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Effects of Steaming and Dehydration on Anthocyanins, Antioxidant Activity, Total Phenols and Color Characteristics of Purple-Fleshed Sweet Potatoes (*Ipomoea batatas*)

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Abstract: Purple-Fleshed Sweet Potatoes (PFSP) (*Ipomoea batatas*) are rich sources of acylated anthocyanins. Anthocyanin content, antioxidant activity and total phenols as well as color characteristics of PFSP were determined by UV/visible or fluorescence spectrophotometry and chromametry. The flesh of PFSP cultivar Terlaje produced in the Western Pacific contained total anthocyanins at 0.40 mg g^{-1} fresh weight. PFSP Powders processed by directly freeze-drying or first steaming and then freeze- or hot air-drying contained anthocyanins at 0.94-0.97 mg g^{-1}, Oxygen Radical Absorbance Capacity (ORAC) at 70.0-93.0 μmole Trolox g^{-1}, Trolox Equivalent Antioxidant Capacity (TEAC) at 11.8-12.7 μmole Trolox g^{-1} and total phenols at 4-5 mg gallic acid g^{-1} dry weight. PFSP powder processed by hot air-drying without steaming lost 65% of anthocyanin content, 35% of antioxidant activity and 40% of total phenols. Steaming of PFSP roots at atmosphere pressure for 0.5 h increased 40% of anthocyanin content and enhanced the purple color of PFSP. Dehydration at 60°C for 24 h retained anthocyanin content and purple color of steamed PFSP. Both steaming and dehydration increased the percentage of polymeric anthocyanins in PFSP. The results suggested the PFSP powders exhibited potentials as colorants and neutraceutical ingredients for formulated foods.

Key words: Anthocyanins, purple-fleshed sweet potatoes, *Ipomoea batatas*

INTRODUCTION

Anthocyanins are natural, nontoxic and water soluble pigments displaying orange, red, purple, or blue color in plants and foods (Bridle and Timberlake, 1997; Clifford, 2000). Using anthocyanins as natural colorants in formulated food products lessens consumers' concerns about the safety of synthetic colorants. However, natural anthocyanins are not as stable when exposed to heat, light and pH as the synthetic colorants (Fossen *et al*., 1998; Dyrby *et al*., 2001).

Anthocyanins consist of anthocyanidins, sugars and acylating acids (Giusti and Wrolstad, 2003). The acylated anthocyanins with aromatic acids are more stable than nonacylated ones in aqueous solution (Redus *et al*., 1999; Giusti and Wrolstad, 2003). Purple-Fleshed Sweet Potatoes (PFSP) are good sources of acylated anthocyanins with aromatic acids (Miyazaki *et al*., 1991; Odake *et al*., 1992; Goda *et al*., 1997; Terahara *et al*., 1999). Anthocyanins in the Japanese PFSP breeding cultivar Ayamurasaki consist of 71-73% acylated peonidin and 12-19% acylated cyanidin (Tsukui *et al*., 1999; Yoshimoto *et al*., 1999). The major anthocyanins from PFSPs are mono- or di-acylated derivatives of 3-(2-glucosyl)glucosyl-5-glucosyl peonidin (Pn) and cyanidin (Cy) (Terahara *et al*., 1999; Oki *et al*., 2003; Suda *et al*., 2003).

The PFSP anthocyanins possess biological functions, such as scavenging free radicals, antimutagenicity, anticarcinogen activity and antihypertensive effect (Furuta *et al*., 1998;

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Yoshinaga *et al*., 1999; Yoshimoto *et al*., 2001; Hagiwara *et al*., 2002; Masuda *et al*., 2002; Kano *et al*., 2005). Acylated anthocyanins in PFSP increased the plasma antioxidative capacity of humans and rats by direct absorption into their blood streams (Suda *et al*., 2002, 2003; Harada *et al*., 2004; Kano *et al*., 2005). Beverages and juices made of PFSP are commercially available for human health benefits in Japan (Oki *et al*., 2006). Extracts from PFSP are also used as natural colorants in confectionery and foods such as ice cream, beverages, milk, chewing gum and salad dressing (Yamakawa, 1998).

Sweet potato flours, powder and flakes processed by steaming and dehydration are ingredients used in formulated foods (Manlan *et al*., 1985; Collins and Pangloli, 1997; Yadav *et al*., 2006). For example, the PFSP powder is used in noodles, bread and beverages (Yamakawa, 1998; Yoshinaga *et al*., 1998). Huang *et al*. (2006) reported steaming increased anthocyanin contents, total phenols and antioxidant activity of sweet potatoes in Taiwan. However, both steaming and dehydration affect the anthocyanin content, antioxidant activity and total phenol content as well as color characteristics of purple-fleshed sweet potatoes is still lacking.

Several PFSP cultivars, *Ipomoea batatas*, are produced under the tropical climate and soil conditions in the western Pacific islands: Guam, Rota and Saipan. Investigation how steaming and dehydration affect anthocyanins, antioxidant capacity and color characteristics will provide valuable information to use natural PFSP anthocyanin ingredients in formulated food products. The objectives of the research were to determine the anthocyanin content of PFSP cultivars grown on western Pacific islands and effects of steaming and dehydration on anthocyanins, antioxidant capacities, total phenols and color characteristics of PFSP roots.

MATERIALS AND METHODS

Materials

Two PFSP cultivars, Terlaje, a purple-skinned PFSP and Luta, a white-skinned PFSP, were obtained from local farmers in the spring on Guam. The PFSP roots were cleaned, washed, sorted, dried and stored at 20°C for less than 1 week before use.

Methanol, sodium carbonate, sodium fluorescein, monosodium phosphate monohydrate and disodium phosphate heptahydrate were purchased from Sigma-Aldrich (St. Louis, MO, USA). Folin-Ciocalteau reagent, gallic acid, potassium metabisulfite, potassium persulfate and citric acid were purchased from Spectrum Chemicals (Gardena, CA, USA). The chemicals 2,2-azobis (2-methylpropionamidine) dihydrochloride (AAPH) and 2,3'-azino-bis(3-ethylbenthiazoline-6-sulfonic acid) diammonium salt (ABTS) were purchased from Wako Pure Chemical Industries, Ltd. (Chuo-Ku, Osaka, Japan) and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) was obtained from Aldrich (Milwaukee, WI, USA).

Steaming

Roots of the PFSP cultivar Terlaje were randomly assigned to five groups of five roots each. Each group was steamed in a stainless cooker-steamer at atmospheric pressure for 0.5 h for further dehydration or 0, 0.5, 1, 2, or 4 h for storage at -20°C in sealed plastic bags before further analysis.

Dehydration

The raw PFSP roots were divided into groups of five roots each and cut into the peel about 0.5 cm cortex, the end about 2-3 cm of both tips and the flesh tissues. The peel, end and flesh tissues were sliced and freeze dried with a Lab Conco Lyph-Lock 6 freeze dry system, model 77520 (Kansas City, Missouri, USA) at -40°C for 2 days. Flesh tissues of PFSP were also air-dried with a Nesco/American Harvest Dehydrator (Two Rivers, WI, USA) at 60°C for 24 h. The freeze- or air-dried PFSP tissues were then ground to powders with a blade coffee grinder and were stored at -20°C in sealed plastic bags for further analysis.

The PFSP roots steamed for 0.5 h were peeled, cut and sliced. The sliced steamed PFSP was freeze dried or hot-air dried in the same system and by the same procedure as was the raw PFSP. The steamed PFSP were also smashed, spread on trays in a Nesco/American Harvest Dehydrator (Two Rivers, WI) and air-dried at 60°C for 0, 4, 8, 20, or 24 h. The dried PFSP tissues were ground to powders and stored at -20°C in sealed plastic bags for further analysis.

Anthocyanin Analysis

Two gram of PFSP powder were extracted with 20 mL of 1% Hcl acidic water on a shaker for 90 min. The mixture was then centrifuged in a Beckman-Coulter Allegra X-22R Centrifuge (Kansas City, MO, USA) at 9200 g for 30 min. The supernatant was collected as extract. The pellets were extracted two more times with 20 mL of 1% HCl acidic water. The combined supernatants were used as anthocyanin extract for assays.

The anthocyanin extract was then diluted with McIlvaine buffer (pH 1.0) at the ratio of 1:4 and equilibrated for 15 min. The spectrum from 250 to 700 nm of the diluted anthocyanin extract (like all absorbances measured for this study) was measured with the Varian Cary 50 UV spectrophotometer (Walnut Creek, CA, USA). The absorbance at λ_{max} of 525 nm was used to calculate the anthocyanin content in the PFSP on the basis of the monomeric anthocyanin cyanidin-3-glucoside with a molar extinction coefficient of 2.69×10^4 M^{-1} cm^{-1} and molecular weight of 449.2 by a method from Furuta *et al*. (1998) with modification. The anthocyanin content of the PFSP was expressed as equivalent cyanidin-3-glucoside mg g^{-1} fresh weight (f.wt.) or g^{-1} dry weight (d.wt.).

Polymeric anthocyanins of the PFSP powder were assayed with the method described by Giusti and Wrolstad (2001). The PFSP extract was diluted with distilled water at a ratio of 1:4 and 0.2 mL of 20% potassium metabisulfite solution or distilled water was added to 2.8 mL of diluted anthocyanin extract. After 15 min equilibration, the absorbances of the bisulfite-treated and untreated anthocyanin extracts were measured spectrophotometrically at 420 nm, λ_{max} of 525 nm and 700 nm. The percentage of the polymeric anthocyanins was calculated according to this formula: percentage polymeric anthocyanins = $100 \times [(A_{420\ nm} - A_{700\ nm}) + (A_{\lambda_{max}} - A_{700\ nm})]_{bisulfite\ treated} / [(A_{420\ nm} - A_{700\ nm}) + (A_{\lambda_{max}} - A_{700\ nm})]_{untreated}$, where $A_{420\ nm}$ was the absorbance at 420 nm, $A_{\lambda_{max}}$ ax was the maximum absorbance at 525 nm and $A_{700\ nm}$ was the absorbance at 700 nm.

Antioxidant Activity (ORAC)

The antioxidant capacity of PFSP was also determined with the Oxygen Radical Absorbance Capacity (ORAC) assay in 96-well fluorescent microplates as described by Huang *et al*. (2002). Before the assay, 75 mM phosphate buffer (pH 7.4) was used to prepare 1.17 mM sodium fluorescein stock solution stored at 5°C in dark until use and 40 mM AAPH solution daily. For determination of ORAC value, 3 μL sodium fluorescein stock solution was diluted with 30 mL of 75 mM phosphate buffer (pH 7.4). After 120 μL of diluted sodium fluorescein solution was added to experimental wells, 20 μL of PFSP extract, 75 mM phosphate buffer (pH 7.4) as a blank and Trolox as a standard were added in the experimental wells. After the solutions equilibrated in the microplate in the Synergy™ HT Mulit-Detection Microplate Reader (BioTek Instruments, Winooski, VT, USA) at 37°C for 15 min, 60 μL of 40 mM AAPH solution was added to the wells to initiate the reactions. The fluorescence of each well was then measured kinetically with an excitation wavelength at 485 nm and an emission wavelength at 528 nm. Oxygen-radical absorbance capacity of PFSP powder was calculated in ORAC units as described by Cao and Prior (1999) and expressed as μmol Trolox g^{-1} d.wt.

Antioxidant Activity (TEAC)

The antioxidant activity of PFSP was assayed by the radical-scavenging methods of the Trolox equivalent antioxidant capacity (TEAC) described by Re *et al*. (1999) and Cai *et al*. (2004). The free-radical cations ($ABST^+$) were generated by mixing of 2.5 mL of 7 mM ABTS diammonium salt with

0.5 mL of 15 mM potassium persulfate at 20°C and stored in the dark for 24 h. The $ABST^+$ free-radical solution was diluted with distilled water to yield an absorbance of 0.700 at 734 nm and 20 μL of diluted PFSP extract was added to 2 mL of diluted $ABST^+$ free-radical solution and mixed thoroughly. After 60 min at 20°C, the absorbance of the mixture was measured at 734 nm. Radical-scavenging activity of the PFSP extract was calculated as a percentage inhibition by the formula inhibition (%) = $((A_{t=0} - A_{t=60})/A_{t=0}) \times 100$, where $A_{t=0}$ was the absorbance at the time the sample was added and $A_{t=60}$ was the absorbance after 60 min. The antioxidant activity of PFSP powder was expressed as Trolox equivalent μmol g^{-1} d.wt.

Total Phenol Analysis

The total phenolic content of PFSP powder was measured with a modified method using the Folin-Ciocalteu reagent described by Slinkard and Singleton (1977) and Singleton *et al*. (1999). A 20 μL sample of diluted PFSP extract was added to 1.58 mL of distilled water in a test tube. After addition of 100 μL of Folin-Ciocalteu reagent and 300 μL of saturated Na_2CO_3 (20 %), the solution was incubated at 40°C for 30 min. The absorbance of the samples was then measured at 765 nm. Total phenols of PFSP powder were expressed as mg gallic acid (GAE) g^{-1} d.wt.

Color Analysis

The color values of lightness (L*) and the chromaticity coordinates (a*, b*) of PFSP tubers or powders were measured by the CIELAB method with a Konica Minolta CR-410 Chromameter (Ramsey, NJ, U.S.A.). The hue angle (h°) and chroma (C*) of PFSP tubers or powders were calculated by arctan (b*/a*) and $[a^{*2} + b^{*2}]^{1/2}$, respectively.

Statistical Analysis

Two or three replications were performed for each experiment. Analysis of variance and least-significant-difference tests conducted with SPSS 12.0 for Windows (SPSS, 2003) were used to identify significant differences among means. Mean differences were considered significant at the $p<0.05$ level.

RESULTS AND DISCUSSION

Anthocyanin Contents and Characteristics

The purple-skinned cultivar Terlaje contained anthocyanins of 0.40 mg g^{-1} f.wt. in flesh, which is lower than that in peel and ends (Fig. 1A). The white-skinned cultivar Luta contained anthocyanins of 0.11 mg g^{-1} f.wt. in flesh, which is higher than that in peel and ends (Fig. 1A). Terlaje's anthocyanin content was about 3 times greater in flesh and 10 times greater in peel and ends than was Luta's. Furuta *et al*. (1998) reported that 5 PFSP cultivars contain total anthocyanins ranging from 0.053 to 0.54 mg g^{-1} f.wt. Huang *et al*. (2006) reported that 2 PFSP flours contained anthocyanins at 0.0899 and 0.0526 mg g^{-1} d.wt. Based on the flesh color, Teow *et al*. (2007) reported 4 PFSP cultivars in the group of purple have a total anthocyanin content from 0.24 to 0.53 mg g^{-1} f.wt. and 2 PFSP cultivars in the group of 'light purple' have a total anthocyanin content from 0.03 to 0.07 mg g^{-1} f.wt. The cultivar Terlaje contained anthocyanins similar to that of the purple group and the cultivar Luta contained anthocyanins close to that of the 'light purple' group.

Both Terlaje and Luta exhibited absorption bands at 290, 325 and 525 nm (Fig. 1). The presence of an absorption band in the 310-360 nm range revealed the presence of hydroxycinnamic acid acylation (Giusti and Wrolstad, 2003). The absorption bands of PFSP extracts at 325 nm suggested acylation of hydroxycinnamic acids in anthocyanidins. Oki *et al*. (2003) reported that mono- or di-acylated forms of cyanidin and peonidin acylated with the caffeoyl group, exhibiting absorption maxima near 325, were the predominant anthocyanins in PFSP cultivars. Two major 3-caffeylferulysophoroside-5-glucosides of cyaniding and peonidin were identified from PFSP cultivar

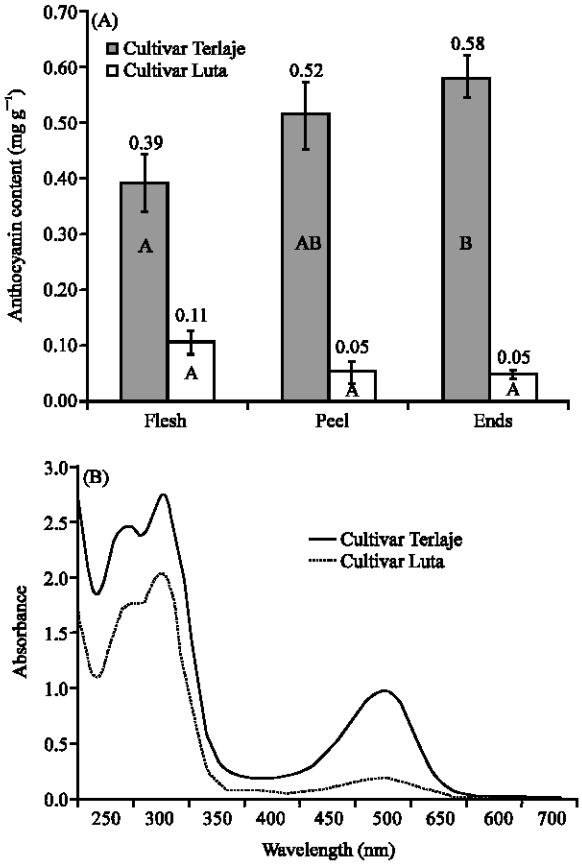

Fig. 1: Total anthocyanin content (means±standard deviations) expressed as cyaniding-3-glucoside mg g^{-1} fresh weight (f.wt.) (A) and spectrum (B) of the purple-fleshed sweet potato cultivar Terlaje and Luta. Within the same cultivar, means with different letters differed significantly ($p<0.05$)

Yamagawamurasaki (Odake *et al*., 1992). Six diacylated cyanidin and peonidin with the caffeoyl group and acyl substituents were identified in PFSP cultivar Yamagawamurasaki (Terahara *et al*., 1999). In addition, the ratio of λ_{max} absorbance at the 310-360 nm to the visible λ_{max} absorbance is used to estimate the number of aromatic acylating groups of anthocyanins (Harborne, 1958; Giusti and Wrolstad, 2003). The ratio of the λ_{max} absorbances at 330 nm and 525 nm was 2.5 for Terlaje and 10 for Luta. The high ratios showed that Terlaje and Luta both had high contents of acylated anthocyanins; Luta may have a higher percentage than Terlaje.

Effects of Steaming and Dehydration on Total Anthocyanin Content

With fresh PFSP, freeze-dried powders contained total anthocyanins at 0.97 mg g^{-1} d.wt. which was 3 times higher than that of air-dried powder (Table 1). With steamed PFSP, freeze-dried and air-dried powders had the same content of anthocyanins as that of fresh freeze-dried power (Table 1). The results suggested steaming is critical in retaining total anthocyanin content in PFSP powder. Shi *et al*. (1992) reported that sweet potatoes contain active enzymes that degrade anthocyanin pigments. Wrolstad *et al*. (2005) stated that polyphenoloxidase, peroxidase and glycosidase degrade

Table 1: The total anthocyanin and polymeric anthocyanin content (means±standard deviations) of powdered flesh of the purple-fleshed sweet potato cultivar Terlaje

Sweet potatoes	Dehydration	Total anthocyanin content (mg g^{-1} f.wt.)	Polymeric anthocyanins (%)
Fresh	Freezing dried	0.966±0.080^{a}	10.0±0.9^{c}
	Air dried	0.328±0.125^{b}	30.0±3.7^{ab}
Steamed	Freezing dried	0.971±0.066^{a}	27.0±2.5^{b}
	Air dried	0.945±0.424^{a}	35.0±0.1^{a}

a, b, c: Means with different letters in the same column differed significantly ($p<0.05$)

Table 2: The antioxidant activity and total phenols (means±standard deviations) of powdered flesh of the purple-fleshed sweet potato cultivar Terlaje

Sweet potatoes	Dehydration	ORAC (μmol Trolox g^{-1} d.wt.)	TEAC (μmol Trolox g^{-1} d.wt.)	Total phenols (mg gallic acid g^{-1} d.wt.)
Fresh	Freezing dried	70.10±5.20^{b}	12.30±0.98^{a}	3.85±0.98^{ab}
	Air dried	53.50±3.18^{c}	3.12±1.30^{b}	2.69±0.07^{b}
Steamed	Freezing dried	92.80±6.35^{a}	12.70±1.50^{a}	5.01±0.11^{a}
	Air dried	75.70±1.09^{b}	11.80±1.10^{a}	3.94±1.02^{ab}

a, b, c: Means with different letters(s) in the same column differed significantly ($p<0.05$)

and anthocyanins in plant tissues. Therefore, steaming inactivated these indigenous enzymes in fresh PFSP, retaining anthocyanins in powders. During the freeze-drying of fresh PFSP, the low temperature inhibited enzymatic degradation of anthocyanins in PFSP, retaining total anthocyanins in fresh freeze-dried powder.

The polymeric anthocyanins represent anthocyanins that do not change color with an increase of pH or with bisulfite treatment (Wrolstad *et al*., 2005). Steaming and air dehydration significantly increased the percentage of polymeric anthocyanins in PFSP powders by 2.7 times (from 10 to 27%) and 3.0 times (from 10 to 30%) compared to fresh freeze-dried powder, respectively (Table 1). Together, steaming and air drying resulted in a percentage of polymeric anthocyanins 3.5 times higher than that of the fresh freeze-dried powder (Table 1). Steaming and air dehydration may induce formation of polymeric anthocyanins in PFSP through condensation of anthocyanins with phenolic compounds.

Effects of Steaming and Dehydration on Antioxidant Activity and Total Phenols

Steamed freeze-dried PFSP powder exhibited the ORAC antioxidant activity at 92.8 μmol Trolox g^{-1} d.wt., which was significantly higher than that of fresh air-dried powder by 40%, fresh freeze-dried powder by 30% and steamed air-dried powder by 20%, (Table 2). The two fresh prepared powders were significantly lower in the ORAC value than the two steamed prepared powders. The four prepared powders exhibited similar trends of the TEAC antioxidant activity and the total phenol content as the ORAC value in spite of insignificant difference (Table 2). The fresh air-dried powder exhibited antioxidant activity of ORAC and TEAC and total phenol content significantly lower than the others. High antioxidant activities and total phenolic content of steamed powders suggested that inactivation of active enzymes by steaming was essential to retention of not only anthocyanin content but also antioxidants and phenolic compounds in PFSP powders. In addition, freeze-drying had less effect on antioxidant activity and total phenolic content than did air-drying. Powders from PFSP steamed and then freeze-dried had the highest antioxidant activity and total phenolic content among four prepared powders.

The dominant antioxidant activity in PFSP was attributed to anthocyanins (Masuda *et al*., 2002). Suda *et al*. (2003) suggested that at least one caffeoyl group acylated to anthocyanins contributes to a high radical-scavenging activity. Administration of anthocyanin concentrate from PFSP resulted in a significant increase of the plasma antioxidant activity of rats (Suda *et al*., 2002). Teow *et al*. (2007) reported 6 PFSP cultivars contain the ORAC antioxidant activity at 9.0-27.0 μmol Trolox g^{-1} f.wt.

Table 3: The time effects of steaming and air dehydration on the total anthocyanin and polymeric anthocyanin content (means±standard deviations) of the purple-fleshed sweet potato cultivar Terlaje

Steaming (h)	Anthocyanin content (mg g^{-1} f.wt.)	Polymeric anthocyanins (%)	Dehydration (h)	Anthocyanin content (mg g^{-1} f.wt.)	Polymeric anthocyanins (%)
0	0.212±0.001[a]	16.0±4.3[a]	0	0.275±0.009[a]	21.8±5.9[a]
0.5	0.299±0.001[b]	20.6±3.7[ab]	4	0.279±0.006[a]	30.4±0.7[b]
1	0.213±0.006[a]	19.7±0.1[a]	8	0.275±0.011[a]	31.7±0.4[b]
2	0.214±0.002[a]	23.3±1.5[ab]	20	0.283±0.004[a]	32.9±1.4[b]
4	0.204±0.002[a]	26.2±0.1[b]	24	0.270±0.008[a]	33.4±1.4[b]

a, b: Means with different letters(s) in the same column differed significantly ($p<0.05$)

Table 4: The color characteristics (means±standard deviations) of powdered flesh of the purple-fleshed sweet potato cultivar Terlaje

Treatments	L*	a*	b*	Hue angle (h°)	Chroma (C*)
Fresh freeze-dried	68.9±2.0[a]	17.97±0.49[b]	-8.88±0.43[b]	-24.64±0.39[b]	20.04±0.63[b]
Fresh air-dried	68.4±0.9[a]	11.23±3.18[c]	6.67±3.06[a]	27.88±14.14[a]	13.41±1.14[d]
Steamed freeze-dried	70.2±0.6[a]	14.39±0.04[bc]	-8.50±0.84[b]	-28.04±1.89[b]	16.73±0.45[c]
Steamed air-dried	61.4±1.9[b]	25.52±1.79[a]	-9.04±0.44[b]	-18.82±0.35[b]	27.07±1.84[a]

a, b, c: Means with different letters(s) in the same column differed significantly ($p<0.05$)

the total phenol content at 0.25-0.95 mg chlorogenic acid g^{-1} f.wt. (equivalent to 0.45-1.69 mg gallic acid g^{-1} f.wt.). Oki *et al*. (2003) reported that PFSP cultivars assayed by DPPH radicals exhibited the radical-scavenging activity at 8.6-49.0 μmol Trolox equivalent g^{-1} f.wt. Yoshimoto *et al*. (1999) reported that PFSP cultivar Ayamurasaki roots contain phenolic contents at 16.5-19.0 mg chlorogenic acid g^{-1} flour. The PFSP cultivar Terlaje exhibited the ORAC antioxidant activity within the range of the ORAC values reported by Teow *et al*. (2007) and the total phenol content higher than the values reported by Teow *et al*. (2007) but lower than the values reported by Yoshimoto *et al*. (1999).

The Time Effect of Steaming and Dehydration on Anthocyanin Contents

Compared with fresh PFSP, steaming of PFSP exhibited a significant increase of total anthocyanin content by 40% at 0.5 h but no significant increase after 1 h (Table 3). Steaming of PFSP did not significantly change the polymeric anthocyanin content during first 2 h, but significantly increased polymeric anthocyanins by 60% after 4 h of steaming. Air dehydration at 60°C for 24 h did not decrease the total anthocyanin content of steamed PFSP (Table 3). However, air dehydration at 60°C for 24 h significantly increased the percentage of polymeric anthocyanins by 50% in steamed PFSP (Table 3).

Steaming may release bound anthocyanins from the damaged tissues by heat or form anthocyanin copigmentation to produce a hyperchromic effect, producing the observed increase in anthocyanin content during steaming for 0.5 h. Huang *et al*. (2006) observed that steaming of PFSP for 40 min resulted in an increase of anthocyanins by 5-6 times, which is much higher than the increase of anthocyanin content during steaming in our observation. After 1 h of steaming, the heat degraded anthocyanins, resulting in the observed decrease of anthocyanin content. During dehydration 60°C for 24 h, a decrease of the water activity of PFSP was observed from 0.99 to 0.20. The decrease of water activity may stabilize anthocyanin from degradation during dehydration and also promote the formation of polymeric anthocyanins. Garzon and Wrolstad (2001) and Wrolstad *et al*. (2005) reported that anthocyanin pigment was stable in dried forms with low water activities.

Effects of Steaming and Dehydration on Color Characteristics of PFSP Powders

The fresh air-dried PFSP powder lost its negative b* value while the fresh freeze-dried and steamed freeze and air-dried PFSP powders retained the same level of b* values (Table 4). The fresh freeze-dried and steamed freeze and air-dried PFSP powders exhibited hue angles of a purplish color, whereas the fresh air-dried PFSP powder exhibited a hue angle of a brownish color. The fresh air-dried PFSP powder also exhibited a significantly lower chroma than the other powders. The substantial

Table 5: The time effect of steaming on the color characteristics (means±standard deviations) of the flesh of the purple-fleshed sweet potato cultivar Terlaje

Steaming (h)	L*	a*	b*	Hue angle (h°)	Chroma (C*)
0	50.56±1.25^{a}	26.23±5.25^{a}	-6.28±0.13^{ab}	-8.45±4.71^{ad}	28.69±2.73^{a}
0.5	41.35±0.67^{b}	18.96±1.60^{a}	-10.40±2.33^{a}	-26.45±2.72^{b}	21.64±2.53^{b}
1	42.21±3.10^{b}	19.27±2.68^{a}	-9.81±2.34^{ab}	-25.04±1.92^{bc}	21.63±3.45^{b}
2	45.07±1.70^{b}	19.93±2.21^{a}	-5.58±1.01^{b}	-15.40±4.05^{ac}	20.72±1.85^{b}
4	45.35±1.70^{b}	19.60±0.34^{a}	-0.65±2.04^{c}	-1.94±5.98^{d}	19.66±0.27^{b}

a, b, c: Means with different letters(s) in the same column differed significantly ($p<0.05$)

Table 6: The time effect of air-drying at 60°C on the color characteristics (means±standard deviations) of powdered flesh of the purple-fleshed sweet potato cultivar Terlaje.

Dehydration (h)	L*	a*	b*	Hue angle (h°)	Chroma (C*)
0	41.4±0.7^{a}	18.96±1.60^{a}	-10.40±2.33^{a}	-26.45±2.72^{a}	21.64±2.53^{a}
4	58.0±3.4^{b}	27.27±0.21^{b}	-8.41±2.11^{a}	-16.59±3.82^{b}	28.57±0.41^{b}
8	57.2±3.2^{b}	27.38±0.30^{b}	-8.62±1.90^{a}	-16.92±3.48^{b}	28.74±0.27^{b}
20	60.2±2.7^{b}	26.29±0.44^{b}	-9.12±1.65^{a}	-18.43±3.18^{ab}	27.86±0.13^{b}
24	59.2±5.2^{b}	26.40±0.21^{b}	-8.96±1.81^{a}	-18.05±3.07^{ab}	27.90±0.78^{b}

a, b: Means with different letters(s) in the same column differed significantly ($p<0.05$)

changes of color value in the fresh air-dried PFSP powder were attributed to the degradation of anthocyanins by active enzymes. Steamed air-dried PFSP powder exhibited a significantly lower L* value, a higher a* value and higher chroma than the other powders (Table 4). The changes of color value in steamed air-dried PFSP powder were attributed to formation of polymeric anthocyanins and some non-enzymatic browning pigments. Masuda *et al*. (2002) reported that freeze-dried PFSP powders of cultivars Ayamurasaki and Kyushu-132 have, respectively, L* values of 44.0 and 45.5, a* values of 21.6 and 21.5, b* values of -6.7 and -7.7 and C* values of 22.6 and 22.9. Aside from L*, our freeze-dried PFSP powder (Table 4) showed color values similar to those reported by Masuda *et al*. (2002). Yoshinaga *et al*. (1998) observed that the anthocyanin concentration in the tubers was negatively correlated with the L* value. The anthocyanin contents of Ayamurasaki and Kyushu-132 powders may be higher than that of our PFSP powder.

The Time Effect of Steaming and Dehydration on Color Characteristic of PFSP

Steaming of PFSP tubers for 0.5 h significantly decreased the L* value, hue angle and chroma compared to fresh PFSP prior steaming, exhibiting an increasing in the darkness and the purplish color (Table 5). The changes of color at 0.5 h during steaming were attributed to a release of anthocyanins from PFSP tissues damaged by heating. The intramolecular co-pigmentation of anthocyanins with phenolic compounds during steaming may contribute to an increase in bluish attribute and a change of hue angle. Steaming PFSP tubers from 1 to 4 h significantly increased the b* value and hue angle (h°), resulting in a loss of purple color. The color change of PFSP during steaming also indicated a degradation of anthocyanins from 1 to 4 h. This result was consistent with the decrease of anthocyanin content after 1 h (Table 3). Yoshinaga *et al*. (1998) reported that, if a PFSP paste exhibited a ratio of b*-to-a* greater than -1.1, the PFSP paste had a red dominant color and a high ratio of peonidin:cyanidin. The Terlaje paste steamed for 0.5 to 1 h exhibited a ratio of b*-to-a* at -0.5. Based on the ratio of b*-to-a*, PFSP cultivar Terlaje had a red dominant color with a high peonidin-to-cyanidin ratio in the roots.

During the first 4 h, air dehydration of steamed PFSP at 60°C significantly increased L* value, hue angle and chroma, resulting in an increase in lightness and a little shift of purplish color to the direction of reddish color (Table 6). Air dehydration during the first 4 h did not change the color b* but significantly increased the color a* value (Table 6). The increase of Chroma may result from an increase of anthycanin concentration because the most of moisture content lost in steamed PFSP paste within first 4 h during dehydration. Formation of some Maillard browning products during dehydration may attribute to the increase of the color b* value. After air dehydration from 4 to 24 h, the color values

of L*, a*, b*, h° and C* of PFSP did not change significantly, suggesting that the decrease of water activity in PFSP powder stabilized the color after 4 h of dehydration. An increase of polymeric anthocyanin content during air dehydration may also contribute to the stabilization of the color.

CONCLUSIONS

Purple-fleshed sweet potatoes from the Western Pacific were good sources of acylated anthocyanins. Steaming PFSP for 0.5 h not only increased total anthocyanin content but also retained anthocyanin content, antioxidant activity, total phenols and color of PFSP roots. Air dehydration at 60°C for 24 h did not decrease total anthocyanin content of PFSP but increased the percentage of polymeric anthocyanin content. The antioxidant activity, total phenols and color characteristics of PFSP powder processed by air dehydration at 60°C were comparable to that of PFSP powder processed by freeze-drying. Steamed air-dried PFSP powder exhibited properties as an ingredient that could be used to enhance the color and antioxidant activities of formulated foods.

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