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Comparative analysis of starch properties of different root and tuber crops of Sri Lanka

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ABSTRACT

The physicochemical properties of starches of six different root and tuber crop species grown mainly in Sri Lanka showed significant differences among the tested crop species and varieties. The median granule size of starch of tested root and tuber crop species varied from 33.5 to 10.2 μm. The largest granule size and the highest blue value were given by the canna, Buthsarana, and yam species, in that order. The amylose content of cassava was higher than those of sweet potato and many yams. High peak viscosities, high breakdown, and high final viscosities were observed in yams, and, generally, such starch showed a high swelling power. According to the correlation analysis, these pasting properties would mainly be due to their larger starch granule size. Based on the thermal properties, cassava starch showed less energy requirement for gelatinization and thus gelatinized at lower temperatures. Furthermore, a higher susceptibility of raw cassava starch toward fungal glucoamylase was observed. The low enzyme digestibility of raw yam starch would be due to its large granules. Correlation analysis showed that the blue value and starch granule size were important in determining the pasting, thermal, and other properties of starch.

1. Introduction

Starch is the major caloric source in a variety of diets of people worldwide. Thus, starches from various plant species, especially cereals, have received very extensive attention in food research. Starch is also an important ingredient in various food systems as a thickener, gelling agent, and binder. Corn, potato, and cassava are the most common sources of starch for such industries (Tester & Karkalas, 2002). However, since they are the main caloric sources for people in many countries, they are in high demand. Furthermore, the use of natural starches in food or non-food industries is difficult, as there are no starches with essential properties for a particular application. Thus, different modifications must be made before applying natural starch for industrial purposes, which is expensive. Therefore, it is important to identify different alternative starch sources with wide variability in starch properties.

Root and tuber crops are grown worldwide and usually have low commercial value for direct consumption. Even though the information available on such underutilized crops is sparse, it has been proved that the starch of such crops would be a good source for different food industries (Alves, Grossmann, & Silva, 1999; Amani, Kamenan, Rolland-Sabate, & Colonna, 2005; Brunnschweiler et al., 2005; Moorthy, Thankamma Pillai, & Unnikrishnan, 1993). Since starches from various plant species have their own characteristics, the physicochemical properties of starches from different root and tuber crops, mainly from Sri Lanka, were analyzed.

2. Materials and methods

2.1. Materials

Two different yams (Higurala and Rajala), 3 typical cassava varieties (Kirikawadi, MU 51 and CARI 555), 2 typical sweet potato varieties (Gannoruwa white and Ranabima), and one each from edible canna (Buthsarana), taro (Kiriala), and arrowroot (Hulankeeriya) grown in Sri Lanka were used in the study. All samples were kindly provided by the Horticultural Crop Research and Development Institute, Department of Agriculture, Sri Lanka. Furthermore, Japanese starch samples from yam Nagaimo (JPYam) and sweet potato (JPSP) and cassava (JPCS) starch obtained from Japan were used.

For the isolation of starch from Sri Lankan yams and tuber crops, fresh roots/tubers harvested at full maturity were used. Tubers were washed and peeled manually and cut into small pieces. Then, they were homogenized with distilled water for 1–2 min. The slurry was then passed through a 106 μm sieve. The filtrate was allowed to settle for a minimum of 3 h at 4 °C, and the precipitated starch

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was then washed three times with distilled water. Finally, starch was washed with 70% ethanol and dried at room temperature for 2 days. The moisture content of isolated starch samples was estimated by drying them in an oven at 115 °C for 3 h.

Among samples from Japan, sweet potato starch was purchased from Haraigawa Starch Factory, Kimotsuki Agricultural Cooperative Association, Kanoya, Kagoshima, Japan. Cassava starch, isolated from cassava tubers grown in Thailand, was obtained from Nippon Starch Chemical Co., Ltd., Osaka, Japan. Yam starch was isolated from fresh yam tubers obtained from Kawanishi Agricultural Cooperative Association, Obihiro, Hokkaido, Japan, as described by Zaidul, Nik Norulaini, Mohd. Omar, Yamauchi, and Noda (2007).

2.2. Particle size distribution

The particle size distribution of samples was analyzed with a Helos Particle Size Analyzer [Sympatech HELOS, (H1169) and RODOS, Germany] as described previously (Noda et al., 2004), and the median particle diameter of each sample was measured.

2.3. Blue value and amylose content

The amylose content was estimated by the blue value method, as described by Noda, Takahata, Nagata, and Monma (1992) without defatting starch. A 2% starch suspension was prepared by dissolving starch in dimethyl sulfoxide (DMSO) at 70 °C for 3 h and diluting the mixture to a 0.1% starch suspension using distilled water. The absorbance at 680 nm was recorded for a mixture (5 ml) containing 0.2 mg of starch, 0.4 mg of iodine, and 4 mg of potassium iodide (KI) 30 min after colour development.

The apparent amylose content was calculated using the blue values of the samples. For the calculations, the blue values of purified amylose and amylopectin of sweet potato (Takeda, Tokunaga, Takeda, & Hizukuri, 1986), cassava and canna (Thitipraphunkul, Uttapap, Piyachomkwan, & Takeda, 2003), and yam nagaimo (Suzuki, Kanayama, Takeda, & Hizukuri, 1986) were used.

2.4. Pasting properties

The pasting properties of a 6% starch suspension (dry weight basis) were analyzed using a Rapid Visco Analyzer (RVA-4, Newport Scientific Pty. Ltd., Australia) as described earlier (Wickramasinghe, Miura, Yamauchi, & Noda, 2003). The peak viscosity, breakdown, final viscosity, setback, pasting temperature and peak time were recorded for samples with two replications.

2.5. Thermal properties

The thermal properties were measured using a differential scanning calorimeter (DSC 6100, Seiko Instruments, Inc., Tokyo, Japan) as described previously (Noda et al., 2004). A pan with distilled water was used as the reference, and the peak gelatinization temperature, onset gelatinization temperature, and enthalpy for the starch gelatinization were measured for each sample with two replicates.

2.6. Swelling power

The starch slurry (50 mg of starch on dry weight basis in 5 ml of distilled water) was gelatinized at 80 °C for 20 min with frequent mixing to avoid the formation of starch clots. Gels were cooled at 20 °C for 5 min and then centrifuged at 1700*g* for 5 min. The swelling power was calculated and expressed as the weight of swelled starch residue per 1 g of starch (dry weight). The analysis was repeated three times.

2.7. Enzyme digestibility

One milliliter of a 2% raw starch suspension was digested with 3.71 units of crystalline glucoamylase from *Rhizopus* sp. (Oriental Yeast Co., Ltd., Tokyo, Japan) for 4 h at 40 °C according to a modified method from Noda et al. (1992). The amount of glucose released during enzyme digestion was estimated by the phenol–sulfuric method (Dubois, Gilles, Hamilto, Rebers, & Smith, 1956), and enzyme digestibility was calculated as the percentage of glucose released during incubation with the enzyme, of the total equivalent sugar content in the starch on a weight basis.

2.8. Data analysis

Data were analyzed using Microsoft Excel 2003, and the means were compared by using the least significant difference (LSD) for each property.

3. Results and discussion

3.1. Particle size

The median particle size of the tested starch samples varied from 33.5 μm (canna) to 10.2 μm (taro) (Table 1). Even though cassava and sweet potato of Sri Lanka showed significant variation in

Table 1

Median particle size, blue value and apparent amylose content of starches from root and tuber crops, mainly of Sri Lanka

Crop	Variety name	Botanical name	Median particle size (μm)[A]	Blue value	Apparent amylose content[B]
Yams	Higurala	*Dioscorea* spp.	28.7^{b}	0.417^{e}	18.0
	Rajala	*Dioscorea alata*	26.2^{c}	0.518^{b}	25.4
	JPYam	*Dioscorea opposita* T.	22.8^{e}	0.524^{b}	25.8
Cassava	Kirikawadi	*Manihot esculenta* Crantz	11.3^{j}	0.375^{f}	25.4
	MU 51		12.4^{hi}	0.379^{f}	25.7
	CARI 555		11.5^{i}	0.381^{f}	25.9
	JPCS		15.7^{g}	0.417^{e}	28.8
Sweet potato	Gannoruwa white	*Ipomoea batatas* L. Lam	12.0^{i}	0.418^{e}	19.3
	Ranamiba		13.0^{h}	0.383^{f}	16.6
	JPSP		19.4^{f}	0.474^{c}	23.5
Canna	Buthsarana	*Canna indica* L	33.5^{a}	0.550^{a}	34.2
Taro	Kiriala	*Colocasia esculenta* (L.) Schott.	10.2^{k}	0.431^{d}	[C]
Arrowroot	Hulankeeriya	*Maranta arundinacea* L.	23.7^{d}	0.410^{e}	[C]

[A] Values followed by the same letters in the same column are not significantly different at $P < 0.05$ level.

[B] Mean separation was not done as amylose content was derived by average blue value of each sample.

[C] Apparent amylose content could not be calculated as blue values of purified amylose and amylopectin of *Colocasia esculenta* and *Maranta arundinacea* were not available.

their mean granule sizes, the variation was only between 11.3 μm and 13.0 μm. The starch granules of all yams and arrowroot were larger than those of cassava and sweet potato. The Japanese sweet potato and cassava varieties also showed similar results; however, compared to the Sri Lankan varieties, relatively larger granules were observed. Taro, which is a *Colocasia* crop, had the smallest starch granules of the tested root and tuber crops.

The granule size of taro starch was comparable with a previous observation by Gunaratne and Hoover (2002), but very low values were observed by Perez, Schultz, and Delahaye (2005) and Moorthy et al. (1993). Moorthy et al. (1993) observed that the starch granule size of *Colocasia* was low and the average granule size ranged from 2.96 to 5.15 μm for 10 cultivars. They further observed that the granule size among cultivars was strongly correlated with the amylose content; the larger the starch granule, the higher was the amylose content. Our results on the granule size of the yams were comparable with those from previous reports, in which the granule size of *Dioscorea alata* was noted as 20–40 μm (Huang, Lin, & Wang, 2006).

3.2. Blue value and apparent amylose content

The blue values of all yams were higher than those of cassava and sweet potato (Table 1). The highest blue value was observed for canna, and the lowest, for one Sri Lankan cassava variety, Kirikawadi. The amylose contents of yams ranged from 18.0% to 25.9%, those of cassava, from 25.4% to 28.8%, and those of sweet potato, from 16.5% to 23.5%. Therefore, generally higher amylose contents were shown in cassava than in yams. Brunnschweiler et al. (2005) characterized different yam starches and observed amylose contents ranging from 22.3% to 25.5%; those values were comparable with the amylose content of commercial starches from potato and tapioca that were also tested. Furthermore, these researchers found that the amylose content could vary according to the variety, sample position within the tuber, and storage duration. The yam samples were collected from the tubers harvested at full maturity, and the storage conditions, duration, and sampling were identical. Thus, the differences observed in amylose content could be explained by the varieties studied.

The iodine binding properties seemed to be different in starches from different plant species, as observed by other researchers (Suzuki et al., 1986; Takeda et al., 1986; Thitipraphunkul et al., 2003). These studies provide information on the polymer compositions of starch and the fine structures of each polymer, amylose and amylopectin. Higher blue values and higher amylose contents were again shown in cassava and sweet potato obtained from Japan. Variations in amylose content were previously observed with different varieties, environmental conditions and maturity stages (Aryee, Oduro, Ellis, & Afuakwa, 2005; Moorthy & Ramanujam, 1986; Noda, Kobayashi, & Suda, 2001). The amylose content of sweet potato was previously reported to be as low as 18.8% for many cultivars (Madhusudhan, Goeda, and Tharanathan (1996). Similar information was also reported by Takeda et al. (1986). Among 31 different cultivars of cassava, the amylose content varied from 10.9% to 44.3% (Aryee et al., 2005). Freitas, Paula, Feitosa, Rocha, and Sierakowski (2004) have shown that the amylose content of yam (*D. alata*) and cassava were 36% and 23%, respectively. However, our results on the amylose contents of yam starch were in good agreement with those by Brunnschweiler et al. (2005).

Higher amylose was previously observed in different edible canna species than in cassava (Thitipraphunkul et al., 2003). According to these reports, canna starch has a relatively high amylase content, but its molecular size is small and less branched. It was proved that canna starch had a larger percentage of long amylopectin branch chains than had amylopectins of cassava or mung bean. Therefore, the highest blue value of the Sri Lankan canna, Buthsarana, would be explained by the structural properties of amylose and amylopectin.

Since no data are available for the blue values of purified amylose and amylopectin of taro starch, the amylose contents of taro and Kiriala could not be calculated. However, the higher blue value of taro starch than of cassava and sweet potato in this study suggested the presence of high amylose in taro as well, as shown by previous studies (Gunaratne & Hoover, 2002; Perez et al., 2005).

3.3. Pasting properties by RVA

The pasting properties, peak viscosity, breakdown viscosity, final viscosity, setback, pasting temperature, and time to peak of starches of different root and tuber crops are shown in Table 2. The highest peak, highest breakdown, very high final viscosity, and very low setback were noted in the yam, Higurala. In contrast, the lowest peak viscosity, breakdown and final viscosity were observed in taro, which had the smallest starch granules. Moorthy et al. (1993) showed that the viscosity properties of *Colocasia* were low compared to those of cassava or *Dioscoria* starches and higher than those of cereal starches.

Relatively higher pasting properties were shown by yams as well as the canna, Buthsarana. This could be mainly due to the size of the starch granules. Irrespective of the botanical source, starches with larger granules showed very high peak viscosities in the study. However, the pasting behaviours of sweet potato and cassava starches were different, with relatively low peak viscosity and breakdown but higher setback. Japanese sweet potato (JPSP) starch would be very hard to gelatinize, as it showed the highest pasting temperature and longest time to the peak.

The pasting characteristics play an important role in the selection of a variety for use in the industry as a thickener and binder. Previous findings on the pasting behaviours of yam starches demonstrated that, in terms of peak viscosity, yam starches took an intermediate position between potato and cassava starches. Yam starches did not show a strong viscosity decrease upon further heating, as was the case for potato starch, and they showed higher final viscosity with cooling (Brunnschweiler et al., 2005). Thus, yam starch has been identified as a potential thickening and gelling agent in food. Therefore, the varietial differences observed in the pasting properties among the root and tuber crops in the present study could be useful in selecting a proper variety for a particular industrial application.

3.4. Swelling power

The swelling power of the tested starch samples varied from 42.2 g (yam Higurala) to 22.6 g (JPSP) per 1 g of dry starch (Fig. 1). A very high swelling power of starches was demonstrated by yams, followed by canna, cassava, taro, sweet potato and arrowroot. The highest swelling power shown in yam Higurala would be explained by its starch granule size and amylose content. Usually, starch with large granules swells rapidly when heated in water, and amylose is considered to be a resistant factor for high swelling (Tester & Morrison, 1990).

3.5. Thermal properties

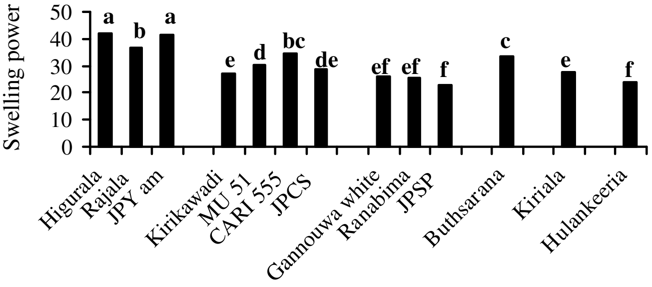
All thermal properties, peak gelatinization temperature (T_p), onset gelatinization temperature (T_o), and enthalpy for starch gelatinization (ΔH) varied significantly among starch samples tested (Table 3). The highest T_p and T_o were observed for taro, and the lowest, for one cassava variety, Kirikawadi. Among all samples, starches from cassava varieties gelatinized at lower temperatures with low energy. Unlike cassava starches, sweet potato starches required higher energy for gelatinization. Their peak gelatinization

Table 2
RVA pasting properties of starches from root and tuber crops, mainly of Sri Lanka

Common name	Peak viscosity (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback (RVU)	Pasting temperature (°C)	Peak time (min)
Yam						
Higurala	442^{a*}	242^{a}	239^{b}	40^{g}	76.8^{d}	3.9^{h}
Rajala	450^{a}	209^{b}	278^{a}	37^{h}	77.5^{c}	4.8^{d}
JPYam	224^{cd}	52^{i}	240^{b}	67^{c}	71.1^{g}	4.4^{c}
Cassava						
Kirikawadi	236^{c}	149^{d}	167^{f}	80^{a}	64.6^{f}	3.2^{i}
MU 51	180^{cde}	100^{f}	153^{g}	74^{b}	66.2^{i}	4.1^{f}
CARI 555	158^{def}	81^{g}	140^{h}	63^{d}	68.7^{h}	4.2^{e}
JPCS	135^{ef}	59^{h}	123^{i}	47^{f}	72.7^{f}	4.3^{d}
Sweet potato						
Gannoruwa white	139^{ef}	18^{l}	173^{e}	52^{e}	78.7^{b}	4.4^{c}
Ranamiba	152^{def}	22^{l}	189^{d}	59^{d}	77.6^{c}	5.0^{a}
JPSP	133^{ef}	37^{j}	139^{h}	42^{g}	80.8^{a}	4.5^{b}
Canna (Buthsarana)	348^{b}	172^{c}	217^{c}	40^{g}	73.5^{e}	3.8^{h}
Taro (Kiriala)	100^{f}	28^{k}	106^{j}	38^{h}	79.1^{b}	4.2^{f}
Arrowroot (Hulankeeriya)	128^{ef}	120^{e}	163^{f}	50^{ef}	73.1^{ef}	3.9^{g}

[*] Values followed by the same letters in the same column are not significantly different at $P < 0.05$ level.

(a). Swelling power (g/g)



(b). Enzyme digestibility (%)

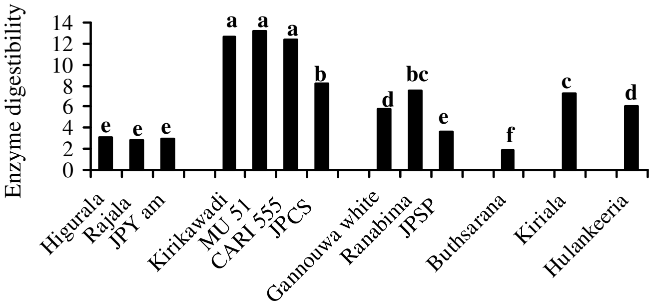


Fig. 1. Swelling power and enzyme digestibility of starches from root and tuber crops mainly of Sri Lanka. Bars labelled with different letters are significantly different at $P < 0.05$ level for each property separately.

temperatures were also very high and, among sweet potatoes, JPSP showed the highest T_p. Zhang and Oates (1999) observed that the T_p and T_o of different sweet potatoes were 83–78 °C and 81–75 °C, respectively. Although there could be differences in thermal properties according to the type and conditions of equipment used, the thermal properties observed for samples were relatively low. The same report gave the enthalpy for starch gelatinization of sweet potato as 11.95–14.83 J/g, and that was comparable with that of sweet potato from Sri Lanka.

Table 3
Thermal properties of starches from root and tuber crops, mainly of Sri Lanka

Sample	T_p (°C)	T_o (°C)	Enthalpy (J/g)
Yam			
Higurala	74.8^{c*}	72.2^{b}	20.3^{b}
Rajala	74.9^{c}	73.4^{b}	20.2^{a}
JPYam	67.3^{f}	64.3^{e}	20.3^{a}
Cassava			
Kirikawadi	59.4^{i}	54.5^{h}	13.0^{d}
MU 51	61.7^{h}	56.2^{g}	14.1^{d}
CARI 555	64.4^{g}	60.3^{f}	14.1^{d}
JPCS	69.7^{e}	65.9^{e}	16.8^{c}
Sweet potato			
Gannoruwa white	76.6^{b}	61.1^{f}	18.1^{bc}
Ranamiba	74.9^{c}	71.1^{c}	17.1^{c}
JPSP	77.8^{a}	70.6^{c}	17.7^{c}
Canna (Buthsarana)	71.3^{d}	68.7^{d}	20.1^{a}
Taro (Kiriala)	77.5^{a}	75.0^{a}	18.1^{bc}
Arrowroot (Hulankeeriya)	69.8^{e}	67.8^{d}	19.2^{ab}

T_p, Peak gelatinization temperature; T_o, onset gelatinization temperature; enthalpy, enthalpy for starch gelatinization.

[*] Values followed by the same letters in the same column are not significantly different at $P < 0.05$ level.

Yam starches showed the highest energetic gelatinization process. Even though the Japanese nagaimo, JPYam, gelatinized at relatively lower temperature, all starches from Sri Lankan yams required higher temperatures to reach peak gelatinization. Generally, yam starches showed narrower peaks in DSC thermograms than did cassava and sweet potato starches (data not shown). Within different crop species, varietal differences were significant regarding the thermal properties of starches.

3.6. Enzyme digestibility

The enzyme digestibility of the raw starch of tested samples by fungal crystalline glucoamylase is presented in Fig. 1. The highest enzyme digestibility of raw starch was shown by one cassava variety, MU 51, and all other Sri Lankan cassava varieties showed higher digestibility values, which did not vary significantly for the enzyme digestibility of MU 51. The highest resistance of raw starch to glucoamylase was shown by canna; in general, yam starch showed lower enzyme digestibility. Among sweet potato starches, JPSP had the lowest susceptibility to glucoamylase. Starches from canna and all yam varieties had larger granules, which was one of the major reasons for their lower digestibility. Szylit et al. (1978) reported that the low digestibility of yam starch could be due to the size of the granule, as well as the structural properties of the granules. Unlike cassava or sweet potato, yam usually has B-type starch granules (Gunaratne & Hoover, 2002; Jayakody, Hoover, Liu, & Weber, 2005), and the previous report also indicated the low digestibility of B-type than of A-type starch granules by enzymes (Szylit et al., 1978).

3.7. Correlation analysis among tested properties

Even though significant correlations were observed among some starch properties in the present study, as shown in Table 4, they were fewer and weaker than the correlations observed previously for rice or wheat (Noda, Nishiba, Sato, & Suda, 2003; Wickramasinghe et al., 2003). That, basically, may be due to a wide variation in terms of the botanical origin of the starch samples tested.

After the blue values of samples were converted into the apparent amylose content (except for taro), the correlation coefficient of the blue value with the amylose content was calculated. This coefficient was 0.47, only significant at the 10% error probability level. Furthermore, the blue value showed a positive correlation with the final viscosity (0.57), enthalpy (0.74), and median particle size (0.73) and a negative correlation with the enzyme digestibility (−0.81), but such significant correlations were not evident with the apparent amylose content.

The peak viscosity significantly correlated with the median particle size of the starch granule. Since this relationship is positive, very high peak viscosity was given for starches with larger granules, such as yams. As the swelling power, too, positively correlated with the peak viscosity, larger granules seemed to have swelled more, and the viscosity of the starch slurry increased during heating but dramatically reduced the viscosity due to granule disruption with further heat. This was demonstrated by our samples, in which the breakdown positively correlated with the granule size and peak viscosity. As the final viscosity positively correlated with the granule size and peak viscosity, this demonstrated that starches with larger granules made a thicker gel upon cooling in the viscosity profile. Thus, the properties of gels made by different starches would be primarily determined by the granule size, molecular composition of the starch polymers, and structural properties of the starch polymer.

According to our results, samples with higher peak viscosity, breakdown and final viscosity showed higher swelling power. However, no correlation was observed between the swelling power and blue value or granule size. Therefore, rather than the granule size or amylose content, other properties of starches would be important in determining the swelling power of a starch.

Raw starch digestibility was the most interesting property, correlating with most of the properties studied. It positively correlated with the setback and negatively with the starch granule size, blue value, final viscosity, pasting temperature, T_p, T_o, and enthalpy for starch gelatinization. Small starch granules with low amylose and low compactness could be easily digested by enzymes, and such starch was also easy to gelatinize. A negative relationship between the amylose content and the raw starch digestibility was shown in previous studies (Noda et al., 2003; Noda et al., 2002; Asaoka, Takahashi, Nakahira, Inouchi, & Fuwa, 1994).

Table 4
Correlation coefficients among starch properties of root and tuber crops, mainly of Sri Lanka

Property	Blue value	Peak viscosity	Breakdown	Final viscosity	Setback	Pasting temperature	Peak time	Enzyme digestibility	Swelling power	T_p	T_o	Enthalpy	Median particle size
Amylose content	0.49	0.18	0.25	0.08	0.06	−0.47	−0.37	−0.02	0.17	−0.45	−0.29	−0.04	0.40
Blue value		0.47	0.22	0.57^{*}	−0.49	0.33	0.10	-0.81^{**}	0.40	0.35	0.44	0.74^{**}	0.73^{**}
Peak viscosity			0.89^{**}	0.85^{**}	−0.28	0.03	−0.28	−0.47	0.72^{**}	0.06	0.25	0.45	0.73^{**}
Breakdown				0.63^{*}	−0.19	−0.20	-0.58^{*}	−0.23	0.56^{*}	−0.17	0.10	0.26	0.67^{*}
Final viscosity					−0.13	0.09	0.02	-0.59^{*}	0.68^{**}	0.10	0.23	0.60^{*}	0.70^{**}
Setback						-0.81^{**}	−0.23	0.72^{**}	−0.04	-0.84^{**}	-0.87^{**}	-0.71^{**}	−0.51
Pasting temperature							0.56^{*}	-0.69^{**}	−0.17	1.00^{**}	0.82^{**}	0.64^{*}	0.21
Peak time								−0.24	−0.10	0.53	0.40	0.25	−0.15
Enzyme digestibility									−0.31	-0.70^{**}	-0.72^{**}	-0.95^{**}	-0.79^{**}
Swelling power										−0.14	0.09	0.38	0.50
T_p											0.84^{**}	0.67^{*}	0.24
T_o												0.74^{**}	0.45
Enthalpy													0.77^{**}

T_p, Peak gelatinization temperature; T_o, onset gelatinization temperature; enthalpy, enthalpy for starch gelatinization.
* and ** are significant at $P < 0.05$ and $P < 0.01$ levels, respectively.

Among the thermal properties, the energy needed for starch gelatinization depended upon the granule size and blue value and, therefore, more energy was required to gelatinize starch with larger granules and higher blue values. However, T_p and T_o had no correlations with the granule size or blue value and were negatively correlated with the enzyme digestibility and setback but positively with the pasting temperature. Noda et al. (1998) demonstrated that the amylose content was independent of the starch gelatinization properties determined by DSC. That was also true for our samples except for the enthalpy for starch gelatinization.

4. Conclusions

Starches separated from different root and tuber crops, mainly of Sri Lanka, showed obvious differences in pasting, thermal, and other physicochemical properties studied. The blue value and starch granule size were important in determining the pasting, thermal, and other properties of starch.

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