

## Thai Purple Sweet Potato Flours: Characteristic and Application on Puffed Starch-Based Snacks

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### Abstract

Characteristics and properties of 4 Thai purple sweet potato flours, Maejo 343, Phichit 65-3, Phichit 290-9 and Torperk were determined in terms of native and pre-gelatinized flours. Color, physicochemical properties and antioxidant activity of native and pre-gelatinized flours depend on their varieties. All native flours showed low redness ( $a^*$ ) and blueness ( $-b^*$ ) values but high pasting properties. Pre-gelatinized flours had a unique purple color and high antioxidant activity. Flours produced by Phichit 65-3 showed a deep intense purple color, high anthocyanins and good antioxidant activity. Both native and pre-gelatinized Phichit 65-3 flours were used as the main raw materials of air-puffed pre-gelatinized flours with different ratios at 10%, 30% and 50%. Increasing the content of pre-gelatinized flours improved color, expansion and antioxidant activity of snacks. Low hardness (9.55-11.65 kg) was presented in all snacks prepared from sweet potato flours. Purple sweet potato snacks prepared from 50% pre-gelatinized flour had good appearance, light texture, high anthocyanins and high antioxidant activity. Results showed that Thai purple sweet potato flours can be used to produce healthy snacks with improved appearance and texture. They also have potential as sources of natural colorants and antioxidants in food products.

**Keywords:** sweet potato, physicochemical properties, antioxidant activity, snack, microstructure

### 1. Introduction

Starch-based snacks are well-known global food products with a unique appearance, taste and texture. Normally, starch-based snacks are puffed to create a porous structure and crispy texture (Mariotti et al., 2006; Nemš et al., 2015). Expansion of the puffed snacks depends on several factors such as raw materials used, amylose-amylopectin ratio, degree of gelatinization, moisture content and puffing methods (Norton et al., 2011; Wang et al., 2012; Jiamjariyatam et al., 2017). Starch-based snacks have been traditionally puffed by deep-frying; however, high oil content in these products can cause health problems and short shelf life (Chen et al., 2016). Air-puffing or baking were applied to snacks for health-conscious consumers for convenient operation. Addition of dietary fiber, protein from plant sources and natural antioxidants were also used to improve the nutritional and health benefits of the snacks (Nath & Chattopadhyay, 2007; Reddy et al., 2014; Nemš et al., 2015). Moreover, root and tuber crops such as potato, sweet potato, yam, taro and beet root were selected to develop the appearance and nutritional properties of snacks from corn and black gram flour (Reddy et al., 2014). Snacks produced with colored potato flour had 2-3 times higher antioxidant activity, high content of polyphenols, attractive color and better expansion. Losses of anthocyanins during snack processing depended on potato varieties (Nemš et al., 2015). The utilization of starchy tubers and air-puffing has become an alternative method of producing healthy snacks with good expansion, increasing acceptance and source of phytochemicals.

Purple sweet potatoes (*Ipomoea batatas* L. Lam) are starchy tubers which have good nutritional value and positive health benefits as excellent sources of carbohydrate, fiber, vitamins, minerals and phytochemical compounds (Van Hal, 2000; Teow et al., 2007). They show an intense purple color due to the accumulation of acylated anthocyanins as peonidin-based and cyanidin-based which provide various biological functions such as free radical scavenging, anticarcinogenic activity and antihypertensive effects (Oki et al., 2002; Yang & Gadi,

2008). Purple sweet potato anthocyanins can be used as natural food-safe edible colorants (Suda et al., 2003; Terahare et al., 2004). Sweet potatoes have great potential to contribute to the human diet and food production as starch, bakery and snacks. Moreover, they can be used as functional ingredients in various food products, especially in flour form. Flour production is a common technique for root preservation with many advantages including longer shelf life, ready usage and easy delivery, thus increasing the economic value of sweet potatoes.

In recent years, purple sweet potatoes have been widely grown in several areas of Thailand. The four selected varieties had outstanding characteristics. Phichit 290-2 is the base for new purple-fleshed breeding while Torperk is widely consumed in Thai markets. The two new breeding varieties, Maejo 343 and Phichit 65-3, are fast-growing and have higher productivity. Moreover, Phichit 65-3 variety has a noticeable deep purple color. The properties of Thai purple sweet potato flours are sparsely reported in the literature; however, the characteristics and physicochemical properties of flour-based plants play important roles in the commercial application of starch in various food product categories.

This study investigated and compared characteristics, physicochemical properties and antioxidant activity of native and pre-gelatinized Thai purple sweet potato flours. Applications of purple sweet potato flour on air-puffed snacks were formulated from selected varieties that exhibited deep intense purple color, high anthocyanin content and high antioxidant activity. Physical properties of purple sweet potato snacks as expansion ratio, hardness, crispiness, macrostructure and antioxidant activity were observed.

## **2. Method**

### *2.1 Samples*

Four varieties of purple sweet potato (Maejo 343, Phichit 65-3, Phichit 290-9 and Torperk) were provided by the Agriculture Development and Research Center, Phichit, Thailand. Fresh roots (50 kg per each variety) were stored at 10 °C prior to use (Figure 1).

### *2.2 Flour Preparation*

#### *2.2.1 Native Flour*

Purple sweet potato flours were prepared following the method of Aina et al. (2009) with some modifications. Briefly, all the roots were cleaned, hand-peeled and cut into 2 mm thick slices using a food processor (CombiMax 600, Braun, Hungary). The thin slices were dried in a hot air oven at 50 °C (Memmert, Germany) until the moisture content was below 12%. They were then ground and sieved through a 100 mesh screen. The native flours were stored in polyethylene bags at 4 °C until required for use.

#### *2.2.2 Pre-gelatinized Flour*

The peeled purple sweet potatoes were cut into 4 cm pieces crosswise, then steamed at 100 °C for 30 min (Tefal steam cooker, France), cooled and cut into 2 mm thick slices with a sharp knife. The steamed samples were dried in a hot air oven at 50 °C (Memmert, Germany) until the moisture content was below 12%, then ground to a powder using a laboratory grinder and sieved through a 100 mesh screen. The pre-gelatinized flours were stored in polyethylene bags at 4 °C until required for use.

### *2.3 Flour Characteristics*

#### *2.3.1 Chemical Compositions and Color Measurement*

Purple sweet potato flours were analyzed for proximate composition (AOAC, 2000). Color attributes as Hunter  $L^*$ ,  $a^*$ ,  $b^*$  values (Lightness, redness and yellowness) were determined using a Datacolor Spectrophotometer Spectraflash SF 600 plus (Datacolor International, USA).



Figure 1. Thai purple sweet potatoes (A) Maejo 343, (B) Phichit 65-3, (C) Phichit 290-9 and (D) Torperk

### 2.3.2 Flour Hydration Properties

The water holding capacity (WHC), swelling volume (SV) and water binding capacity (WBC) of purple sweet potato flours were evaluated following the method reported by Cornejo and Rosell (2015). A sample of 1 g (db) was mixed with distilled water (10 ml) at room temperature for 24 h. The supernatant was carefully removed and WHC was calculated by the weight of sediment after removal supernatant per gram of solid. SV was determined by the total volume of swollen sample after 24 h at room temperature per gram of sample. WBC expressed the amount of water retained by the sample under low-speed centrifugation. Briefly, the mixture of sample (1 g db) and distilled water (10 ml) was centrifuged at  $3,000 \times g$  for 10 min. WBC was described by weight of sediment after centrifugation per gram of solid. WHC, SV and WBC were calculated by Equations (1-3):

$$\text{WHC (g/g)} = \text{Weight of sediment after draining supernatant} / \text{Sample weight} \quad (1)$$

$$\text{SV (ml/g)} = \text{Total volume of swollen sample} / \text{Sample weight} \quad (2)$$

$$\text{WBC (g/g)} = \text{Weight of sediment after centrifugation} / \text{Sample weight} \quad (3)$$

### 2.3.3 Flour Gelling Behavior

The purple sweet potato flours were measured for water absorption index (WAI), water solubility index (WSI) and swelling power (SP) according to the method of Cornejo and Rosell (2015) with some modifications. Flour sample (1 g db) was suspended in 10 ml distilled water and cooked at  $90^\circ\text{C}$  for 30 min in a water bath. After the cooked paste was cooled, it was centrifuged at  $3,000 \times g$  for 10 min. The supernatant was decanted into an evaporation dish and the sediment was weighed. Dry solids of supernatant were determined. WAI, WSI and SP were calculated by Equations (4-6):

$$\text{WAI (g/g)} = \text{Weight of sediment} / \text{Sample weight} \quad (4)$$

$$\text{WSI (g/g)} = \text{Weight of dissolved solids in supernatant} / \text{Sample weight} \quad (5)$$

$$\text{SP (g/g)} = \text{Weight of sediment} / \text{Weight of dissolved solids in supernatant} \quad (6)$$

For the determination of oil absorption capacity (OAC) the modified method of Fiorda et al. (2015) was applied. Flour sample (1 g db) was mixed with soya oil (10 ml) and centrifuged at  $3,000 \times g$  for 10 min. The sediment was weighed after draining soya oil and OAC was calculated by Equation (7):

$$\text{OAC (g/g)} = \text{Weight of sediment after draining oil} / \text{Sample weight} \quad (7)$$

### 2.3.4 Pasting Properties

Pasting properties of purple sweet potato flours were evaluated using a Rapid Visco Analyzer (RVA Super 3, Newport Scientific, Australia). Flour suspension was prepared with 3 g samples in 25 ml water at 12% moisture content. Heating and cooling were programmed, with the sample held at  $50^\circ\text{C}$  for 1 min, heated to  $95^\circ\text{C}$  at

6 °C/min and held for 5 min, then cooled to 50 °C in 2 min. Peak viscosity, trough viscosity, final viscosity, breakdown, and setback viscosity were recorded.

### 2.3.5 Antioxidant Activity

Purple sweet potato flours were extracted using modified methods of Bridgers et al. (2010). Briefly, a mixture of 10 g flour sample and 100 ml 80% ethanol (ratio 1:10) was placed in a shaking water bath at 80 °C for 2 h and then filtered through Whatman No.1 filter paper. Extracts were kept at -20 °C until required for analysis. Total phenolic contents (TPC) of extracts were determined following the Folin-Ciocalteu method described by Singleton et al. (1999) and TPC was calculated and expressed as mg gallic acid equivalent (GAE) per g db. Total anthocyanin content (TAC) was determined following the procedure of Huang et al. (2006) and TAC was calculated from Equation (8):

$$\text{TAC} = A \times M_w \times \text{DF} \times 100/(\epsilon \times W) \quad (8)$$

Where,  $A = (A_{520} - A_{700})_{\text{pH}1.0} - (A_{520} - A_{700})_{\text{pH}4.5}$ ,  $M_w$  = molecular weight of cyanidin-3-glucoside (449.2),  $\text{DF}$  = dilution factor,  $\epsilon$  = molar absorptivity (26,900), and  $W$  = sample weight (g).

Antioxidant activities of extract were investigated by 3 different assays. The DPPH free radical scavenging activity assay followed a modified method described by Brand-Williams et al. (1995). Briefly, 1 ml of extract was mixed with 3 ml of 0.2 mM DPPH. After 30 min of incubation in the dark, the absorbance was measured at 517 nm. The %inhibition was calculated using the equation:

$$\text{Inhibition (\%)} = [1 - (A_{\text{sample}}/A_{\text{blank}}) \times 100] \quad (9)$$

Trolox equivalent antioxidant capacity (TEAC) assay was performed as described by Zhou and Yu (2004) and ferric-reducing antioxidant power (FRAP) assay was tested according to Benzie and Strain (1999). The calibration curve of Trolox was constructed and antioxidant activities (DPPH, TEAC and FRAP values) were expressed as mg of Trolox equivalent (TE) per g db.

## 2.4 Preparation of Purple Sweet Potato Snacks

Purple sweet potato snacks were prepared using purple sweet potato flour, composite flour (tapioca, corn and wheat flour) and water at ratio 1:1:1.5 (w/w). Salt at 0.75% was added and the mixture was kneaded for 15 min. The dough was rolled out to a thickness of 40 mm and steamed for gelatinization. After cooling, the dough was cut into strips (40 × 20 × 450 mm) and dried at 50 °C for 1 h. The dough was formulated with 10, 30 and 50% pre-gelatinized flour (w/w). For preparing the control snack, sweet potato flours were replaced by steamed purple sweet potato (db) at the same ratio. All dried dough was puffed in an oven (Healsio AX-1500X, Sharp, Japan) at 230 °C for 80 seconds. The purple sweet potato snacks were kept in polyethylene bags until required for physical analysis.

## 2.5 Physical Properties of Air-Puffed Purple Sweet Potato Snacks

### 2.5.1 Color Measurement

Surface color of snacks was measured by a Datacolor spectrophotometer Spectraflash SF 600 plus (Datacolor International, USA) and expressed as  $L^*$ ,  $a^*$ ,  $b^*$  values (Lightness, redness and yellowness).

### 2.5.2 Expansion Ratio

Expansion ratio of snacks was determined using the modified method of Segnini et al. (2004). A ratio of the difference between final volume and initial volume was expressed.

### 2.5.3 Bulk Density

Bulk density of snacks was determined using the sesame seed displacement method described by Sahin and Sumnu (2006). Bulk density ( $\rho$ ) was calculated as:

$$\text{Bulk density} = \text{Mass of snacks} / \text{Volume of snacks} \quad (10)$$

### 2.5.4 Microstructure of Purple Sweet Potato Snacks

Cross sections of snacks were mounted on a specimen holder and then coated with gold. Fixed specimens were examined using SEM (Jeol JSM-6390, Korea).

### 2.5.5 Textural Properties

Hardness and crispiness were examined on a Texture Analyzer (TA-XT2, Macro stable systems, UK) with 5-blade Kramer shear cell and 5.0 kg load cell. Hardness value was considered as maximum peak force (kg) and

crispiness value was determined by linear distance (kg s). The study was conducted at a distance of 20 mm with test speed at 2 mm/s. An average of 15 measurements was reported.

### 2.5.6 Antioxidant Activity

Extraction of snacks followed the same manner as in section 2.3.5 and they were kept at -20 °C until required for analysis. Total phenolic content, total anthocyanin content and 3 different antioxidant activity assays in 2.3.5 were applied to snack extracts. Values of TPC, TAC, DPPH, TEAC and FRAP were expressed as previously described.

### 2.6 Statistical Analysis

All experiments were performed in triplicate. Statistical analyses of all data were conducted using one-way ANOVA analysis of variance. Duncan's multiple range test (DMRT) at  $p < 0.05$  significance was used to estimate differences between the means with SPSS software for Windows (Version 15). Data were also evaluated using Pearson's correlation coefficient to establish the relationship among variables.

## 3. Results and Discussion

### 3.1 Flour Characteristics

Appearance of native and pre-gelatinized purple sweet potato flours prepared from Maejo 343, Phichit 65-3, Phichit 290-9 and Torperk are shown in Figure 2. Moisture content of 4 native flours produced from Thai purple sweet potato ranged from 6.35 to 7.54%. Fat, ash and protein contents ranged at 0.45-0.56%, 2.48-4.00% and 2.61-3.47%, respectively. Thai sweet potato flours showed fat and protein contents lower than previous studies. Ramesh Yadev et al. (2006) reported 1.0-1.1% fat and 6.3-6.6% protein contents of Indian red skin sweet potato flours. Aina et al. (2009) reported fat and protein contents of Caribbean sweet potato flour at 0.2-1.8% and 2.7-4.4%, respectively. Variations may be due to different sweet potato varieties with diverse preparation and drying processes. Phosphorus, total sugar and amylose content of Thai sweet purple potato flours ranged at 0.175-0.351 g/100 g, 6.06-7.78 g/100 g and 13.83-16.9%, respectively. Phosphorus and amylose contents of Torperk flours were significantly lower than other varieties. However, there were no significant differences between native and pre-gelatinized flours of each variety (data not shown).

Color attributes were expressed as Hunter values ( $L^*$ ,  $a^*$  and  $b^*$ ). Results indicated that both native and pre-gelatinized flours showed significantly different color parameters (Table 1). All pre-gelatinized flours had higher redness ( $a^*$ ) but lower yellowness ( $b^*$ ) and lightness ( $L^*$ ) values than native flours. An increase in  $a^*$  value after thermal pretreatment was reported in several varieties of Thai purple sweet potato and correlated with the formation of polymeric anthocyanins (Reugmaneeapaitoon, 2009; Soison et al., 2014). Among these, both native and pre-gelatinized flours produced from Phichit 65-3 showed an intense purple color with the highest redness ( $+a^* = 11.66$  and  $15.48$ , respectively) and blueness ( $b^* = 1.58$  and  $-6.55$ , respectively). These results compared favorably with previous studies (Ruttarattanamongkol et al., 2016). Phichit 65-3 variety is, therefore, a good source for flour production with heat stable purple color.



Figure 2. Appearance of Thai purple sweet potato flours. (A) Native Flour And (B) Pre-Gelatinized Flour

Table 1. Color parameters of Thai purple sweet potato flours

Flour	Variety	Color value		
		$L^*$	$a^*$	$b^*$
Native	Maejo 343	75.44±0.40 <sup>d</sup>	7.51±0.17 <sup>c</sup>	4.94±0.08 <sup>c</sup>
	Phichit 65-3	66.85±0.24 <sup>b</sup>	11.66±0.05 <sup>g</sup>	1.58±0.02 <sup>c</sup>
	Phichit 290-9	79.04±0.12 <sup>f</sup>	4.28±0.02 <sup>a</sup>	10.90±0.04 <sup>f</sup>
	Torperk	76.51±0.26 <sup>e</sup>	4.84±0.08 <sup>b</sup>	12.52±0.13 <sup>g</sup>
Pre-gelatinized	Maejo 343	67.16±0.30 <sup>b</sup>	10.21±0.11 <sup>f</sup>	-2.47±0.03 <sup>b</sup>
	Phichit 65-3	62.50±0.44 <sup>a</sup>	15.48±0.19 <sup>h</sup>	-6.55±0.08 <sup>a</sup>
	Phichit 290-9	75.61±0.43 <sup>d</sup>	6.25±0.17 <sup>d</sup>	1.88±0.07 <sup>d</sup>
	Torperk	74.72±0.40 <sup>c</sup>	6.03±0.15 <sup>c</sup>	4.88±0.12 <sup>e</sup>

Note. Each value represents mean values ± standard error.

Color values:  $L^*$ ,  $a^*$  and  $b^*$  mean lightness, redness and yellowness, respectively.

<sup>a-g</sup> Mean values within the same column with different letters are significantly different at  $p < 0.05$ .

Native and pre-gelatinized sweet potato flours were evaluated for hydration properties as presented in Table 2. The WBC, WHC and SV values of pre-gelatinized flours were 2 times higher than native flours. Highest hydration properties were observed in pre-gelatinized Torperk flours. The WAI and WSI of native Torperk flours were 8.18 g/g and 33.53 g/g, higher than WAI and WSI (2.57 g/g and 16.58 g/g) reported by Soison et al. (2014). Native flours had higher WAI and SP values than pre-gelatinized flours at 90 °C, while high WSI was presented in pre-gelatinized flour. Soison et al. (2014) reported that pre-gelatinized flour showed 3 times higher WSI than native flour. Swelling behavior of Phichit 290-9 flours gave the lowest WSI and SP values, possibly due to the high fat and protein contents. Oil absorption capacity (OAC) of flours ranged between 2.19 and 2.60 g/g with no significant differences ( $p < 0.05$ ) among varieties or types. The oil absorption implied the nonpolar sited of protein or lipid in starch granules (Fiorda et al., 2015). Hydration properties and gelling behavior of flours depended on their characteristic of starch granules. Water-binding capacity constituted the ability of hydrophilic part in starch molecules, water was absorbed in the amorphous zone of the starch and become swollen. The change in small crystallites caused the striping of chains and melting of crystallites. Pre-gelatinized flours showed the high hydration properties due to the structural rearrangement or degradation of starch granules during thermal processing (Neelam et al., 2012). Moreover, the variation in solubility and swelling power could be caused by differing degrees of engagement of the hydroxyl groups, forming hydrogen and covalent bonds between the starch chains (Gunarate & Hoover, 2002). Results indicated that thermal pre-treatment improved both the hydration properties and gelling behavior of flours of Thai purple sweet potato flours and pre-gelatinized flours showed the cold water-soluble ability.

Table 2. Hydration properties of purple sweet potato flours

Flour	Variety	WBC	WHC	SV	WAI	WSI	SP	OAC
Native	Maejo 343	3.25±0.18 <sup>a</sup>	3.83±0.16 <sup>a</sup>	2.59±0.16 <sup>a</sup>	8.69±0.33 <sup>d</sup>	33.39±2.25 <sup>c</sup>	12.95±0.15 <sup>c</sup>	2.29±0.04 <sup>a</sup>
	Phichit 65-3	3.08±0.01 <sup>a</sup>	3.93±0.12 <sup>a</sup>	2.80±0.12 <sup>a</sup>	8.21±0.07 <sup>bc</sup>	32.69±0.51 <sup>c</sup>	12.07±0.12 <sup>b</sup>	2.55±0.04 <sup>a</sup>
	Phichit 290-9	3.23±0.10 <sup>a</sup>	3.83±0.10 <sup>a</sup>	2.66±0.11 <sup>a</sup>	8.46±0.25 <sup>cd</sup>	25.06±0.31 <sup>a</sup>	10.87±0.07 <sup>a</sup>	2.43±0.17 <sup>a</sup>
	Torperk	3.19±0.09 <sup>a</sup>	3.66±0.10 <sup>a</sup>	2.45±0.01 <sup>a</sup>	8.18±0.10 <sup>bc</sup>	33.45±0.33 <sup>c</sup>	12.19±0.07 <sup>b</sup>	2.25±0.05 <sup>a</sup>
Pre-Gelatinized	Maejo 343	7.03±0.25 <sup>c</sup>	6.04±0.15 <sup>b</sup>	4.87±0.02 <sup>b</sup>	6.45±0.11 <sup>a</sup>	40.82±0.23 <sup>d</sup>	10.89±0.13 <sup>a</sup>	2.19±0.06 <sup>a</sup>
	Phichit 65-3	6.49±0.13 <sup>b</sup>	7.00±0.21 <sup>c</sup>	5.70±0.27 <sup>c</sup>	6.45±0.00 <sup>a</sup>	41.80±1.17 <sup>d</sup>	11.53±0.75 <sup>ab</sup>	2.34±0.14 <sup>a</sup>
	Phichit 290-9	6.46±0.06 <sup>b</sup>	6.06±0.05 <sup>b</sup>	5.04±0.07 <sup>b</sup>	7.84±0.05 <sup>b</sup>	27.89±0.06 <sup>b</sup>	11.08±0.03 <sup>a</sup>	2.60±0.48 <sup>a</sup>
	Torperk	6.85±0.04 <sup>c</sup>	7.50±0.15 <sup>d</sup>	6.35±0.19 <sup>d</sup>	6.82±0.14 <sup>a</sup>	42.75±0.83 <sup>d</sup>	11.96±0.27 <sup>b</sup>	2.53±0.04 <sup>a</sup>

Note. Each value represents mean values ± standard error.

WBC: Water Binding Capacity, WHC: Water Holding Capacity, SV: Swelling Volume, WAI: Water Absorption Index, WSI: Water Solubility Index, SP: Swelling Power, OAC: Oil Absorption Capacity.

<sup>a-h</sup> Mean values within the same column with different letters are significantly different at  $p < 0.05$ .

Pasting properties of Thai purple sweet potato flours were determined by a Rapid Visco Analyzer (RVA) (Table 3). Sweet potato varieties and flour preparation both significantly affected the pasting properties ( $p < 0.05$ ). Pasting temperature (PT) was only observed in native Phichit 65-3, Maejo 343 and 290-9 flours (83.32, 85.02 and 86.53 °C, respectively). Results indicated that starch granules of Torperk and pre-gelatinized flours swell more rapidly beyond the gelatinization temperature. Phichit 290-9 flours exhibited the highest values of final viscosity and set back, indicating the starch granule had high capacity to form gel with high retrogradation tendency. Breakdown reflects the shear stability of hot paste, all pre-gelatinized flours presented lower breakdown viscosity than native flour. Differences in breakdown have been related to disparate rigidities of swollen granules. Pre-gelatinized Torperk flours showed the lowest breakdown (1.17 RVU) and setback (8.11 RVU), indicating the high sensitivity to thermal processing and the low rate of retrogradation. Viscosity profiles of Maejo 343 and Phichit 65-3 flours showed more similar patterns than other varieties. Peak time ranged between 4.13 and 6.98 min. The short peak time supported that all Thai purple sweet potato flours were easy to cook. Different pasting properties might be due to the genetic factor, the accumulation of starch granules and their structural properties (Aina et al., 2009; Soison et al., 2014).

Table 3. Pasting properties of purple sweet potato flours

Flour	Variety	Viscosity (RVU)				
		Peak	Trough	Breakdown	Final	Setback
Native	Maejo 343	102.03±1.21 <sup>f</sup>	55.00±0.37 <sup>d</sup>	47.03±0.89 <sup>e</sup>	73.69±0.38 <sup>e</sup>	18.69±0.17 <sup>e</sup>
	Phichit 65-3	86.83±0.63 <sup>e</sup>	53.69±0.49 <sup>d</sup>	33.14±0.77 <sup>c</sup>	70.31±0.71 <sup>d</sup>	16.61±0.26 <sup>d</sup>
	Phichit 290-9	163.42±9.31 <sup>g</sup>	116.67±8.37 <sup>f</sup>	46.75±0.95 <sup>d</sup>	171.34±0.47 <sup>g</sup>	59.67±1.77 <sup>g</sup>
	Torperk	69.75±0.14 <sup>d</sup>	63.22±0.13 <sup>e</sup>	6.53±0.18 <sup>b</sup>	85.80±0.50 <sup>f</sup>	22.58±0.55 <sup>f</sup>
Pre-Gelatinized	Maejo 343	24.66±0.58 <sup>b</sup>	23.58±0.65 <sup>c</sup>	1.08±0.09 <sup>a</sup>	34.25±0.59 <sup>c</sup>	10.66±0.14 <sup>b</sup>
	Phichit 65-3	20.14±0.13 <sup>a</sup>	18.75±0.14 <sup>b</sup>	1.39±0.05 <sup>a</sup>	27.39±0.10 <sup>b</sup>	8.64±0.24 <sup>a</sup>
	Phichit 290-9	57.83±0.87 <sup>c</sup>	57.03±0.78 <sup>d</sup>	0.81±0.13 <sup>a</sup>	70.00±0.80 <sup>d</sup>	12.97±0.13 <sup>c</sup>
	Torperk	16.28±0.31 <sup>a</sup>	15.11±0.39 <sup>a</sup>	1.17±0.09 <sup>a</sup>	23.22±0.56 <sup>a</sup>	8.11±0.17 <sup>a</sup>

Note. Each value represents mean values ± standard error.

<sup>a-g</sup> Mean values within the same column with different letters are significantly different at  $p < 0.05$ .

Antioxidant activity of Thai sweet potato flours is dependent on the phytochemical content and several in vitro mechanisms. Total phenolic content (TPC) and total anthocyanin content (TAC) were measured (Table 4). TPC and TAC values ranged between 22.7-226.9 mg GAE/100g db and 10.3-182.8 mg/100g db, respectively. TPC and TAC values of flours differed between varieties and increased in pre-gelatinized flours. The pre-gelatinized 290-9 flour showed the higher TPC at almost 10 times than native. Among the pre-gelatinized flours, Phichit 65-3 showed the highest TPC and TAC values, while Torperk presented the lowest values. In this study, Torperk flours recorded lower TPC and TAC values than previously reported (Soison et al., 2014) which might be related to the cultivation area, growing conditions and environment of Torperk root production. High TPC and low TAC were found in both Phichit 290-9 and Torperk varieties. Results suggested that anthocyanin quantities as the large group of phenolic compounds in purple sweet potatoes varied depending on the cultivar.

Table 4. Antioxidant activity of purple sweet potato flours

Flour	Variety	TPC (mg GAE/g db)	TAC (mg/g db)	DPPH (mg TE/g db)	TEAC (mg TE/g db)	FRAP (mg TE/g db)
Native	Maejo 343	0.393±0.014 <sup>b</sup>	0.378±0.008 <sup>b</sup>	0.779±0.012 <sup>a</sup>	8.987±0.244 <sup>b</sup>	2.001±0.066 <sup>b</sup>
	Phichit 65-3	0.697±0.042 <sup>c</sup>	0.678±0.052 <sup>c</sup>	2.162±0.015 <sup>ab</sup>	18.03.2±0.566 <sup>c</sup>	3.768±0.092 <sup>c</sup>
	Phichit 290-9	0.227±0.007 <sup>a</sup>	0.163±0.008 <sup>a</sup>	0.556±0.051 <sup>a</sup>	4.966±0.136 <sup>a</sup>	1.150±0.036 <sup>a</sup>
	Torperk	0.399±0.009 <sup>b</sup>	0.103±0.002 <sup>a</sup>	1.356±0.084 <sup>a</sup>	10.239±0.070 <sup>b</sup>	2.240±0.052 <sup>b</sup>
Pre-Gelatinized	Maejo 343	0.877±0.041 <sup>d</sup>	0.829±0.034 <sup>c</sup>	3.264±0.081 <sup>c</sup>	25.729±0.338 <sup>d</sup>	5.629±0.088 <sup>d</sup>
	Phichit 65-3	1.797±0.049 <sup>f</sup>	1.828±0.025 <sup>f</sup>	6.630±0.093 <sup>c</sup>	62.765±1.363 <sup>g</sup>	10.936±0.092 <sup>f</sup>
	Phichit 290-9	2.269±0.72 <sup>g</sup>	0.602±0.030 <sup>d</sup>	9.094±0.043 <sup>c</sup>	74.836±2685 <sup>f</sup>	14.847±0.098 <sup>g</sup>
	Torperk	1.101±0.95 <sup>e</sup>	0.478±0.042 <sup>c</sup>	4.128±0.199 <sup>b</sup>	38.391±1.117 <sup>e</sup>	7.129±0.099 <sup>e</sup>

Note. Each value represents mean values ± standard error.

TPC: Total Phenolic Content, TAC: Total Anthocyanin Content, DPPH: DPPH free radical scavenging activity, TEAC: Trolox equivalent antioxidant capacity, FRAP: Ferric-reducing antioxidant power.

<sup>a-g</sup> Mean values within the same column with different letters are significantly different at  $p < 0.05$ .

Here, well-known *in vitro* methods such as DPPH, TEAC and FRAP assays were used to measure antioxidant activities of Thai purple sweet potato flours. DPPH and TEAC assays determined the free radical scavenging capacity in different conditions while FRAP assays assessed the chelating metal ion. Antioxidant activity differed depending on the sweet potato variety and preparation method. An increase in antioxidant activity of pre-gelatinized flours was observed in all analyses. DPPH and TEAC values ranged between 0.556-9.094 mg TE/g db and 4.966-74.836 mg TE/g db, respectively. Different flour preparation directly affected DPPH and TEAC values of Phichit 290-9 flours; native flour had the lowest values while pre-gelatinized flour showed the highest. The FRAP assays followed the same trend as DPPH and TEAC assays. All flours had FRAP values ranging between 1.150-14.847 mg TE/g db with pre-gelatinized Phichit 290-9 flour giving the highest FRAP values. The Phichit 65-3 variety showed high levels of anthocyanins and antioxidant activity for both native and pre-gelatinized flours, while pre-gelatinized Phichit 290-9 flour had the highest phenolic content and antioxidant activity.

Changes in the phenolic compounds after thermal processing related to the loss of heat-sensitive constituents. Degradation of phenolic compounds occurs through enzyme activity as a result of thermal processing. Degradation rate of phenolic compounds depends on many factors including the number of substituents, the molecular structure and the accumulation of phenolic compounds in the plant. However, an increase in phenolic compounds after thermal processing was reported by several authors as the degraded polyphenols resulted in free and smaller molecules with easy extraction of constituents (Huang et al., 2006; Tokusoglu & Yildirim, 2012). Many studies reported that thermal treatment enhanced anthocyanins content in several purple sweet potato varieties including Stokes purple, NC415, Okinawa, Phichit 65-3 and Torperk (Truong et al., 2010; Soison et al., 2014; Ruttarattanamongkol et al., 2016). Phenolic compounds and anthocyanins in purple sweet potatoes show powerful antioxidant activity. The main anthocyanins in purple sweet potatoes are 3,5-diglucoside derivatives from cyanidin and peonidin, acylated with p-hydroxybenzoic acid, ferulic acid, or caffeic acid, respectively (Kim et al., 2012). High concentrations of anthocyanins were observed in Phichit 65-3 and Maejo 343 flours. Their pre-gelatinized flours also showed strong antioxidant activity which might be due to higher amounts of acylated anthocyanidins which are more stable during processing and storage. Acylation of anthocyanin improves its stability through intermolecular co-pigmentation (Giustri & Wrolstad, 2003; Cevallos-casals & Cisneros-Zevallos, 2004). The high antioxidant activity of Phichit 290-9 and Torperk flours related to their high phenolic compounds. Results also confirmed that Thai purple sweet potatoes are good sources of natural antioxidant constituents and very stable under thermal processing. Flours produced from Thai purple sweet potatoes show potential as good sources of natural colorants, and dietary phytochemicals and antioxidants. Moreover, steam pre-treatment enhanced the deep purple color and improved the pasting properties of Thai sweet potato flours as beneficial for use in food products.

### 3.2 Physical Properties of Air-Puffed Purple Sweet Potato Snacks

From results in 3.1, native and pre-gelatinized flours produced from Phichit 65-3 variety showed good characteristics for color, pasting properties, high anthocyanin and antioxidant activity. Thus, Phichit 65-3 flours were used for purple sweet potato snack production. Figure 3 presents air-puffed purple sweet potato snacks with



different ratios of pre-gelatinized flours at 10%, 30% and 50% (G10, G30 and G50), respectively. Snacks made from sweet potato flours showed better shape and size than control but a deep purple color was presented in control and G50. Formulation of snacks using sweet potato flours can be increased and expanded depending on the content of pre-gelatinized flours (Table 5). The G10 showed the highest expansion ratio followed by G50 (6.65 and 4.41, respectively) while control snack had the lowest values (2.49). Low bulk density relates to high expansion, G10 and G50 showed the lowest bulk density (0.276 and 0.277, respectively). Changing expansion of snacks depended on raw materials, amylose-amylopectin ratio, the amount of native starch and degree of gelatinization (Norton et al., 2011; Wang et al., 2012; Jiamjariyatam et al., 2017). This result supported that the ratio of native and pre-gelatinized sweet potato flours was important to improve expansion properties of air-puffed snacks.



Figure 3. Appearance of air-puffed Thai purple sweet potato snacks

Color of snacks showed significant difference in redness and blueness values ( $p < 0.05$ ). Increasing the content of pre-gelatinized flour increased the  $a^*$  and  $-b^*$  values of snacks. Maximum values of  $a^*$  and  $-b^*$  were observed in G50 prepared by maximum content of pre-gelatinized flour. Native flours showed lower redness than pre-gelatinized flour; thus, decreasing the content of pre-gelatinized flour in G10 and G30 directly affected the low  $a^*$  value of snacks. Conversely, control snacks showed higher  $a^*$  and  $-b^*$  values than G10 and G30, supporting the notion that steamed pre-treatment played an important role in heat stable pigment formation. Purple sweet potato snacks obtained by G50 had good appearance with deep intense purple color, high expansion ratio and low bulk density.

Table 5. Expansion and color of purple sweet potato snacks

Sample	Expansion ratio	Bulk density (g/cm <sup>3</sup> )	Color value		
			$L^*$	$a^*$	$b^*$
Control	2.49±0.20 <sup>a</sup>	0.470±0.009 <sup>c</sup>	44.82±3.01 <sup>b</sup>	19.52±0.84 <sup>c</sup>	0.96±0.13 <sup>b</sup>
G10	6.65±1.11 <sup>c</sup>	0.276±0.011 <sup>a</sup>	43.57±2.01 <sup>ab</sup>	10.25±0.82 <sup>a</sup>	6.47±0.63 <sup>d</sup>
G30	3.11±0.55 <sup>ab</sup>	0.389±0.011 <sup>b</sup>	40.00±2.65 <sup>a</sup>	12.54±1.03 <sup>b</sup>	3.70±0.28 <sup>c</sup>
G50	4.41±0.38 <sup>b</sup>	0.277±0.014 <sup>a</sup>	44.65±3.01 <sup>b</sup>	19.39±0.69 <sup>c</sup>	-2.67±0.29 <sup>a</sup>

Note. Each value represents mean values ± standard error.

Color values:  $L^*$ ,  $a^*$  and  $b^*$  mean lightness, redness and yellowness, respectively.

<sup>a-d</sup> Mean values within the same column with different letters are significantly different at  $p < 0.05$ .

Macrostructures of purple sweet potato snacks were determined using SEM as shown in Figure 4. There was obvious difference between the structures of each air-puffed snack. Thickening of cell wall, rigid structure and fewer air cells mainly affected the lowest expansion of control snack. G10 had a more homogeneous network with smaller pore size. The uniform air cell distribution and size also found in G10. Occurrence of highly small porous structures with thin cell walls in G10 might support the highest expansion recorded in our results. Large expanded bubbles presented in G30 and G50 were prepared by high content of pre-gelatinized flours. G30 found many visible empty holes in the structure and larger air cells with various size and shape was observed. G50

presented a homogeneous network, thinner cell wall and large air cells. From the results, both G10 and G50 showed high expansion with different macrostructure. Native flour was the main ingredients of G10 causing the network of many small air cells while pre-gelatinized flours in G50 presented as highly porous with large pore-size. In contrast, steamed sweet potato used in control snacks gave dense structure and low expansion. The ratio between native and pre-gelatinized flours was a key factor to develop physical structure of purple sweet potato snacks.

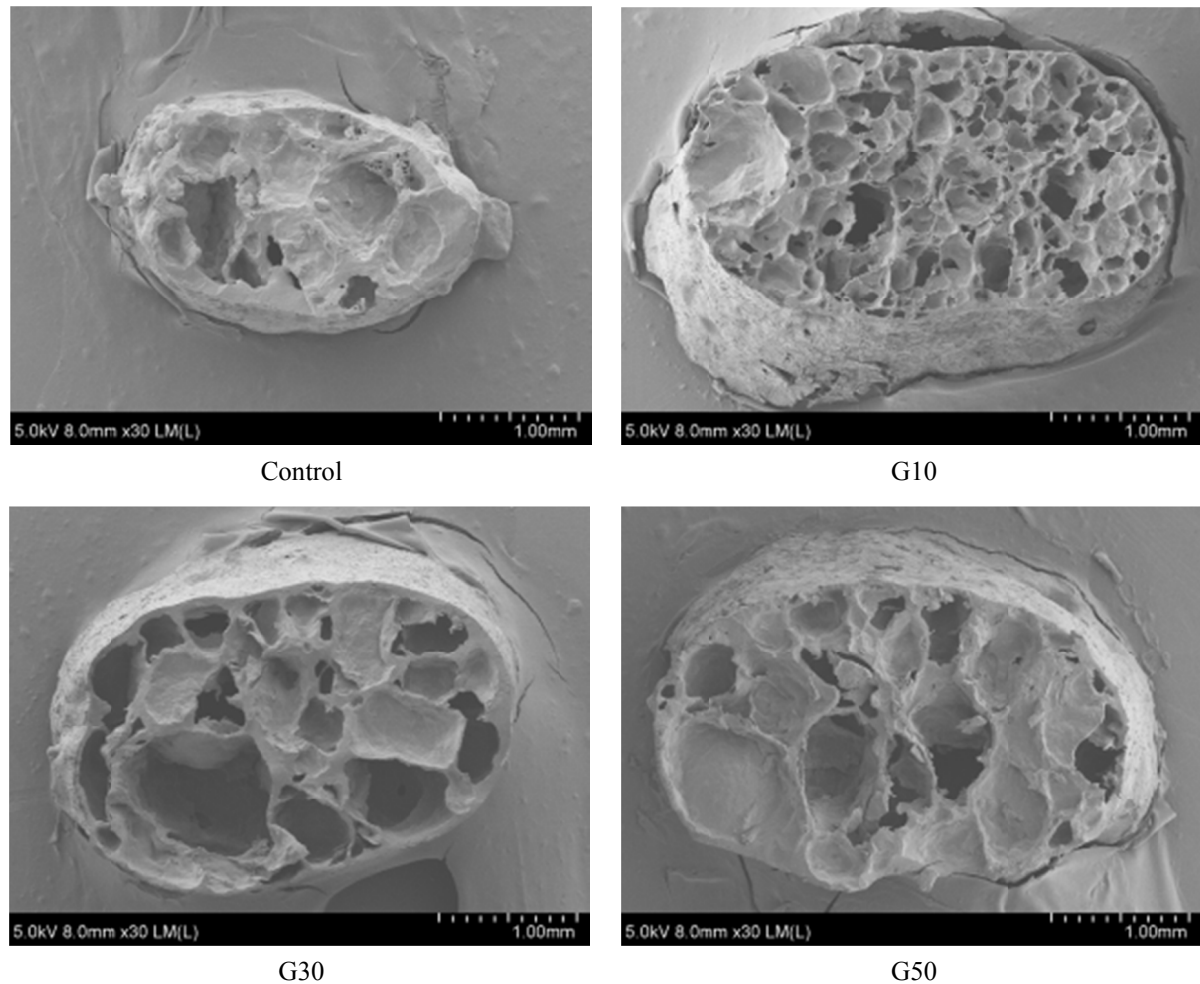


Figure 4. SEM image of air-puffed purple sweet potato snacks

Results of hardness and crispiness measured by texture analyzer were presented in Figure 5 and control snack showed higher hardness than others significantly ( $p < 0.05$ ). Highest hardness of control snack might be involved with low expansion, especially the dense structure and thickening cell wall confirmed with SEM image. There was no significant difference ( $p < 0.05$ ) in hardness when increasing the content of pre-gelatinized sweet potato flour (10%, 30% and 50%). Decreasing hardness related to high expansion of all snacks formulated by sweet potato flour. Crispiness of snacks ranged between 94.41 and 115.64 kg. sec. Lowest crispiness was found in G50, while control snacks showed highest values. Pre-gelatinized flour content was considered for texture modification of air-puffed sweet potato snacks because of their expansion. Colored potato flour can be used as a component of fried snacks to improve their texture and expansion ratio dependent on the content of gelatinized starch (Nemš et al., 2015).

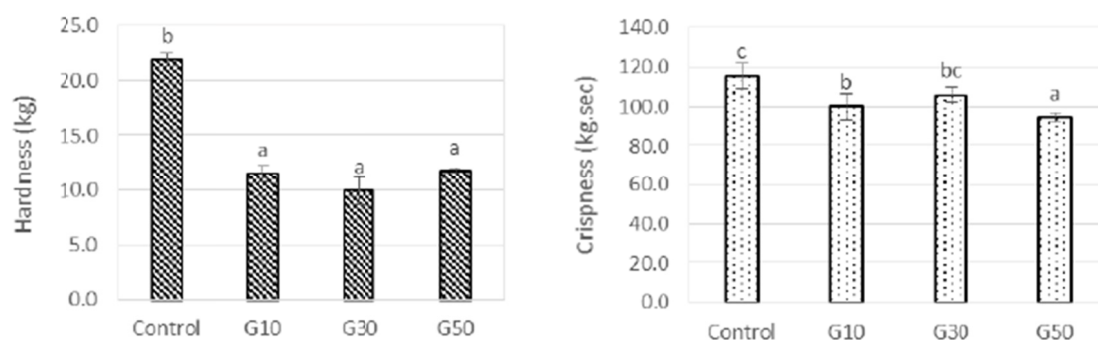


Figure 5. Texture of purple sweet potato snacks (A) hardness and (B) Crispiness

Note. <sup>a-c</sup> Mean values with different letters are significantly different at  $p < 0.05$ .

Total phenolic and anthocyanin content of snacks increased significantly ( $p < 0.05$ ) when content of pre-gelatinized flour increased. G50 had the highest values following by control snack and G30. Steamed sweet potato and pre-gelatinized flour showed high content of heat stable phenolic and anthocyanin. While the native flour showed 3 times lower anthocyanin content than pre-gelatinized flour, thus G10 formulated with high native flour had the lowest TAC values (0.046 mg/g). Antioxidant activity of snacks showed the same trend of total phenolic content and total anthocyanin content. G50 showed the highest values of DPPH, TEAC and FRAP while G10 showed the lowest in all assays. However, control snacks prepared by steamed sweet potato showed similar antioxidant activity with snacks prepared by 50% pre-gelatinized flour (G50). Results of air-puffed snacks also confirmed that phytochemicals in steamed sweet potato and pre-gelatinized flours were heat stable compounds, while native flours were heat sensitive. According to Nemš et al. (2015), total phenolic content and antioxidant activity of snacks enriched with colored potato flour depended on variety, quantity and profiles of these compounds in raw material.

Table 6. Antioxidant activity of purple sweet potato snacks

Sample	TPC (mg GAE/g db)	TAC (mg/g db)	DPPH (mg TE/g db)	TEAC (mg TE/g db)	FRAP (mg TE/g db)
Control	1.877±0.060 <sup>c</sup>	0.495±0.037 <sup>c</sup>	3.095±0.029 <sup>c</sup>	4.671±0.109 <sup>c</sup>	0.904±0.29 <sup>c</sup>
G10	0.860±0.059 <sup>a</sup>	0.046±0.006 <sup>a</sup>	0.977±0.032 <sup>a</sup>	0.908±0.013 <sup>a</sup>	0.269±0.008 <sup>a</sup>
G30	1.214±0.046 <sup>b</sup>	0.177±0.026 <sup>b</sup>	1.606±0.057 <sup>b</sup>	2.175±0.034 <sup>b</sup>	0.427±0.005 <sup>b</sup>
G50	2.222±0.057 <sup>d</sup>	0.549±0.013 <sup>d</sup>	4.144±0.068 <sup>d</sup>	5.701±0.108 <sup>d</sup>	1.079±0.022 <sup>d</sup>

Note. Each value represents mean values ± standard error.

TPC: Total Phenolic Content, TAC: Total Anthocyanin Content, DPPH: DPPH free radical scavenging activity, TEAC: Trolox equivalent antioxidant capacity, FRAP: Ferric-reducing antioxidant power.

<sup>a-d</sup> Mean values within the same column with different letters are significantly different at  $p < 0.05$ .

#### 4. Conclusion

Different varieties of Thai purple sweet potatoes flours showed unique attributes in terms of color, pasting properties and antioxidant activity. Native flours maintained pasting properties compared to pre-gelatinized flours. Pre-gelatinized flours showed color improvement with increasing TPC, TAC and antioxidant activity. Phichit 65-3 flours showed a deep intense purple color with high anthocyanin content, antioxidant activity and good pasting properties. Application of purple sweet potato flours in air-puffed snacks improved the appearance, expansion ratio, physical structure and texture. Combination of native and pre-gelatinized flour directly affected the color and antioxidant activity. Purple sweet potato snacks prepared by pre-gelatinized flour 50% (G50) had unique purple color with good appearance and texture. They were also a good source of phenolic compounds, anthocyanins and antioxidant activity. Thai purple sweet potato flours showed promising potential application in healthy snack products with antioxidant enrichment and natural colorants. This knowledge can support the commercialization of purple sweet potato flour in health food products and for other specific purposes.

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