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# Studies on the morphological, thermal and rheological properties of starch separated from some Indian potato cultivars

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**Abstract**

The starches separated from five different Indian potato cultivars (Kufri Chandermukhi, Kufri Badshah, Kufri Jyoti, Kufri Sindhuri and S1) were investigated for morphological, thermal, rheological, turbidity and water-binding properties. The starch separated from all the five potato cultivars had a granule size ranging between 15–20 μm and 20–45 μm. The shape of starch granules varied from oval to irregular or cuboidal. Starch isolated from cv. Kufri Badshah had largest irregular or cubiodal granules while starch from cv. Kufri Chandermukhi had small and oval granules. The transition temperatures and enthalpy of gelatinization ($\Delta H_{gel}$) were determined using differential scanning calorimetry (DSC). The enthalpy of retrogradation ($\Delta H_{ret}$) of gelatinized starch was also determined after 14 days of storage at 4°C using DSC. Kufri Chandermukhi starch showed the lowest $\Delta H_{gel}$ and $\Delta H_{ret}$ while Kufri Badshah starch showed the highest values. $\Delta H_{gel}$ and $\Delta H_{ret}$ values of 12.55 J/g and 6.42J/g, respectively, for Kufri Chandermukhi starch against 13.85 J/g and 8.61 J/g, respectively, for Kufri Bhadshah starch were observed. Rheological properties of starches from different potato cultivars, measured using the Dynamic Rheometer during heating and cooling, also differed significantly. The starch from cv. Kufri Badshah showed the highest peak $G'$ and $G''$ and lowest tan δ. The starches having higher peak $G'$($G'$ at gelatinization temperature) showed higher breakdown in $G'$ and vice versa. The turbidity of gelatinized aqueous starch suspensions from all potato cultivars increased with increase in storage period. Starches with low water binding capacity had higher $G'$ and $G''$ and lower tan δ values. © 2001 Elsevier Science Ltd. All rights reserved.

*Keywords:* Morphological; Thermal; Rheological; Turbidity; Water binding capacity; Potato starch

## 1. Introduction

Potato starch is used for its characteristics, which differ significantly from those of starch from other plant sources (Madsen & Christensen, 1996). Identification of native starch sources is required for desired functionality and unique properties (Duxbury, 1989). Barichello and Yada (1991) suggested that paste characteristics and other physicochemical properties of starches vary with genotype and cultural practices. Hopkins and Gormley (2000) reported the rheological properties of pastes and gels made from starch isolated from different Irish potato cultivars. Kim, Wiesenborn, Orr, and Grant (1995) and Wiesenborn, Orr, Casper, and Tacke (1994) reported the paste behaviour from various potato genotypes and correlated the physicochemical characteristics with functional properties. McComber, Osman, and Lohnes (1988) studied paste characteristics from four potato cultivars and suggested that synthetically cross-linked starches might be replaced by native starch sources with desired characteristics. Many methods of characterizing starch have been developed, which could be used for screening large number of genotypes for unique properties (Kim et al., 1995). Scanning Electron Microscopy (SEM) has been used to relate granule morphology to starch genotype (Fannon, Hauber, & BeMiller, 1992a). SEM has also been used to relate paste structures to paste properties (Fannon & BeMiller, 1992c; Fannon, Hauber, & BeMiller, 1992b). Laser light scattering has been used to characterize granule diameter, based on the assumption that granules are spherical, but this technique may not be accurate for potato starch granules which are slightly oblong, irregular or cuboidal (Wiesenborn et al., 1994). Differential Scanning Calorimetery (DSC) has been applied in many studies of thermal properties of starch since its first use by Stevens and Elton (1971). Starch transition temperatures

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and gelatinization enthalpies by DSC may be related to characteristics of the starch granule, such as degree of crystallinity (Krueger, Knutson, Inglett, and Walker, 1987). Kim et al. (1995) have studied the thermal properties of 42 potato cultivars and correlated these properties with physicochemical characteristics. Starch exhibits unique viscosity behaviour with change of temperature, concentration and shear rate (Nurul, Azemi, & Manan, 1999). The Brabender viscoamylograph has been extensively used for measuring starch paste viscosity in which viscosity is plotted versus time during a standard cycle of heating with continuous stirring (Wiesenborn et al., 1994). Many researchers have used the dynamic rheometer for studying the viscoelastic or rheological properties of starches (Hsu, Lu, & Huang, 2000; Lii, Tsai, & Tseng, 1996; Tsai, Li, & Lii, 1997). Tsai et al. (1997) reported the effect of granular structure of rice starch on the pasting behaviour using a dynamic rheometer. Fannon and BeMiller (1992) correlated the structural differences of swollen granule remnants with the rheological behaviour of starch. After gelatinization and during cooling, the starch chains in the gelatinized paste associate and this leads to the formation of a more ordered structure which causes turbidity effects. Perera and Hoover (1999) studied turbidity effects on native, hydroxypropylated, alkali-treated and defatted potato starch. The objective of the present study was to investigate the morphological, thermal and rheological characteristics of starches separated from different Indian potato cultivars.

## 2. Material and methods

### 2.1. Materials

The potatoes of five cultivars (cv.) i.e. Kufri Chandermukhi, Kufri Badshah, Kufri Jyoti, Kufri Sindhuri and S1, were procured from Sangha Potato Farms, Jalandhar, India from the 1999 harvest. Uniform-size potatoes were selected from each cultivar before starch isolation.

### 2.2. Starch isolation

Potatoes were washed, brushed and peeled. The eyes and all bruises were pitted out. Immediately after peeling, the potatoes were cut into small pieces (4 $cm^2$) and dipped in water containing a small amount of potassium metabisulfite (35 g/100 l). The pieces with dark spots were discarded. The juice was extracted from potato pieces using a laboratory scale juicer. A small quantity of potassium metabisulfite (5 g/l) was added to the juice to avoid browning. The juice was filtered through muslin cloth. The residue left on the muslin cloth was washed with distilled water, until only small amounts of starch were passing the muslin cloth. Filtrate was collected in a glass beaker and residue left on the muslin cloth was discarded. The beaker containing filtrate was kept undisturbed over night. A solid layer of starch settled down. The supernatant liquid was decanted, the starch layer was reslurried in distilled water and, again, starch was allowed to settle. This was repeated for 4–5 times until the supernatant become transparent. The starch cake was collected and dried at a temperature of 40°C in a hot-air cabinet drier.

### 2.3. Scanning electron microscopy (SEM)

Scanning electron micrographs were obtained with a scanning electron microscope (Jeol JSM-6100, Jeol Ltd., Tokyo, Japan). Starch samples were suspended in ethanol to obtain a 1% suspension. One drop of the starch–ethanol solution was applied on an aluminium stub, and the starch was coated with gold-palladium (60:40). An accelerating potential of 15 kV was used during micrography.

### 2.4. DSC

Thermal properties of isolated starches were analyzed using a DSC-821$^e$ (Mettler Toledo, Switzerland) equipped with a thermal analysis data station. Starch (3.5 mg, dry weight basis) was weighed into a 40 μl capacity aluminium pan (Mettler, ME-27331) and distilled water was added with the help of a Hamilton microsyringe to achieve a starch–water suspension containing 70%

Table 1
Differential scanning calorimetry (DSC) Thermal properties of starch separated from different potato cultivars[a]

| Cultivar | $T_o$(°C) | $T_p$(°C) | $T_c$(°C) | $\Delta H_{gel}$ J/g | PHI | $R$ | $\Delta H_{ret}$ J/g | %$R$ |
|---|---|---|---|---|---|---|---|---|
| Kufri Chandermuki | 60.27bc | 63.39a | 67.28a | 12.55a | 4.022c | 7.01a | 6.42a | 51.50a |
| Kufri Badshah | 59.72a | 63.45a | 68.35c | 13.85c | 3.713ab | 8.63c | 8.61d | 62.16e |
| Kufri Jyoti | 59.86ab | 63.26a | 67.66ab | 13.68c | 4.023c | 7.80b | 7.53c | 55.04c |
| Kufri Sindhuri | 60.70c | 64.58b | 70.34d | 13.38b | 3.439a | 9.65d | 7.84c | 58.59d |
| S1 | 59.78a | 63.41a | 68.00bc | 13.36b | 3.680a | 8.21bc | 7.12b | 53.3b |

[a] $T_o$ = onset temperature, $T_p$ = peak temperature, $R$ = gelatinization range ($T_c$–$T_o$); $\Delta H_{gel}$ = Enthalpy of gelatinization (dwb, based on starch weight), PHI = peak height index $\Delta H_{gel}$/ ($T_p$–$T_o$), $\Delta H_{ret}$ = enthalpy of retrogradation,%$R$ = percentage of retrogradation (ratio of enthalpy of gelatinization to enthalpy of retrogradation). Values with similar superscripts in column do not differ significantly ($P < 0.05$).

water. Samples were hermetically sealed and allowed to stand for 1 h at room temperature before heating in DSC. The DSC analyzer 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 ($T_c$), peak temperature ($T_p$), conclusion temperature ($T_c$) and enthalpy of gelatinization ($\Delta H_{gel}$) were calculated automatically. Because the peaks were symmetrical the gelatinization range ($R$) was computed as ($T_c - T_o$) as described by Vasanthan and Bhatty (1996). Enthalpies were calculated on starch dry basis. The peak height index (PHI) was calculated by the ratio $\Delta H/ (T_p - T_o)$, as described by Krueger et al (1987).

After cooling, the samples were stored in the refrigerator at 4°C for 14 days. Retrogradation was measured by reheating the sample pans containing the starches of five cultivars at the rate of 10°C /min from 20 to 100°C. The enthalpy of retrogradation ($\Delta H_{ret}$) was calculated automatically and percentage of retrogradation (%$R$) was calculated from the ratio of $\Delta H$ of retrogradation to $\Delta H$ of gelatinization (White, Abbas, & Johnson, 1989).

### 2.5. Rheological properties

A small amplitude oscillatory rheological measurement was made for starches from each potato cultivar, with a dynamic rheometer (Carri-Med CSL$^2$-100, TA Instruments Ltd, Surrey, UK) equipped with parallel plate system (4 cm dia). 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 potato cultivars. Starch suspensions of 20% (w/w) concentration were loaded on the ram of the rheometer and covered with a thin layer of low-density silicone oil (to minimize evaporation losses). The starch samples were

Table 2
Rheological properties of starch separated from different potato cultivars during heating[a]

| Cultivar | $TG'$(°C) | Peak $G'$(Pa) | Peak $G''$(Pa) | Breakdown in $G'$(Pa) | Peak tan δ |
|---|---|---|---|---|---|
| Kufri Chandermukhi | 60.6b | 34,430a | 25,500a | 11,510a | 0.8549d |
| Kufri Badshah | 54.5a | 109,600d | 38,130c | 52,830e | 0.3498a |
| Kufri Jyoti | 54.6a | 88,630c | 35,960b | 28,420c | 0.6657c |
| Kufri Sindhuri | 60.0b | 59,190b | 34,960b | 21,120b | 0.6816c |
| S1 | 54.7ab | 99,550c | 37,000c | 34,000d | 0.5907b |

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

Table 3
Rheological properties of starches from different potato cultivars during cooling[a]

| Cultivar | Peak $G'$ (Pa) | Peak $G''$ (Pa) | Peak tan δ |
|---|---|---|---|
| Kufri Chandermukhi | 18,250a | 8295a | 0.454d |
| Kufri Badshah | 738,000e | 108,000e | 0.146a |
| Kufri Jyoti | 424,300c | 88,220c | 0.207b |
| Kufri Sindhuri | 126,100b | 48,480b | 0.384c |
| S1 | 560,500d | 90,860c | 0.1621a |

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

Table 4
Effect of storage conditions on the turbidity and WBC of starch from different potato cultivars[a]

| Cultivar | Turbidity (Absorbance at 640 nm) | | | | WBC (%) |
|---|---|---|---|---|---|
| | 2nd day | 3rd day | 4th day | 5th day | |
| Kufri Chandermukhi | 1.186b | 1.356b | 1.495ab | 1.683b | 90.8b |
| Kufri Badshah | 0.838a | 1.110a | 1.410a | 1.465a | 89.2a |
| Kufri Jyoti | 1.029b | 1.308b | 1.533ab | 1.635ab | 91.0b |
| Kufri Sindhuri | 1.147b | 1.368b | 1.602b | 1.675b | 89.9ab |
| S1 | 0.766a | 1.129a | 1.466ab | 1.538ab | 89.2a |

[a] WBC = water-binding capacity (% dwb). Values with similar superscripts in column do not differ significantly ($P < 0.05$).

heated from 30 to 75°C at a rate of 2°C/ min and cooled from 75°C to 35°C at the rate of 5°C/ min.

### 2.6. Turbidity

Turbidity of starches from different potato cv. was measured as described by Perera and Hoover (1999). A 2% aqueous suspension of starch from each potato cultivar was heated in a boiling water bath 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).

### 2.7. Water binding capacity (WBC)

A method described by Yamazaki (1953), as modified by Medcalf and Gilles (1965), was adopted for measuring WBC of starch from different potato cultivars. A suspension of 5 g starch (dwb) in 75 ml distilled water was agitated for 1 h and centrifuged ($3000\times g$) for 10 min. The free water was decanted from wet starch, drained for 10 min, and wet starch was weighed.

### 2.8. Statistical analysis

The data reported are average of triplicate observations. The data reported in Tables 1–4 (see below) were

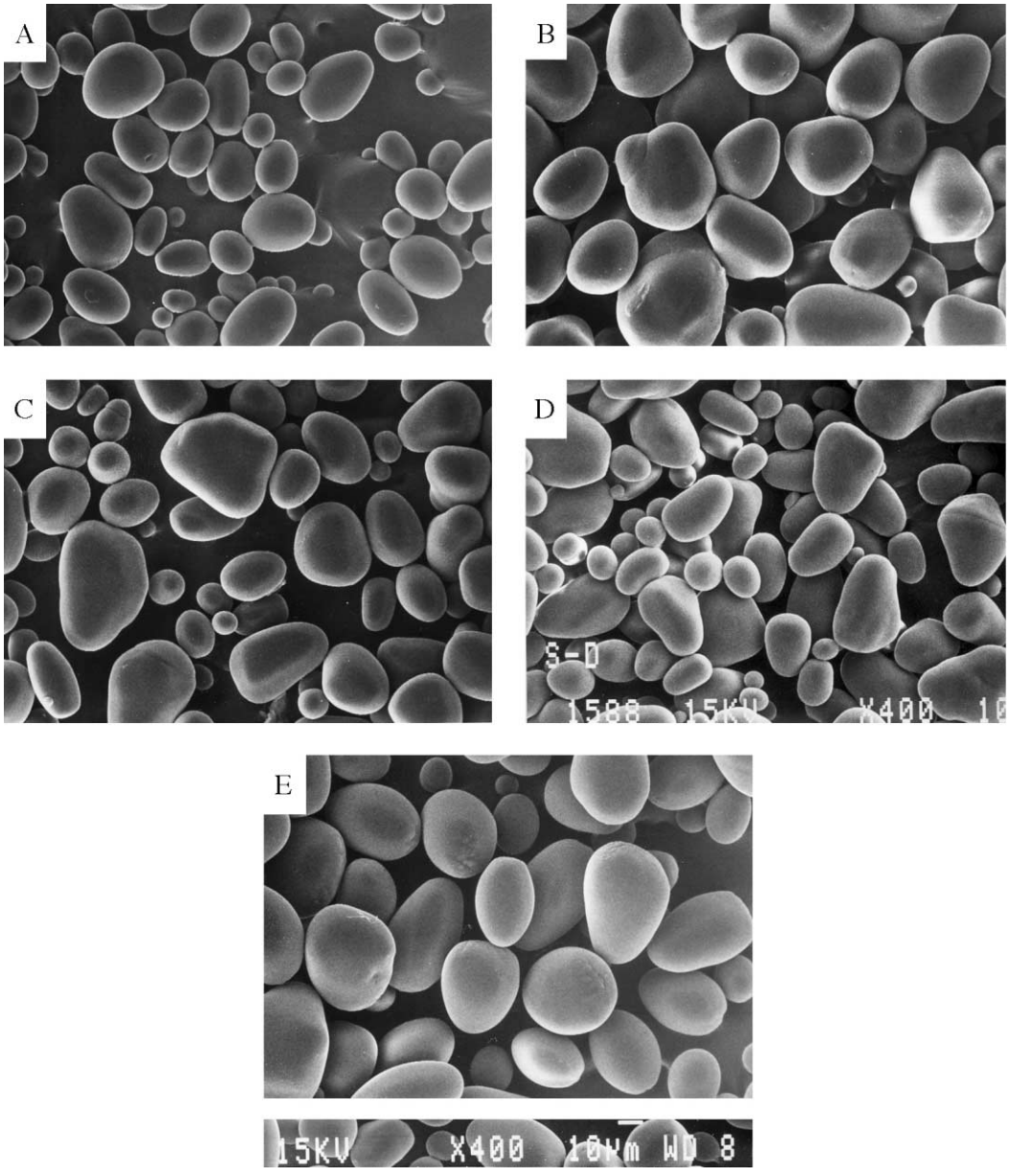


Fig. 1. Scanning electron micrographs (SEM) of starches separated from different potato cultivars (A) Kufri Chandermukhi, (B) Kufri Badshah, (C) Kufri Jyoti, (D) Kufri Sindhuri, (E) S1.

subjected to statistical analysis using Minitab software (State College, PA).

## 3. Results and discussion

### 3.1. Scanning electron microscopy (SEM)

The starches isolated from the five potato cultivars differed significantly in granule size and shape. Starch granules ranged from large to small and oval to irregular or cuboidal with diameter ranges between 15–20 μm and 20–45 μm, respectively, for small and large granules (Fig. 1). The surface of the granules appeared to be smooth when viewed at 400 × magnification. Kufri Badshah starch showed the presence of irregular or cubiodal granules in large number and very much less or negligible numbers of small and oval granules. S1 starch also showed the presence of large irregular or cuboidal granules with a few small oval granules. Starch separated from cv. Kufri Chandermukhi showed large numbers of small and large oval granules. Small oval to round and irregular or cuboidal granules, in fairly large numbers, were observed in Kufri Jyoti and Kufri Sindhuri starches. The variation in size and shape of starch granules may be due to the biological origin (Svegmark & Hermansson, 1993). The morphology of starch granules depends on the biochemistry of the chloroplast or amyloplast, as well as physiology of the plant (Badenhuizen, 1969).

### 3.2. DSC

#### 3.2.1. Gelatinization properties

The results of DSC analysis of starches separated from different potato cultivars are summarized in Table 1. The transition temperatures ( $T_o$; $T_p$; and $T_c$ ), range ($T_c$–$T_o$), enthalpies of gelatinization ($\Delta H_{gel}$) and Peak height indices (PHI) of starches from different potato cultivars differ significantly. Kufri Badshah starch showed highest $\Delta H_{gel}$ value of 13.85 J/g and Kufri Chandermukhi starch showed the lowest $\Delta H_{gel}$ value of 12.55 J/g. Kufri Sindhuri starch had the highest $T_o$ (60.69°C), followed by Kufri Chandermukhi starch (60.27°C), while it was lowest for Kufri Badshah starch (59.72°C). $T_p$ and $T_c$ of starches from different cultivars ranged between 63.26–64.58°C and 67.28–68.35°C, respectively. Kufri Sindhuri starch showed the highest

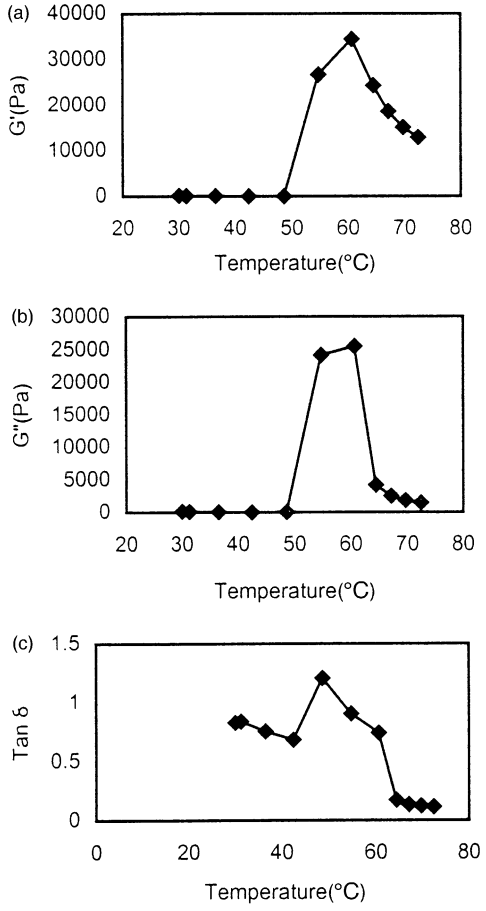


Fig. 2. Storage modulus ($G'$), loss modulus ($G''$) and loss factor (tan δ) of starch from cv. Kufri Chandermukhi during heating.

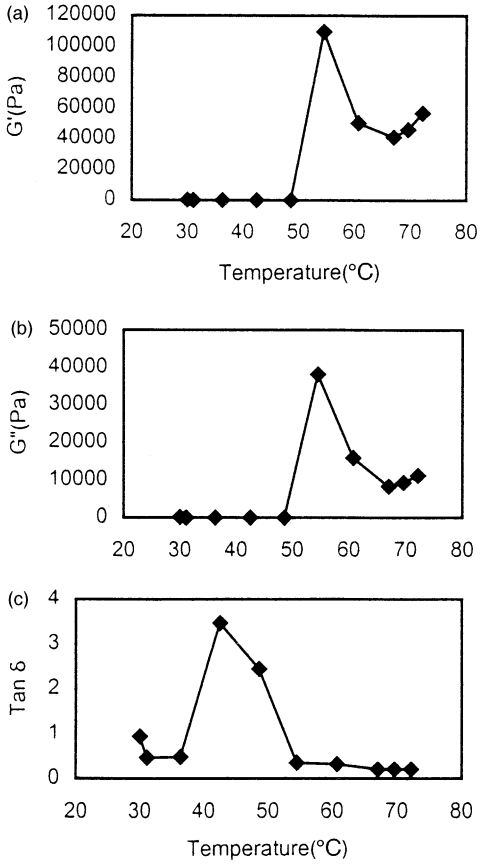


Fig. 3. Storage modulus ($G'$), loss modulus ($G''$) and loss factor (tan δ) of starch from cv. Kufri Badshah during heating.

$T_p$ and $T_c$ of 64.6 and 70.34°C, respectively. Kim et al. (1995) reported similar ranges of transition temperatures and enthalpies of gelatinization for starches from 42 American potato cultivars. Kufri Badshah and Kufri Sindhuri starches showed maximum R values while the PHI were narrow for the same. Double helical and crystalline structures are disrupted in starches during gelatinization. This order-disorder phase transition showed melting of crystals which was illustrated by DSC endotherms, in the range 50–70°C, for various native starches (Jacobs, Eerlingen, Clauwaert, & Delcour, 1995). The $\Delta H_{gel}$ reflected the loss of double helical rather than crystalline order (Cooke & Gidley, 1992). High transition temperatures have been reported to result from a high degree of crystallinity which provided structural stability and made the granule more resistant to gelatinization (Barichello, Yada, Coffin, & Stanley, 1990). A higher enthalpy for Kufri Badshah starch may be attributed to the presence of a higher percentage of irregular or cuboidal shaped and large granules while Kufri Chandermukhi starch, contained small and oval granules, which may be responsible for its low $\Delta H_{gel}$. The starch from potato cultivars having smaller starch granules showed lower $\Delta H_{gel}$ and vice versa. Vasanthan and Bhatty (1996) reported the higher $\Delta H_{gel}$ and lower $T_o$ and $T_p$ for large barley starch granules. Granule shapes, percentage of large and small granules, and presence of phosphate esters have been reported to effect the gelatinization enthalpy values of starches (Stevens & Elton, 1971; Yuan, Thompson, & Boyer, 1993). Yamin, Lee, Pollak, and White (1999) reported that starch with low $T_o$, broad R and low PHI might have irregularly shaped granules. The differences in the R values among the starch cultivars may be due to the presence of crystalline regions within a starch granule and were composed of small crystallites having slightly different crystal strength (Banks & Greenwood, 1975). The variation in $T_o$, ΔH and R in starches from different cultivars might be due to differences in amounts of longer chains in amylopectins. These longer chains require a higher temperature to dissociate completely than that required for shorter double helices (Yamin et al., 1999).

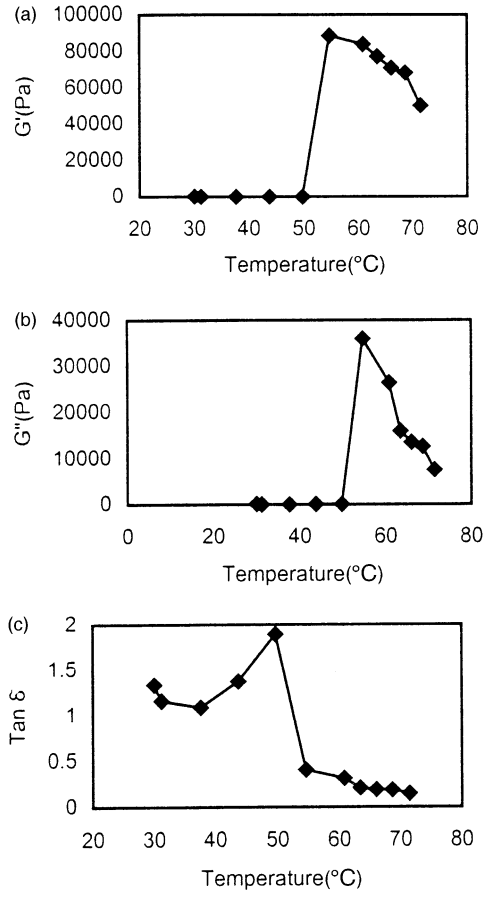


Fig. 4. Storage modulus ($G'$), loss modulus ($G''$) and loss factor (tan δ) of starch from cv. Kufri Jyoti during heating.

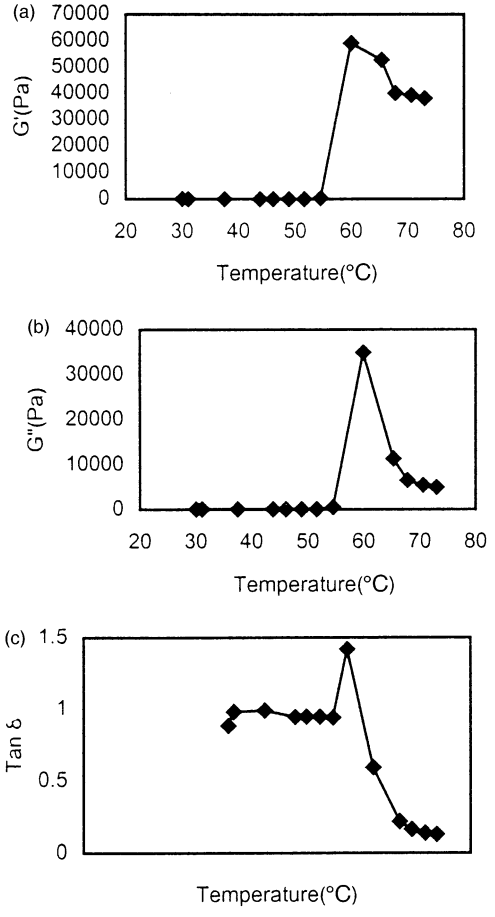


Fig. 5. Storage modulus ($G'$), loss modulus ($G''$) and loss factor (tan δ) of starch from cv. Kufri Sindhuri during heating.

### 3.2.2. Retrogradation properties

Endothermic peaks of starches after gelatinization and 14 days of storage at 4°C, appeared from 45–58°C. The retrogradation enthalpy ($\Delta H_{ret}$), at the end of the storage period dropped down significantly (Table 1). The $\Delta H_{ret}$ was highest for Kufri Badshah starch (8.6 J/g) while it was lowest for Kufri Chandermukhi starch (6.4 J/g). Recrystallization of starch molecules occurred during gel storage and reheating of aged starch gel in a DSC produced an endothermic transition which was absent in freshly gelatinized samples (Perera & Hoover, 1999). The $\Delta H_{ret}$ values were observed at lower temperature ranges than for gelatinization (Russel, 1987). Recrystallization of amylopectin branch chains has been reported to occur in less ordered manner in stored starch gels than in native starches. This would explain the observation of amylopectin retrogradation endotherms at a temperature range below that for gelatinization (Ward, Hoseney, & Seib, 1994). $\Delta H_{ret}$ for Kufri Badshah starch suggested its high tendency towards retrogradation; this tendency was lowest for Kufri Chandermukhi and S1 starches. The variation in thermal properties among the starches from different potato cultivars may be attributed to the variation in amylose to amylopectin ratio, size and shape of the granules. Pan and Jane (2000) reported the presence of higher amount of amylose in large size maize starch granules. A greater amount of amylose has traditionally been linked to a greater retrogradation tendency in starches (Whistler & Bemiller, 1996), but amylopectin and intermediate materials also play an important role in starch retrogradation during refrigerated storage (Yamin et al., 1999). The intermediate materials, with longer chains than amylopectin, may also form longer double helices during reassociation at refrigerated storage conditions.

### 3.3. Rheological properties

$G'$ and $G''$ of the five potato starches increased to a maximum and then dropped during heating. The temperature at which $G'$ was maximum ($TG'$) showed a significant variation among starches from all five cultivars (Table 2). Kufri Badshah starch showed the lowest $TG'$ of 54.5°C while it was highest, i.e 60.6°C, for Kufri Chandermukhi starch. Hopkins and Gormley (2000) reported of pasting temperature between 61.1°C and

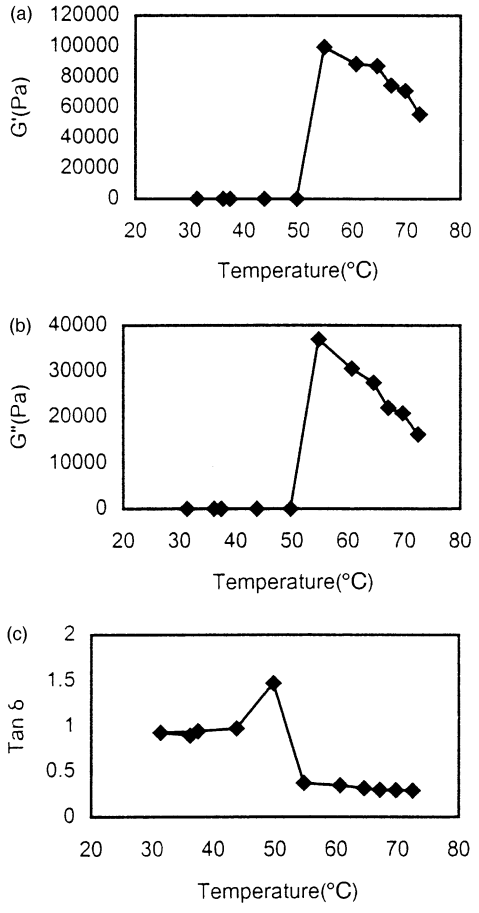


Fig. 6. Storage modulus ($G'$), loss modulus ($G''$) and loss factor (tan δ) of starch from cv. S1 during heating.

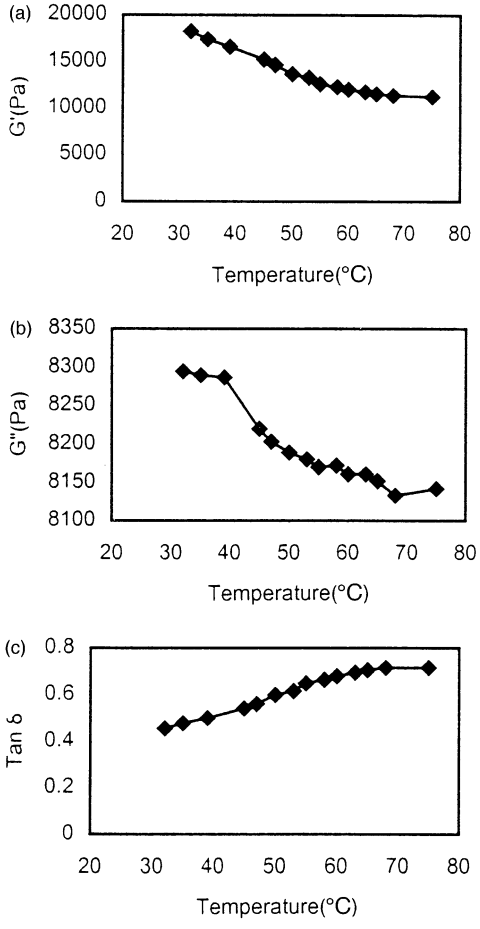


Fig. 7. Storage modulus ($G'$), loss modulus ($G''$) and loss factor (tan δ) of starch from cv. Kufri Chandermukhi during cooling.

63.7°C for starches separated from different Irish potato cultivars using the Brabender viscograph. Highest peak $G'$ and $G''$ of 109600 and 38130 Pa, respectively was observed for Kufri Badshah starch while these were lowest of 34430 Pa and 25500 Pa, respectively for Kufri Chandermukhi starch (Figs. 2 and 3). At early stages of heating, the amylose molecules were dissolved from the swollen starch particles and the suspension was transferred into a "Sol", thus increase in $G'$ and $G''$ were relatively small (Hsu et al., 2000). As the temperature increases, the $G'$ and $G''$ values increased and reached a maximum, which may be attributed to the network of swollen starch granules (Hsu et al., 2000). $G'$ and $G''$ decreased with further increase in temperature, indicating that prolonged heating caused the destruction of gel structure (Tsai et al., 1997). The large and irregular or cuboidal granules in Kufri Badshah starch may be responsible for its higher $G'$, $G''$ and lower tan δ values during the heating cycle. The presence of small and oval granules in Kufri Chandermukhi and Kufri Sindhuri starches may be responsible for the lower $G'$, $G''$ and higher tan δ values (Figs. 2 and 4). Disintegration of starch granules occurred as the heating continued. The extent of breakdown in starch pastes was calculated, as a measure of the degree of disintegration of starch granules (Singh, Singh, & Saxena, 2001). The breakdown in $G'$ is the difference between peak $G'$ at $TG'$ and minimum $G'$ at 75°C. The breakdown in $G'$ values differed significantly in starch from all five potato cultivars (Table 2). Maximum breakdown in $G'$ was observed in Kufri Badshah and S1 starches while it was lowest in Kufri Chandermukhi starch. The differences in breakdown values among the starches from different potato cultivars may be attributed to the differences in morphological characteristics of starch granules and peak $G'$ values.

Peak tan δ values during heating in starches, from all the cultivars, were $< 1$ (Figs. 2–6). Peak tan δ value (at $TG'$) was 0.3479 for Kufri Badshah starch while it was 0.7406 for Kufri Chandermukhi starch. The loss factor, tan δ ($G''/G'$) is the ratio of energy lost to energy stored during a cycle (Ferry, 1970). The difference in the rheological properties, among all the five starches, could be attributed to differences in genotypic or biological origin (Svegmark & Hermansson, 1993). Starches have been reported to differ in granule size, shape, presence of phosphate esters, and amylose to amylopectin ratio, which in turn are responsible for the rheological, thermal and other functional properties (Wiesenborn et al., 1994).

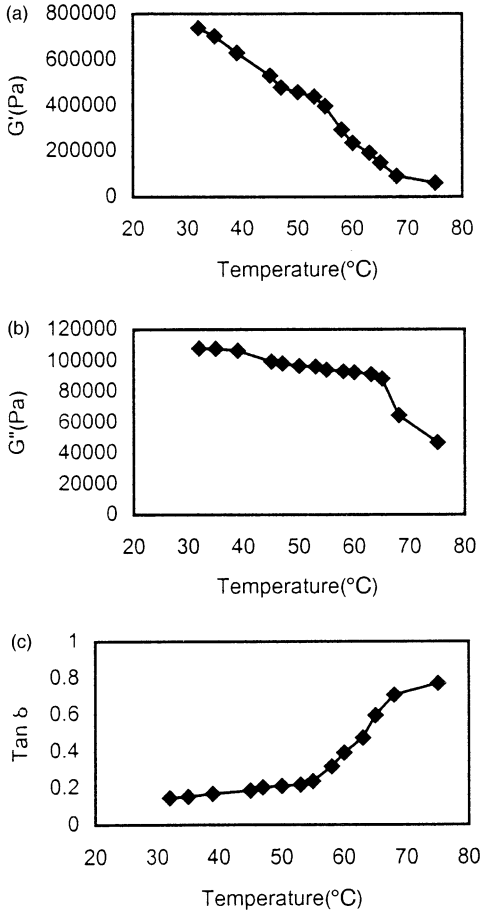


Fig. 8. Storage modulus ($G'$), loss modulus ($G''$) and loss factor (tan δ) of starch from cv. Kufri Badshah during cooling.

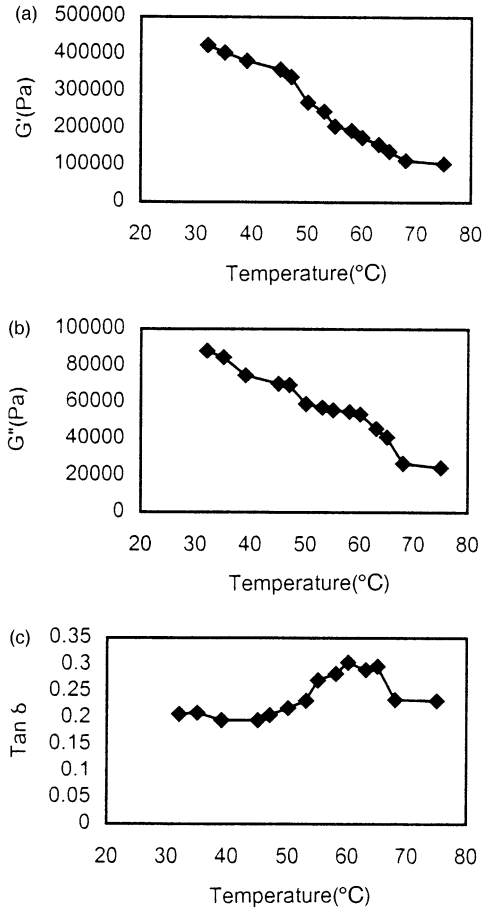


Fig. 9. Storage modulus ($G'$), loss modulus ($G''$) and loss factor (tan δ) of starch from cv. Kufri Jyoti during cooling.

The $G'$ and $G''$ values increased and tan δ values decreased during cooling of the heated starch paste from 75 to 30°C (Figs. 7–11; Table 3). Higher $G'$ and low tan δ values for starches from cv. Kufri Badshah and S1 showed that these starches formed a more rigid gel structure than starches from other cultivars (Figs. 8 and 11). A decrease in tan δ values during cooling of starches has been reported as evidence of gel formation (Reddy & Seib, 2000). Jane and Chen (1992) suggested that corn starch amylopectin, with long chain branches, had a strong tendency to gel formation. The decrease in tan δ might be due to retrogradation of leached components and interaction of molecules remaining inside the granule, reinforcing the gel during cooling (Hsu et al., 2000; Lii et al., 1996; Tsai et al., 1996). The tan δ has been reported to decrease, corresponding to a sol to gel transition, i.e. a three dimensional gel network is constructed from the amylose, reinforced by strong interaction among the swollen starch particles (Vasanthan & Bhatty, 1996). The formation of gel structure at lower tan δ values (0.13–0.21), in the studies on waxy wheat starch and waxy corn starch, has also been reported (Reddy & Seib, 2000).

### 3.4. Turbidity

The turbidity values of gelatinized suspensions of the starches separated from the potato cultivars, measured as absorbance at 640 nm, differed significantly. Kufri Chandarmukhi and Kufri Sindhuri starch suspension showed higher turbidity values. The turbidity values of starch suspensions from all potato cultivars increased progressively during storage. Starches from the potato cultivars having larger size granules showed lower turbidity values, while those having smaller size granules showed higher turbidity values (Table 4). Kufri Chandermukhi and Kufri Sindhuri starches showed the maximum absorbance after storage for 5 days at 4°C, while Kufri Badshah and S1 starches showed lowest absorbance. Factors, such as granule swelling, granule remnants, leached amylose and amylopectin, amylose and amylopectin chain lengths, intra or intermolecular bonding, lipids, cross-linking and substitution, have been reported to be responsible for turbidity development in starches during storage (Jacobson, Obanni, & BeMiller, 1997). The increase in turbidity during storages has been attributed to the interaction between

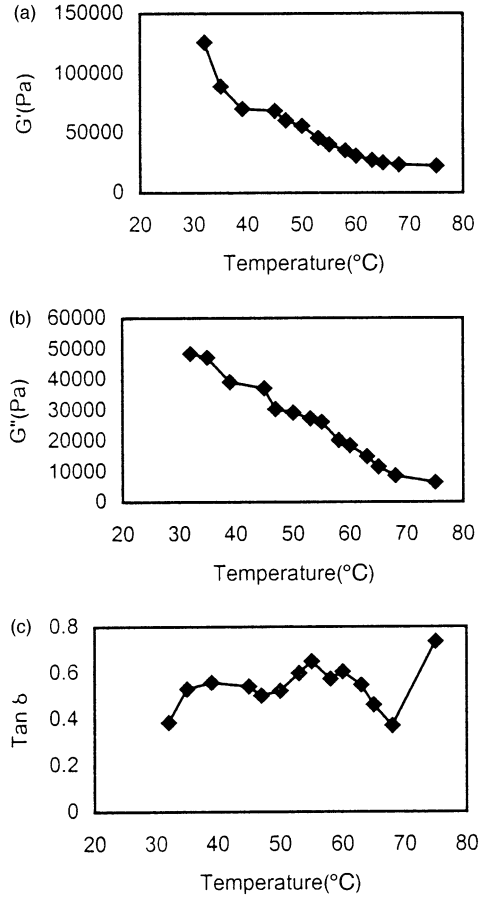


Fig. 10. Storage modulus ($G'$), loss modulus ($G''$) and loss factor (tan δ) of starch from cv. Kufri Sindhuri during cooling.

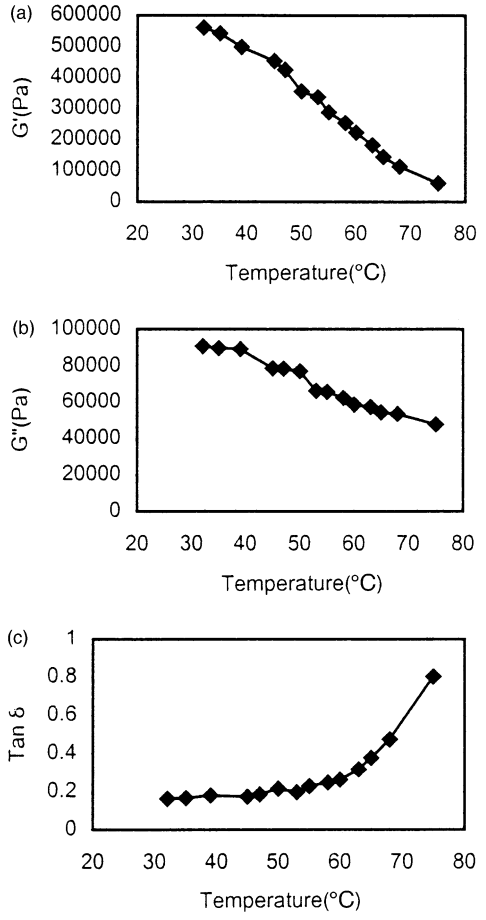


Fig. 11. Storage modulus ($G'$), loss modulus ($G''$) and loss factor (taδ) of starch from cv. S1 during cooling.

leached amylose and amylopectin chains that led to development of function zones, which reflect or scatter a significant amount of light (Perera & Hoover, 1999). Amylose aggregation and crystallization have been reported to be complete within the first few hours of storage while amylopectin aggregation and crystallization occurs during later stages (Miles, Morris, Orford, & Ring, 1985).

### 3.5. Water binding capacity

Water-binding capacity (WBC) of starches from different potato cultivars ranged from 89.2 to 91.1% (Table 4). Kufri Chandermukhi starch showed the highest WBC (91.104%) while Kufri Badshah starch showed the lowest (89.23%). Kim et al. (1995) reported that WBC for starches from 42 American potato cultivars ranged from 77.2 to 89.6%. Their studies indicated that the starches with low WBC had higher peak viscosity (measured by viscoamylograph) and $\Delta H_{gel}$ values, which agrees with our results (Table 4). The $\Delta H_{gel}$ and peak $G'$ values were higher and WBC values were lower for starches from cv. Kufri Badshah and S1. The differences in WBC of starches separated from potato cultivars may be attributed to the variation in granular structure. Loose association of amylose and amylopectin molecules in the native starch granules has been reported to be responsible for high WBC (Soni, Sharma, Bisen, Srivastava, & Gharia, 1987). The engagement of hydroxyl groups to form hydrogen and covalent bonds between starch chains lowers WBC (Hoover & Sosulski, 1986). The differences in degrees of availability of water-binding sites among the starches may have also contributed to the variation in WBC (Wotton & Bamunuarachchi, 1978).

## 4. Conclusion

Starch separated from different potato cultivars differed significantly in morphological, thermal and rheological properties. Kufri Badshah and S1 starch, having large-sized, irregular or cuboidal granules, showed higher $G'$, $G''$ and lower tan δ and T$G'$ while the reverse was true for starches from Kufri Chandermukhi and Kufri Sindhuri, with smaller-size granules, during the heating and cooling cycles. The results revealed that Kufri Badshah and S1 starch had a higher viscous character and Kufri Chandermukhi, Kufri Jyoti, and Kufri Sindhuri had a lower viscous character. Starches with large-sized or irregular granules had higher $\Delta H_{gel}$ and $R$ values, while PHI were found to be lower for these starches. Among the various potato cultivars, Kufri Badshah and S1 showed the lowest turbidity value, that progressively increased during storage in all potato cultivars.

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