Characterization of starch in relation to flesh colors of sweet potato varieties

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Abstract

The properties of sweet potato starch of various varieties of sweet potato found in Thailand may vary. Therefore, the objective of this study was to investigate the effect of different flesh colors of sweet potato varieties on the selected physicochemical properties of the obtained starches. Maejo (MJ), Kaset (KS), Khai (KH) and Torperk (TP) varieties were chosen to represent starch from white, yellow, orange and purple fleshed sweet potato, respectively. Starches were extracted by sedimentation and their physicochemical properties were analyzed. Protein, starch and amylose contents of the extracted starches ranged from 0.1-0.4%, 97.0-99.0% and 16.5-18.5%, on dry weight basis, respectively. Variety with different flesh colors had a significant effect on pasting and thermal properties of starches. KS starch was more stable to high temperature and shear force, and had lower tendency to retrogradation than those of other varieties. TP starch showed the lowest gelatinization temperature (70.3°C) and enthalpy (12.0 J/g), and good swelling power (27.5 g/g) indicating ease of cooking. The characteristics of KH and MJ starches were generally similar.

Introduction

Sweet potato (*Ipomoea batatas* L.) is an important food crop in many countries around the world, especially in tropical countries. It is a good source of food energy. Sweet potato roots with a variety of skin and flesh colors in each area of cultivation are different in the nutritional and physicochemical properties. Sweet potato starch is the potential raw material for applying in many food and non-food products. It can be used as an ingredient in some bakery products such as bread, biscuits, cake, juice and noodles (Zhang and Oates, 1999).

This crop contains starch as a major component; therefore, the properties of its starch are important to study to increase the starch utilization. Variety or genotype of sweet potato root is one of the important factors influencing the sweet potato starch property. Effect of variety on physicochemical property of sweet potato starch was determined previously (Collado *et al*., 1999; Zhang and Oates, 1999; Chen *et al*., 2003; Abegunde *et al*., 2013). However, the physicochemical property of sweet potato starch from different varieties grown in Thailand has been limited as well as its utilization in Thai food industry. The

study of sweet potato starch property and adoption benefits in term of food products are rare compared with other tubers and roots. Therefore, knowledge of the functional properties of sweet potato starch is essential to starch application for specific requirements. The granule size, swelling, solubility, amylose content, gelatinization temperature and pasting property of starch are important characteristics influencing the functional property of starch. For instance, starches with lower amylose contents swell and produce high viscosity paste more than those with higher amylose contents (BeMiller, 2007). Moorthy (2002) noted that the temperature of gelatinization varied among the different tuber starches can be an indication of the variation in the starch intermolecular bonds. High gelatinization temperature can refer to the higher stability of starch crystallites in starch molecules. This corresponded to the review of Elgadir *et al.* (2009).They stated that increasing the gelatinization temperatures of starch might be provided structural stability and made the granule resistant to gelatinization.

The properties of Thai sweet potato have been rarely reported in the literature. Therefore, the objective of the study was to investigate the selected

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physicochemical properties of starch from four varieties of Thai sweet potato with different flesh colors.

Materials and Methods

Materials

Sweet potato varieties with different flesh colors of Maejo (MJ), Kaset (KS), Khai (KH) and Torperk (TP) varieties were obtained from cultivated area through wholesale market. The roots were stored in a cold room (10±2ºC) for further processing within a week.

Preparation of sweet potato starch

Starches were prepared from sweet potato roots according to the method of Collado *et al*. (1999) with minor modification. Roots were cleaned under running tap water, then manually peeled and grinded in a food processor (MK-5080, National, Malaysia) by adding 1:1 (w/w) of clean water ratio for 2 min at medium speed. After filtering through sieve, the residue was repeated extraction with water (1:0.5, w/w). The filtrate was mixed and filtered through muslin cloth. Starch slurry was allowed to settle for 2-3 hours at room temperature (30±2°C). The supernatant was poured off. The starch in the bottom of container was resuspended in water, filtered through cloth bag and kept in the refrigerator (8±1°C) to settle. The settling process was repeated three times. The sediment starch was dried in a convection oven at 50°C for 6-8 hours, cooled to room temperature, packed and sealed in polyethylene bags. Two batches of each starch were prepared from the same lot of sweet potato roots. Dried starch was milled and passed through a 100-mesh sieve before analysis.

Yield and color of starches

The percent yield of the extracted starch was calculated from weight of oven-dried starch based on fresh root weight. The color values in CIELAB system (L*, a*, b* and hue angle) were determined by spectrophotometer (CM-3500d, Minolta, Japan).

Chemical composition of starches

The sweet potato starches were analyzed for moisture and protein contents according to the method of AOAC (2000). Total starch content was measured by Polarimetric method (European Economic Community (EEC), 1999). Amylose content based on iodine affinity described by Takeda *et al.* (1987) was analyzed.

Starch granule shape and size

Sweet potato starch granules were examined on a Scanning Electron Microscope (SEM) (XL30, Philips, Finland) at an accelerating voltage of 13.0 KV and magnification at 1500x. Starch granules were sprinkled onto double-sided tape attached to a SEM stub and coated with gold using EDWARDS model scancoat six. The size of starch granule was measured by using Image Analysis at a magnification of 40x. The analysis system using Image Pro Plus 6.0 software was connected to a light microscope (Zeiss, Canada) and Micro Publisher 3.3 RTV. Starch suspension was prepared following the method of Singh *et al.* (2005) with modification. Starch granules at 1% of solution were suspended in the glycerol-distilled water solution with concentration of 50% at room temperature. The solution was dropped on the glass slide and covered with cover glass.

Swelling power and solubility

Swelling power and solubility were determined at 55, 65, 75 and 85ºC by the method of Schoch (1964) with slight modification. The 0.35 g of dried starch was weighed into a centrifuged tube and suspended in 12.5 ml distilled water at room temperature (30±2ºC) with intermittent shaking for 5 min. The suspended starch tube was then heated by continuous shaking in water bath for 30 min. After cooling, a tube was centrifuged at 2500 rpm for 15 min. The supernatant was oven-dried at 105ºC until constant weight. The dried solid content was calculated as the percentage of solubility (equation 1). The gel paste in a tube was weighted for calculation as swelling power (equation 2).

$$\text{Solubility (\%, dry basis)} = B \times 100/A \qquad (1)$$

$$\text{Swelling power (g/g, dry basis)} = C \times 100/[A \times (100 - \%\text{solubility})] \qquad (2)$$

Where A, B and C were dried sample weight (g), dried solid weight after oven drying (g) and gel paste weight (g), respectively.

Thermal characteristics of starches

Thermal characteristics were determined using a differential scanning calorimeter (DSC) (DSC822e Module, Mettler Toledo, Switzerland). Three milligram of dried starch was weighed into DSC pan. Distilled water was added to make a starch concentration of 30% on dry basis. An empty pan was used as the reference (Noda *et al.*, 1997). Sample was heated from 25 to 110ºC at heating rate of 10ºC per minute. The following gelatinization parameters were computed from the software provided:

onset temperature (To), peak temperature (Tp), conclusion temperature (Tc) and enthalpy (ΔH). The gelatinization temperature range (ΔT) was calculated from a difference between To and Tc.

Pasting property of starches

Pasting profile of starch was determined by a Rapid Visco Analyser (RVA-4D, Newport Scientific Pty. Ltd., Australia). The starch slurry was prepared at a concentration of 10% dry solids in an aluminum canister and heated from 50 to 95°C with constant stirring at 160 rpm using the STD1 profile (AACC, 2000). The parameters measured were pasting temperature (PT), peak viscosity (PV), trough, final viscosity (FV), breakdown (BD; calculated as PV-trough) and setback (SB; calculated as FV-trough).

Statistical analysis

The measurements were done in triplicate from two independent duplicate starch samples. All data were subjected to analysis of variance (ANOVA). The least significant difference (LSD) was performed for post hoc multiple comparison using SPSS® version 12 (SPSS Thailand Co., Ltd.). Statistically significant difference was established at P ≤0.05. Correlation between the qualities was determined using a two-tailed Pearson's correlation test.

Results and Discussion

Starch yield and color

The starch yield obtained by sedimentation of starch slurry from all sweet potato varieties ranged from 6 to13% (Table 1). The means of moisture content of fresh roots for TP, KS, KH and MJ varieties were 63.1, 72.4, 79.1 and 65.9%, respectively. The amount of extracted starch from TP variety fresh roots was significantly higher than that from MJ, KS and KH varieties, respectively. The extracted starch yield was directly correlated with total carbohydrate content in fresh root (data not shown). This yield was similar to the study of Zhang and Oates (1999) reporting the starch yield of 10-14.8% from six sweet potato varieties. The starch color was white and it was significantly affected by the flesh color (Table 1). The sediment starch was washed several times with water which could remove the pigments in sweet potato flesh without using chemicals. However, starch from MJ variety had the highest whiteness, followed by KH, KS and TP, respectively.

The chemical composition of sweet potato starches

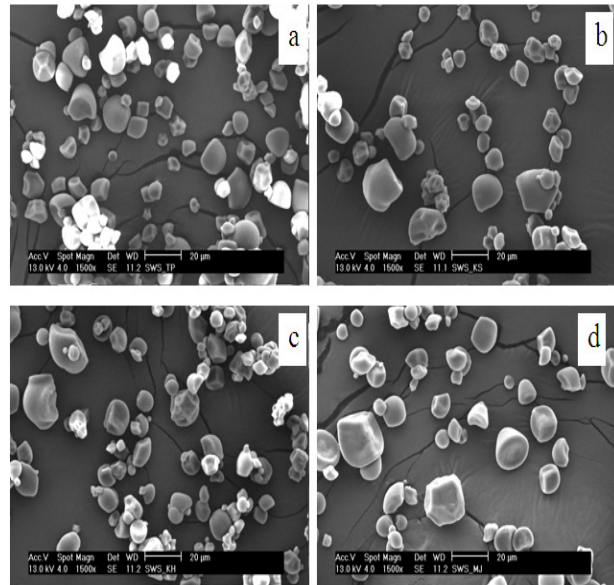The moisture contents of starches from all varieties were ranged from 11 to 12%. The extracted

Figure 1. SEM images of sweet potato starch granule from different varieties
Torperk, TP (a); Kaset,KS (b); Khai,KH (c); Maejo, MJ (d) varieties

starch contained high starch content (97-99%) with high purity (Table 2). KS starch had the lowest starch content due to lower carbohydrate content in fresh root (data not shown). The previous studies reported starch content of sweet potato starches in different ranges of 81 to 85% (Narkrugsa and Kulmanochwong, 2007), 92 to 96% (Abegunde *et al*., 2013) and 94 to 99% (Collado *et al.,* 1999). This variation may be due to a difference in sweet potato variety, the extraction method and analysis method. Amylose content determined by iodine affinity method ranged from 16.5 to 18.5% of dry starch weight. Starch obtained from KH variety (an orange flesh) had the highest amylose content whereas that obtained from TP variety (a purple flesh) had the lowest amylose content (Table 2). This result was corresponded to the result of Noda *et al*. (1997) found that amylose content in orange fleshed cultivar was higher (19.0-21.6%) than that in purple fleshed cultivar (15.4-16.6%). Jangchud *et al.* (2003) reported that amylose content of orange flesh starch was higher (20.8%) than that of purple flesh starch (17.3%). From literature, amylose content of sweet potato starches had large variation with ranging from13 to 30% (Collado *et al*., 1999; Abegunde *et al*., 2013).

Starch granule shape and size

The starch granules of each sweet potato variety were examined by light microscope linked to Image Analyzer. Granule size of starches ranged from 3 to 38 μm. Starch from MJ variety was broader range than the other varieties, as well as the median size (Table 1). The granule shapes of the starches viewed

Table 1. The yield and color of sweet potato starch from different varieties

Varieties	Starch yield	Granule	Color values			
	(%)	size[1](μm)	L*	a*	b*	Hue
TP	12.9±0.2[a]	3.4-29.2 (10.4)	91.9±0.1[d]	0.3±0.0[a]	5.3±0.1[a]	86.5±0.4[d]
KS	11.1±1.1[b]	4.6-34.1 (11.5)	92.7±0.1[c]	-0.42±0.0[c]	4.7±0.6[b]	95.1±0.3[b]
KH	6.2±0.2[c]	3.1-23.9 (9.4)	93.1±0.3[b]	0.09±0.1[b]	3.9±0.3[c]	88.7±1.4[c]
MJ	11.2±0.4[b]	3.9-37.7 (13.2)	94.5±0.2[a]	-0.48±0.1[d]	2.9±0.2[d]	99.4±1.8[a]

[a-d] Means within the same column with different letters are significantly different (P≤ 0.05).
[1] =Values in parentheses are mean size of all starch granules (300).
Torperk (TP), Kaset (KS), Khai (KH) and Maejo (MJ) varieties

Table 2. The chemical composition (% dry basis) of sweet potato starches from different varieties

Varieties	Moisture	Starch	Amylose	Protein
TP	12.0±0.0	99.0±1.0[a]	16.5±0.3[c]	0.1±0.0[b]
KS	11.4±0.0	97.0±0.3[b]	16.6±0.5[c]	0.4±0.0[a]
KH	11.1±0.0	98.5±0.2[a]	18.5±0.3[a]	0.1±0.0[b]
MJ	11.3±0.0	98.9±0.4[a]	17.2±0.1[b]	0.1±0.0[b]

[a-c] Means within the same column with different letters are significantly different (P≤0.05).
Torperk (TP), Kaset (KS), Khai (KH) and Maejo (MJ) varieties

through SEM were found to be heterogeneous shapes including round, polygonal and oval shape as shown in Figure 1. These shapes were similar to literature reports (Noda *et al.*, 1995; Chen *et al.*, 2003; Osundahunsi *et al.*, 2003; Yadav *et al.*, 2007). Granule size of sweet potato starches has been previously studied, which widely varied from 2 to 60 μm (Walter *et al.*, 2000; Chen *et al.*, 2003; Singh *et al.*, 2005).

Swelling power and solubility

When starch granules are heated above the initial gelatinization temperature in excess water, they swell as hydrogen bonds in amorphous regions are disrupted and dramatic changes occur (BeMiller, 2007). These indicated a water holding capacity of starch granules. Since difference in granule size and different contents of starch, protein and amylose, the functional characteristics such as pasting viscosity, gelatinization temperature, swelling power and solubility were also influenced. The swelling power and solubility of all starches showed similar changing patterns as the temperature increased. These values

were rapidly increased when heated over 65°C until up to 85°C. The swelling power at 85°C ranged from 19.0 to 27.5 g/g dry starch. TP Starch had the highest swelling power (27.5 ± 0.5) compared with the other starches (23.1±0.2, 21.0±0.5 and 19.0±1.2 g/g dry starch for KH, MJ and KS starches, respectively). This result implied that bonding force in starch molecules of TP starch was weaker than the others. Likewise, KS starch was stronger bonding force than the others. However, there was the inconsistency between changing trends of swelling power and solubility. Heating between 55 and 65°C, solubility of each starch was low and similar among varieties because native starch was not dissolved in water at lower gelatinization temperature. However, there was some amylose molecules located in noncrystalline regions leached out (BeMiller, 2007). When temperature increased to 85°C, the solubility of starch increased to 7.8±0.4, 9.1±1.9, 10.5±0.6 and 11.2±0.7 % for KS, TP, KH and MJ starches, respectively. It is noticeable that KS starch was low in both swelling power and solubility. Chen *et al.* (2003) noted that swelling volume of three sweet potato starches were different

Table 3. Gelatinization properties of sweet potato starches from different varieties by DSC

Varieties	To (°C)	Tp (°C)	Tc (°C)	△H (J/g, db)	△T (°C)
TP	65.7±0.2[d]	70.3±0.3[c]	75.7±0.4[c]	12.0±2.9[b]	10.0±0.2[a]
KS	76.8±0.3[b]	80.8±0.2[a]	84.9±0.2[ab]	16.2±0.6[a]	8.1±0.5[b]
KH	74.7±0.4[c]	78.3±0.4[b]	84.3±0.7[b]	15.5±1.7[a]	9.6±0.3[a]
MJ	77.9±0.3[a]	80.9±0.3[a]	85.6±0.5[a]	16.6±0.7[a]	7.7±0.2[b]

[a-d] Means within the same column with different letters are significantly different (P≤ 0.05).
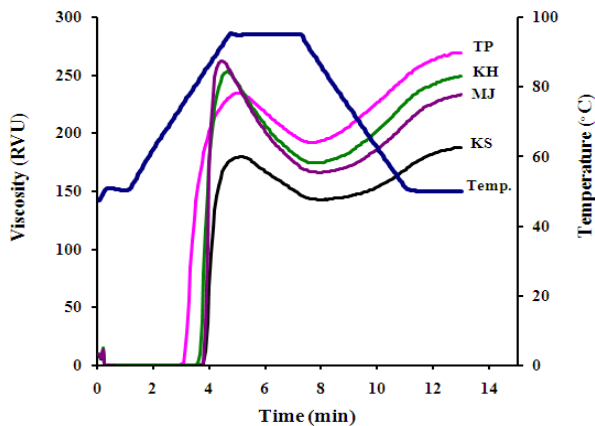Torperk (TP), Kaset (KS), Khai (KH) and Maejo (MJ) varieties

Figure 2. RVA pasting curves of sweet potato starches Torperk (TP), Kaset (KS), Khai (KH) and Maejo (MJ) varieties

which may be affected by presence of phosphorus in starch molecule (0.01-0.02%, db) as amylose content of starches was similar (19.3-20.0%, db).

Thermal characteristics of starches

Gelatinization behavior of sweet potato starches analyzed by DSC showed a single endothermic peak. Temperature and enthalpy (ΔH) of gelatinization can indicate the molecular structure and crystalline arrangement of starch granule. Gelatinization temperatures and ΔH of sweet potato starches were significantly different (P≤ 0.05) among varieties as shown in Table 3. The gelatinization temperatures (To, Tp, Tc) of MJ and KS starches were similar, but they were higher than those of KH and TP starches. TP starch exhibited the lowest gelatinization temperature and the lowest ΔH indicating the easy cooking. These may suggested that crystallinity and crystalline arrangement of TP starch granules was lower than the other starches. In addition, a broader in ΔT of TP starch was also referred to a low crystalline homogeneity of starch. The results observed that the rise of gelatinization temperatures affected the increase of ΔH and the decrease of ΔT. Therefore, these may indicate that the arrangement of

crystalline structure of MJ and KS starches was more homogeneity than those of KH and TP starches. From the data, it was found that gelatinization temperatures (To, Tc, Tp) of starches were significantly negative correlated with swelling power. As the gelatinization temperature decreased, the swelling power increased. Gelatinization property of these starches was similar to the result of Collado *et al.* (1999) who studied the physical properties of starch from forty-four sweet potato varieties.

Pasting properties of starches

Pasting profiles determined by RVA are presented in Figure 2. The starches exhibited a significant difference (P≤0.05) in PT, PV, trough, FV, BD and setback. PT refers to the onset temperature for initial rise in viscosity ranged from 76.4°C in TP starch to 85.0°C in KS starch. PT of TP starch was the lowest that associated with the lowest values of the gelatinization properties, including To (65.7°C), Tp (70.3°C), Tc (75.7°C) and enthalpy (12.0 J/g) determined by DSC (Table 3). These findings, as well as the highest swelling power mentioned above, indicated that the viscosity of TP starch was more rapidly occurred than the other starches due to a weak intermolecular force. Thus, TP starch granules became more sensitive to shear force as the temperature increased. For the highest PT in KS starch considered with low swelling power and solubility, these could be implied to the highest resistance of starch granules on heat and shear force. PV indicates the water binding capacity of the starch (Newport Scientific, 1998). It was in the range of 179.7 to 262.5 RVU among starch from four varieties. PV of MJ starch was higher than that of the other starches. From the literature, the peak viscosity of sweet potato starches had a high variation, ranged from 66 RVU (Collado *et al.*, 1999) to 741.5 RVU (Singh *et al.*, 2005). This variation was not only resulted from sweet potato variety, but also depended on starch concentration, starch source, starch preparation and heating profile

of measurement.

A difference in peak viscosity and minimum viscosity is BD. Viscosity with low BD indicated the strong stability of starch granule under heat and shear stress (Singh *et al.*, 2005). The BD of MJ starch was the highest followed by KH, TP and KS starches, respectively. KS starch exhibited the most stability, but not significantly different (P>0.05) to TP starch. Setback, caused by the re-arrangement of amylose molecules that excreted from swollen starch granules, is an indication of the starch to retrograde (Newport Scientific, 1998). From the results, setback viscosity ranged from 45.6 to 77.3 RVU. KS starch had significantly lower setback than the others that referred to low retrogradation tendency of starch.

The result from this study confirmed that some properties of starch from different flesh color of sweet potato varieties were similar and some were different, especially TP starch. Sweet potato starch obtained from TP variety was very pure and seemed to have lower amylose content than KH and MJ. TP starch with lower amylose content absorbed water more readily than starches from other varieties as indicated by higher swelling power. In addition, TP starch had lower onset gelatinization temperature and enthalpy than others. These different properties of TP variety might be due to the effect of genetic factor, yielding starches with different structural properties and hence different physico-chemical properties.

Therefore, consideration of starch property is important to select the appropriate sweet potato variety for application. Generally, these starches could be applied in starch based products and used as food additives. For example, TP starch would be suitable for products made by low processing temperature and required low gelatinization temperature and high swelling power, such as soup, sauce, pudding and elderly foods. However, sensory property of incorporating sweet potato starch product is also needed to evaluate the feasibility.

Conclusion

The physicochemical properties of sweet potato starches were significantly affected by the different flesh colors of sweet potato varieties. KS starch was more stable to heat and shear force and lower tendency to retrogradation than the other starches. TP starch showed the evident properties, including the highest starch yield, high starch content and good swelling power. Characteristics of KH and MJ starches were generally similar, particularly RVA pasting profiles, swelling power and solubility. Therefore, the physicochemical properties of these

sweet potato starches are essential and should be considered for application in agro-industrial product development.

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