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Physicochemical characterization of sweet potato starches popularly used in Chinese starch industry

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A B S T R A C T

Physicochemical properties of starches isolated from 11 sweet potato cultivars popularly used in Chinese starch industry were studied. Moisture, protein, ash, lipid and phosphorus content of the starches varied from 3.86 to 6.52%, 0.28 to 0.75%, 0.10 to 0.47% and 0.00 to 0.02%, respectively. Amylose content varied between 13.33 and 26.83%. The starches differed in their mean granule sizes, particle size distribution, and susceptibility to pancreatin hydrolysis. Swelling power and solubility ranged from 13.46 to 26.13 g/g and 8.56 to 18.77%, respectively. Higher retrogradation tendency was observed in pastes of starches of high amylose content. Gelatinization temperature and enthalpy ranged from 55.54 to 69.11 °C and 6.40 to 11.89 J/g, respectively. Pasting properties including peak viscosity (134–255 BU), breakdown viscosity (91–162 BU), setback viscosity (26–112 BU), peak time (5.97–7.03 min) and pasting temperature (67.20–73.00 °C) varied significantly among the sweet potato starches. Pearson's correlation analysis showed that phosphorus content of the starches had substantial effect on their swelling power ($r = 0.70$, $p \leq 0.05$) showing positive correlations. There was significant positive correlation between swelling power and solubility of the starches ($r = 0.64$, $p \leq 0.05$). Thermal and pasting parameters also showed significant correlations.

1. Introduction

Sweet potato (*Ipomoea batatas* L.) is a dicotyledonous plant that belongs to the family *Convolvuceae*. It is believed to have its center of origin in tropical America. Sweet potato was brought to Europe by Columbus and subsequently introduced to Africa and Asia by the Portuguese and Spanish traders (Salawu & Mukhtar, 2008). However, sweet potato is now cultivated wherever there is sufficient water to support its growth. China accounts for about 90% of worldwide sweet potato production with an annual production of 117 million tons (CIP, 2011). Sweet potato has been playing an important role in the Chinese economy, of which its characteristic high yield and wide adaptability had once made great contributions to feeding the drastically increasing Chinese population (Ma et al., 2010). In addition, sweet potato roots and its products have been widely used in starch noodles, bakery foods, snack foods, confectionery products, starch syrup, alcohol and the brewing industries in China (Chen, Schols, & Voragen, 2003).

Generally, root and tuber crops are rich sources of starch containing 70–80% of water, 16–24% of starch, and less than 4% of trace quantities of protein and lipids besides other minerals and vitamins (Hoover, 2001). The major food consumed by human is starch, providing 75–80% of the total caloric intake worldwide (Bemiller & Whistler, 1996). Starch plays a vital role in developing food products either as a raw material or as a food additive, such as thickener, stabilizer or texture enhancer (Aina, Falade, Akingbala, & Titus, 2010). Starch is useful in maintaining the quality of stored food products; it improves moisture retention and consequently controls water mobility in food products. It could also be used as delivery vehicle of substances of interest in food and pharmaceutical industries such as antioxidants, colourants, flavours as well as pharmaceutically active proteins (Guan, McKean, & Keeling, 2000).

The physicochemical properties of starches dictate their functionality in various applications. For instance, starches with low amylose content gelatinize easily and produce clear pastes suggesting its usefulness in paper manufacturing industries. Interest in new value added starch products has spurred researches towards investigating the physicochemical and functional properties of starches isolated from different genotypes and botanical sources. These starches are known to differ in their physicochemical

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properties and these differences have been attributed to differences in mean granule size, granule size distribution, amylose/amylopectin ratio in starch granules, mineral content and the presence of naturally occurring non carbohydrate impurities in the starches (Aina et al., 2010; Garcia & Walter, 1998; Oduro, Ellis, Aryeetey, Ahenkora, & Otoo, 2000).

Although, numerous cultivars of sweet potato are produced in China, there have just been few reports on the physicochemical properties of Chinese sweet potato starches (Chen et al., 2003; Lin, Wheatley, Chen, & Song, 1996 Zhu, Yang, Cai., Berfotoft, & Corke, 2011). However, these reports are on relatively fewer cultivars. In addition, none has specifically reported the physicochemical properties of the cultivars used in the Chinese starch industry. Nevertheless, a systematic documentation of the physicochemical properties of the starches from these selected sweet potato cultivars will be useful in promoting their utilization in diverse industrial applications. Thus, this study was aimed at investigating the physicochemical properties of starches isolated from some sweet potato cultivars popularly used for starch production in different regions of China.

2. Materials and methods

2.1. Materials

11 cultivars of sweet potato popularly used for industrial starch production were selected for this study. These sweet potato cultivars were grown in different regions of China. The cultivar names and regions where they were cultivated are listed in Table 1.

2.2. Starch extraction

The tubers were washed, cut into small pieces, placed in 0.1% (w/v) sodium bisulphite solution (1 kg of tuber in 1 L of solution) for 10 min, and then blended in a domestic juice extractor for 3–4 min. The resulting slurry was passed through fine muslin cloth to separate the cell debris and the suspension as described by Peshin (2001). The suspension was filtered three times using 150 mm sieve, and allowed to settle overnight at room temperature. The precipitated starch was then collected from the container into oven trays lined with aluminium foil, and dried in a hot air drier (DGG-9240B, Senxin Instruments, Shanghai, China) at 45 °C for 24 h. The dried starch was finely ground using a FW100 high-speed universal hand mill (TaiSiTe Instrument, Tianjin, China) and then packaged in tightly covered polypropylene containers and stored in a refrigerator at 4 °C prior to use.

2.3. Proximate composition

Ash and lipid content was determined according to the method of AOAC method 923.03 (2000) and AOAC method 960.39 (2000), respectively. Protein content was analysed as total nitrogen content by Kjeldahl procedure; a factor of 6.25 was used for conversion of nitrogen to crude protein (AOAC, 2000 method 955.04). A standard spectrophotometric method (ISO 3946, 1982) was employed to determine the phosphorus content. The starch content was determined enzymatically using the amyloglucosidase/α-amylase assay kit (Megazyme, Ireland) based on the total starch standard assay procedure (AOAC, 2000, method 996.11).

2.4. Amylose and amylopectin content

Amylose content of the starch samples was determined colorimetrically according to the method of Hoover and Ratnayake (2001, E2.3–E2.3.5) based on amylose–iodine complex formation. Amylopectin content was calculated by difference (100 − amylose %).

2.5. General physicochemical properties

2.5.1. Colour of starches

The colour of the starches was measured using a chromameter (Chroma Meter CR-400, Konicca Mimolta Sening Inc., Japan) as L*, a*, and b* values. The L* values state the position on the white/black axis, the a* values state the position on the red/green axis, and the b* values state the position on the yellow/blue axis.

2.5.2. Starch granular characterization

The starch granules were observed using a Scanning Electron Microscope (SEM, Hitachi S3400N). The starch samples were sprinkled on a double-sided tape mounted on a SEM stub, coated with gold and placed in the SEM chamber. Photomicrographs were taken using a SEM apparatus at an accelerating voltage of 15 kV.

2.5.3. Starch particle size distribution

Particle size distribution of the starch granules was measured by laser diffraction in a Baite particle size analyzer (BT-9300H, Dandong better size instrument Ltd., Dandong, China). The mean granule size (MGS) of each starch sample characterized by volume mean diameter ($d_{4,3}$) was measured.

2.5.4. Invitro digestibility of starches

The enzyme digestibility of starch samples was carried out based on pancreatin hydrolysis as previously described (Zhu et al.,

Table 1
Chemical composition of various sweet potato starches (w/w, %).[a]

Cultivar	Origin	Moisture	Protein (db)[b]	Ash (db)	Lipid (db)	Starch (db)	Amylose	Amylopectin	P^3 (db)
Mi xuan no.1	Beijing	5.93 ± 0.05cd	0.75 ± 0.08a	0.15 ± 0.01cd	0.00 ± 0.00c	94.27±1.08abc	20.50 ± 0.24f	79.5 ± 0.24b	0.02 ± 0.00e
Chuan shu 217	Sichuan	3.86 ± 0.27h	0.33 ± 0.01b	0.10 ± 0.01d	0.00 ± 0.00c	92.20 ± 1.08dc	26.83 ± 0.24a	73.17 ± 0.24g	0.02 ± 0.00e
Xicheng shu 007	Sichuan	4.20 ± 0.01g	0.34 ± 0.09b	0.47 ± 0.02a	0.00 ± 0.00c	92.87 ± 0.19bdc	24.17 ± 0.24c	75.83 ± 0.24e	0.02 ± 0.00e
Xushu 28	Jiangsu	5.19 ± 0.01f	0.31 ± 0.06b	0.12 ± 0.00d	0.00 ± 0.00c	94.07 ± 0.18abc	22.00 ± 0.47de	78.00 ± 0.47dc	0.02 ± 0.01e
Luoshu 10	Henan	5.77 ± 0.03d	0.39 ± 0.00b	0.31 ± 0.11b	0.00 ± 0.00c	94.77 ± 1.47ab	23.83 ± 0.24c	76.17 ± 0.24e	0.02 ± 0.00e
Shangshu 19	Henan	6.52 ± 0.05a	0.39 ± 0.01b	0.22 ± 0.01c	0.05 ± 0.01a	91.90 ± 0.53d	21.50 ± 0.24de	78.50 ± 0.24dc	0.02 ± 0.00e
Xushu 22	Jiangsu	6.12 ± 0.00bc	0.32 ± 0.10b	0.17 ± 0.01cd	0.02 ± 0.01b	93.17 ± 1.49bdc	22.17 ± 0.24d	77.83 ± 0.24d	0.02 ± 0.00
Xushu 27	Jiangsu	5.79 ± 0.03d	0.28 ± 0.01b	0.17 ± 0.02cd	0.00 ± 0.00c	91.90 ± 1.30d	21.33 ± 0.47e	78.67 ± 0.47c	0.01 ± 0.00c
Chuan shu 34	Sichuan	4.22 ± 0.04g	0.29 ± 0.02b	0.17 ± 0.01cd	0.00 ± 0.00c	93.13 ± 0.58bdc	13.33 ± 0.47g	86.67 ± 0.47a	0.002 ± 0.001d
Xushu 18	Jiangsu	6.25 ± 0.04b	0.30 ± 0.05b	0.19 ± 0.02cd	0.00 ± 0.00c	95.60 ± 1.10a	23.50 ± 0.24c	76.50 ± 0.24e	0.01 ± 0.00c
Shi 5	Sichuan	5.53 ± 0.04e	0.30 ± 0.05b	0.31 ± 0.06b	0.00 ± 0.00c	95.32 ± 0.32a	25.83 ± 0.24b	74.17 ± 0.24f	0.01 ± 0.00b
Mean		5.40	0.36	0.214	0.01	93.56	22.27	77.73	0.02

[a] Means in a column with the same letters are not significantly different at $p < 0.05$.
[b] Dry basis.

2011). 500 mg raw starch was dispersed in 15 ml sodium phosphate buffer (0.15 M, pH 6.5) with 60 mg of gelatin and pancreatin (1:1, w/w) (Sigma/Aldrich, St Louis, MO) in a precisely weighed tube. The tubes were capped and incubated in a water bath at 37 °C with constant shaking for 6 h. 5 ml of H_2SO_4 (1.0%, w/v) was added to stop the reaction, and the suspension was centrifuged at 20,000 × g for 10 min. The supernatant was discarded, and the precipitate was re-suspended in 80% aqueous ethanol solution (15 ml) and centrifuged at 20,000 × g for 5 min. The supernatant was discarded and the tubes with the precipitate were dried in a forced-air oven at 80 °C overnight to a constant weight. The starch enzyme digestibility was calculated from the weight loss after digestion and expressed as percentage (%).

2.5.5. Syneresis (%)

Starch retrogradation measured by syneresis was carried out according to the method described by Kuar, Singh, and Sodhi (2002) with slight modifications. 6% (w/w) of starch suspension was heated at 85 °C for 30 min in a temperature controlled water bath, and then cooled to room temperature in an ice water bath. The starch samples were stored for 1, 2, 3 and 7 days at 4 °C. Syneresis was measured as the amount of water (%) released after centrifugation at 3000 × g for 15 min.

2.5.6. Swelling power and solubility

Swelling power and solubility of the starches at different temperatures were determined according to the method described by Crosbie (1991) with slight modifications. 0.35 g of dry starch was mixed with 12.5 ml of distilled water, and heated in a water bath at 90 °C for 30 min, with constant mixing. The resulting slurries were cooled to room temperature and centrifuged at 2000 × g for 15 min. The supernatant was decanted into an evaporating dish, dried at 100 °C for 4 h. The dried supernatant and the sediment were weighed. The solubility (S, %) and swelling power (SP, g/g, dry basis) was calculated as follows:

$$\mathrm{SP}\ (\mathrm{g/g}) = \text{sediment weight/mass of dry starch} \times (100 - S)$$

$$S\ (\%) = \text{mass of dried supernatant/mass of dry starch} \times 100\%$$

2.6. Thermal properties

Thermal properties were analysed using Differential Scanning Calorimeter (DSC, Q200 TA instruments, New Castle, DE) according to the method of Kuar et al. (2002) with slight modifications. Starch (2–5 mg) was accurately weighed into an aluminium pan and water was added (1:3, w/w, dry basis: water). The pans were hermetically sealed and equilibrated at room temperature for 2 h prior to the analysis. DSC was calibrated using indium and an empty pan was used as the reference. Samples were heated at 10 °C/min over a temperature range of 30 °C–120 °C. These gelatinization parameters: Peak temperature (T_p); Onset gelatinization temperature (T_o); conclusion temperature (T_c) and enthalpy of gelatinization (ΔH_{gel}) were recorded. Gelatinization temperature range (R) was calculated as ($T_c - T_o$).

2.7. Pasting properties

The pasting properties of the sweet potato starches were measured using Brabender Amylograph (Brabender-803200, Micro Visco-Amyl-Graph, Germany) according to the modified method of Chen et al. (2003). 6% (w/w) starch suspension prepared using distilled water was used for the analysis. This was subjected to the following standard temperature profile: heating from 30 °C to 95 °C, holding at 95 °C for 20 min, cooling from 95 °C to 50 °C, and holding at 50 °C for 20 min with heating/cooling rate of 6 °C/min while stirring at 250 rpm. The peak, breakdown, hot paste, cold paste and setback viscosities, peak time and pasting temperature were recorded.

2.8. Statistical analysis

All experiments were conducted in duplicates. The data were analysed using analysis of variance. Pearson's correlation coefficients (r) were calculated for the various physicochemical properties and means were compared by lsd test at $p < 0.05$ using SAS 8.1 software (version 8.0, SAS Institute Inc., NC) (SAS, 2000).

3. Results and discussion

3.1. Proximate composition of sweet potato starches

The chemical composition of the different sweet potato starches is shown in Table 1. The purity of the starches was reasonably high (>91%). Moisture content (3.86–6.52%) fall within the moisture level (<20%) recommended for commercial starches (Soni, Sharma, Dun, & Gharia, 1993). It is also within the range (<13%) recommended for safe storage in most starch producing countries (ISI, 1970). The moisture content of Xushu 18 and Xushu 22 sweet potato varieties were found to be lower than the values 8.7 for Xushu 18 and 10% for Xushu 22, reported in previous studies (Chen et al., 2003; Zhu et al., 2011). This could be attributed to the variation in the extent of drying of the starches. The protein content of the starches varied between 0.28 and 0.75% with Mi xuan no.1 having the highest protein content. A lower level of protein (0.23%) was previously reported for Xushu 18 (Chen et al., 2003) which could be ascribed to the extent of the removal of protein present in the starting material. The ash content varied significantly among the starches with values ranging from 0.10% to 0.47% ($p < 0.05$). This is in agreement with the results of Aina et al. (2010) on the physicochemical properties of Caribbean sweet potato starches and also fall within the limit (≤0.5%) recommended for grade A industrial starches (Radley, 1976, pp. 189–229). Many of the starches contained no lipid in them except for starches of Shangshu 19 and Xushu 22 sweet potato cultivars. However, Chen et al., 2003 reported a lipid content of 0.5% in Xushu 18 which is higher than that reported in this study. Amylose and amylopectin content varied significantly among the starches with values ranging from 13.33 to 26.83% and 73.17 to 86.67%, respectively. Among the starches, Chuan shu 217 showed the highest amylose content while the lowest was found in Chuan shu 34. Amylose and amylopectin content plays an important role in influencing the functional properties of starches. High amylose starches are characterized by their high gelling strength which suggests their usefulness in the production of pasta, sweets, bread and in the coating fried products (Hung, Yamamori, & Morita, 2005; Vignaux et al., 2005). Differences in amylose content of sweet potato starches have been reported and ascribed to genotypic differences, environmental factors and starch processing methods (Garcia & Walter, 1998; Oduro et al., 2000).

3.2. General physicochemical properties

3.2.1. Colour, shapes and size distribution of starch granules

The colour of the various sweet potato starches is presented in Table 2. There were significant differences in the colour of the sweet potato starches with starch of Shangshu 19 being the whitest ($p < 0.05$). The starch of Chuan shu 34 was found to be redder than other starches, while Xushu 28 showed greater extent of yellowness. Colour is an important criterion in evaluating starch quality.

Table 2
Colour, granule size distribution and shapes of various sweet potato starches.[a]

Cultivar	Colour			Diameter range (μm)	Average diameter (μm)	Shape
	L*	a*	b*			
Mi xuan no.1	97.44 ± 0.11fab	0.01 ± 0.00cd	0.75 ± 0.01de	0.85–44.69	13.07 ± 0.04a	Round, Cupoliform, Polygonal
Chuan shu 217	95.76 ± 0.15g	0.24 ± 0.01b	0.61 ± 0.03ef	0.76–29.12	8.83 ± 0.23fg	Round, Cupoliform, Polygonal
Xicheng shu 007	96.75 ± 0.15de	−0.02 ± 0.01d	0.68 ± 0.01e	0.76–29.12	9.43 ± 0.24f	Round, Cupoliform, Polygonal
Xushu 28	94.47 ± 0.02h	−1.21 ± 0.13e	4.21 ± 0.21a	0.76–29.12	9.31 ± 0.09f	Round, Cupoliform, Polygonal
Luoshu 10	97.19 ± 0.32bc	0.03 ± 0.01cd	0.89 ± 0.00d	0.85–29.12	8.67 ± 0.00g	Round, Cupoliform, Polygonal
Shangshu 19	97.61 ± 0.16a	0.03 ± 0.01cd	1.06 ± 0.05c	0.85–32.41	9.08 ± 0.00c	Round, Cupoliform, Polygonal
Xushu 22	96.88 ± 0.06de	0.22 ± 0.02b	0.51 ± 0.06f	0.76–29.12	8.10 ± 0.03h	Round, Cupoliform, Polygonal
Xushu 27	96.44 ± 0.06f	0.08 ± 0.01cd	1.67 ± 0.02b	0.85–36.08	10.91 ± 0.24d	Round, Cupoliform, Polygonal
Chuan shu 34	96.05 ± 0.08g	0.38 ± 0.01a	0.63 ± 0.02ef	0.85–40.15	12.37 ± 0.12b	Round, Cupoliform, Polygonal
Xushu 18	96.65 ± 0.08ef	0.00 ± 0.00cd	1.62 ± 0.05b	0.85–40.15	11.53 ± 0.28cd	Round, Cupoliform, Polygonal
Shi 5	96.98 ± 0.09c	0.09 ± 0.01c	1.54 ± 0.04b	0.85–32.41	9.93 ± 0.01e	Round, Cupoliform, Polygonal
Mean	96.56	−0.01	1.29		10.31	

[a] Means in a column with the same letters are not significantly different at $p < 0.05$.

Any form of pigmentation on starch will negatively affect its acceptability and that of its products (Galvez & Resurrection, 1992). A high value of lightness is desired for starches.

The micrographs of the granules of the various sweet potato starches are shown on Fig. 1. The shapes of the various starch granules varied from polygonal, round to cupoliform/bell shapes. This is in agreement with previous reports on sweet potato starch granules (Chen et al., 2003; Zhu et al., 2011). From the results of starch particle size distribution analyses shown in Table 2, Mi xuan no.1 cultivar showed the highest mean granule size (13.07 μm) and the widest granule size range of 0.85–44.69 μm, on the other hand, starch of Xushu 22 showed the lowest mean granule size (8.10 μm) and the narrowest granules size range (0.76–29.12 μm). Hoover (2001) reported sweet potato starch granules as round oval and polygonal with sizes ranging from 2 to 42 μm which is in good agreement with the results of this study. In comparison to granules of starches from other sources, higher (25.8 μm), lower (1.05–1.32 μm) and relatively similar values (7.3–9.7 μm) values of mean granules sizes were reported for potato, amaranth and cassava starches respectively (Angrainni, Sudarmonowati, Hartati, Suurs & Visser, 2009; Chen et al., 2003; Kong, Bao,& Corke 2009). The differences in the granule size of the starches are presumably attributed to cultivar differences, growing conditions and plant physiology. Moreover, starch granule size plays a significant role in influencing the pasting parameters of starches (Noda, Tsuda, Mori, & Takigawa, 2004; Zaidul et al., 2007). Fine starch granules could be used as fat substitutes in high fat foods (Ma, Cai, Wang & Cun, 2006). However, starches with larger proportion of small starch granules like Xushu 22, Luoshu 10 and Chuan shu 217 will find use in applications requiring relatively small starch granules.

3.2.2. *Digestibility, syneresis, swelling power and solubility of starches*

The enzyme digestibility of raw sweet potato starches as measured by pancreatin hydrolysis exhibited significant differences as shown in Fig. 2. Enzyme digestibility of raw starches is an important factor to be considered when evaluating their usefulness in diverse food applications. The digestibility of the starches showed variations from 10.35% in Xicheng shu 007 to 15.15% in Xushu 18 cultivar with a mean value of 14.00%. The variability in the digestibility of the various starches might be due to environmental conditions associated with the crop growth location, such as temperature, precipitation and soil. In addition, granule size and structural characteristics of starches has been previously observed to exert substantial influence on invitro digestibility of starches (Jayakody, Hoover, Liu, & Weber, 2005; Szylit et al., 1978). Also the interaction of various factors including starch source, amylose–lipid complex, binding site, hydrolysis condition and type of hydrolyzing enzyme influences starch digestibility (Rocha, Carnero, & Franco, 2010). However, no significant correlation was found between the digestibility and the amylose content of starches obtained from eight sweet potato cultivars hydrolyzed by glucoamylases (Noda, Takahata, & Nagata, 1992).

Syneresis, an index for the degree of starch retrogradation at low temperatures are presented in Table 3. The syneresis of the various sweet potato starches increased with increase in storage days (data not shown). After 7 days of storage the percentage syneresis varied significantly ($p < 0.05$) between 32.45 and 44.68% with a mean value of 39.02% (Table 3). In accordance with this study, Biliaderis and Juliano (1993) reported an increase in the retrogradation of rice starch pastes with increase in storage days at 8 °C and also attributed the differences in the rate of starch retrogradation to cultivar differences. Starch paste of Chuan shu 217 exhibited higher retrogradation tendency due to the large volume of water expelled during the retrograding process compared with other starches regardless of the storage period, while Chuan shu 34 showed the lowest syneresis ($p < 0.05$). The higher retrogradation tendency observed in the starch pastes from the Chuan shu 217 might be due to its higher amylose content (Singh, Singh, Kuar, Sodi, & Gill, 2003). Syneresis exhibited a significant positive correlation with amylose content ($r = 0.70$, $p \le 0.05$), while it showed a negative correlation with MGS ($r = -0.59$, $p \le 0.05$). The structural arrangement of the chains within the amorphous and crystalline regions of starches has been reported to strongly influence the interaction that occurs between these starch chains during gel storage (Singh, Kuar, Sandhu, Kuar, & Nishinari, 2006).

Swelling power and solubility pattern of the starches were studied to understand the interactions between the water molecules and the starch chains in the crystalline and amorphous regions during heating. The swelling power and solubility of the starches are shown in Table 3. The various sweet potato starches exhibited different swelling power and solubility when heated in water at 90 °C. The swelling power of the starches from the various sweet potato cultivars ranged from 13.46 to 26.13 g/g. Starch of Xushu 22 showed the highest swelling power, while the lowest was observed in Mi xuan no.1 cultivar ($p < 0.05$). The solubility of the starches ranged from 8.56 to 19.97%, with the lowest found in Mi xuan no.1 whereas Xushu 18 showed the highest solubility ($p < 0.05$). Differences in the swelling power and solubility of the starches could be attributed the variations in the associative bonding forces within the starch granules. Previous studies attributed differences in the swelling and solubility patterns of starches to differences in amylose content, phosphorus and starch granular properties (Kaur, Singh, Ezekiel, & Guraya, 2007). However, no significant correlation was observed between the swelling power and amylose content in this present study but the swelling

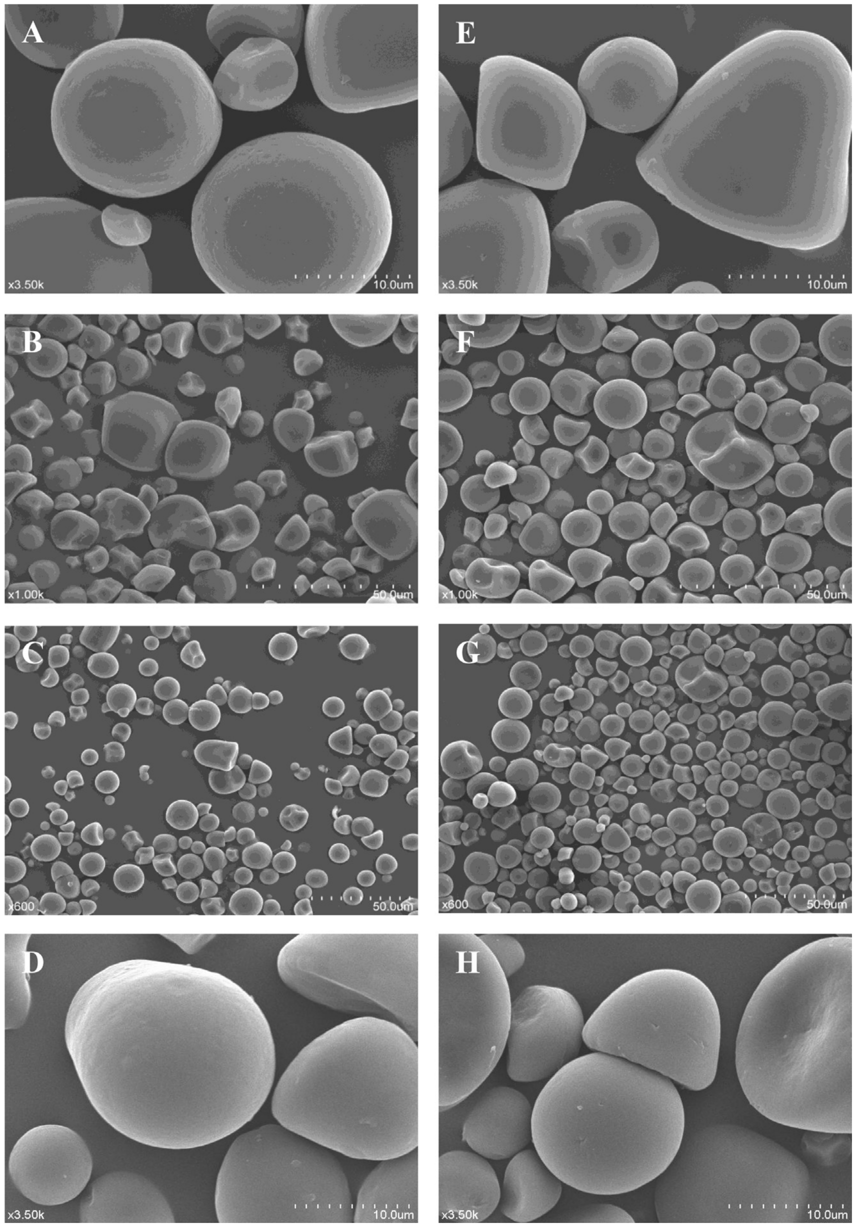

Fig. 1. Scanning electron micrographs of starch granules of various sweet potato cultivars, showing diversity in shapes and sizes. Figures in parentheses denote the degree of magnification. A, Mi xuan no.1 (×3500); B, Xicheng shu 007 (×1000); C, Xushu 28 (×600); D, Xushu 18 (×3500); E, Chuan shu 34 (×3500); F, Xushu 27 (×1000); G, Xushu 27(×600); H, Shi 5 (×3500).

power and solubility of the starches positively correlated with each other ($r = 0.64$, $p \leq 0.05$).

3.3. Thermal properties

The thermal properties of the sweet potato starches are presented in Table 3. Gelatinization temperature is the temperature at which heated starch granules undergo transition from the crystalline state to a gel. Starch gelatinization is an important parameter in starch characterization. These various thermal parameters (onset transition temperature – T_o; peak temperature – T_p; conclusion transition temperature – T_c; gelatinization range – R and enthalpy of gelatinization – ΔH_{gel}) were recorded. T_o and T_p of the starch samples ranged between T_o and T_p ranges are 54.5–69.1 and 62.5–75.9 °C with mean values of 62.31 and 71.23 °C respectively. Starches of Xushu 28, Xushu 22, Luoshu 10, Chaun shu 34 and Shi 5 showed significantly lower T_o, T_p and T_c compared to starches of other cultivars. Moreover, T_o, T_p and T_c values previously reported for Xushu 18 sweet potato starch by Chen et al., 2003 are similar with those reported in this present study. According to Vasanthan, Bergthaller, Driedger, Yeung, and Sporus (1999), starches with higher gelatinization transition temperatures (T_o and T_p) and enthalpy would require higher heat of solubilization. However, in this study, starches with higher transition temperatures, such as Mi xuan no.1, Chuan shu 217 and Xicheng shu 007, showed lower enthalpy of gelatinization. On the other hand, starches of Xushu 28, Luoshu 10 and Chuan shu 34 with lower transition temperatures showed the higher enthalpy of gelatinization (ΔH_{gel}) with values ranging from 11.64, 10.84 and 11.89 J/g, respectively. The gelatinization parameters (T_o, T_p, T_c & ΔH_{gel}) are strongly influenced by the molecular architecture of the crystalline region of starches (Noda, Takahata, Sato, Ikoma, & Mochida, 1996). ΔH_{gel} mainly reflects the

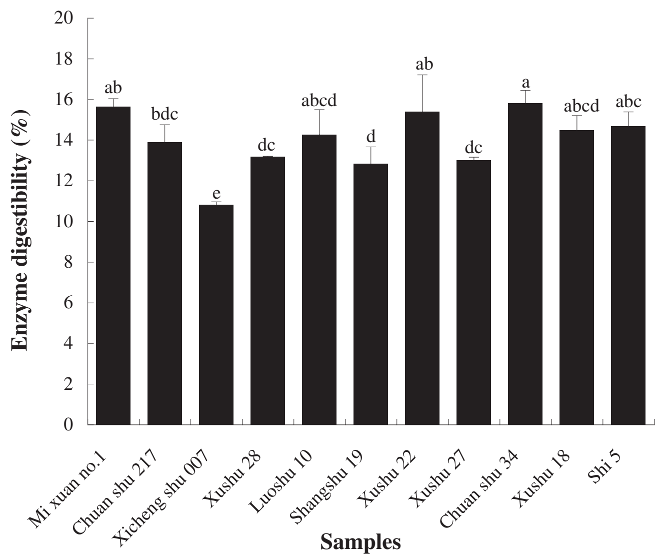

Fig. 2. Enzyme digestibility of starches of various sweet potato cultivars. Error bars represent standard deviations. Columns with same letters are not significantly different at $p < 0.05$.

loss of molecular order within the internal structure of starches (Cooke & Gidley, 1992).

The gelatinization range (R) of the sweet potato starches varied significantly among the sweet potato starches ($p < 0.05$). Chuan shu 34 showed the highest gelatinization range, while the lowest was observed in Chuan shu 217 cultivar. The results showed that the numbers of double helices (in the amorphous and crystalline domains) that disentangled and melted during gelatinization were relatively similar in Mi xuan no.1, Chuan shu 217 and Xicheng shu 007 starches compared to the starches of other cultivars. It also showed that the degree of heterogeneity of the starch crystallites within Mi xuan no.1, Chuan shu 217 and Xicheng shu 007 starch granules was lower than those of other starches (Ratnayake, Hoover, Shahidi, Perera, & Jane, 2001). Furthermore, variation in the gelatinization properties of the starches could be attributed to various factors including; mineral composition, proportion of large and small granules and the molecular architecture of the crystalline region of starches (Kaur et al., 2007).

3.4. Pasting properties

The pasting properties of the various sweet potato starches are presented in Table 4 and Brabender viscosity profiles in Fig. 3. The sweet potato starches exhibited significant variations in their pasting behaviours ($p < 0.05$). Plant source, starch purity and the interaction among starch component strongly influence the pasting properties of starches. The peak viscosity (PV) of the starches varied from 134 to 255 BU being lowest for Shangshu 19 followed by Xushu 28 (Fig. 3 and Table 4) and being highest for Chuan shu 34 followed by Xicheng shu 007 with an average value of 209.09 BU (Table 4). All the Brabender viscosity parameters we detected were low, especially for the Xushu 18 and Xushu 22 were lower than the results of previous literatures (Chen et al., 2003; Zhu et al., 2011). However, it is still difficult to define and compare across studies of the pasting characteristics of the starches, maybe due to differences in chemical components of the starches such as phosphorous content, lipid and so on and detective environment on starch structure within species. Starch of Xushu 28 showed the lowest hot paste viscosity (HPV), while the highest was observed in Xushu 18. Aina et al. (2010) stated that starches with high HPV would be preferred in applications which requires high starch consistency during prolonged cooking. However, amylose leaching, amylose–lipid complex formation, friction between swollen granules and granule swelling has been reported as key influencing factors of HPV (Singh et al., 2006).

Breakdown viscosity (BDV); a measure of the starch paste resistance to heat and shear, varied significantly between 91 and 162 BU in the various sweet potato starches being values for Shangshu 19 and Chuan shu 34 cultivars respectively. The lower BDV observed in Shangshu 19 starch variety suggested its greater resistance to shear as compared to the starches of other cultivars. Setback viscosity (SBV) showed the tendency of starch pastes to retrograde. Starches of Xicheng shu 007, Xushu 18, Xushu 27 and Xushu 28 showed higher retrogradation tendency due to their higher setback viscosity. On the other hand, starch of Shangshu 19, Shi 5, Luoshu 10 and Xushu 22 showed lower setback viscosity suggesting lower retrogradation tendency. The peak time (PT) of the sweet potato starches ranged from 5.97 to 7.03 min. Highest value was observed in Shi 5, while the lowest was observed in Luoshu 10. Low swelling starches are characterized by high peak times. The pasting temperature (P_{temp}) of the starches varied significantly ($p < 0.05$) from 67.20 to 73.20 °C in starches of Chaun shu 34 and Mi xuan no. 1 respectively with a mean value of 70.89 °C. These values above are in accordance with the P_{temp} range (50–86.6 °C) reported in previous studies (Chen et al., 2003; Liu, Donner, Yin, Huang, & Fan, 2006; Osundahunsi, Fagbemi, Kessleman, & Shimoni, 2003; Zhu et al., 2011).

Pasting and thermal properties are the most important properties when considering starches for use as gelling and thickening agents. Starches having relatively high peak viscosity, high

Table 3
Physicochemical and thermal properties of various sweet potato starches.[a]

Cultivar	Syneresis (%)	Swelling power (g/g)	Solubility (%)	T_o (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J/g)	R (°C)
Mi xuan no.1	37.23 ± 1.50fe	13.46 ± 0.22f	8.56 ± 0.44e	68.18 ± 0.36a	75.41 ± 0.14ab	81.60 ± 0.96cde	6.98 ± 0.57c	13.43 ± 1.32f
Chuan shu 217	44.68 ± 1.50a	17.08 ± 0.48e	11.56 ± 0.23de	69.11 ± 0.28a	74.53 ± 0.00bc	82.18 ± 0.27cd	6.40 ± 0.48c	13.08 ± 0.01f
Xicheng shu 007	41.22 ± 1.13bc	17.43 ± 0.55e	12.82 ± 0.53d	68.55 ± 0.07a	75.17 ± 0.00ab	81.88 ± 0.95dc	9.32 ± 0.07c	13.33 ± 1.02f
Xushu 28	43.88 ± 0.38ab	22.20 ± 0.22dc	12.92 ± 2.12d	54.54 ± 0.08f	63.81 ± 0.00f	78.88 ± 0.74fg	11.64 ± 0.54a	24.34 ± 0.82ab
Luoshu 10	39.63 ± 1.88cde	21.37 ± 1.93d	12.35 ± 0.37d	58.79 ± 1.01d	72.74 ± 1.42d	82.75 ± 0.54cd	10.84 ± 1.53a	23.97 ± 1.55ab
Shangshu 19	38.30 ± 1.50de	23.95 ± 1.70abc	18.77 ± 1.27ab	63.93 ± 0.10c	73.90 ± 0.00c	84.69 ± 0.34a	9.985 ± 0.40b	20.76 ± 0.44dc
Xushu 22	37.23 ± 0.00fe	26.13 ± 0.99a	13.15 ± 1.82cd	59.97 ± 0.11d	66.75 ± 0.42e	81.26 ± 0.34de	10.08 ± 0.39b	21.29 ± 0.23dc
Xushu 27	39.89 ± 0.75cde	24.48 ± 1.51abc	12.12 ± 1.98d	64.36 ± 0.71c	75.90 ± 0.19a	84.46 ± 0.12ab	9.78 ± 0.89b	20.10 ± 0.59d
Chuan shu 34	32.45 ± 0.75g	23.33 ± 1.65bcd	11.62 ± 2.65de	55.11 ± 0.05ef	66.91 ± 0.00e	80.16 ± 0.54ef	11.89 ± 0.26a	25.06 ± 0.59a
Xushu 18	34.57 ± 2.56cde	25.62 ± 0.22ab	19.97 ± 1.42a	66.92 ± 1.2b	75.84 ± 0.57a	83.03 ± 1.08bc	8.88 ± 0.53b	16.12 ± 2.28e
Shi 5	40.16 ± 1.13cd	23.63 ± 1.19abcd	16.20 ± 0.58bc	56.00 ± 0.0f	62.54 ± 0.21g	78.59 ± 0.88g	8.95 ± 0.46b	22.59 ± 0.91bc
Mean	39.02	21.70	13.64	62.31	71.23	81.77	9.52	19.46

T_o = Onset transition temperature; T_p = Peak transition temperature; T_c = Conclusion transition temperature; R = gelatinization range ($T_c - T_o$). ΔH_{gel} = enthalpy of gelatinization.

[a] Means in a column with the same letters not significantly different at $p < 0.05$.

Table 4
Pasting properties of various sweet potato starches.[a]

Cultivar	PV (BU)	HPV (BU)	BDV (BU)	CPV (BU)	SBV (BU)	PT (Min)	P_{temp} (°C)
Mi xuan no.1	236d	81f	155c	167d	86e	6.90b	73.20a
Chuan shu 217	226d	82e	144d	166d	84f	6.67f	72.50c
Xicheng shu 007	248b	91d	157b	201b	110b	6.73e	72.30d
Xushu 28	138i	8k	130h	120g	112a	6.37h	69.70i
Luoshu 10	202f	75g	127j	134e	59g	7.03a	71.00g
Shangshu 19	134j	43j	91k	69i	26i	6.47g	71.10f
Xushu 22	200g	71h	129i	130f	59g	6.30i	70.20h
Xushu 27	237c	100b	137e	200b	100c	6.77d	72.60b
Chuan shu 34	255a	93c	162a	192c	99d	6.00j	67.20k
Xushu 18	236d	101a	135f	211a	110b	6.80c	72.10e
Shi 5	188h	58i	130g	94h	36h	5.97k	67.90j
Mean	209.09	73	136.09	153.1	80.09	6.55	70.89

PV, peak viscosity; HPV, Hot paste viscosity; BDV, breakdown viscosity; CPV, Cold paste viscosity; SBV, setback viscosity; PT, peak time; P_{temp}, Pasting temperature.
[a] Means with the same letters in the same column are not significantly different at $p < 0.05$.

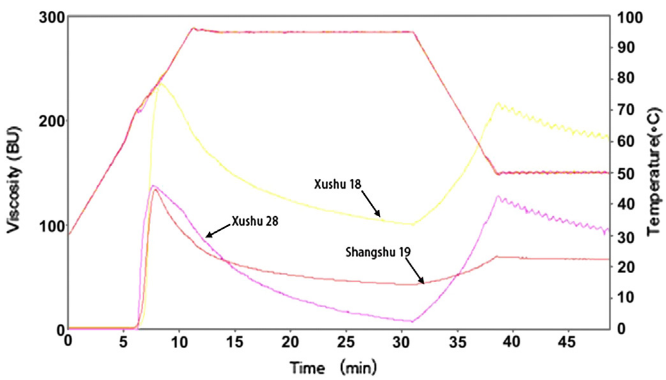

Fig. 3. Brabender amylograms of 3 Chinese sweet potato starches (Xushu 18, Xushu 28, Shangshu 19) at concentration of 6%.

breakdown viscosity and low setback viscosity like Luoshu 10, Xushu 22 and Shi 5 could be considered for use as thickening or gelling agents. However, low peak viscosity starches like Xushu 28 and Shangshu 19 would be suitable for the manufacture of weaning foods where low paste viscosity food ingredient is required. At present, cereals used in weaning food applications needs to be malted to reduce the viscosity of their pastes (Akingbala, Uzo-Peter, Jaiyeoba & Baccus-Taylor, 2002). Compositional and morphological properties of starch such as amylose content, phosphorus content and mean granule size play crucial role in influencing the pasting and rheological properties of starches (Liu, Weber, Currie, & Yada, 2003; Singh et al., 2006; Zaidul et al., 2007).

3.5. *Correlation analysis among the various properties of sweet potato starches*

The Pearson's correlation coefficient for the relationship among the various physicochemical properties of the starches is shown in Table 5. Swelling power showed significant positive correlation with solubility ($r = 0.64$, $p \le 0.05$). This is in agreement with previous findings on sweet potato starch (Zhu et al., 2011), but not in accordance with the report of Kaur et al. (2007) on potato starches. According to the study of Collado and Corke (1997), amylose was significantly negatively correlated to the peak viscosity, our data here showed that there was no obvious correlation between the amylose content and peak viscosity of 11 Chinese sweet potato starches although the amylose content of those starches were different. T_p positively correlated with T_o ($r = 0.88$, $p \le 0.001$) and T_c positively correlated to T_o ($r = 0.62$, $p \le 0.05$) and T_p ($r = 0.85$, $p \le 0.01$). The positive correlations between the transition temperatures are in accordance with previous reports (Kong et al., 2009; Singh & Kuar, 2004). ΔH_{gel} negatively correlated to T_o ($r = -0.78$, $p \le 0.01$) whereas the gelatinization range showed

Table 5
Pearson correlation coefficients among different properties of the various sweet potato starches.

	MGS	AC	Digest	Sol	SP	T_o	T_p	T_c	ΔH_{gel}	R	PV	P_{temp}	HPV	CPV	BD	SBV	PT
AC	−0.58																
Digest	0.40	−0.39															
Sol	−0.20	0.24	−0.18														
SP	−0.24	−0.16	0.12	0.64*													
T_o	0.13	0.37	−0.34	−0.03	−0.51												
T_p	0.21	0.15	−0.33	−0.02	−0.37	0.88***											
T_c	−0.04	0.06	−0.32	0.22	0.06	0.62*	0.85***										
ΔH_{gel}	−0.14	−0.55	−0.04	0.13	0.60	−0.78**	−0.49	−0.20									
R	−0.17	−0.42	0.27	0.13	0.65*	−0.94***	−0.70*	−0.33	0.85***								
PV	0.53	−0.21	0.17	−0.39	−0.29	0.42	0.43	0.11	−0.30	−0.45							
P_{temp}	0.03	0.41	−0.38	−0.14	−0.48	0.89***	0.87***	0.67*	−0.6*	−0.79**	0.23						
HPV	0.43	−0.12	0.13	−0.13	−0.09	0.52	0.59	0.42	−0.33	−0.45	0.92***	0.33					
CPV	0.52	−0.21	−0.04	−0.28	−0.20	0.44	0.50	0.19	−0.16	−0.45	0.88***	0.36	0.79**				
BD	0.54	−0.28	0.17	−0.64*	−0.49	0.15	0.07	−0.36	−0.18	−0.34	0.83**	0.03	0.54	0.77**			
SBV	0.41	−0.22	−0.19	−0.31	−0.22	0.20	0.23	−0.09	0.05	−0.29	0.52	0.26	0.30	0.83**	0.69*		
PT	0.03	0.33	−0.28	−0.18	−0.43	0.67*	0.83**	0.64*	−0.38	−0.54	0.24	0.88***	0.34	0.37	0.04	0.26	
Syn	−0.59	0.70*	−0.56	−0.20	−0.35	0.13	−0.04	−0.11	−0.27	−0.20	−0.37	0.28	−0.46	−0.26	−0.15	0.01	0.19

*$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$. MGS, mean granule size; AC, Amylose content; Digest, Digestibility; Sol, Solubility; SP, Swelling power; T_o, onset transition temperature; T_p, peak transition temperature; T_c, conclusion transition temperature; ΔH_{gel}, enthalpy of gelatinization; R, Gelatinization temperature range; PV, peak viscosity; P_{temp}, pasting temperature; HPV, Hot paste viscosity; CPV, cold paste viscosity; BD, breakdown viscosity; SBV, setback viscosity; PT, peak time; Syn, Syneresis.

significant positive correlation with SP ($r = 0.65$, $p \leq 0.05$) and ΔH_{gel} ($r = 0.85$, $p \leq 0.001$) but negatively correlated to T_o ($r = -0.94$, $p \leq 0.001$) and T_p ($r = -0.70$, $p \leq 0.05$). Pasting temperature positively correlated to T_o ($r = -0.89$, $p \leq 0.001$), T_p ($r = 0.87$, $p \leq 0.01$) and T_c ($r = 0.67$, $p \leq 0.05$). These results partially disagreed with previous reports (Singh et al., 2006; Wang et al., 2010) on rice starches.

HPV showed significant positive correlations with PV ($r = 0.92$, $p \leq 0.001$). CPV was found to positively correlate to HPV ($r = 0.79$, $p \leq 0.01$) and PV ($r = 0.88$, $p \leq 0.001$). BD showed significant positive correlation with PV ($r = 0.83$, $p \leq 0.01$) and CPV ($r = 0.77$, $p \leq 0.01$). SBV positively correlated to CPV ($r = 0.83$, $p \leq 0.01$) and BD ($r = 0.69$, $p \leq 0.05$), respectively. PT positively correlated with P_{temp} ($r = 0.88$, $p \leq 0.001$), T_c ($r = 0.64$, $p \leq 0.05$) and T_p ($r = 0.83$, $p \leq 0.01$). Syneresis showed significant positive correlation with amylose content ($r = 0.70$, $p \leq 0.05$).

However, the agreements and also discrepancies observed in the relationship between the physicochemical properties in this study and previous studies could be ascribed to the differences in starch types and their biological sources. In addition, the physicochemical properties showing insignificant or no correlations might have resulted from lack of variations rather than lack of intrinsic relationship (Zhu et al., 2011).

4. Conclusion

The starches of 11 sweet potato varieties popularly used in Chinese starch industry were isolated and characterized for their physicochemical properties. The relationships among the various properties were also evaluated. Significant variations were observed in the properties of the sweet potato starches ($p < 0.05$). The sweet potato starches differed in amylose, ash, phosphorus contents, granule sizes, particle size distribution and enzyme digestibility. Swelling power, solubility, retrogradation, thermal and pasting properties also varied among the starch cultivars. Pearson correlation analysis showed that amylose content had a significant positive correlation with mean granule size. Phosphorus content also showed significant positive correlation with swelling power. Swelling power and solubility of the starches showed positive correlation with each other. Syneresis showed significant positive correlation with amylose content and negatively correlated with swelling power. Some of the thermal and pasting parameters showed significant positive and negative correlations with each other. In all, the variability and the relationships observed among the physicochemical properties of these various sweet potato starches further projected their useful potentials in various food and non-food applications.

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References

Aina, A. J., Falade, K. O., Akingbala, J. O., & Titus, P. (2010). Physicochemical properties of Caribbean sweet potato (*Ipomoea batatas* (L.) Lam) starches. *Food and Bioprocess Technology*, http://dx.doi.org/10.1007/s11947-009-0316-6.

Akingbala, J. O., Uzo-Peters, P. I., Jaiyeoba, C. N., & Baccus-Taylor, G. S. H. (2002). Changes in the physical and biochemical properties of Pearl millet (*Pennisetum americanum*) on conversion to Ogi. *Journal of the Science of Food and Agriculture, 82*, 1458–1464.

Anggraini, A. V., Sudarmonowati, E., Hartati, N. S., Suurs, L., & Visser, R. G. F. (2009). Characterization of cassava starch attributes of different genotypes. *Starch/Stärke, 61*, 472–481.

AOAC. (2000). *Official method of analysis* (17th ed.). Gaithersburg, MD: AOAC International.

Bemiller, J. N., & Whistler, R. N. (1996). Carbohydrates. In O. R. Fennema (Ed.), *Food chemistry* (pp. 157). New York: Marcel Dekker Inc.

Biliaderis, C. G., & Juliano, B. O. (1993). Thermal and mechanical properties of concentrated rice starch gels of varying composition. *Food Chemistry, 48*, 243–250.

Chen, Z., Schols, H. A., & Voragen, A. G. J. (2003). Physicochemical properties of starches obtained from three different varieties of Chinese sweet potatoes. *Journal of Food Science, 68*, 431–437.

CIP. (2011). International Potato Centre. http://www.cipotato.org/sweetpotato/ Assessed 03.05.11.

Collado, L. S., & Corke, H. (1997). Properties of starch noodles as affected by sweet potato genotype. *Cereal Chemistry, 74*(2), 182–187.

Cooke, D., & Gidley, M. J. (1992). Loss of crystalline and molecular order during starch gelatinization: origin of the enthalpy transition. *Carbohydrate Research, 227*, 103–112.

Crosbie, G. B. (1991). The relationship between starch swelling properties, paste viscosity and boiled noodle quality in wheat flours. *Journal of Cereal Science, 13*, 145–150.

Galvez, F. C., & Resurrection, A. V. A. (1992). Reliability of the focused group technique in determining the quantity characteristics of mung bean (*Vigna radiate* (L.) *Wilezee*) noodles. *Journal of Sensory Studies, 7*, 315–326.

Garcia, A. M., & Walter, M. W. (1998). Physicochemical characterization of starch from Peruvian sweetpotato selections. *Starch/Stärke, 50*, 331–337.

Guan, H. P., McKean, A. L., & Keeling, P. L. (2000). *Starch encapsulation technology for producing recombinant proteins in plants*. Abstract 115 of the American Association of Cereal Chemists, Kansas City November 5–9.

Hoover, R. (2001). Composition, molecular structure and physicochemical properties of tuber and root starches: a review. *Carbohydrate Polymers, 45*, 253–267.

Hoover, R., & Ratnayake, W. S. (2001). *Determination of total amylose content of starch*. In *Current protocols in Food and Analytical chemistry*. John willey & Sons, Inc.

Hung, P. V., Yamamori, M., & Morita, N. (2005). Formation of enzyme resistant starch in bread as affected by high amylose wheat flour substitutions. *Cereal Chemistry, 82*, 690–694.

ISI. (1970). *Specifications for tapioca starch for use in cotton textile industries, IS 1605-1960*. New Delhi: Indian Standards Institution.

ISO 3946, (1982) (EN). Starches and derived products – Determination of total phosphorus content – Spectrophotometric method.

Jayakody, L., Hoover, R., Liu, Q., & Weber, E. (2005). Studies on tuber and root starches. I. Structure and physicochemical properties of innala (*Solenostemon rotundifolius*) starches grown in Sri Lanka. *Food Research International, 36*(6), 615–629.

Kaur, A., Singh, N., Ezekiel, R., & Guraya, S. H. (2007). Physicochemical, thermal and pasting properties of starches separated from potato cultivars grown at different locations. *Food Chemistry, 101*, 643–651.

Kong, X. L., Bao, J. S., & Corke, H. (2009). Physical properties of *Amaranthus* starch. *Food Chemistry, 113*, 371–376.

Kuar, L., Singh, N., & Sodhi, S. N. (2002). Some properties of potatoes and their starches II. Morphological, thermal and rheological properties of starches. *Food Chemistry, 79*, 183–192.

Lin, L., Wheatley, C. C., Chen, J., & Song, B. (1996). Studies on the physicochemical properties of starches of various sweet potato varieties grown in China. In. *Proceedings of the international symposium held in Nanning, Guanxi, China*: *CIAT Regional Cassava Program for Asia* (pp. 216–223).

Liu, Q., Donner, E., Yin, Y., Huang, R. L., & Fan, M. Z. (2006). The physicochemical properties and invitro digestibility of selected cereals, tubers and legumes grown in China. *Food Chemistry, 99*, 470–477.

Liu, Q., Weber, E., Currie, V., & Yada, R. (2003). Physicochemical properties of starches during potato growth. *Carbohydrate Polymers, 51*, 213–221.

Ma, Y., Cai, C. G., Wang, J., & Sun, D. W. (2006). Enzymatic hydrolysis of corn starch for producing fat mimetics. *Journal of Food Engineering, 73*, 297–303.

Ma, D., Li, H., Tang, J., Xie, Y., Li, Q., Cao, Q., et al. (2010). Current status and future prospects of development if sweet potato industry in China. In. *Proceedings of China Xuzhou 4th international sweet potato symposium & 4th China–Japan–Korea sweet potato workshop held in Xuzhou Jiangsu, China*: *Sweet potato in food and energy security* (pp. 3–10).

Noda, T., Takahata, Y., & Nagata, T. (1992). Properties of sweet potato starches from different tissue zones. *Starch/Stärke, 44*, 405–409.

Noda, T., Takahata, Y., Sato, T., Ikoma, H., & Mochida, H. (1996). Physicochemical properties of starches from purple and orange fleshed sweet potato roots at two levels of fertilizer. *Starch/Stärke, 48*, 395–399.

Noda, T., Tsuda, S., Mori, M., & Takigawa, S. (2004). Properties of starches from potato varieties grown in Hokkaido. *Journal of Applied Glycoscience, 51*, 241–246.

Oduro, I., Ellis, W. O., Aryeetey, S. K., Ahenkora, K., & Otoo, J. A. (2000). Pasting characteristics of starch from new varieties of sweet potato. *Tropical Science, 40*, 25–28.

Osundahunsi, O. F., Fagbemi, T. N., Kessleman, E., & Shimoni, E. (2003). Comparison of the physicochemical properties and pasting characteristics of flour and starch from red and white sweet potato cultivars. *Journal of Agricultural and Food Chemistry, 15*, 2232–2236.

Peshin, A. (2001). Characterization of starch isolated from potato tubers (*Solanum tuberosum* L.). *Journal of Food Science and Technology, 38*, 447–449.

Radley, J. A. (1976). *Starch production technology*. London: Applied Science Publishers Ltd.

Ratnayake, W. S., Hoover, R., Shahidi, F., Perera, C., & Jane, J. (2001). Composition, molecular structure, and physicochemical properties of starches from four field pea (*Pisum sativum* L.) cultivars. *Food Chemistry, 74*, 189–202.

Rocha, T. S., Carnero, A. P. A., & Franco, C. M. L. (2010). Effect of enzymatic hydrolysis on some properties of root and tuber granular starches. *Ciencia e technologia de Alimentos, 30*, 544–551.

Salawu, I. S., & Mukhtar, A. A. (2008). Reducing the dimension of the growth and yield characters of sweet potato (*Ipomea batatas* L.) varieties as affected by varying rates of organic/inorganic fertilizer. *Asian Journal of Agricultural Research, 2*(1), 41–44.

SAS. (2000). *SAS/STAT software version 8.1*. Cary, North Carolina, USA: SAS Institute Inc.

Singh, N., & Kuar, L. (2004). Morphological, thermal, rheological and retrogradation properties of potato starch fractions varying in granule size. *Journal of the Science of Food and Agriculture, 84*, 1241–1252.

Singh, N., Kuar, L., Sandhu, K. S., Kuar, J., & Nishinari, K. (2006). Relationships between physicochemical, morphological, thermal, rheological properties of rice starches. *Food Hydrocolloids, 20*, 532–542.

Singh, N., Singh, J., Kuar, L., Sodi, N. S., & Gill, B. S. (2003). Morphological, thermal and rheological properties of starch separated from different botanical sources. *Food Chemistry, 81*, 219–231.

Soni, P. L., Sharma, H., Dun, D., & Gharia, M. M. (1993). Physicochemical properties of *Quercus leucotrichophora* (Oak) starch. *Starch/Stärke, 45*, 127–130.

Szylit, O., Durand, M., Borgida, L. P., Atinkpahoun, H., Prieto, F., & Devort-Lavel, J. (1978). Raw and steam-pelleted cassava, sweet potato and yam cayensis as starch sources for ruminant and chicken diets. *Animal Feed Science and Technology, 3*, 73–87.

Vasanthan, T., Bergthaller, W., Driedger, D., Yeung, J., & Sporus, P. (1999). Starch from Alberta potatoes: wet isolation and some physicochemical properties. *Food Research International, 132*, 355–365.

Vignaux, N., Doehlert, D. C., Elias, E. M., McMullen, M. S., Grant, L. A., & Kianian, S. F. (2005). Quality of spaghetti made from full and partial waxy durum wheat. *Cereal Chemistry, 82*, 93–100.

Wang, L., Xie, B., Shi, J., Xue, S., Deng, Q., Wei, Y., et al. (2010). Physicochemical properties and structure of starches from Chinese rice cultivars. *Food Hydrocolloids, 24*, 208–216.

Zaidul, I. S. M., Yamauchi, S., Takigawa, C., Matsuura-Endo, T., Suzuki, T., & Noda, T. (2007). Correlation between the compositional and pasting properties of various sweet potato starches. *Food Chemistry, 105*, 164–172.

Zhu, F., Yang, X., Cai, Y. Z., Berfotoft, E., & Corke, H. (2011). Physicochemical properties of sweet potato starch. *Starch/Stärke, 00*, 1–11.