures of Giusti and Wrolstad (2001). The sweet potato flour (0.5 g) was treated with 10 ml of acidified methanol (1% HCl) in a rotary mixer at a 45° angle and 200 rpm for 30 min in the dark. After centrifuging at 1600*g* and 4 °C for 15 min, the residue was extracted again with an additional 10 ml portion of acidified methanol, as described above. The combined supernatant was diluted to 25 ml and the absorbance was read at

530 nm. The anthocyanin content was calculated on the basis of the following equation:

$$\text{Anthocyanins content(mg/100 g of dry matter)} = A \times \text{MW} \times \text{DF} \times 100/(\varepsilon \times W)$$

where A = absorbance, MW = molecular weight of cyanidin-3-glucoside chloride ($C_{21}H_{21}ClO_{11}$, 484.84 Da), DF = dilution factor, ε = molar absorptivity (34,300), W = sample weight (g).

2.4.4. Ascorbic acid

Ascorbic acid was measured according to the method of Klein and Perry (1982). The sweet potato flour (0.5 g) was treated with 10 ml of 1% metaphosphoric acid (pH 1.86) in a rotary mixer at a 45° angle and 200 rpm for 30 min in the dark. After centrifuging at 1600*g* and 4 °C for 15 min, the supernatant was collected. A portion of supernatant (1 ml) was mixed with 9 ml of 2,6-dichloroindophenol (15 mg l^{-1}), and the absorbance was measured at 515 nm within 15 s. Content of ascorbic acid was calculated on the basis of the calibration curve of authentic L-ascorbic acid, and was expressed as mg ascorbic acid per 100 g dry matter.

2.5. Determination of antioxidant properties of extracts

2.5.1. Reducing power

The reducing power was measured using the method described by Oyaizu (1986). Each extract (1–10 mg ml^{-1}) in methanol (2.5 ml) was mixed with 2.5 ml of 0.2 M sodium phosphate buffer (pH 6.6) and 2.5 ml of 1% potassium ferricyanide, and the mixture was incubated at 50 °C for 20 min. After 2.5 ml of 10% trichloroacetic acid (w/v) was added, the mixture was centrifuged at 1600*g* for 10 min. The upper layer (5 ml) was mixed with 5 ml of deionized water and 1 ml of 0.1% ferric chloride. The mixture was shaken and left to stand for 10 min in the dark, and the absorbance was read at 700 nm against a blank. A higher absorbance indicates a stronger reducing power. EC_{50} value (mg ml^{-1}) is the effective concentration at which the absorbance was 0.5 for reducing power and was obtained by interpolation from linear regression analysis (Mau, Chang, Huang, & Chen, 2004). Butylated hydroxyanisole (BHA) was used as the control.

2.5.2. Scavenging effect on 1,1-diphenyl-2-picrylhydrazyl radical

Scavenging effect was determined according to the method of Shimada, Fujikawa, Yahara, and Nakamura (1992). Each extract (0.2–10 mg ml^{-1}) in methanol (2 ml) was mixed with 2 ml of freshly prepared methanolic solution containing 80 ppm of 1,1-diphenyl-2-picrylhydrazyl (DPPH) radicals. The mixture was shaken vigorously and left to stand for 30 min in the dark. The absorbance was then measured at 517 nm. The percentage of DPPH scavenging activity was calculated as follows: [1 − (absorbance of sample/absorbance of blank)] × 100. A lower absorbance indicates a higher scavenging effect. EC_{50} value (mg ml^{-1}) is the effective concentration at which DPPH radicals were scavenged by 50% and was obtained by interpolation from linear regression analysis (Mau et al., 2004). BHA was used as the control.

2.5.3. Chelating effect on ferrous ions

The chelating effect on ferrous ions was determined according to the method of Dinis, Madeira, and Almerida, 1994. Each extract (0.2–10 mg ml^{-1}) in methanol (2 ml) was mixed with 0.1 ml of 2 mM $FeCl_2$ and 0.2 ml of 5 mM ferrozine solutions. After reaction for 10 min, the absorbance was measured at 562 nm. The percentage of ferrous ion chelating effect was calculated as follows: [1 − (absorbance of sample/absorbance of blank)] × 100. A lower absorbance indicates a stronger chelating ability. EC_{50} value (mg ml^{-1}) is the effective concentration at which ferrous ions were chelated by 50% and was obtained by interpolation from linear regression analysis (Mau et al., 2004). Ethylenediaminetetraacetic acid (EDTA) was used as the control.

2.6. Statistical analysis

For each methanolic extract from sweet potato, three samples were prepared for assays. Analysis of variance (ANOVA), Duncan's multiple range tests (at $P < 0.05$) and regression analysis were performed by using the SAS program (SAS Institute, Cary, NC).

3. Results and discussion

3.1. Yield of 80% methanolic extracts

Six genotypes of sweet potato used in the study had different colored peels and fleshes. TNG57 was yellowish orange-fleshed with brownish yellow-peel, TNG66 was orange red-fleshed with brownish red-peel, TYY1 was yellowish orange-fleshed with purple red-peel, RP was purple-fleshed with purple-peel, WP was light purple-fleshed with white-peel, and TNG68 was light yellow-fleshed with light yellow-peel. While the color of extracts from TNG57, 66 and TYY1 were yellow, extracts from TNG68, WP and RP were bright-white, irony-gray and purple in color, respectively. The different colors of the methanolic extracts of sweet potato resulted from the natural colorants of the respective tuber.

Table 1 shows the extraction yields, using 80% methanol solution, of sweet potato after different treatments. Yields of extract from raw flours ranged from 12.00 to 16.12% (db). However, the yields of steamed and kneaded with pre-steaming treatment flours were

Table 1
Yields of methanolic extract of raw, steamed and kneaded flours of sweet potato

Sweet potato	Yield (%, db)*		
	Raw	Steamed	Kneaded
TNG57	$^{B}15.47 \pm 0.17^{ab}$	$^{A}51.25 \pm 0.44^{b}$	$^{A}49.84 \pm 0.98^{b}$
TNG66	$^{B}16.12 \pm 0.16^{a}$	$^{A}50.56 \pm 0.44^{b}$	$^{A}53.49 \pm 2.61^{a}$
TNG68	$^{B}13.01 \pm 0.22^{c}$	$^{A}45.23 \pm 0.75^{c}$	$^{A}44.03 \pm 0.90^{c}$
TYY1	$^{B}14.59 \pm 0.38^{b}$	$^{A}53.97 \pm 0.33^{a}$	$^{A}51.35 \pm 1.51^{a}$
RP	$^{B}12.80 \pm 0.95^{c}$	$^{A}51.75 \pm 0.77^{b}$	$^{A}53.50 \pm 1.27^{a}$
WP	$^{B}12.00 \pm 0.03^{c}$	$^{A}50.62 \pm 0.18^{b}$	$^{A}49.60 \pm 0.94^{b}$

[a–c] Means in a column with different small letters are significantly different ($p < 0.05$).
[A–B] Means in a row with different capital letters are significantly different ($p < 0.05$).
* Each value is expressed as mean ± standard deviation ($n = 3$).

between 50% and 54% (db), except for TNG68 (45.23% and 44.03% for steamed and kneaded flours, respectively). For the same genotype of sweet potato, no significant difference was found in the extraction yield between steamed and kneaded samples. Generally speaking, the yields from steamed and kneaded flours were 3–4 times higher than that from the corresponding raw flour. This implied that cell structure damage and/or partial hydrolysis of biopolymers might occur during steaming and kneading treatments.

3.2. Antioxidant components

3.2.1. Total phenols

Antioxidant components of sweet potato flours with different treatments are shown in Table 2. The total phenolic contents of raw flours ranged from 4.79 to 6.42 mg 100 g^{-1} of dry matter, and the total phenols of the steamed flours were between 10.13 and 80.78 mg. For each genotype of sweet potato, the phenolic content of steamed flour was higher than that of raw flour. Steaming treatment could cause the damage of cell structures of tubers with peel and resulted in more easy extraction of antioxidant components from the tuber itself or those from the peel diffusing to the tuber. Dewanto et al. (2002b) also found the free phenolic content of sweet corn increased with increasing heating temperature and time. However, thermal processing had no effect on the phenolic content of tomato (Dewanto et al., 2002a). The total phenolic contents of kneaded flours ranged from 8.36 to 89.04 mg (Table 2). This indicates that the kneading treatment has less impact, compared to the steam treatment, on the increase of phenolic content of sweet potato.

Table 2
Antioxidant components of raw, steamed and kneaded flours of sweet potato

Treatment	Sweet potato	Total phenols (mg 100 g^{-1}, db)*	Total flavonoids (mg 100 g^{-1}, db)	Total anthocyanins (mg 100 g^{-1}, db)	Ascorbic acid (mg 100 g^{-1}, db)
Raw	TNG57	$^{C}4.79 \pm 0.35^{c}$	$^{B}22.02 \pm 1.16^{c}$	$^{B}0.48 \pm 0.03^{de}$	$^{C}9.80 \pm < 0.01^{d}$
	TNG66	$^{C}5.60 \pm 0.22^{b}$	$^{A}34.23 \pm 0.37^{b}$	$^{C}0.73 \pm 0.04^{c}$	$^{A}9.63 \pm 0.62^{a}$
	TNG68	$^{C}4.92 \pm 0.08^{c}$	$^{A}34.09 \pm < 0.01^{b}$	$^{B}0.36 \pm 0.06^{e}$	$^{C}9.49 \pm < 0.01^{c}$
	TYY1	$^{C}5.52 \pm 0.12^{b}$	$^{A}35.68 \pm 0.09^{a}$	$^{B}0.66 \pm 0.06^{cd}$	$^{C}8.95 \pm 0.15^{c}$
	RP	$^{C}6.42 \pm 0.14^{a}$	$^{C}34.83 \pm 0.08^{ab}$	$^{C}8.99 \pm 0.27^{a}$	8.64 ± 0.14^{b}
	WP	$^{C}6.29 \pm 0.13^{a}$	$^{C}35.47 \pm < 0.01^{a}$	$^{C}5.26 \pm 0.23^{b}$	$7.57 \pm < 0.01^{b}$
Steamed	TNG57	$^{A}10.13 \pm 0.20^{e}$	$^{C}19.39 \pm 0.47^{d}$	$^{B}0.40 \pm 0.04^{d}$	$^{A}24.22 \pm 0.66^{b}$
	TNG66	$^{B}10.42 \pm 0.17^{e}$	$^{B}32.79 \pm 0.92^{b}$	$^{B}0.96 \pm 0.05^{c}$	$^{A}32.08 \pm 0.43^{a}$
	TNG68	$^{A}12.70 \pm 0.14^{d}$	$^{C}29.28 \pm 1.94^{c}$	$^{B}0.38 \pm 0.04^{d}$	$^{B}18.07 \pm 3.29^{c}$
	TYY1	$^{B}15.71 \pm 0.36^{c}$	$^{C}28.85 \pm 0.22^{c}$	$^{A}1.00 \pm < 0.01^{c}$	$^{A}18.82 \pm 0.38^{c}$
	RP	$^{B}80.78 \pm 0.69^{a}$	$^{B}45.53 \pm 0.44^{a}$	$^{A}52.84 \pm 0.32^{a}$	ND**
	WP	$^{A}32.57 \pm 1.69^{b}$	$^{B}31.87 \pm 0.29^{b}$	$^{B}25.01 \pm 0.12^{b}$	13.48 ± 0.49^{c}
Kneaded	TNG57	$^{B}8.36 \pm 0.33^{d}$	$^{A}30.52 \pm 0.15^{d}$	$^{A}0.63 \pm 0.02^{d}$	$^{B}16.34 \pm 0.25^{b}$
	TNG66	$^{A}12.29 \pm 0.59^{c}$	$^{B}21.01 \pm 0.51^{e}$	$^{A}1.28 \pm 0.09^{c}$	$^{B}32.15 \pm 0.86^{ab}$
	TNG68	$^{B}9.31 \pm 0.53^{d}$	$^{B}31.16 \pm 0.39^{d}$	$^{A}0.47 \pm 0.04^{e}$	$^{A}15.04 \pm 0.66^{a}$
	TYY1	$^{A}26.94 \pm 1.53^{b}$	$^{B}34.05 \pm 0.39^{d}$	$^{A}1.08 \pm 0.10^{c}$	$^{A}10.45 \pm 0.29^{b}$
	RP	$^{A}89.04 \pm 2.51^{a}$	$^{A}69.58 \pm 0.80^{a}$	$^{B}40.33 \pm 0.25^{b}$	ND
	WP	$^{B}29.04 \pm 1.29^{b}$	$^{B}41.84 \pm 0.23^{b}$	$^{A}54.59 \pm 0.31^{a}$	ND

[a-c] Means in a column of the same treatment with different small letters are significantly different ($p < 0.05$).
[A–C] Means in a column of the same genotype of sweet potato with different capital letters are significantly different ($p < 0.05$).
* Each value is expressed as the mean ± standard deviation ($n = 3$).
** Not detected.

Among the six genotypes of sweet potato studied, RP after steaming or kneading with pre-steaming treatments had the highest content of total phenols, followed by WP. TNG57, TNG66 and TNG68 had relatively lower phenolic contents (<13 mg 100 g^{-1} of dry matter). The phenolic contents of steamed or kneaded RP were lower than that of heat-treated tomato (~300 mg 100 g^{-1} of dry matter, Dewanto et al., 2002b), but was comparable to that of the blanched yam flour (0.97–1.23 mg 100 g^{-1} of dry matter, Hsu, Chen, Weng, & Tseng, 2003).

3.2.2. Total flavonoids

Total flavonoids content of raw sweet potato flour ranged from 22.02 to 35.47 mg 100 g^{-1} of dry matter (Table 2), and among the six raw sweet potato flours TNG57 had the lowest content of flavonoids. The flavonoids content of sweet potato was much higher than that of potato (0.13 mg kg^{-1} of fresh weight, Chu, Chang, & Hsu, 2000), and also comparable to or higher than that of the interior part of onion (27.11 mg kg^{-1}), spinach (25.02 mg kg^{-1}), perilla (13.51 mg kg^{-1}) (Chu et al., 2000), radish roots (0.16 mg g^{-1} of dry matter, Chiang, Hsu, & Chang, 2003), but comparable to or lower than the flavonoids contents of apples (26.4–73.9 μg g^{-1} of fresh weight, Price, Prosser, Richetin, & Rhodes, 1999) and blueberries and blackberries (21–390 mg 100 g^{-1} of fresh weight, Sellappan, Akoh, & Krewer, 2002). After steaming and kneading treatments, contents of flavonoids of sweet potato flours were in the range of 19.39 and 69.58 mg 100 g^{-1} of dry matter (Table 2). Different genotypes of sweet potato showed discrepancy responses to the steaming and kneading treatments on the extraction of flavonoids. Flavonoids content of RP increased from 34.83 to 45.53 or 69.58 mg after steaming or kneading treatments, respectively, which were the highest contents compared to other sweet potatoes with the same treatment. Conversely, the flavonoids content of TNG66 decreased from 34.23 to 32.79 or 21.01 mg after steaming or kneading treatments, respectively.

3.2.3. Total anthocyanins

Total anthocyanins contents of raw, steamed and kneaded sweet potato flours were 0.36–8.99, 0.38–52.84 and 0.47–54.59 mg 100 g^{-1} dry matter, respectively (Table 2). RP and WP had higher contents of anthocyanins than those of the other four genotypes of sweet potato with the same treatment. Easier extraction and/or diffusion of anthocyanins from peel to tuber due to steam treatment might be the reasons for the higher anthocyanins contents of steamed flours of WP and RP than those of the corresponding raw flours. However, for the genotypes of sweet potato with low anthocyanins contents, steaming and kneading treatments showed little effect.

Steamed and kneaded sweet potato flours of RP and WP had higher contents of anthocyanins than that of blanched flour of yam (0–0.22 mg g^{-1} of dry matter, Hsu et al., 2003), but were comparable to or lower than the contents of blueberry purée (12.8 mg 100 g^{-1} of fresh weight, Kalt, McDonald, & Donner, 2000), blueberries and blackberries (12.7–197.34 mg 100 g^{-1} of fresh, Sellappan et al., 2002), and purple carrots (38–98 mg 100 g^{-1} of fresh, Lazcano, Yoo, & Pike, 2001).

3.2.4. Ascorbic acid

Ascorbic acid contents of sweet potato raw flours ranged from 7.57 to 9.80 mg 100 g^{-1} of dry matter (Table 2), which was equal to 2.48 to 3.08 mg 100 g^{-1} of fresh sweet potato tuber. The ascorbic acid content of sweet potato was lower than that reported in another study (Reddy & Sistrunk, 1980). The lower content of heat-unstable ascorbic acid in this study was attributed to the pre-treatment and storage procedures before measurement. Due to the fast color-fading within the 15 s before the absorbance measured at 515 nm, the ascorbic acid contents of steamed RP, kneaded RP and kneaded WP could not be detected. Decay of ascorbic acid could be caused by the presence of anthocyanins (Von Elbe & Schwartz, 1996), therefore, the ascorbic acid content of RP or WP with higher anthocyanins might be underestimated.

3.3. Antioxidant properties

3.3.1. Reducing power

Reducing powers of extracts of sweet potato flours are illustrated in Fig. 1. For the raw flours, the extracts from six genotypes of sweet potato showed no reducing power at 2.5 mg ml^{-1}, whereas the reducing powers of RP and WP were 0.29 and 0.53 at 5 mg ml^{-1}, and 0.85 and 1.10 at 10 mg ml^{-1}, respectively. Reducing powers of the other four genotypes were lower than 0.30 even at 10 mg ml^{-1} concentration level. The reducing powers of the steamed and kneaded flours of RP and WP were 0.47–0.60 and 0.18–0.26 at 1 mg ml^{-1}, and were increased to 1.22–1.97 and 0.90–1.53 at 10 mg ml^{-1}, respectively. Reducing powers of kneaded TYY1 and TNG66 were 0.91 and 0.72 at 10 mg ml^{-1}, respectively. Kneaded flours of TNG57 and TNG68 had reducing power lower than 0.30 at 10 mg ml^{-1}. Evidently, the reducing power of kneaded sweet potato flours was superior to the raw and steamed flours.

The antioxidant properties expressed as EC_{50} are summarized in Table 3. For reducing powers, EC_{50} values for extracts of raw and steamed flours from TNG57, TNG66, TNG68 and TYY1 were higher than 10 mg ml^{-1}. This indicates that the four genotypes of sweet potato had very low reducing power. However, both steaming and kneading treatments increased the reducing powers of sweet potato flours. The higher extraction of antioxidant components from both steaming and kneading with pre-steaming treatments could

lead to the higher reducing powers of steamed and kneaded flour, compared with those of the raw flours. EC_{50} values of reducing powder of the kneaded flours were in the order of RP < WP < TYY1 and TNG66 < TNG57 and TNG68.

Steamed or kneaded flours of RP and WP, and kneaded flours of TNG66 and TYY1 had much lower EC_{50} values of reducing power than that of blanched yam flour (~45–100 mg ml^{-1}, Hsu et al., 2003) and purple yam at 100 °C (~25 mg ml^{-1}, Chiou & Wang, 2003). Moreover, steamed or kneaded flours of RP had EC_{50} values similar to the raw broccoli flower, stem and leaf (~1–2 mg ml^{-1}, Guo, Lee, Chiang, Lin, & Chang, 2001), radish root, leaf, leafstalk (~1–2 mg ml^{-1}, Chiang et al., 2003), sprouts of radish and mungbean (~1.3–1.50 mg ml^{-1}, Wong & Yen, 1997), but lower than soybean sprout (~3.3 mg ml^{-1}, Wong & Yen, 1997), lotus seed, black soybean, and Job's tears (~4–4.5 mg ml^{-1}, Liou, Chen, & Yen, 1999).

3.3.2. Scavenging DPPH radical effect

The scavenging activity of sweet potato flours with different treatments were in the order of kneaded flour > steamed flour > raw flour (Fig. 2). For the six genotypes of sweet potato studied, the scavenging activities were in the order of RP > WP > TYY1, TNG66, TNG57 and TNG68. Among the six genotypes of sweet potato studied, scavenging DPPH radical effects of RP and WP were superior to the other four genotypes. The scavenging effects of RP and WP flours

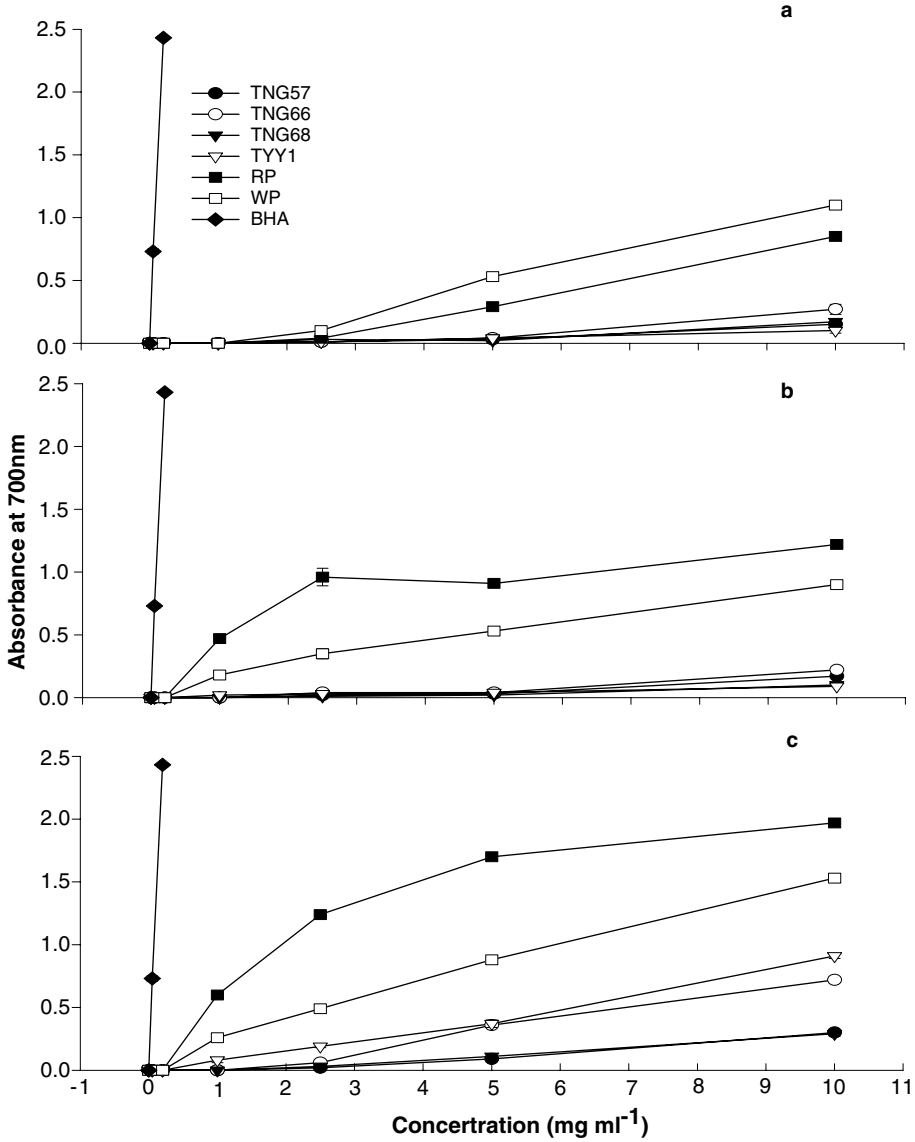

Fig. 1. Reducing powers of 80% methanolic extracts from sweet potato flours after different treatments: raw (a), cooked (b) and kneaded (c).

Table 3
EC_{50} in antioxidant properties of methanolic extracts from sweet potato flours

Treatment	Sweet potato	EC_{50} (mg ml^{-1})[a]		
		Reducing power	Scavenging effect on DPPH radicals	Chelating effect on ferrous ions
Raw	TNG57	>10	$^{A}9.77 \pm 0.53$	$^{C}0.22 \pm 0.02$
	TNG66	>10	$^{A}8.43 \pm 0.54$	$^{C}0.28 \pm < 0.01$
	TNG68	>10	$^{A}9.76 \pm 0.34$	$^{B}0.58 \pm 0.02$
	TYY1	>10	$^{A}9.14 \pm 0.28$	$^{B}0.35 \pm 0.04$
	RP	$^{A}6.92 \pm 0.19$[b]	$^{A}2.37 \pm 0.07$	$^{A}0.18 \pm < 0.01$
	WP	$^{A}4.80 \pm 0.13$	$^{A}1.95 \pm 0.06$	$^{C}0.19 \pm < 0.01$
Steamed	TNG57	>10	$^{B}4.03 \pm 0.17$	$^{A}0.60 \pm 0.02$
	TNG66	>10	$^{B}4.13 \pm 0.17$	$^{A}0.67 \pm 0.04$
	TNG68	>10	$^{B}5.23 \pm 0.13$	$^{A}0.73 \pm 0.05$
	TYY1	>10	$^{B}5.14 \pm 0.02$	$^{A}0.53 \pm 0.07$
	RP	$^{B}1.09 \pm 0.04$	$^{B}0.49 \pm 0.01$	$^{A}0.19 \pm < 0.01$
	WP	$^{A}4.54 \pm 0.47$	$^{B}1.54 \pm 0.01$	$^{A}1.06 \pm 0.05$
Kneaded	TNG57	>10	$^{B}3.80 \pm 0.30$	$^{B}0.30 \pm 0.03$
	TNG66	6.91 ± 1.81	$^{C}2.32 \pm 0.07$	$^{B}0.57 \pm 0.02$
	TNG68	>10	$^{C}3.91 \pm 0.19$	$^{B}0.57 \pm 0.03$
	TYY1	6.20 ± 0.25	$^{C}4.01 \pm 0.02$	$^{C}0.19 \pm 0.03$
	RP	$^{C}0.77 \pm 0.03$	$^{B}0.49 \pm 0.01$	$^{A}0.19 \pm < 0.01$
	WP	$^{B}2.56 \pm 0.12$	$^{C}1.42 \pm 0.04$	$^{B}0.78 \pm 0.02$

[A–C] Means in a column of the same genotype of sweet potato with different capital letters are significantly different ($p < 0.05$).
[a] EC_{50}, the effective concentration at which the antioxidant activity was 50%, the absorbance was 0.5 for reducing power, the DPPH radicals were scavenged by 50%, and ferrous ions were chelated by 50%, respectively.
[b] EC_{50} was obtained by interpolation from linear regression analysis. Each value is expressed as mean ± standard deviation ($n = 3$).

with steaming or kneading treatments were all above 90% at 2.5 mg ml^{-1}, however the 90% scavenging activity of the steamed or kneaded flours for the other four genotypes were at or above 10 mg ml^{-1}. The steamed or kneaded flours of RP possessed a similar DPPH scavenging activity at 1.0 mg ml^{-1} to those of BHA and α-tocopherol at 0.05 mg ml^{-1}.

Furuta, Suda, Nishiba, and Yamakawa (1998) reported that the purple-fleshed sweet potato cultivar have a higher radical-scavenging or antioxidant activity than those with white, yellow or orange flesh. Furthermore, anthocyanins and phenols were the major compounds for DPPH radical-scavengers in purple-fleshed sweet potato (Oki et al., 2002). Similar results were found in this study. RP and WP, both were purple-fleshed sweet potato genotypes, had significantly higher contents of total anthocyanins and phenols than the other genotypes studied.

EC_{50} values for scavenging DPPH radicals of sweet potato flours with different treatments were 0.49–9.77 mg ml^{-1} (Table 3). The EC_{50} values of RP and WP ranged from 0.49 to 2.37 mg ml^{-1}, which were much lower than potato (∼>125 mg ml^{-1}, Chu et al., 2000), blanched raw yam (∼100–200 mg ml^{-1}, Hsu et al., 2003) and purple yam treated at 70–100 °C (20–73 mg ml^{-1}, Chiou & Wang, 2003), and lower than the leaves, roots, and leafstalks of radish (∼3–6.5 mg ml^{-1}, Chiang et al., 2003). Furthermore, the EC_{50} values of the steamed and kneaded flours of RP (both 0.49 mg ml^{-1}) were lower than those of the flowers, stems and leaves of broccoli (∼1.0–1.5 mg ml^{-1}, Guo et al., 2001), lotus seed and black soybean (∼0.65–1 mg ml^{-1}, Liou et al., 1999).

3.3.3. Chelating effect on ferrous ions

Chelating effect on ferrous ions of the sweet potato flours with different treatments were 40–55% and 75–97% at 0.2 and 5.0–10.0 mg ml^{-1}, respectively (Fig. 3). EDTA showed chelating ability of 90% at 0.2 mg ml^{-1}, and was equivalent to most of the sweet potato flours at 5.0 mg ml^{-1}. The EC_{50} values for chelating effect of sweet potato flours were 0.18–0.78 mg ml^{-1} (Table 3). Results in Table 3 indicate that not only the genotype of sweet potato but also the different treatments affected the chelating effect of sweet potato flours.

RP had the highest chelating effect and the lowest EC_{50} value (∼0.19 mg ml^{-1}), which was much lower than that of blanched raw yam (∼40 mg ml^{-1}, Hsu et al., 2003) and purple yam treated at 100 °C (∼45–80 mg ml^{-1}, Chiou & Wang, 2003), and lower than that of leaves, roots and leafstalks of radish (∼1.5–20 mg ml^{-1}, Chiang et al., 2003), flowers, stems and leaves of broccoli (∼1 mg ml^{-1}, Guo et al., 2001).

3.3.4. Relationship between antioxidant components and antioxidant properties

The antioxidant components including phenols, flavonoids and anthocyanins were significantly ($p < 0.01$) positively correlated with reducing power

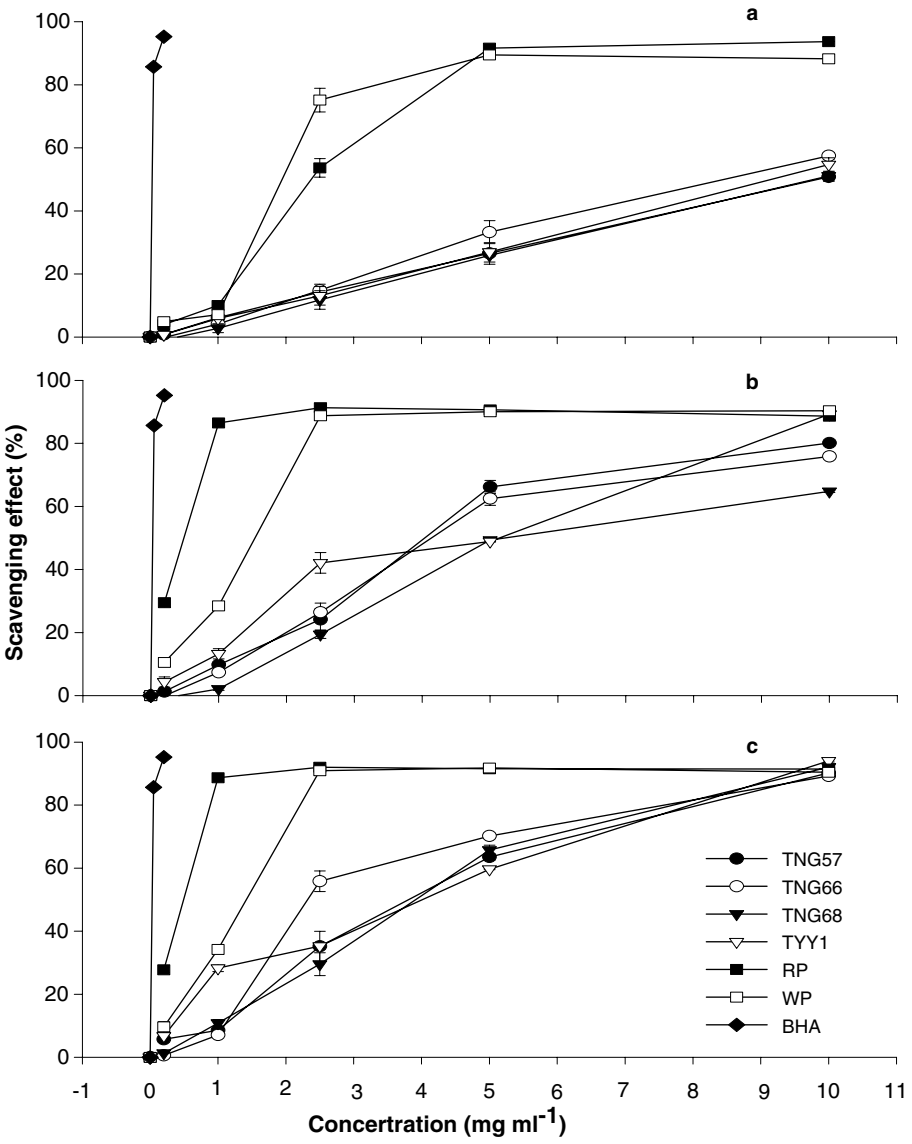

Fig. 2. Scavenging DPPH radical effects of 80% methanolic extracts from sweet potato flours after different treatments: raw (a), cooked (b) and kneaded (c).

and scavenging DPPH radical effect, respectively (see Table 4). No correlation was found between the antioxidant components and the chelating iron ion effect. The ascorbic acid contents of sweet potato flours also showed insignificant ($p > 0.05$) correlations with any antioxidant property measured in the study (data not shown).

Overall, the raw sweet potato flour of six genotypes had similar levels of total phenolics and flavonoids to each others. The anthocyanin content of raw RP and WP flours were higher than those of the other four genotypes. Steam treatment could improve the extraction yields of all genotypes (3–4 times), total phenols contents of all genotypes (2–13 times), flavonoids content of RP (1.3 times) and anthocyanin contents of RP and WP (5–6 times). Kneading treatment also increased the contents of antioxidant components from some genotypes; however, the effect of kneading treatment was not as obvious as that of steaming treatment. In general, sweet potato tubers are eaten as cooked products. Steamed and kneaded flours of all six genotypes showed excellent scavenging effects on DPPH radicals with EC_{50} values at 0.49–5.23 mg ml^{-1}, and chelating effects on ferrous ion with EC_{50} values at 0.19–0.78 mg ml^{-1}. In addition, the reducing power of steamed and kneaded RP and WP with EC_{50} values ranged from 0.83 to 4.54 mg ml^{-1}. Results of this study indicate that the extracts of raw, steamed, and kneaded flours from six genotypes of sweet potato showed good antioxidant properties, and among the six genotypes RP and WP

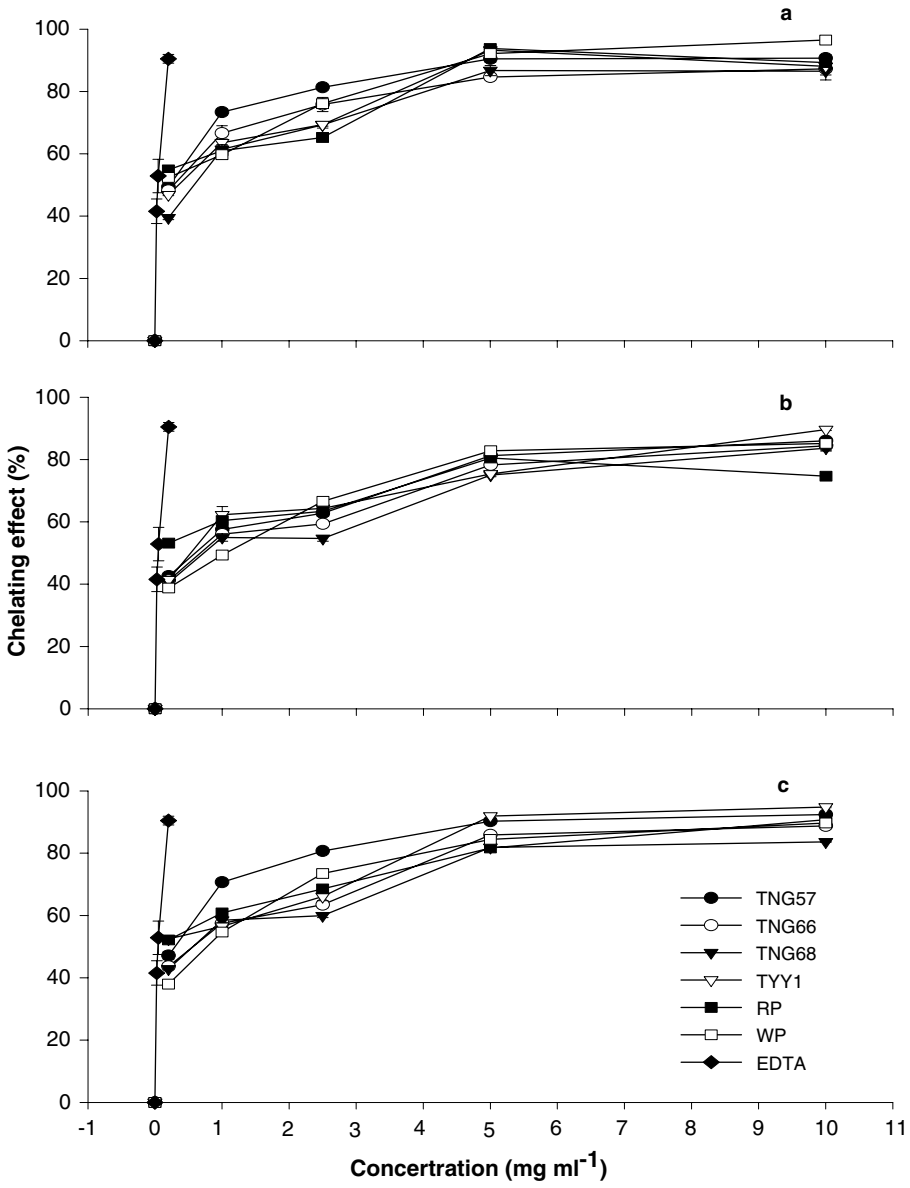

Fig. 3. Chelating effects of 80% methanolic extracts from sweet potato flours after different treatments: raw (a), cooked (b) and kneaded (c).

Table 4
Correlation coefficients (r) between antioxidant components and antioxidant properties on methanolic extracts from sweet potato flours

Antioxidant component	Antioxidant property		
	Reducing power	Scavenging effect on DPPH radicals	Chelating effect on ferrous ions
Total phenols	0.98***	0.71***	−0.13
Flavonoids	0.85***	0.67**	−0.09
Anthocyanins	0.97***	0.68***	−0.003

,* Significant at $p < 0.01$ and 0.001, respectively.

had the superior antioxidant properties. From our results, consumption of steamed and/or kneaded sweet potato products might be beneficial for the human body against oxidative damage.

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