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Physicochemical, morphological, thermal and rheological properties of starches separated from kernels of some Indian mango cultivars (*Mangifera indica* L.)☆

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Abstract

The starches separated from kernels of five different Indian mango cultivars (Chausa, Totapuri, Kuppi, Langra and Dashehari) were investigated for physicochemical, morphological, thermal and rheological properties. Mean granule length and width of the starches separated from mango cultivars ranged between 15.8–21.7 and 8.7–14.1 μm, respectively. The shape of starch granules varied from oval to elliptical. Amylose content of mango kernel starches from different cultivars ranged from 9.1 to 16.3%. Totapuri kernel starch, with the largest mean granular size, had the highest amylose content, while Chausa kernel starch, with the lowest mean granular size had the lowest amylose content. The transition temperatures (T_o, T_p and T_c) and enthalpy of gelatinization (ΔH_{gel}) were determined using differential scanning calorimetry (DSC). T_o, T_p and T_c varied from 73.4 to 76.3, 78.1 to 80.3 and 83.0 to 85.7 °C, respectively. Chausa kernel starch showed the highest T_o, T_p, T_c, ΔH_{gel} and peak height index among starches from different mango cultivars. The rheological properties of the starches from different mango cultivars measured using a dynamic rheometer, showed significant variations in the peak G', G'' and peak tan δ values. Totapuri kernel starch showed the highest peak G', G'', breakdown in G' and lowest peak tan δ values. The large-size granules of Totapuri kernel starch appeared to be associated with higher values of peak G' and G''. The turbidity of the gelatinized aqueous starch suspensions, from all mango cultivars, increased with increase in storage period. Dashehari starch paste showed lower turbidity values than other mango cultivars.

Keywords: Mango kernel starch; Physicochemical; Thermal; Morphological; Rheological; Amylose content

1. Introduction

Starch, the principle carbohydrate constituent of most plant materials, merits a detailed investigation to better understand its biochemical and functional characteristics as well as its variations. Extensive research has been conducted on the structure and functional properties of the main starches of commerce, such as wheat, corn, potato, and rice, due to their ready availability and their extensive utilization in food and non-food applications (Singh, Singh, Kaur, Sodhi, & Gill, 2003). Starches from different sources vary, particularly in their qualitative and quantitative make up, as well as in some of their physicochemical and functional properties. Identification of native starch sources is required for desired functionality and unique properties (Duxbury, 1989). The physical properties of starch granules have been determined by the fine structure of the polysaccharide and the percentage distributions of amylose and amylopectin (Boyer & Shannon, 1987). Starch granules from different sources have been characterized by size, shape, amount of minor components (such as lipids), and the amylose–amylopectin ratio. The literature contains very little information on isolation and properties of starches from non-conventional sources, such as seeds of fruits.

Mango (*Mangifera indica*) is an important fruit crop cultivated in tropical regions. Among fruits, mango

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occupies top position in India, covering an area of roughly 1.28 million hectares (Srivastva, 1998). India is the largest producer of mangoes in the world (11,500,000 Mt; FAO, 2002), the total world production being 25,760,848 Mt (FAO, 2002). After industrial processing of mango, considerable amounts of mango kernel (stones) are discarded as waste (Narasimha & Azeemoodin, 1989). Approximately 40–60% waste is generated during processing of mango, out of which peel and kernel constitute 12–15 and 15–20%, respectively. Mango kernel is rich in carbohydrates, fats, proteins and minerals (Anand & Maini, 1997). Mango kernel, on a dry weight basis, contains, on average, 58% starch, 2.9% reducing sugars, 5.7% proteins, 0.8% pectin, 9.3% fat and 1.1% tannins (Garg & Tandon, 1997). The kernel obtained after decortication of mango stone can be utilized as a supplement to wheat flour or for extraction of edible oils (Tandon & Kalra, 1989). Besides its use in animal feed, mango kernel flour can be utilized for edible purposes (Jain, 1961; Patel, Shukla, & Patel, 1971). The residue left after extraction of oil from mango kernel, usually termed as total waste, has sufficient amounts of starch. The researches on the characterization of starches from Indian potato, rice and corn cultivars have been reported in our earlier research papers (Kaur, Singh, & Sodhi, 2002; Singh & Singh, 2001; Sodhi & Singh, 2003). No information is available on starches separated from mango kernel. This prompted us to undertake the present investigation. The present study reports the physicochemical, thermal, morphological and rheological characteristics of starches separated from kernels of different Indian mango cultivars.

2. Materials and methods

2.1. Materials

Five mango cultivars (cv.), i.e. Chausa, Totapuri, Kuppi, Langra and Dashehari were procured from a local market, Amritsar, India, from the 2002 harvest.

2.2. Starch isolation

Mangoes from different cultivars were washed, peeled and the stones were separated from pulp using a pulper. Stones were washed to remove any traces of adhering pulp and then dried at 40 °C in a hot air cabinet drier for 10 h. Kernels of each cultivar were removed from the stones after breaking them open. Kernels were cut into small pieces (2 cm^2) and steeped in water containing 0.16% sodium hydrogen sulphite for 12 h at 50 °C. The steep water was drained off, and the kernels were ground in a laboratory blender. The ground slurry was screened through nylon cloth (100 mesh). The material left on the nylon cloth was washed thoroughly with distilled water. The filtrate slurry was allowed to stand for 1 h. The supernatant was removed by suction and the settled starch layer was resuspended in distilled water and centrifuged in wide-mouthed cups at 2800 rpm for 5 min. The upper non-white layer was scraped off. The white layer was resuspended in distilled water and re-centrifuged 3–4 times. The starch was then collected and dried in a vacuum oven at 50 °C/100 mm Hg for 6–7 h.

2.3. Physicochemical properties of starch

2.3.1. Amylose content

Amylose content of the isolated starches was determined by using the method of Williams, Kuzina, and Hlynka (1970).

2.3.2. Swelling power (g/g) and solubility (g/g)

Swelling power and solubility were determined, in triplicate, using the method of Leach, McCowen, and Schoch (1959).

2.3.3. Turbidity

Turbidity of starches from kernels of different mango cultivars was measured as described by Perera and Hoover (1999). A 1% aqueous suspension of starch from each mango kernel cultivar was heated in a water bath at 90 °C for 1 h with constant stirring. The suspension was cooled for 1 h at 30 °C. The samples were stored for 5 days at 4 °C in a refrigerator and turbidity was determined every 24 h by measuring absorbance at 640 nm against a water blank with a Shimadzu UV-1601 spectrophotometer (Shimadzu Corporation, Kyoto, Japan).

2.3.4. Water-binding capacity (WBC)

WBC of the starches from different mango cultivars was determined using the method described by Yamazaki (1953), as modified by Medcalf and Gilles (1965). A suspension of 5 g starch (dry weight) in 75 ml distilled water was agitated for 1 h and centrifuged (3000 × g) for 10 min. The free water was removed from wet starch, drained for ten minutes and wet starch was weighed.

2.4. Thermal properties

Thermal characteristics of isolated starches were studied using a differential scanning calorimeter- 821^e (Mettler Toledo, Switzerland) equipped with a thermal analysis data station. Starch (3.5 mg, dwb) was loaded into a 40 μl capacity aluminium pan (Mettler, ME-27331) and distilled water was added with the help of a Hamilton micro syringe to achieve a starch–water suspension containing 70% water. Samples were hermetically sealed and allowed to stand for 1 h at room temperature before heating in the DSC. The DSC ana-

lyser was calibrated using indium and an empty aluminium pan was used as reference. Sample pans were heated at a rate of 10 °C/min from 20 to 100 °C. Onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy of gelatinization (ΔH_{gel}) were calculated automatically. The gelatinization temperature range (R) was computed as $2(T_p–T_o)$ as described by Krueger, Knutson, Inglett, and Walker (1987). Enthalpies were calculated on a starch dry basis. The peak height index (PHI) was calculated by the ratio $\Delta H_{gel}/(T_p–T_o)$, as described by Krueger et al. (1987).

2.5. Morphological properties

Scanning electron micrographs were taken by a Jeol JSM-6100 scanning electron microscope (Jeol Ltd., Tokyo, Japan). Starch samples were suspended in ethanol to obtain a 1% suspension. One drop of the starch–ethanol solution was applied to an aluminium stub using double-sided adhesive tape and the starch was coated with gold–palladium (60:40). An accelerating potential of 10 kV was used during micrography.

2.6. Particle size analysis

Particle size analysis of starches was done using a Coulter small volume module model LS 230 laser light scattering particle size analyser. 0.25 grammes of mango kernel starch was combined with 3 ml of distilled water in a small glass vial and vortexed, followed by sonication for 1 h. Dried sample was completely deagglomerated after approximately 10 min of sonication at 40 °C. The sample was vortexed and approximately 10 drops were added to the sample port until the instrument read 45% polarization intensity differential scattering (PIDS) or 10–14% obscuration. Isopropanol was used as the suspension fluid within the instrument. The sample was allowed to equilibrate the isopropanol for 15 min before starting the analysis.

2.7. Rheological properties

A small amplitude oscillatory rheological measurement was made for starches from each mango kernel cultivar, with dynamic rheometer (Carri- Med CSL^2-100, TA Instruments Ltd., Surrey, England) equipped with parallel plate system (4 cm diameter). The gap size was set at 1000 μm. The strain and frequency were set at 0.5% and 1 Hz, respectively, for all determinations. The dynamic rheological properties, such as storage modulus (G'), loss modulus (G'') and loss factor (tan δ) were determined for starches from different mango cultivars. Starch suspensions of 20% (w/w) concentration were loaded onto the ram of the rheometer and covered with a thin layer of low-density silicon oil (to minimize evaporation losses). The starch samples were subjected to temperature sweep testing and were heated from 45 to 90 °C at the rate of 2 °C/min.

2.8. Statistical analysis

The data reported in all the tables are averages of triplicate observations. The data were subjected to statistical analysis using Minitab Statistical Software (Minitab Inc., USA).

3. Results and discussion

3.1. Physicochemical properties of mango kernel starches

The amylose contents of starches of different mango kernel cultivars differed significantly (Table 1). Totapuri, Langra, Kuppi, Dashehari and Chausa kernel starches showed amylose contents of 16.3, 14.0, 11.3, 9.7 and 9.1%, respectively. The amylose content observed for mango kernel starches was lower than amylose contents observed for corn and potato starches (Singh & Singh, 2003). The higher amylose content of Totapuri and Langra kernel starches may be due to the presence of more large-size granules. Peng, Gao, Abdel-Aal, Huel, and Chibbar (1999) also reported higher amylose content of large size A-type granules in the six wheat cultivars. Similar findings have been reported earlier for potato starches (Kaur et al., 2002). Swelling power of starches from different mango cultivars ranged from 18.0 to 19.7 g/g, the highest for Totapuri and lowest for Langra kernel starches. The solubility of the mango kernel starches ranged from 0.141 to 0.149 g/g. Dashehari mango starch showed significantly higher solubility than starches from Totapuri, Kuppi and Langra. The solubilities of Totapuri, Kuppi and Langra kernel starches did not differ significantly. Swelling power and solubility provide evidence of the magnitude of interaction between starch chains within the amorphous and crystalline domains. The extent of this interaction has been reported to be influenced by the amylose/amylopectin ratio, and by the characteristics of amylose and amylopectin in terms of molecular weight distribution, degree and length of branching, and conformation (Hoover, 2001). Swelling power observed for mango kernel starches was less than those reported earlier for rice (Sodhi & Singh, 2003) and potato starches (Kaur et al., 2002). WBC of mango kernel starches differed significantly (Table 1). WBC of starches from mango kernel cultivars ranged from 89.5 to 97.7%. Langra kernel starch showed significantly higher WBC than the starches from other mango cultivars. WBC of mango kernel starches was lower than those reported for different potato cultivars (Kaur et al., 2002). Loose association of amylose and amylopectin molecules in the starches

Table 1
Swelling power, solubility, water binding capacity and amylose content of starches separated from different mango kernel cultivars[a]

Mango cultivar	Swelling power (g/g)	Solubility (g/g)	Water-binding capacity (%)	Amylose content (%)
Chausa	18.1a	0.144ab	89.5a	9.1a
Totapuri	19.7b	0.141a	93.2b	16.3d
Kuppi	18.6ab	0.142a	93.4b	11.3b
Langra	18.0a	0.142a	97.7d	14.0c
Dashehari	18.9ab	0.149b	96.3c	9.7a

[a] Values with similar letters in a column do not differ significantly ($P < 0.05$).

has been reported to affect the WBC (Soni, Sharma, Bisen, Srivastava, & Gharia, 1987). The turbidity values of gelatinized starch suspensions from five mango cultivars are summarized in Table 2. Dashehari kernel starch paste showed lower turbidity values than other mango kernel starch pastes. The turbidity values of starch suspensions from all the mango cultivars increased progressively during storage. The granule swelling, granule remnants, leached amylose and amylopectin chain lengths have been reported to be responsible for turbidity development in starches during storage (Jacobson, Obanni, & BeMiller, 1997). The changes in turbidity during storage has been attributed to the interaction between leached amylose and amylopectin chains that lead to development of function zones, which might reflect or scatter a significant amount of light (Perera & Hoover, 1999). The turbidity value did not change significantly after 48 h of storage. This may be attributed to amylose aggregation and crystallization that are completed within the first few hours of storage while amylopectin aggregation and crystallization occur during later stages (Miles, Morris, Orford, & Ring, 1985).

3.2. Thermal properties of mango kernel starches

The results of DSC analysis of starches separated from kernels of different mango cultivars are summarized in Table 3. The transition temperatures (T_o; T_p; T_c), range 2(T_p–T_o), enthalpies of gelatinization (ΔH_{gel}) and peak height indices (PHI) of starches from different mango cultivars differ significantly. Chausa kernel starch showed the highest ΔH_{gel} value of 13.2 J/g, whereas Kuppi kernel showed the lowest ΔH_{gel} value of 12.0 J/g. Chausa kernel starch showed significantly higher T_o than starches from other mango cultivars, while the lowest was observed for Totapuri kernel starch. T_p and T_c of starches from different mango cultivars ranged from 77.9 to 80.2 and 83.0 to 85.7 °C, respectively. Kuppi kernel starch showed the lowest T_p and T_c of 77.9 and 83.0 °C, respectively while Chausa kernel starch showed the highest T_p and T_c. The transition temperatures observed for mango kernel starches were higher than those earlier observed for corn, rice, potato, and wheat starches (Singh et al., 2003). Totapuri and Langra kernel starches showed maximum R values while PHI were narrow for the same. Chausa kernel starch showed lower R values and higher PHI than other mango cultivars. The differences in the R values among the starches from different cultivars may be due to the presence of crystalline regions of different strength in the granule (Banks & Greenwood, 1975). Totapuri kernel starch, with low T_o, broad R, low PHI had irregular and large-size granules. Yamin, Lee, Pollak, and White (1999) reported that low T_o, broad R and low PHI of starches might be due to presence of irregularly-shaped granules. Krueger et al. (1987) reported that the higher the amylopectin content of the starch, the narrower was the temperature range of gelatinization. Knutson, Khoo, Cluskey and Inglett (1982) also found that more heterogeneous granules broaden the enthalpy range.

Table 2
Effect of storage duration on the turbidity of starches separated from different mango kernel cultivars[a]

Mango cultivar	Turbidity (absorbance at 640 nm)				
	0 h	24 h	48 h	72 h	120 h
Chausa	1.47ab	2.18c	2.20b	2.26b	2.35b
Totapuri	1.57b	1.95ab	2.17ab	2.24b	2.35b
Kuppi	1.49ab	1.83a	2.06a	2.14a	2.25a
Langra	1.52ab	2.06b	2.22b	2.27b	2.37b
Dashehari	1.41a	1.89ab	2.09a	2.18ab	2.27a

[a] Values with similar letters in a column do not differ significantly ($P < 0.05$).

3.3. Morphological properties of mango kernel starches

The scanning electron micrographs in Fig. 1 show the presence of starch granules varying in size and shape from small to large and oval to elliptical, respectively. A representative curve of particle size analysis of mango kernel starch is shown in Fig. 2. The figure clearly indicates that particle size of majority of starch granules ranged from 7 to 28 μm. Some granules also showed particle sizes ranging from 1.5 to 6 μm. The starches isolated from the kernels of five mango cultivars differed

significantly in granule size and shape (Table 4). The mango starch granules ranged from 10.9 to 27.2 μm in length and from 6.5 to 16.3 μm in width. The shape and size of starch granules has been reported to vary with plant species and maturity (Manners, 1974). Totapuri kernel starch showed the presence of large-size granules with mean granule length and width of 21.7 and 14.1 μm, respectively. Dashehari kernel starch showed the presence of uniform-size oval granules. The smallest mean granule length and width, of 15.8 and 8.7 μm, respectively, was observed in Chausa kernel starch. The starch granules of the mango kernel cultivars were observed to be morphologically similar to legume starch granules and different from corn, rice, wheat and potato

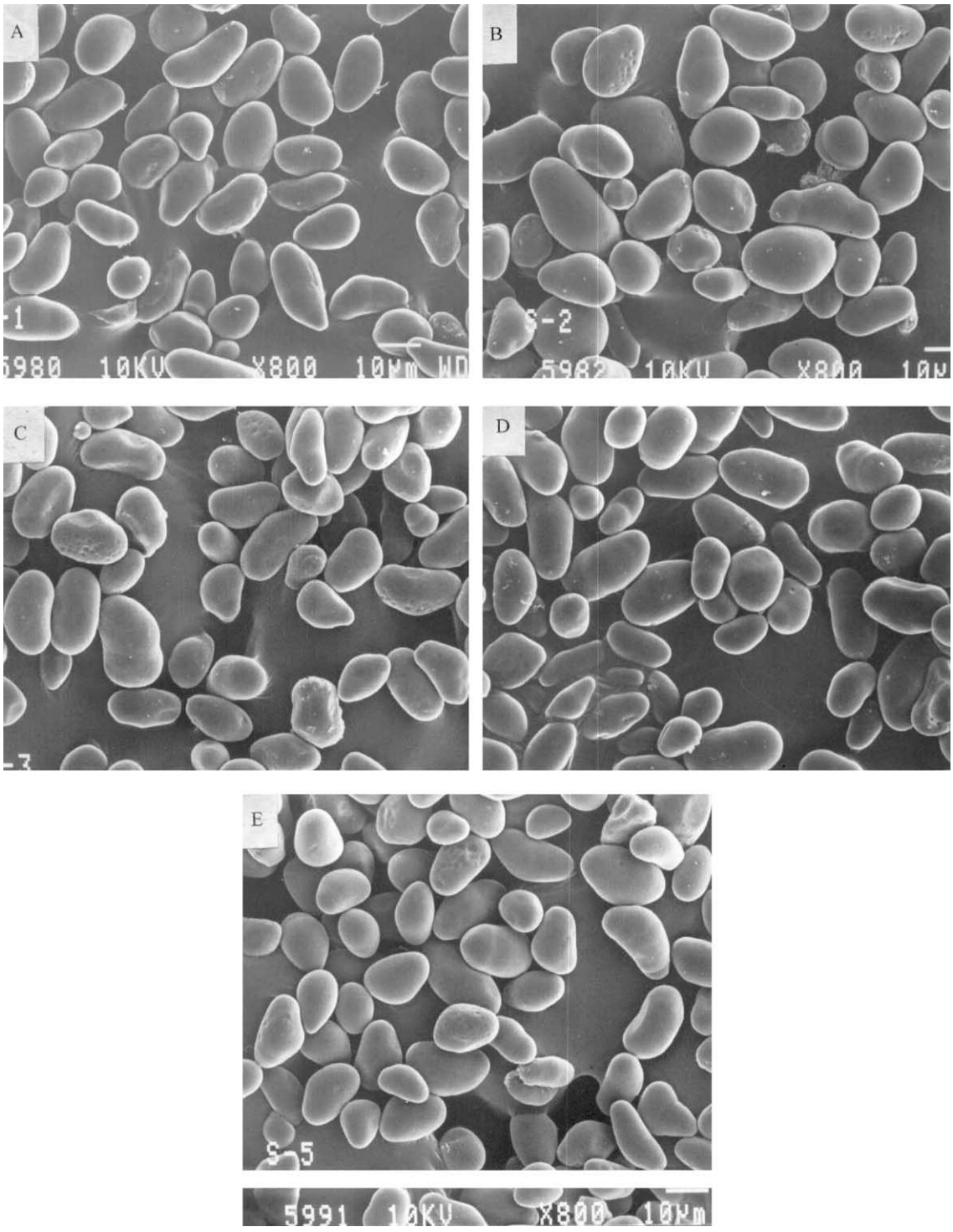

Fig. 1. Scanning electron micrographs (SEM) of starches separated from different mango kernel cultivars: (A) Chausa, (B) Totapuri, (C) Kuppi, (D) Langra, (E) Dashehari.

Table 3
Thermal properties of starches separated from different mango kernel cultivars[a]

Mango cultivar	T_o(°C)	T_p(°C)	T_c(°C)	ΔH_{gel} (J/g)	PHI	R
Chausa	76.3d	80.2c	85.7c	13.2b	3.4c	7.8b
Totapuri	73.4a	78.1ab	84.3b	12.8ab	2.7a	9.5c
Kuppi	74.4b	77.9a	83.0a	12.0a	3.4c	7.1a
Langra	75.2c	80.2c	85.3bc	12.8ab	2.5a	10.1d
Dashehari	74.7bc	78.5b	84.1ab	12.2a	3.2b	7.6ab

T_o = onset temperature, T_p = peak temperature, R = gelatinization range $2(T_p - T_o)$; ΔH_{gel} = Enthalpy of gelatinization (dwb, based on starch weight), PHI = peak height index $\Delta H_{gel}/(T_p - T_o)$.

[a] Values with similar letters in a column do not differ significantly ($P < 0.05$).

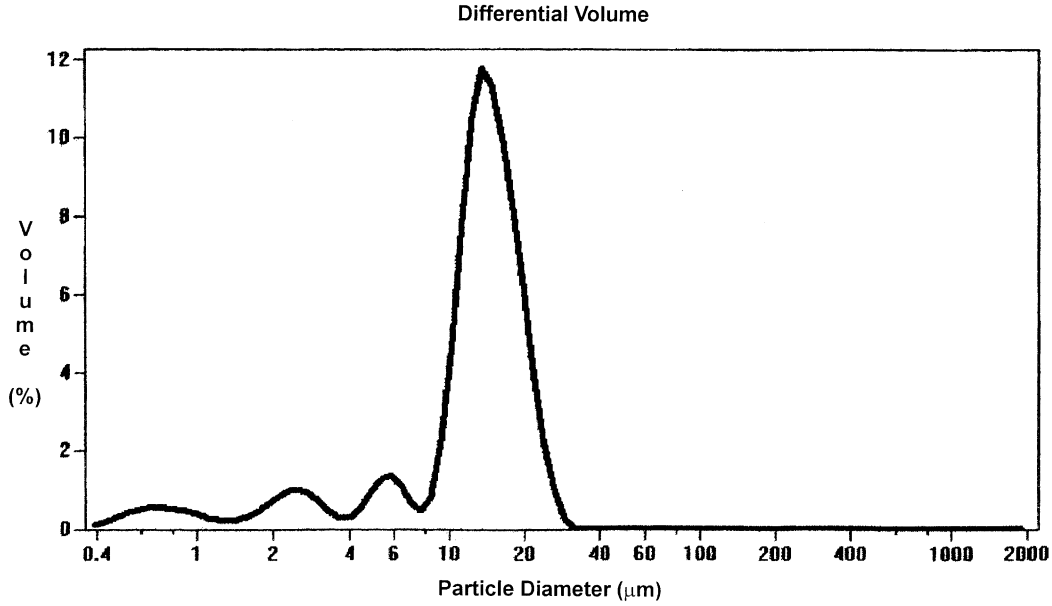

Fig. 2. Particle size analysis of the starches separated from different mango kernel cultivars.

Table 4
Particle size of mango kernel starch granules from different cultivars[a]

Mango cultivar	Mean granule length (μm)	Length range (μm)	Mean granule width (μm)	Width range (μm)
Chausa	15.8a	10.9–20.7	8.7a	6.5–10.9
Totapuri	21.7c	16.3–27.2	14.1c	11.9–16.3
Kuppi	16.3ab	10.9–21.7	11.4bc	9.8–13.0
Langra	17.7b	13.0–22.3	10.3b	8.7–11.9
Dashehari	15.8a	11.9–19.6	10.3b	8.6–11.9

[a] Values with similar letters in a column do not differ significantly ($P < 0.05$).

starch granules. The surfaces of the majority of granules were smooth. Some granules showed the presence of pores when viewed at 800× magnification. These surface pores were similar to those observed in corn starch granules by Fannon and BeMiller (1992).

3.4. Rheological properties of mango kernel starches

The rheological properties of starches separated from different mango kernel cultivars are illustrated in Figs. 3–7. Among the five cultivars studied, Chausa kernel starch showed the highest TG' of 89.4 °C during the heating cycle, whereas Totapuri kernel starch showed the lowest TG' of 86.9 °C. The G' and G'' of all five cultivars increased progressively during heating and then dropped. The mango kernel starch granules seemed to be less deformable, as indicated by their lower swelling tendency. Eliasson (1986) observed that less swollen granules are less deformable. Highest peaks, G' and G'', of 44,502 and 14,920 Pa, respectively, were observed for Totapuri kernel starch while these were lowest for Chausa kernel starch (Table 5). Peaks G' and G'',

Table 5
Rheological properties of starches from different mango kernel cultivars during heating[a]

Mango cultivar	TG' (°C)	Peak G' (Pa)	Peak G'' (Pa)	Breakdown in G' (Pa)	Peak tan δ
Chausa	89.4c	29,003a	11,231a	15,500a	0.387b
Totapuri	86.9a	44,502d	14,920b	39,502d	0.335a
Kuppi	87.4ab	33,209b	11,600a	26,509b	0.349a
Langra	87.8b	42,701c	14,500b	34,663c	0.339a
Dashehari	87.5ab	30,240ab	11,753a	17,140a	0.388b

[a] Values with similar letters in a column do not differ significantly ($P < 0.05$).

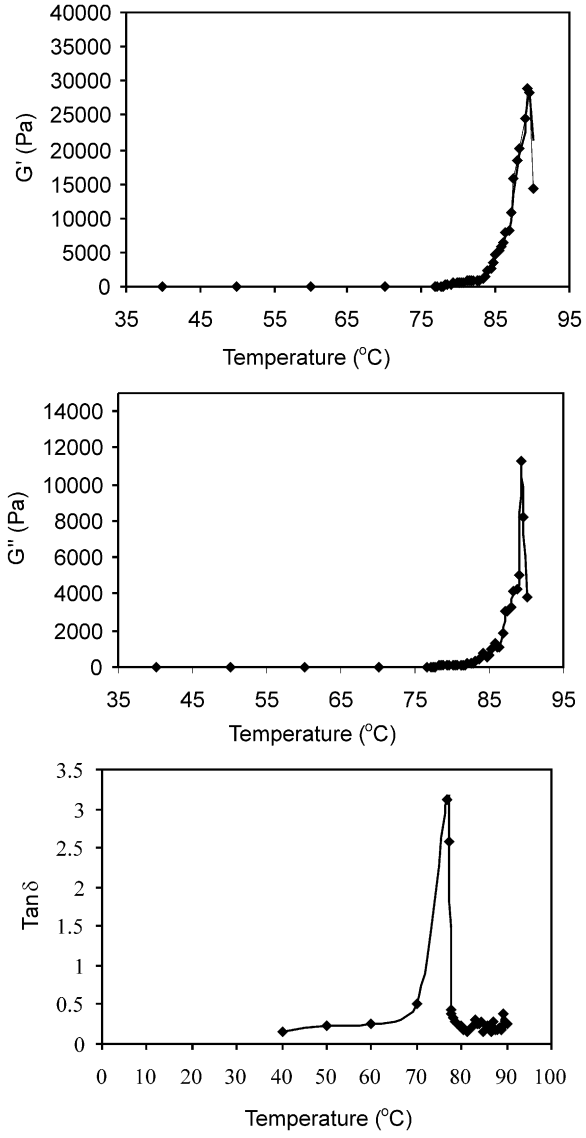

Fig. 3. Storage modulus (G'), Loss modulus (G'') and Loss factor (tan δ) of starch from cv. Chausa during heating.

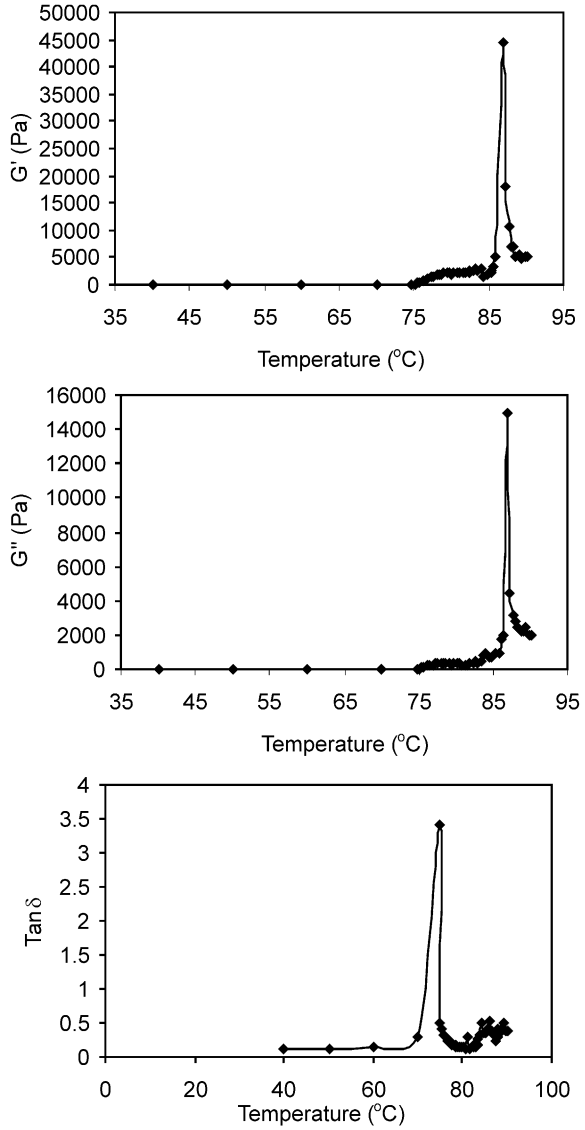

Fig. 4. Storage modulus (G'), Loss modulus (G'') and Loss factor (tan δ) of starch from cv. Totapuri during heating.

observed for mango kernel starches, were higher than rice starches (Sodhi & Singh, 2003) and lower than potato starches (Singh & Singh, 2001). The difference in the G', G'' and tan δ during the heating cycle may be attributed to the difference in amylose contents and granular structures (Svegmark & Hermansson, 1993). Results clearly illustrated that the starches with lower amylose contents showed lower peaks G' and G''. Similar inferences have been drawn for potato and rice starches (Kaur et al., 2002; Sodhi & Singh, 2003).

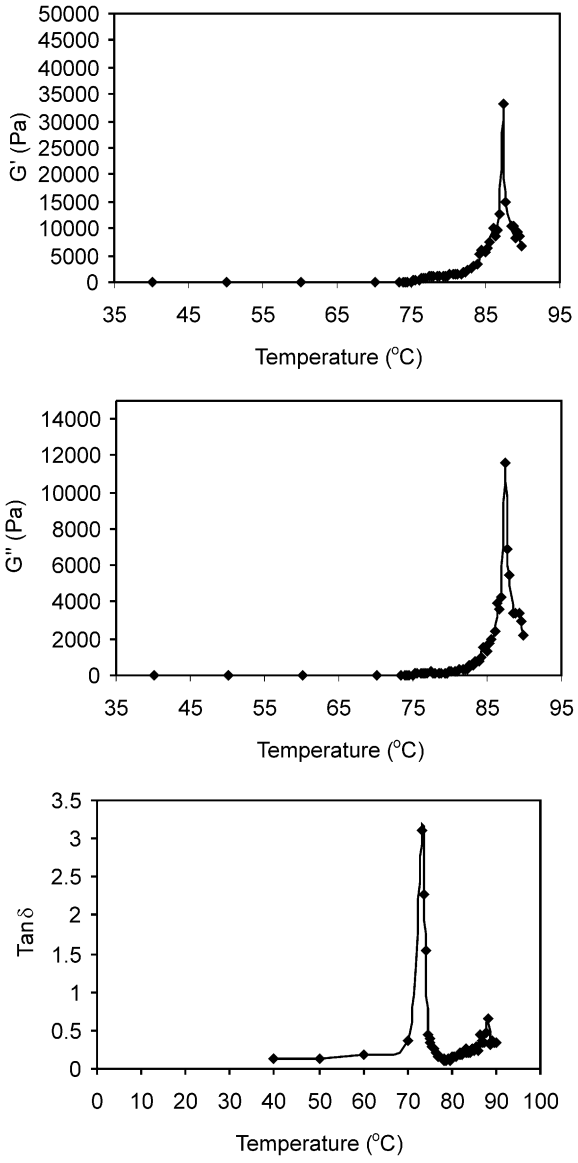

Fig. 5. Storage modulus (G'), Loss modulus (G'') and Loss factor (tan δ) of starch from cv. Kuppi during heating.

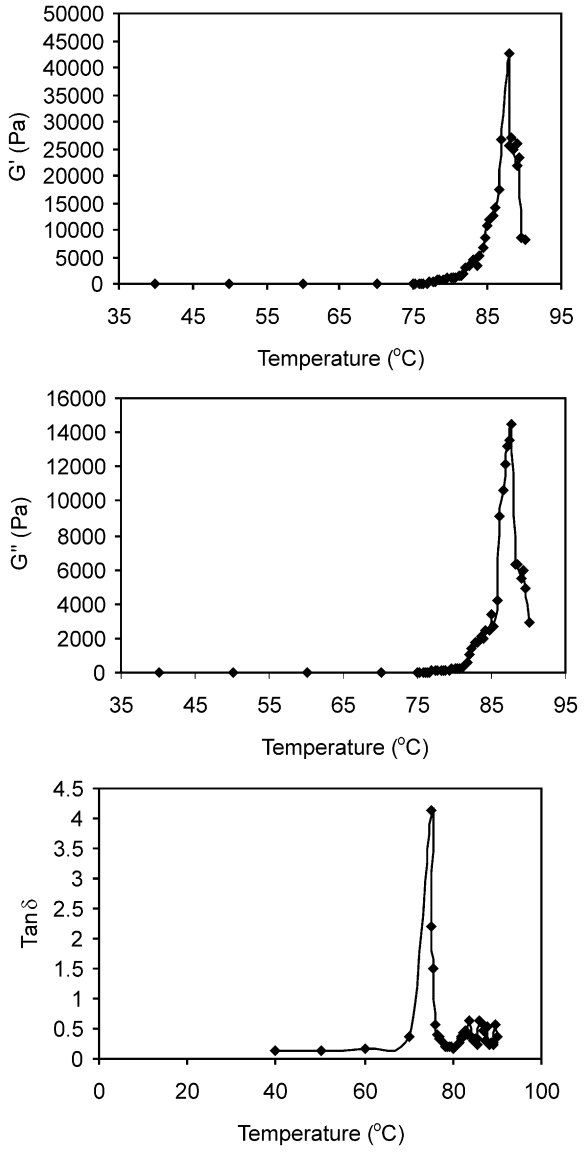

Fig. 6. Storage modulus (G'), Loss modulus (G'') and Loss factor (tan δ) of starch from cv. Langra during heating.

Disintegration of starch granules occurred as the heating continued. The breakdown in G' is the difference between peak G' at TG' and minimum G' at 90 °C. Maximum breakdown was observed in Totapuri kernel starch while it was lowest in Chausa kernel starch. The differences in breakdown values among the mango kernel starches may be attributed to the differences in morphological characteristics of starch granules and peak G' values. The loss factor, tan δ (G''/G') is the ratio of energy lost to energy stored during a cycle (Ferry, 1970). Peak tan δ values of starches from all the cultivars were <1 (Figs. 3–7). Peak tan δ values for Chausa and Dashehari kernel starches were significantly higher than for starches from other mango cultivars.

4. Conclusion

Starches separated from various mango kernel cultivars showed significant differences in physicochemical, morphological, thermal and rheological properties. Amylose content of mango kernel starches was observed to be lower than those of corn and potato starches. Mango kernel starches showed oval-to elliptical-shaped granules, similar to those of legume starch granules. Some mango starch granules showed the presence of surface pores similar to those found in corn starch granules. Transition temperatures of the mango kernel starches were higher than those of corn, rice, wheat and potato. Peak G' and G'', observed for mango

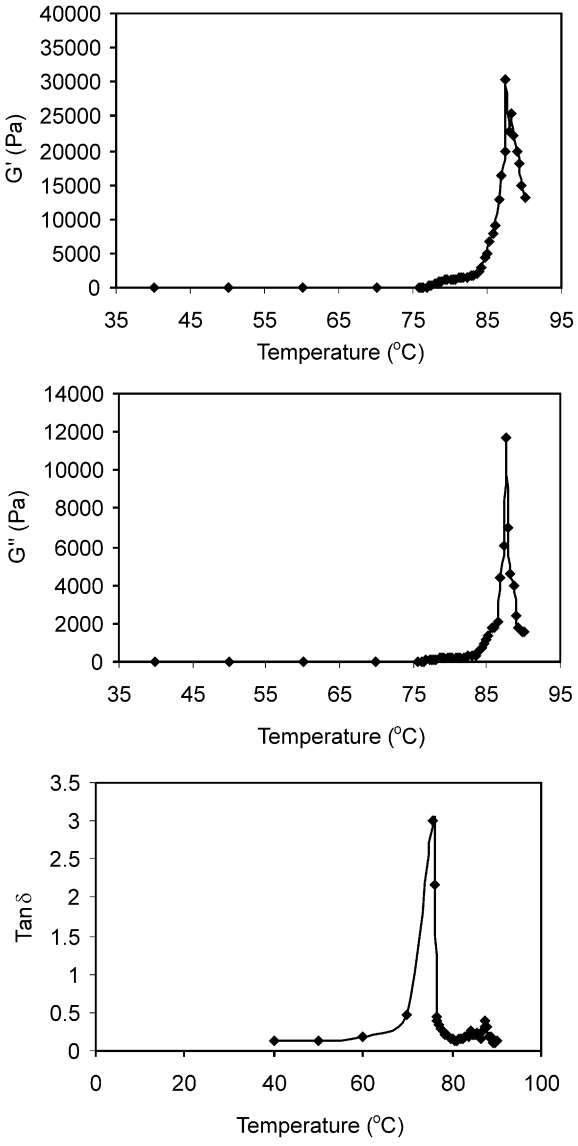

Fig. 7. Storage modulus (G'), Loss modulus (G'') and Loss factor (tan δ) of starch from cv. Dashehari during heating.

kernel starches, were higher than those of rice starches and lower than those of potato starches. Various properties of mango kernel starches are comparable with the starches from corn, wheat, rice and potato and could be effectively utilized as a starch source. There is thus, a need to carry out detailed investigation involving more mango cultivars to gather further information on various properties of their starches.

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