Effect of drying conditions on properties, pigments and antioxidant activity retentions of pretreated orange and purple-fleshed sweet potato flours

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Abstract Pigmented sweet potatoes (SPs) are outstanding sources of anthocyanin, β -carotene and other color-related phytonutrients. However, fresh SP roots are highly perishable and difficult to store. To reduce losses and extend their uses, fresh SP could be converted into flour. SP cultivars with deep purple (Phichit 65–3) and orange-fleshed (T101) colors newly developed in Thailand were studied. The influence of drying methods on physico-chemical properties, anthocyanin, β -carotene and antioxidant activity retentions of purple and orange-fleshed SP flours (SPFs) was investigated. Peeled purple and orange SPs were pretreated by blanching (100 °C, 5 sec) and soaking in 0.5 % (w/v) sodium metabisulphite, then dried in either hot air oven at 50–80 °C or steamed for 10 min and placed to the drum dryer at 80–110 °C and 3–7 rpm drum speed. The drying processes significantly enhanced anthocyanin contents of SPFs by 1.8 to 3.8 times; however, there was a significant loss of β -carotene occurred during drying processes. Drum drying yielded SPFs with better color, higher total phenolic contents and antioxidant activity than the hot air drying. Pasting temperatures of hot air dried orange-fleshed SPFs (84–85 °C) were slightly higher than those of purple-fleshed SPFs (80–83 °C). Drum drying process produced pre-gelatinized (instant) SPFs as indicated by RVA and DSC results. The optimal conditions for drum dried and hot air dried SPF manufactured were 95 °C at 5 rpm and

70 °C, respectively, based on anthocyanin, β -carotene, total phenolic, antioxidant activity, color retentions, and pasting properties.

Keywords Drying · Sweet potato · Anthocyanin · β -carotene · Antioxidant activity

IntIntroduction

The sweet potato (*Ipomoea batatas* L. Lam) is mainly cultivated in developing countries, where it serves as a principal and nutritious source of food for low income people (UN/FAO 2014). According to FAOstat (2006), sweet potato ranks as the third most important starchy food, after cassava and potato in the world. Sweet potato cultivars with deep orange and purple-fleshed color are an excellent source of nutrients and natural health-promoting compounds, such as carotenoids, anthocyanin, polyphenols, ascorbic acid and dietary fiber (Van Hal 2000; Teow et al. 2007). These phytochemical compounds especially polyphenols have high free-radical scavenging activity, intermediate antioxidant activity and antimutagenicity which help to reduce the risk of chronic diseases, such as cardiovascular disease, cancer, and age-related degenerative diseases (Teow et al. 2007; Bellail et al. 2012; Huang et al. 2006; Bengtsson et al. 2008). Therefore, a high concentration of anthocyanin in purple-fleshed sweet potatoes and β -carotene in orange-fleshed sweet potatoes has a high potential for consuming as a functional food for improving human health.

Fresh sweet potato root is highly perishable due to its high moisture and nutrients.

In many developing countries, fresh sweet potatoes are commonly preserved and processed into dried slices, flakes, and flour for uses in a variety of formulated foods such as

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noodles, soups, beverages, bakery and confectionery products and snacks (Bovell-Benjamin 2007; Yang and Gadi 2008). Dehydration processes have been reported to significantly affect the β -carotene content, anthocyanin content, antioxidant capacity and total phenol content as well as color of the sweet potato flours and dried slices (Bengtsson et al.; Yang and Gadi 2008; Yadav et al. 2006; Ahmed et al. 2010a). The traditional drying methods are hot-air drying and sun-drying.

Sun-drying is the cheapest drying method. A major disadvantage associated with sun-drying method is the time consumption and quality control. Hot air drying is relatively cheap and commonly used in the food preservation (Ahmed et al. 2010a). In addition to, drum drying is an alternative drying technique that can process steamed sweet potato mash into instant dried flakes followed by milling and sieving to produce flour. This drying technique relatively takes shorter drying time compared to the conventional drying processes. However, drying processes generally reduce the physico-chemical properties, color and nutritional qualities of sweet potato flours. The discoloration of tuber flesh during preparation is mainly associated with enzymatic browning due to the action of polyphenoloxidase and peroxidase (Akissoé et al. 2003). Therefore, various pretreatments by chemical, thermal and physical means of sweet potatoes before drying processes have been investigated (Ahmed et al. 2010a; Akissoé et al., 2003; Ahmed et al. 2010b).

In Thailand, sweet potatoes are widely grown in several parts of the country especially in the lower north regions. Due to a high demand for nutrition and health-food markets, the Agriculture Development and Research Center located in Phichit Province has recently developed the new sweet potato cultivar with an intense purple color namely “Phichit 65–3”. In addition, orange-fleshed sweet potato cultivar (T101) has been locally available and favorably consumed for its distinguished color, sweet taste, and flavor. In this project, purple-fleshed sweet potato cultivar Phichit 65–3 and orange-fleshed sweet potato cultivar T101 were chosen to study due to their distinguished color and phytochemical compounds. The main objective of this study was to investigate the effects of drying processes (hot air drying and drum drying) and conditions on color, anthocyanin content, β -carotene content, total phenolic content, antioxidant activity and pasting properties of purple and orange-fleshed sweet potato flours.

Materials and methods

Sweet potato root samples

Two sweet potato cultivars: purple-fleshed (Phichit 65–3) and orange-fleshed (T101) harvested at 105 days were harvested and stored in the cooling room controlled at 10–15 °C in the perforated baskets and used within 5 days. The two sweet

potato cultivars were provided by the Agriculture Development and Research Center, Phichit, Thailand. Approximately 20 kg of fresh sweet potato root was prepared for flour production per drying treatment.

Pretreatment

The fresh sweet potato roots were washed, hand-peeled, and cut into 2 mm thick slices. The slices were soaked in 0.5 % (w/v) sodium metabisulfite for 5 min, rinsed with water and then blanched with hot water at 100 °C for 5 s.

Hot air drying

The pretreated sweet potato slices were dried under different temperatures: 50, 60, 70 and 80 °C on a meshed wire tray using a cabinet dryer (Model KPO 700, Kittipoom Equipment Ltd. PART, BKK, Thailand). The moisture content of the slices was monitored every hour to achieve the moisture content below 6 % and the optimal drying time at given temperature was recorded. The flour was prepared by milling the dried slices and then sieved through the 100-mesh screening size. The flour was packed in the double zipper plastic bags and stored in the refrigerator at 4 °C until analyzed.

Drum drying

The pretreated sweet potato slices were steamed for 10 min and made into a mash using a blender. The mashed sweet potatoes were dehydrated on a laboratory atmospheric double drum dryer (model Drum Speed JM-T, Pacific Instrument, BKK, Thailand). The samples were subjected to dry at different drum speeds (3, 5, and 7 rpm) and temperatures (80, 95, and 110 °C) with a fixed clearance between drums of 0.3 mm. The sheets of dried sweet potatoes were collected, milled, and sieved through the 100-mesh screening size to obtain sweet potato flours. The flour was packed in the double zipper plastic bags and stored in the refrigerator at 4 °C until analyzed.

Proximate compositions

Sweet potato flesh and flour samples were analyzed for moisture, fat, protein, and crude fiber (AOAC 2000).

Color measurement

Color values of sweet potato flesh and flour samples were determined using Hunter Lab (DP 9000 tristimulus colorimeter processor, HunterLab Associates, Inc., Reston, Virginia). The L^* , a^* , and b^* values were measured as lightness, components on the red-green axis, and components on the yellow-blue axis, respectively. The white tile was used as the working standard for the instrument calibration.

Total phenolic content

The 3 g of sweet potato flesh and flour samples was vigorously mixed for 1 min in 100 ml of 80 % ethyl alcohol solution. The mixture was then filtered using a filter paper No. 1 and analyzed for total phenolic content using Folin-Ciocalteu method described by Aberoumand and Deokule (2008). Then, 2 ml of the extract solution was mixed with 5 ml of Folin-Ciocalteu phenol reagent for 10 min using a Vortex mixer. Next, the 4 ml of 7.5 % sodium carbonate solution was then added to the mixture and allowed to stand for 15 min in a water bath controlled at 45 °C. The mixture was cooled down and the absorbance of the resulting blue complex was then determined at 765 nm. Finally, the calibration curve of gallic acid was made and the total phenolic content was calculated and expressed as mg gallic acid equivalent (GAE) g⁻¹ dry matter.

Antioxidant activity (DPPH radical scavenging activity)

The DPPH (1,1-diphenyl-2-picrylhydrazyl) radical scavenging activity of sweet potato flesh and flour samples was determined according to Turkmen et al. (2005). The 0.5 g of sweet potato flesh and flour samples was vigorously mixed for 1 min in 50 ml of methanol, then filtered using a filter paper No. 4. Then, 1 ml of the extract solution was mixed and vigorously shaken with 2 ml of freshly prepared 0.1 mM DPPH solution in methanol. The mixture was left to stand for 60 min in the dark. The absorbance was then measured at 517 nm. The percentage of DPPH scavenging activity was calculated as $[1 - (\text{absorbance of sample} / \text{absorbance of control})] \times 100$.

β-carotene content analysis

The content of Vitamin A as β-carotene was evaluated by following the procedures of Compendium of Methods for Food Analysis (2003); Funk et al. (1995) and Munzuroglu et al. (2003) using high performance liquid chromatography (HPLC-DAD, model HP1200, Agilent Technologies, Germany). Approximately 0.1–1 g of sample and 1 g of ascorbic acid were weighed and transferred to the test tube, then extracted with 2 ml of distilled water and 3 ml of 80 % potassium hydroxide solution. In addition, the 3 ml 0.1 % BHT in ethanol was then added to the mixture, vigorously stirred and heated in the water bath shaker at 85 °C for 30 min. The test tube was subsequently cooled down in the cooling bath and the mixture of hexane and ethyl acetate (8:2, 3 ml) was then added and left until the separation occurred. The upper clear layer was carefully transferred to another test tube and the residue was re-extracted until it became colorless. The filtrates were combined and washed with distilled water. The water phase (lower phase) was removed and tested for alkalinity using phenolphthalein. This step was repeated until no pink

color appeared with phenolphthalein. The upper phase was then transferred to a volumetric flask and filtered through Na₂SO₄ anhydrous. The filtrate was then transferred to the vessel and evaporated until dry at 50 °C. Then, 1 ml of 0.1 % BHT in hexane was added and filtered with nylon syringe filter (13 ml, 0.45 μm). The filtrate was then transferred to the insert vial already packed in the 2 ml brown vial before injecting to HPLC. The 20 μl of the extract was injected to HPLC equipped with auto sampler injector, pump and a DAD detector operating at 450 nm. Separations were carried out on the μBondapak C18 column (10 μm, 300 × 3.9 mm i.d.) (Waters Cooperation, Part No. WAT027324, Serial No. W40201s 038, Massachusetts, USA). The mobile phase consisted of methanol:acetone:chloroform (50:45:5, v/v/v). The flow rate was 1 ml/min. β-carotene content (μg/100 g) was calculated as follows:

$$\beta\text{-Carotene content } (\mu\text{g}/100\text{g}) = 100 \text{ CV}/W$$

where C is β-carotene content (μg/ml) obtained from calibration curve, V is the final volume (ml) and W is the sample weight (g).

Anthocyanin content

The total monomeric anthocyanin content was determined using a spectrophotometric pH-differential method described by Lee et al. (2005) and Humadi and Istudor (2009). The 1 mL of extracts was leveled off to 10 mL with the buffer solution of pH 1. A second 1 mL of extracts was diluted to 10 mL using buffer solution of pH 4.5. This procedure was performed on each of the three extracting solvents. The flasks were left at room temperature for 15 min., and then the absorbance was determined at λ = 520 nm, and λ = 700 nm. Distilled water was used as a blank..

The anthocyanins are calculated as cyanidin-3-glucoside equivalents, mg/L, using the equation:

$$\frac{A \times MD \times DF \times 10^3}{\epsilon \times l}$$

where **A** = (A_{520nm} – A_{700 nm}) pH 1.0 – (A_{520 nm} – A_{700 nm}) pH 4.5; **MW** (molecular weight) = 449.2 g/mol for cyanidin-3-glucoside (cyd-3-glu); **DF** = dilution factor (1:10); **l** = path length in cm; **ε** (= 26,900 M extinction coefficient, in L · mol⁻¹ · cm⁻¹, for cyd-3-glu; and **10³** = factor for conversion from g to mg..

Flour pasting properties

Rapid Visco Analyzer (RVA) (Scientific Newport, Model RVA-4, Australia) was used to determine the pasting properties of flours. The 3 g of sweet potato flours in 25 ml of water at 14 % moisture content was subjected to a controlled heating

Table 1 Chemical composition of fresh sweet potatoes from different varieties

Values	Sweet potato cultivar	
	Orange-flesh (T101)	Purple-flesh (Phichit 65–3)
1. Chemical compositions		
Moisture (%)	74.49 ± 0.14	66.51 ± 0.24
Protein (%db)	3.58 ± 0.28	4.96 ± 0.03
Fat (%db)	1.17 ± 0.04	1.57 ± 0.02
Crude fiber (%db)	3.18 ± 0.13	4.40 ± 0.18
Ash (%db)	3.52 ± 0.15	2.72 ± 0.13
2. Color		
L*	74.22 ± 0.54	34.94 ± 0.86
a*	27.93 ± 0.56	24.83 ± 1.41
b*	44.44 ± 0.53	−2.27 ± 0.53
3. Antioxidant activity (%)		
10.34 ± 0.39	19.78 ± 0.84	
4. Total Phenolic content (mg gallic acid/100 g DW)		
12.69 ± 0.33	21.10 ± 1.29	
5. Anthocyanin (mg/100 g wb)		
0.53	4.63	
6. β-carotene (μg/100 g wb)		
12,220	<22.80	

and cooling system under constant shear in the RVA unit. The time-temperature regime of the equipment was as follows: the slurry was heated at 50 °C for 1 min, then increased to 95 °C within 3.42 min at which it was held for 2.70 min and consequently cooled to 50 °C in 3.88 min and finally kept at this temperature for 2 min. Peak viscosity, viscosity at the through, breakdown, final viscosity, setback, peak time, and pasting temperatures were recorded.

Thermal properties of sweet potato flours

Thermal properties of sweet potato flours were evaluated by Differential Scanning Calorimeter (DSC, model DSC1 Stare System, Mettler-Toledo Ltd., Beaumont Leys Leicester, England). The 5 mg of flour was prepared to a paste by mixing with 10 μl of water in a 40 μl size aluminum pan and held for 1 h before analysis. The sample was heated from 20 to 120 °C at a scanning rate of 5 °C/min for a total time of 20 min with an empty pan as a reference. Nitrogen was used as a purging gas

Table 2 Moisture content of hot air dried sweet potato flours

Drying temperature-drying time	Orange-flesh (T101)	Purple-flesh (65–3)
50 °C – 10 h	6.22 ± 0.04	5.36 ± 0.25
60 °C – 8 h	5.14 ± 0.09	4.05 ± 0.75
70 °C – 5 h	4.41 ± 0.07	4.72 ± 0.20
80 °C – 4 h	4.51 ± 0.18	3.03 ± 0.40

Table 3 Moisture content of drum dried sweet potato flours

Speed (rpm)	Drying Temperature (°C)	Orange-flesh (T101)	Purple-flesh (65–3)
3	80	7.50 ± 0.77	12.55 ± 0.39
	95	3.86 ± 0.06	5.46 ± 0.07
	110	2.99 ± 0.06	2.88 ± 0.22
5	80	11.90 ± 0.29	23.87 ± 0.99
	95	5.48 ± 0.03	6.99 ± 0.09
	110	2.57 ± 0.07	4.18 ± 0.09

at 50 μl/min flow rate. Onset temperature, peak temperature, end set temperature and enthalpy were finally recorded.

Statistical analysis

The statistical comparison of data was performed by One-way ANOVA and Fisher's least significant difference (LSD) procedure using Statgraphics Centurion XVI version 16.1.11 (Stat Point Technologies, Inc.). *P* values of <0.05 were considered significant.

Results and discussion

Chemical composition of fresh sweet potatoes

The proximate compositions of raw sweet potato flesh samples are given in Table 1. Both sweet potato cultivars contained high moisture (>66 %). The protein, fat, and crude fiber contents of purple-fleshed sweet potatoes (Phichit 65–3) were slightly higher than those of orange-fleshed sweet potato cultivar (T101). Furthermore, the antioxidant activity and total phenolic content

Fig. 1 Total phenolic content of hot air dried SPFs. The values with same superscript (orange-fleshed sweet potato) or capital (purple-fleshed sweet potato) letters are not significantly different ($P > 0.05$)

Fig. 2 Total phenolic content of drum dried sweet potato flours at **a** 3 rpm, **b** 5 rpm and **c** 7 rpm drum speed. The values with same superscript (orange-fleshed sweet potato) or capital (purple-fleshed sweet potato) letters are not significantly different ($P > 0.05$)

of purple-fleshed sweet potatoes were apparently higher than the orange-fleshed sample. Sweet potato cultivar Phichit 65–3 has an intense purple color ($b^* = -2.27$) due to an accumulation of anthocyanins (Terahara et al. 2004).

Effect of drying conditions on moisture content of sweet potato flours

Moisture content values of sweet potato flours produced by hot air and drum drying were measured and indicated in Tables 2 and 3, respectively. For hot air drying, the moisture content of flours ranged from the lowest value of 3.03 % at 80 °C to the highest value of 5.36 % at 50 °C. Time taken to reduce the moisture content to specific moisture content decreased with increased drying temperature. Similar results were reported by Falade and Solademi (2010). Drum drying yielded sweet potato flours having the moisture content value ranged from 2.57 % (110 °C, 5 rpm drum speed) to 32.44 % (80 °C, 7 rpm drum speed). The effect of drying temperature was most dramatic when the moisture content was decreasing rapidly in increased temperature. Flours produced at lowest temperature of 80 °C at any given drum speed still contained a high moisture content. For these samples, the extended drying was required to reduce the moisture to the level of below 10 %.

Total phenolic content and antioxidant activity

For each cultivar, the total phenolic contents and antioxidant activity of flour samples after heat treatments were noticeably higher than that of raw samples (on dry basis) as shown in Figs. 1, 2, 3 and 4. The results are in agreement with other studies (Bellail et al. 2012; Huang et al. 2006; Ahmed et al.

2010a; Tokusoglu and Yildirim 2012) who reported that phenolic contents and antioxidant activity were affected by cooking processes such as steaming, boiling, and drying. Variation in total phenolic contents and antioxidant activity according to drying conditions were observed. Thermal processing apparently enhanced total phenolic contents of the sweet potato flours. Heat treatment could cause the damage of cell structures of sweet potato flesh tissues and resulted in more easy extraction of antioxidant constituents (Huang et al. 2006; Tokusoglu and Yildirim 2012). It is interesting to note that total phenolic contents and antioxidant activity of purple sweet potato flours (Phichit 65–3) obtained from both drying processes were significantly ($P < 0.05$) higher than that of orange sweet potato flours (T101). It was reported that most anthocyanidins acted as strong antioxidants (Tokusoglu and Yildirim 2012) and the purple-fleshed sweet potatoes contained much higher total phenols than the orange-fleshed sweet potatoes (Truong et al. 2010). For hot air drying, phenolic content and antioxidant activity of T101 and Phichit 65–3 were highest after drying at 70 °C. For drum drying, flour produced at 95 °C and 3 rpm drum speed had the highest phenolic content and antioxidant activity for both cultivars. Drying at 110 °C could degrade the phenolic compounds and resulted in a decrease of phenols amount and antioxidant activity. Obviously, drum drying yielded sweet potato flours with higher phenolic content and antioxidant activity than hot air drying in all cases. This is probably due to the steaming application for 10 min before drum drying because the steaming process could rupture the sweet potato tissues and released more antioxidant components (Tokusoglu and Yildirim 2012). The observation in this study was confirmed by Huang et al. (2006), who reported that steam treatment enhanced the total phenol contents and antioxidant activity of sweet potato genotypes.

Fig. 3 Antioxidant activity (%) of hot air dried sweet potato flours. The values with same superscript (orange-fleshed sweet potato) or capital (purple-fleshed sweet potato) letters are not significantly different ($P > 0.05$)

Fig. 4 Antioxidant activity (%) of drum dried sweet potato flours at **a** 3 rpm, **b** 5 rpm and **c** 7 rpm drum speed. The values with same superscript (orange-fleshed sweet potato) or capital (purple-fleshed sweet potato) letters are not significantly different ($P > 0.05$)

Anthocyanin and β -carotene retention

Table 4 presents the total anthocyanin and β -carotene contents in purple and orange-fleshed sweet potato flours obtained by hot air drying and drum drying process at different temperatures. The total anthocyanin and β -carotene content of flours varied related to the drying process and temperature. Since anthocyanins are a subcategory of phenolic compound presented in purple-fleshed sweet potato, the amount of anthocyanin in the samples followed the same trends of the total phenolic results. In addition, the high antioxidant activity of purple-fleshed sweet potato tended to be associated with its high amount of anthocyanins. The result is in agreement with other studies (Huang et al. 2006; Ahmed et al. 2010c; Oki et al. 2002; Steed and Truong 2008). It was reported that sweet potatoes had intermediate antioxidant activity among 43 vegetables due to the accumulation of anthocyanin (Huang et al. 2006). Suda et al. (2002) indicated that the caffeoyl group acylated to anthocyanins is responsible for the radical-scavenging activity enhancement of purple-fleshed sweet potatoes. The major anthocyanins from purple-fleshed sweet potatoes are found to be mono- or di-acylated derivatives of 3-(2-

glucosyl) glucosyl-5-glucosyl peonidin and cyaniding (Yang and Gadi 2008; Oki et al. 2002; Suda et al. 2002). Truong et al. (2010) also identified anthocyanins and anthocyanidins in various purple-fleshed sweet potato cultivars and found that cyanidin and peonidin were the major anthocyanidins in the acid hydrolyzed extracts. The anthocyanin content of flour samples was enhanced by drying processes. An increase in the total anthocyanin content of flours after heat treatments with reference to fresh sample was also reported by other studies (Huang et al. 2006; Yang and Gadi 2008; Tokusoglu and Yildirim 2012). For hot air drying, among the temperatures studied, the purple-fleshed sweet potato flour produced at 70 °C had the highest anthocyanin content (49.99 mg/100 g dry matter), which was about 3.6 times higher than the fresh sample. The purple-fleshed sweet potato flour produced by drum drying at 95 °C and 5 rpm drum speed yielded highest anthocyanin content (52.88 mg/100 g dry matter) which was slightly higher than that produced by hot air drying. Many studies suggested that steaming is critical in retaining anthocyanin content in purple-fleshed sweet potato powder (Huang et al. 2006; Yang and Gadi 2008; Tokusoglu and Yildirim 2012). Steaming inactivates the indigenous enzymes (polyphenoloxidase, peroxidase and glycosidase) in fresh sweet potatoes that can degrade anthocyanin in plant tissues (Yang and Gadi 2008; Wrolstad et al. 2005). In addition, steaming and air dehydration were reported to enhance the polymeric anthocyanins of purple-fleshed sweet potato powder through condensation of anthocyanins with phenolic compounds (Yang and Gadi 2008).

Drying processes obviously caused a serious loss of β -carotene in orange-fleshed sweet potato cultivar as presented in Table 4. This result was similar to some research findings (Bechoff et al. 2009; Jang et al. 2010). However, the amount of β -carotene was higher in drum dried flours. The β -carotene content was more degraded at higher drying temperature. For hot air drying, the β -carotene decreased by 8.3 times at 50 °C to 22.7 times at 80 °C. The lower level of losses obtained in this study was through drum drying. Drum drying process at the studied temperature range was only slightly varied (3.0–4.0 times). The major cause of larger loss of β -carotene is the significantly longer drying times applied for hot air drying. Bechoff et al. (2010) also indicated the lower total carotenoid losses in various orange-fleshed sweet potato cultivars as a result of shorter drying times. In addition, Wu et al. (2008) reported that duration of drying greatly affected the reduction of β -carotene content in orange-fleshed sweet potato varieties. The significant loss of total amount of beta-carotene in sweet potato during thermal process is caused by isomerization of carotenoids which are easily isomerized by heat, acid, or light (Grabowski et al. 2008). Carotenoids usually exist in an all-trans configuration and can be transformed to a cis configuration typically at the 9, 13, and 15 carbon positions when exposed to heat. In addition, dehydration processes can cause

Table 4 Anthocyanin and β -carotene contents of sweet potato flours

Drying Process	Anthocyanin (mg/100 g dry matter) Purple-fleshed sweet potato (Phichit 65–3)	β -carotene (μ g/100 g dry matter) Orange-fleshed sweet potato (T101)
Hot air drying		
Fresh sample	13.90 ^a	54239 ^c
Drying temperature		
50 °C	25.35 ^b	6535 ^b
60 °C	48.30 ^c	5674 ^b
70 °C	49.99 ^c	2458 ^a
80 °C	44.07 ^d	2393 ^a
Drum drying		
Fresh sample	13.90 ^A	54239 ^C
Drying temperature/Drum speed		
80 °C/3 rpm	45.98 ^E	10718 ^{BC}
80 °C/5 rpm	51.42 ^F	13991 ^{AB}
80 °C/7 rpm	50.35 ^F	15266 ^{AB}
95 °C/3 rpm	43.52 ^D	10951 ^A
95 °C/5 rpm	52.88 ^F	13459 ^{AB}
95 °C/7 rpm	42.85 ^{CD}	12579 ^A
110 °C/3 rpm	47.69 ^E	18197 ^{AB}
110 °C/5 rpm	41.58 ^C	13503 ^{AB}
110 °C/7 rpm	38.68 ^D	19017 ^{AB}

Values are means of triplicate determinations. In a same column, means followed by same superscript or capital letters are not significantly different among samples ($P > 0.05$) according to Fisher's least significant difference (LSD) procedure

Table 5 Color values of fresh sweet potato and flours

Orange-fleshed sweet potato (T101)			
Value	Fresh	Hot air dried ^a	Drum dried ^b
L*	74.21 ± 0.54 ^a	80.88 ± 0.02 ^c	77.12 ± 0.11 ^b
a*	27.94 ± 0.56 ^c	10.54 ± 0.04 ^a	14.21 ± 0.27 ^b
b*	44.72 ± 0.53 ^b	28.11 ± 0.01 ^a	45.61 ± 1.48 ^b
Purple-fleshed sweet potato (Phichit 65–3)			
Value	Fresh	¹ Hot air dried	² Drum dried
L*	34.94 ± 0.86 ^a	60.95 ± 0.01 ^c	46.22 ± 0.11 ^b
a*	24.83 ± 1.41 ^b	19.09 ± 0.41 ^a	31.75 ± 0.16 ^c
b*	−2.27 ± 0.53 ^b	−2.22 ± 0.00 ^b	−11.63 ± 0.05 ^a

Values are means ± SD of triplicate determinations. In a same row, means followed by same superscript or capital letters are not significantly different among samples ($P > 0.05$) according to Fisher's least significant difference (LSD) procedure

^a Sweet potato flour produced by hot air drying at 70 °C

^b Sweet potato flour produced by drum drying at 95 °C and 5 rpm drum speed

oxidative degradation due to exposure to oxygen and an increased surface to mass ratio (Grabowski et al. 2008; von Elbe and Schwartz 1996).

Color measurement

Table 5 represents the color values (Hunter L* a* b*) of sweet potato flours in comparison with the fresh samples. Hot air dried (70 °C) and drum dried (95 °C and 5 rpm drum speed) were selected for comparison. For orange-fleshed sweet potato cultivar, the intensity of yellow-orange color of drum dried sweet potato flours were higher than that of hot air dried samples (Fig. 5). The orange color was more enhanced by drum drying than hot air drying as confirmed by higher a* and b* values indicating deeper orange color. This was the result of higher β-carotene retention in drum dried sweet potato flours.

However, the flour samples appeared lighter after drying as observed from higher L* and lower a* values compared to the fresh sample. Higher in lightness of flours increased after drying treatments for all samples was due to the inhibition of polyphenol oxidase (PPO). Also, higher a* and b* values which indicated yellow, orange color in the fresh sample were recorded higher β-carotene content. Significant decrease in a* and b* values of flours indicated loss of yellow and red color due to the effect of heat treatments.

For purple-fleshed sweet potato cultivar, drum drying significantly ($p < 0.05$) increased the purplish color of the sweet potato flours observed from an increase in negative (−) b* value. This result was consistent with the higher anthocyanin content in the drum dried flours. However, hot air drying did not affect the b* value but it reduced the a* value of the flours in comparison with the fresh sample. Drying processes increased the L* value of all purple-fleshed sweet potato flours. Truong et al. (2010) reported that cyanidin and peonidin contribute to the blue and red hues of purple-fleshed sweet potatoes. Yang and Gadi (2008) also indicated that the change in color values of purple-fleshed sweet potato flour pretreatment with steaming before drying was due to the formation of polymeric anthocyanins and some non-enzymatic browning pigments.

Pasting properties of flours

The pasting properties of sweet potato flours at selected drying conditions are presented in Table 6. For hot air drying, the pasting temperature of orange-fleshed sweet potato flours was higher than that of purple-fleshed sweet potato flours. Orange-fleshed sweet potato flour produced by hot air drying at 70 °C was the highest (85.6 °C). In both cultivars, higher pasting temperature was found in flours produced at higher drying temperature. Higher pasting temperature is associated with higher amylose content and higher

Fig. 5 Appearance of orange and purple sweet potato flours obtained by hot air drying at 70 °C and drum drying at 95 °C 5 rpm drum speed in comparison with fresh samples

Table 6 Pasting properties of sweet potato flours

Sweet potato cultivars	Drying temperature (°C)	Pasting properties						
		Peak viscosity (cP)	Trough viscosity (cP)	Breakdown (cP)	Final viscosity (cP)	Setback (cP)	Peak time (min)	Pasting temperature (°C)
Hot air drying								
Orange-fleshed sweet potato (T101)	60	311 ± 1.2	250 ± 1.4	60.5 ± 0.2	370 ± 0.5	119 ± 0.8	4.5 ± 0.09	84.5 ± 0.02
	70	1164 ± 0.6	932 ± 2.2	232 ± 1.5	1288 ± 1.8	356 ± 0.4	4.9 ± 0.07	85.6 ± 0.07
Purple-fleshed sweet potato (Phichit 65–3)	60	306 ± 0.2	93 ± 0.9	213 ± 1.1	139 ± 0.4	46.0 ± 0.4	4.0 ± 0.0	80.1 ± 0.53
	70	865 ± 0.5	650 ± 0.5	215 ± 0.0	884 ± 1.1	236 ± 0.6	4.5 ± 0.0	83.8 ± 0.35
Drum drying^a								
Orange-fleshed sweet potato (T101)	80	99.9 ± 8.5	82.5 ± 10.6	17.5 ± 2.1	173.5 ± 13.4	91.0 ± 2.8	80.6 ± 1.1	nd ^b
	95	74.5 ± 3.5	61.9 ± 2.8	12.5 ± 0.7	120.5 ± 0.7	58.5 ± 2.1	74.5 ± 1.9	nd
	110	71.5 ± 2.1	53.5 ± 0.7	18.0 ± 2.8	109.9 ± 7.0	56.4 ± 6.3	56.4 ± 6.3	nd
Purple-fleshed sweet potato (Phichit 65–3)	80	113.5 ± 4.9	95.5 ± 4.9	18.0 ± 0.0	181.9 ± 1.4	86.5 ± 6.4	82.7 ± 1.4	nd
	95	133.5 ± 2.1	112 ± 2.8	21.5 ± 4.9	193.0 ± 11.3	81.0 ± 8.4	81.4 ± 0.8	nd
	110	103.5 ± 10.6	82.5 ± 10.6	21.0 ± 0.0	173.5 ± 2.1	90.9 ± 12.7	81.5 ± 0.3	nd

Values are means ± SD of triplicate determinations. In a same column, means followed by same letters are not significantly different among samples ($P > 0.05$) according to Fisher's least significant difference (LSD) procedure

^a Sweet potato flours produced by drum drying at 5 rpm drum speed

^b Not detected

high resistance towards swelling (Nabubuya et al. 2012). Kamolwan et al. (2003) reported the higher pasting temperature of orange-fleshed sweet potato starch compared to purple-fleshed sweet potato starch due to its higher amylose content. In this study, the peak viscosities, trough viscosity, break down viscosity and set back viscosities were positively correlated to the pasting temperature. The peak time, the time required to attain peak viscosity, was also higher in flours produced from hot air drying at 70 °C. The thermal properties of flours were also investigated by DSC and the results were presented in Table 7. Similar to RVA results higher onset temperature, peak temperature and end set temperature were found in flours produced at higher drying temperature. However, differences in pasting properties of flours among sweet potato cultivars must have been due to the differences in components of flours such as sugars, pigments, amylose:amylopectin ratio, fiber, etc.

Drum drying process completely gelatinized all sweet potato flours as observed from RVA and DSC results. As shown in Table 5, under the same RVA testing condition, the peak viscosity, trough viscosity and breakdown viscosity of drum dried flours were apparently lower than those of hot air dried flours. The pasting temperature of all drum dried flours could not be detected while no peak was seen on the DSC analysis (data not shown).

Conclusion

The effects of drying methods and conditions on changes in color, antioxidant activity, total phenolic content, β -carotene and anthocyanin contents of two sweet potato cultivars including T101 (orange-fleshed) and Phichit 65–3 (purple-fleshed) were investigated. Drying conditions significantly affected the

Table 7 Thermal properties of hot air dried sweet potato flours

Sweet potato cultivars	Drying temperature (°C)	Thermal properties			
		Onset temperature	Peak temperature	Endset temperature	Enthalpy (J/g)
Orange-fleshed sweet potato (T101)	60	79.74	85.67	91.3	2.72
	70	82.54	86.76	92.68	3.62
Purple-fleshed sweet potato (Phichit 65–3)	60	77.35	81.33	85.71	2.06
	70	80.52	84.07	88.32	2.84

characteristics and quality of sweet potato flours. Anthocyanin content of the purple-fleshed sweet potato cultivar was significantly enhanced by drying processes. Antioxidant activity and phenolic contents of sweet potato flours were enhanced by drying processes and positively correlated with anthocyanin contents. Drying processes at high temperature caused a serious degradation of β -carotene in the orange-fleshed sweet potato cultivar. Drum drying process instantly produced pregelatinized flour. Both orange and purple-fleshed sweet potato flours have a high potential for uses in a variety of health food products such as bakery, confectionery, snack, noodle, soup and gravy. Further investigation on the pretreatment to improve the color, appearance, and nutritional qualities of the color sweet potatoes will be conducted.

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