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Morphological, thermal and rheological properties of starches separated from rice cultivars grown in India

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Abstract

Morphological, thermal and rheological properties of starches separated from five rice cultivars (PR-106, PR-114, IR-8, PR-103 and PR-113), varying in amylose content, were studied. Amylose contents of starches separated from PR-103, IR-8, PR-106, PR-114 and PR-113 were 7.83, 15.62, 16.05, 16.13 and 18.86%, respectively. The granular size, measured using a Scanning Electron Microscope, varied from 2.4 to 5.4 μm in all rice starches. PR-103 starch, with lowest average granular size, amylose content and solubility, had the highest swelling power, while PR-113 starch, with the highest average granular size and amylose content had the lowest swelling power. PR-103 starch showed highest transition temperatures, enthalpies of gelatinization, peak height index, range and enthalpies of retrogradation. The retrogradation (%) was observed to be highest in PR-113 starch and lowest in PR-103 starch. The changes in rheological parameters of rice starches during heating were measured using a Dynamic rheometer. PR-113 rice starch showed the highest G', G'' and breakdown in G' values, whereas PR-103 starch showed the lowest values for these parameters. Turbidity value of gelatinized pastes from all rice starches progressively increased up to the 3rd day during refrigerated storage, PR-103 starch paste showed the lowest turbidity value and PR-113 starch showed the highest value. The syneresis (%) of starch pastes, from different rice cultivars during storage at 4 °C, was also measured. The syneresis of starch pastes from all rice cultivars, except PR-103, increased with storage. PR-103 starch paste showed negligible syneresis during storage.

Keywords: Rice starch; Morphological; Thermal; Rheological; Amylose; Retrogradation

1. Introduction

The availability of corn to the Indian starch industry is decreasing, day by day, because of increased demand by industries involved in the production of breakfast cereals and snacks. The broken rice, which is cheaper than corn and is available in abundance, can be used in the production of starch. Rice starch exhibits a number of unique characteristics and can be a better substitute of corn starch in a number of food applications (Juliano, 1984). Rice starch, in its gelatinized form, has a bland taste and is smooth, creamy and spreadable, which makes it a good custard starch. In contrast, corn starch is yellowish white, has a protein taste and forms a firm gel. Rice starch granules are of the same size as homogenized fat globules; therefore they provide a texture perception similar to fat. The rice starch granule has been reported to vary from 3 to 10 μm (Juliano, 1984). It is non-allergenic, due to the hypoallergenicity of the associated protein. Rice starch with high amylose content has a low glycemic index (Champagne, 1996). The isolation procedure of starch from rice is different from that of corn, wheat, or potato, due to differences in protein properties. The majority of rice protein is alkali soluble; the alkaline steeping method is commonly used in separation of starch from rice (Resurreccion, Li, Okita, & Juliano, 1993; Yang, Lai, & Lii, 1984). The protease digestion method for starch isolation has been suggested as an alternate to the alkaline steeping method, which results in starch with less damage and properties comparable with that produced by the alkaline method (Wang & Wang, 2001). The starch isolated by the alkaline steeping method with 0.1–0.2% sodium hydroxide had 0.07–0.42% residual protein (Lumdubwong & Seib, 2000; Yang et al., 1984). Hamaker (1994) suggested that gelatinization properties of the starch might be influenced by the protein. Enzymatic

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(actinase) removal of granule associated protein in rice resulted in enhanced starch gelatinization, as indicated by high values in peak viscosity, break down viscosity, apparent viscosity, yield stress, and consistency index (Arai, Aoyama, & Watanabe, 1993).

The rice cultivars show great diversity in genetic background, composition, granule size and gelatinization behaviour. The starch separated from rice significantly varies in its composition, depending on isolation procedure, botanical source, climatic and soil conditions during rice grain development (Asaoka, Okuno, & Fuwa, 1985; Inatsu, Watanabe, Maida, Ito, & Osani, 1974; Juliano, Bautista, Lugay, & Reyes, 1964; Morrison, Milligan, & Azudin, 1984). Rice starch, as other starches, is composed of amylose and amylopectin. High temperatures result in a decrease in amylose content of rice, whereas cool temperatures have the opposite effect. Amylose content in rice has been reported to vary from 0 to 33%. Amylose contents of 0–2, 5–12, 12–20, 20–25 and 25–33%, in rice have been specified as waxy, very low, low, intermediate and high amylose, respectively (Juliano, 1992). In addition to amylose and amylopectin, some minor constituents, such as lipids, protein, phosphorus and trace elements, are also present in rice starch. Lii, Shao, and Tseng (1995) reported that rice starches differing in amylose-amylopectin ratios vary in swelling power. The gelatinization temperature has also been reported to vary in different rice cultivars which are classified as low, intermediate and high (Juliano, 1984). It seems highly probable that starches isolated from different Indian rice cultivars will vary in different physico-chemical, thermal and rheological properties. No work on the characterization of starches separated from different Indian rice cultivars has been reported.

The objective of the present study was to compare the physico-chemical, morphological, thermal, rheological and retrogradation behaviours of starches separated from different Indian rice cultivars.

2. Materials and methods

2.1. Materials

Five *indica* paddy cultivars (cv.), i.e. PR-106, PR-114, IR-8, PR-103 and PR-113, were procured from Punjab Agricultural University, Ludhiana, India from the 2000 harvest. PR-106, PR-114, IR-8 and PR-113 had a maturity period of 144 days while PR-103 had 125 days. All the varieties have 30 days of grain filling period.

2.2. Dehusking and milling

The paddy samples were dehusked and milled to remove 6% bran, as described earlier (Singh, Singh, Kaur, & Bakshi, 2000). The milled rice obtained from all the rice cultivars was used for isolation of starch.

2.3. Starch isolation

Starch was isolated from various rice cultivars by alkali extraction of the protein. Milled rice was steeped in 5 to 6 volumes of sodium hydroxide (0.2–0.3%) solution at 25 °C for 24 h to soften the endosperms. The steep liquor was drained off and the endosperms were ground lightly in successive small fractions with a mortar and pestle. The slurry was then diluted to the original volume with sodium hydroxide (0.2–0.3%). The mixture was stirred for 10 min and allowed to settle overnight. The cloudy supernatant was drained off, and the sediment was diluted to the original volume with sodium hydroxide solution. The process is repeated until the supernatant becomes clear and gives a negative reaction to the biuret test for protein. Starch was suspended in distilled water, passed through a 100–200 mesh nylon cloth, and repeatedly washed with water until the supernatant no longer showed any pink colour with the phenolphthalein. The starch was collected by sedimentation, and the white middle portion was collected and dried in cabinet drier at 40°C (Nikuni & Hizukuri, 1958).

2.4. Amylose content

Amylose content of the isolated starch was determined by using the method of Williams, Kuzina, and Hlynka (1970). The principle of the test lies in the blue colour developed by the addition of an iodine reagent to a solution containing the amylose under standardized conditions. The measurement of amylose was determined from a standard curve developed using amylose and amylopectin blends.

2.5. Swelling power and solubility

Swelling power and solubility were determined using 2% aqueous suspension of the starch by the method of Leach, McCowen, and Schoch (1959).

2.6. Turbidity

Turbidity of starches from different rice cultivars was measured as described by Perera and Hoover (1999). A 2% aqueous suspension of starch from each rice 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 6 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. Morphological properties

Scanning electron micrographs were obtained with a scanning 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 acceleration potential of 10 kV was used during micrography.

2.8. Thermal properties

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, dwb) was weighed in 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% water. Samples were hermetically sealed and allowed to stand for 1 h at room temperature before heating in the 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 25 to 100 °C. Onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy of gelatinization (ΔH_{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 $\Delta H_{gel}/(T_p–T_o)$, as described by Krueger, Knutson, Inglett, and Walker (1987).

After cooling, the samples were stored in the refrigerator at 4 °C for 7 days. Retrogradation was measured by reheating the sample pans containing the starches of five rice cultivars at the rate of 10 °C/min from 25 to 100 °C. The enthalpies of retrogradation (ΔH_{ret}) were calculated automatically and percentage of retrogradation (%R) was calculated from the ratio of ΔH of retrogradation to ΔH of gelatinization (White, Abbas, & Johnson, 1989).

2.9. Rheological properties

A small amplitude oscillatory rheological measurement was made for isolated starches 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 isolated starches. 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 heated from 45 to 85 °C at a rate of 2 °C/min.

2.10. Syneresis (%)

Starch suspension (5%, w/w) was heated at 90 °C for 30 min in a temperature-controlled water bath, followed by rapid cooling in an ice water bath to room temperature. The starch sample was stored for 48, 72, 96 and 168 h at 4 °C. Syneresis was measured as % amount of water released after centrifugation at 5000 rpm for 15 min.

2.11. Statistical analysis

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

3. Results and discussion

3.1. Physico-chemical properties

The amylose content of starches separated from different rice cultivars ranged from 7.83 to 18.86% (Table 1). PR-103 starch had the lowest amylose content (7.83%) whereas PR-113 starch had the highest amylose content (18.86%). The ability of the starches to swell in excess water and solubility also differed significantly. PR-103 starch had the highest swelling power and lowest solubility whereas PR-113 starch showed lowest swelling power. These differences in swelling power and solubility may be attributed to the differences in amylose content, viscosity patterns and weak internal organization resulting from negatively charged phosphate groups within the rice starch granules (Jane, Chen, Lee, McPherson, Wang, Radosavljevic et al., 1999; Jane, Kasemsuwan, & Chen, 1996). Lii et al.

Table 1
Amylose content, swelling power and solubility of starches from different rice cultivars

Cultivar	Amylose content (%)	Solubility (%)	Swelling power (g/g)
PR-106	16.05bc	0.319b	28.80bc
PR-114	16.13c	0.360d	28.60b
IR-8	15.62b	0.307b	30.05c
PR-103	7.83a	0.287a	33.20d
PR-113	18.86d	0.346c	26.06a

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

Table 2
Turbidity of starches from different rice cultivars

Cultivar	Turbidity (absorbance at 640 nm)					
	First day	Second day	Third day	Fourth day	Fifth day	Sixth day
PR-106	0.347bc	0.362b	0.376b	0.380b	0.368b	0.369b
PR-114	0.341b	0.353b	0.365b	0.374b	0.365b	0.366b
IR-8	0.344bc	0.363b	0.374b	0.376b	0.360b	0.368b
PR-103	0.309a	0.322a	0.343a	0.345a	0.331a	0.341a
PR-113	0.349cd	0.357b	0.373b	0.380b	0.368b	0.369b

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

(1995) also observed a higher swelling power during heating for rice starch with lower amylose content.

The turbidity values of gelatinized starch suspension prepared from starches separated from different rice cultivars are summarized in Table 2. The turbidity value of PR-103 starch suspension was significantly lower than the turbidity value of the starch suspensions from other rice cultivars. The lowest turbidity value of PR-103 starch suspension may be attributed to its lowest amylose content and smallest granular size (Jacobson, Obanni, & BeMiller, 1997). Differences in turbidity value, due to phosphate monoester derivatives and phospholipid contents among the starches from different rice cultivars, cannot be also ruled out (Jane et al. 1996). The phosphate-monoester derivatives have been reported to increase paste clarity whereas phospholipids made starch paste opaque (Kasemsuwan & Jane, 1996; Schoch, 1942). The turbidity value of starch suspensions progressively increased with the increase in storage duration up to the third day and further storage caused a slight decrease. However, this decrease was not statistically significant. The increase in turbidity value due to storage may be attributed to leached amylose and amylopectin chains that lead to the development of functional zones which scatter a significant amount of light (Perera & Hoover, 1999). The increase in turbidity value to a maximum was observed up to the fourth day of storage in all the rice cultivars. This indicated that aggregation and crystallization of the amylose occurred with the maximum at the fourth day. Miles, Morris, Orford, and Ring (1985) reported that the aggregation and crystallization of amylose occur early during storage while amylopectin aggregation and crystallization occur later.

3.2. Morphological properties of rice starches

The scanning electron micrographs in Fig. 1 show the presence of mainly polyhedral granules having size in the range of 2.4–5.4 μm in different rice starches. PR-103 starch showed the presence of smallest size granules (2.5–3.5 μm) whereas the PR-113 starch had the largest (3.1–5.4 μm). IR-8 starch granule size ranged from 2.6 to 4.8 μm. IR-8 starch had the round starch granules in addition to polyhedral granules. PR-106 and PR-114 starches had granule sizes of 3.1–4.8 and 2.4–4.2 μm, respectively and the presence of more uniform sizes granules than starches from other rice cultivars. PR-106 starch also showed the presence of hexagonal granules in addition to the normal pentagonal granules. Li and Yeh (2001) reported an average granule size of 6.4 μm for Taiwan rice starch.

3.3. Thermal properties of rice starches

DSC results of starches separated from milled rice obtained from different rice cultivars are summarized in Table 3. Fig. 2 presents the gelatinization thermograms of starches separated from different rice cultivars. The transition temperatures (T_o, T_p & T_c), enthalpies of gelatinization (ΔH_{gel}), range (R) and enthalpies of retrogradation (ΔH_{ret}) of the starches from various rice cultivars differ significantly. T_o, T_p and T_c of PR-103 starch were significantly higher than the starches from other rice cultivars. T_o and T_p did not differ significantly in starches separated from PR-114, IR-8 and PR-113 cultivar. PR-103 starch showed the highest T_c followed by PR-113, PR-114, PR-106 and IR-8 starch. ΔH_{gel} was observed to be highest (11.88 J/g) for PR-103 starch whereas PR-106 starch showed the lowest ΔH_{gel} value (8.16 J/g). ΔH_{gel} reflected the loss of double helical rather than crystalline order (Cooke & Gidley, 1992). The differences in T_o, T_p, T_c and ΔH_{gel} in starches from different rice cultivars may be attributed to differences in amylose contents and granular structures. Larger T_o, T_p, T_c values for PR-103 starch may be attributed to the compact nature of small starch granules and higher degree of molecular order of the granules (Krueger et al., 1987). Because amylopectin plays a major role in starch granule crystallinity, the presence of amylose lowers the melting point of crystalline regions and the energy for starting gelatinization (Flipse, Keetels, Jacobson, & Visser, 1996). More energy is needed to initiate melting in the absence of amylose-rich amorphous regions (Kreuger et al., 1987). The differences in transition temperatures in rice starches may also be due to differences in lengths of the amylopectin (Jane et al., 1999). The transition temperature and enthalpies observed for rice starches in the present study were found to fall within a range similar to those already reported (Lii et al., 1995; Russell & Juliano, 1983). T_o and T_p values of PR-106 and PR-114 starch having amylose contents of 16–16.15% were lower than the values reported earlier by Li and Yeh (2001) for Taiwan rice starch with similar amylose content (16.4%). These differences may be due to differences in granular structure. The presence of smallest starch granules in PR-103 may have resulted in the greatest ΔH_{gel}. PR-103 starch

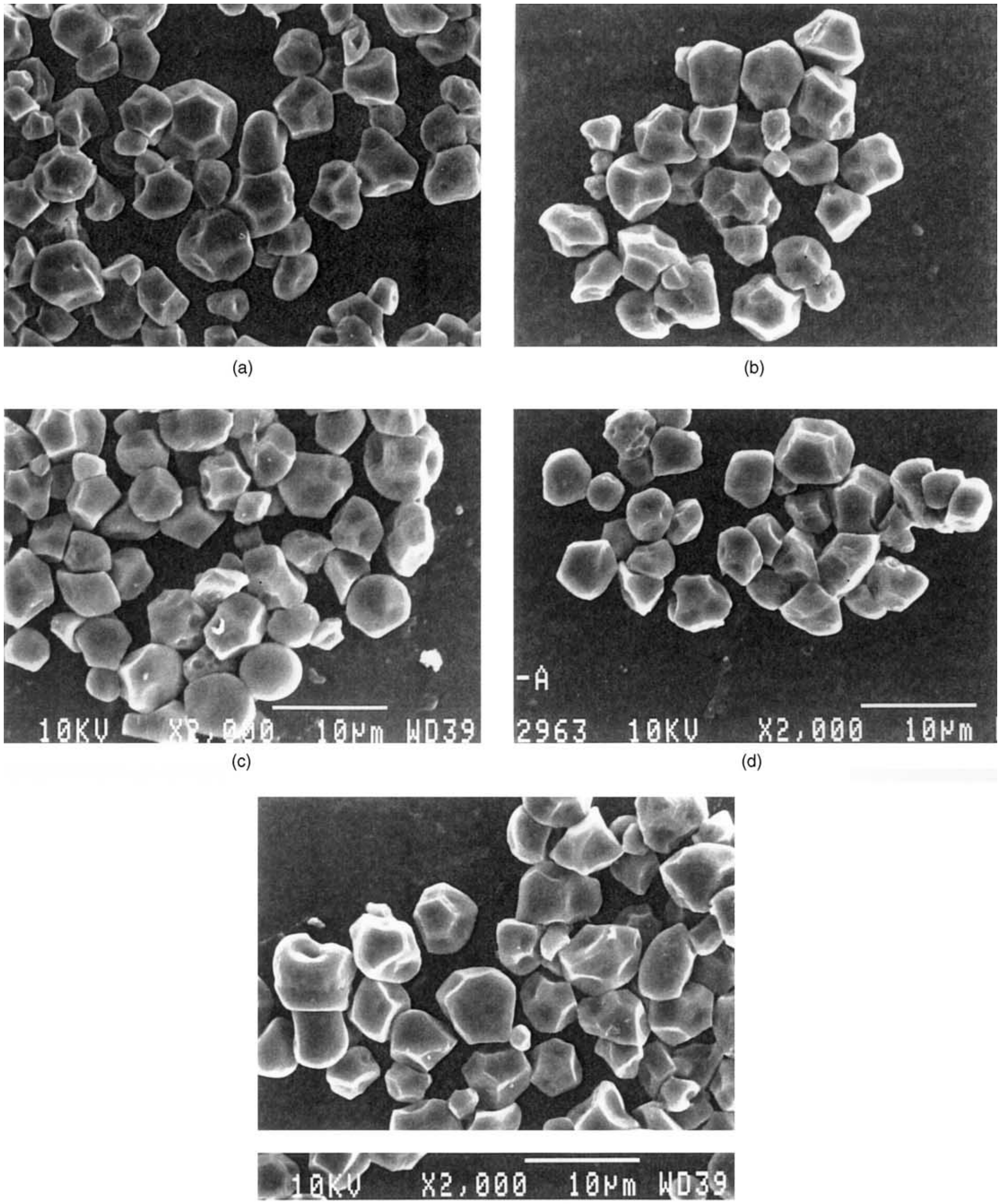

Fig. 1. Scanning electron micrographs (SEM) of starches separated from different rice cultivars (a) PR-106, (b) PR-114, (c) IR-8, (d) PR-103, (e) PR-113.

Table 3
Thermal properties of starches from different rice cultivars

Cultivar	T_o (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J/g)	PHI	R	ΔH_{ret} (J/g)	% R
PR-106	66.84b	70.07a	74.27ab	8.16a	2.53a	7.43a	2.61a	32.00b
PR-114	66.38ab	70.09a	74.75bc	8.97b	2.42a	8.37b	2.84a	31.66ab
IR-8	66.33a	69.74a	74.08a	8.55a	2.51a	7.75a	3.06b	35.79c
PR-103	67.26c	71.94b	78.04d	11.88d	2.54a	10.78d	3.71c	31.23a
PR-113	66.00a	69.75a	75.08c	9.49c	2.53a	9.08c	3.61c	38.04d

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

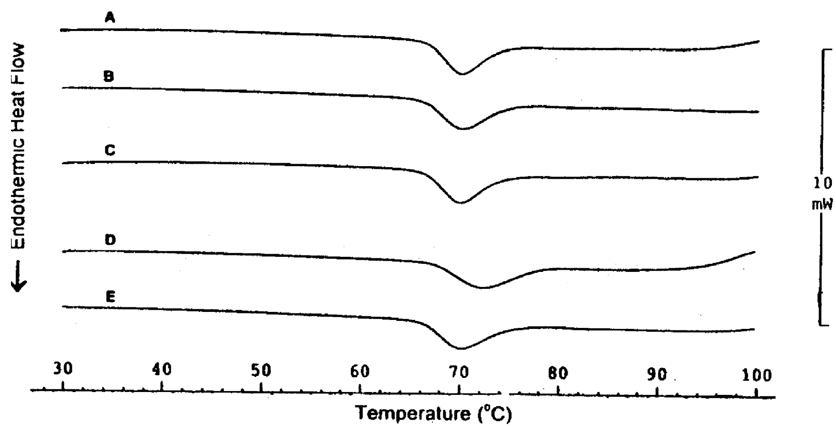

Fig. 2. DSC-endotherms of starches separated from different rice cultivars (A) PR-106, (B) PR-114, (C) IR-8, (D) PR-103, (E) PR-113.

showed higher PHI than the starches from other rice cultivars. The differences in PHI values among various starches were non-significant. The R (gelatization range) of PR-103 starch was highest, followed by PR-113, PR-114, IR-8 and PR-106 starch. These differences may be attributed to variations in size and number of uniform starch granules among the various starches.

The endothermic peaks of starches, after storage of gelatinized rice starches at 4 °C for 7 days, appeared between 38.20 and 60.75 °C. Recrystallization of amylopectin branch chains has been reported to occur in a less ordered manner in stored starch gels than in native starches. This explains the occurrence of amylopectin retrogradation endotherms at a temperature range below that for gelatinization (Ward, Hosney, & Seib, 1994). ΔH_{ret} for starches separated from different rice cultivars ranged from 2.61 to 3.71 J/g; the lowest value of 2.61 J/g was observed for PR-106 starch. The differences in the ΔH_{ret} among the various rice starches suggest differences in tendencies toward retrogradation. The retrogradation (%) was highest for PR-113 starch and lowest for PR-103 starch. The differences in ΔH_{ret} of different starches may be due to differences in amylose–amylopectin ratios, granular structures and phosphate esters (Hizukuri, 1996; Hizukuri, Shirasaka, & Juliano, 1983; Kasemsuwan, Jane, Schnable, Stinard, & Robertson, 1995). The amylopectin and intermediate materials play a significant role in starch retrogradation during refrigerated storage. The intermediate materials with longer chains than amylopectin may also form longer double helices during reassociation under refrigerated storage conditions (Yamin, Lee, Pollak, & White, 1999).

3.4. Rheological properties of rice starches

The rheological properties of starches separated from different rice cultivars during heating are illustrated in Figs. 3–7. Both G' and G'' of all rice starches increased

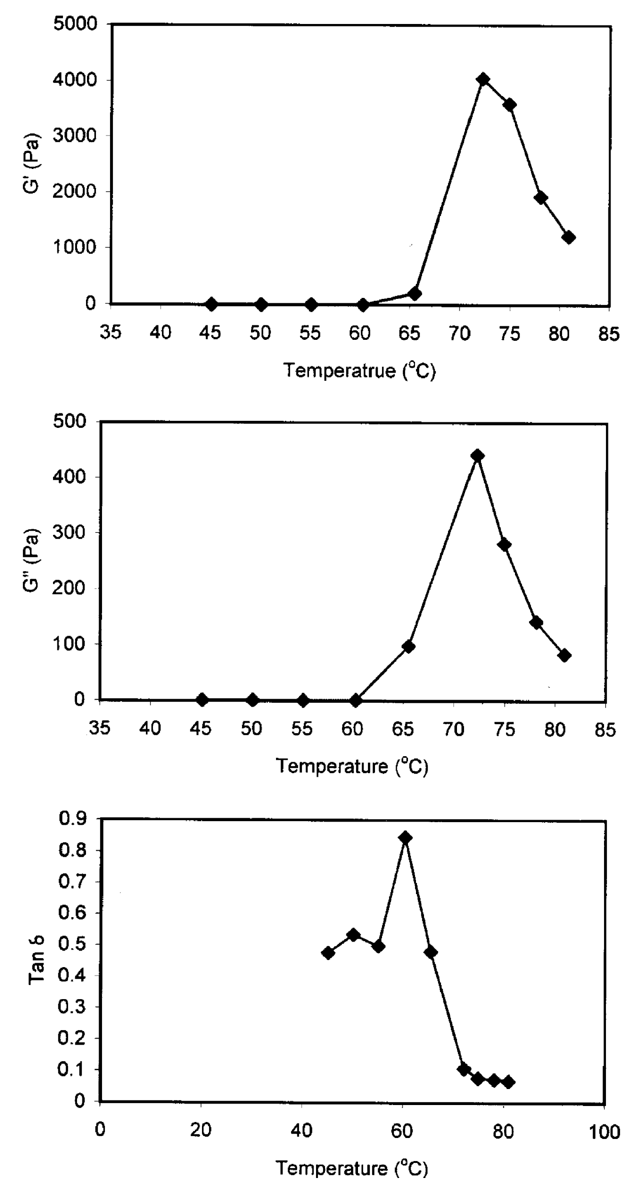

Fig. 3. Storage modulus (G'), Loss modulus (G'') and Loss factor (tan δ) of starch from cv. PR-106 during heating.

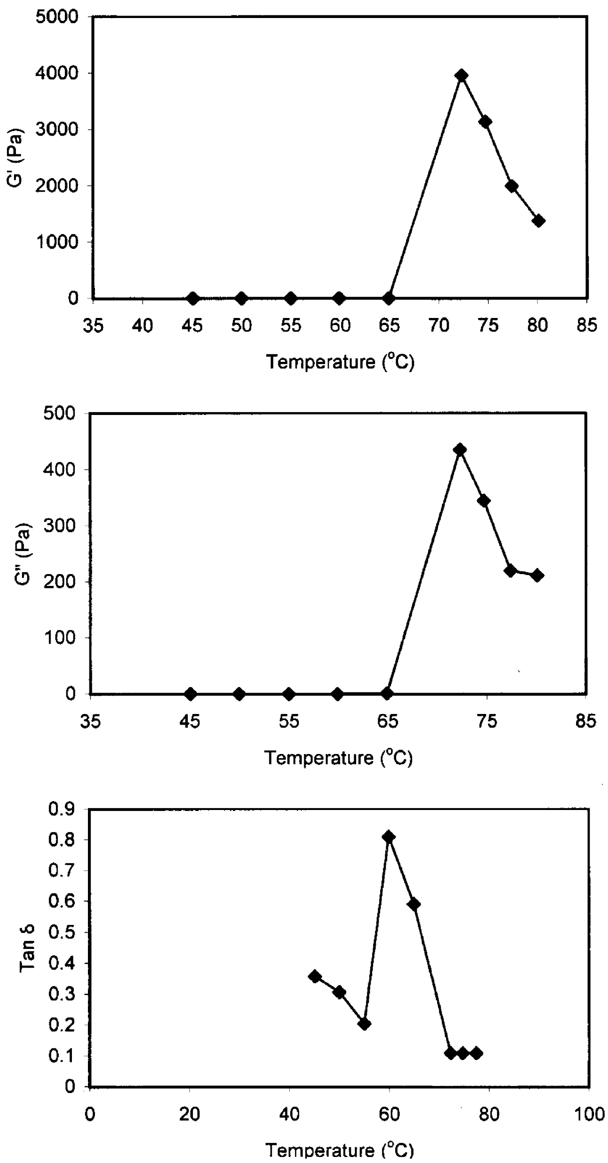

Fig. 4. Storage modulus (G'), Loss modulus (G'') and Loss factor (tan δ) of starch from cv. PR-114 during heating.

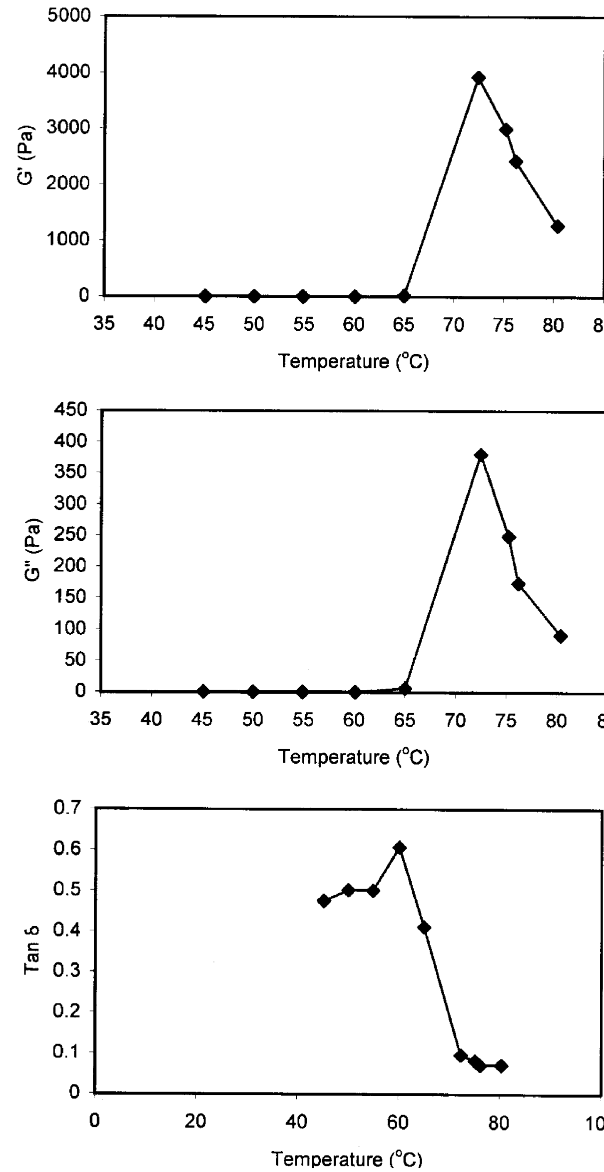

Fig. 5. Storage modulus (G'), Loss modulus (G'') and Loss factor (tan δ) of starch from cv. IR-8 during heating.

with increase in temperature, which indicates transformation of starch suspension into a "sol". G' and G'' increased to maxima between temperatures of 71.8 and 73.0 °C in all rice starches. This indicates a sol-to-gel transition, attributed to formation of a 3-dimensional gel network from the amylose, reinforced by strong interaction among the swollen starch particles (Hsu, Lu, & Huang, 2000; Vasanthan & Bhatty, 1996). The gel network formed by amylose has been reported to be strengthened by gelatinized starch granules (Ring, 1985). Heating beyond TG' caused a decrease in G' and G'' in all rice cultivars, which indicated the destruction of the gel. This could be attributed to disentanglement of the amylopectin molecules in the swollen particles that caused softening of the particles (Keetels & Van Vliet, 1994). The results show that the PR-113 starch gave the highest Peak G' (4524 Pa) and Peak G'' (483 Pa), while PR-103 starch showed lowest values ($G' = 2630$ Pa, $G'' = 350$ Pa) for these parameters during the heating cycle (Table 4, Figs. 6 and 7). Lii et al. (1995) observed G' values of 1732, 1551 and 39 Pa for Taiwan rice starches having amylose contents of 25.6, 14.80 and 0.99%, respectively, at 95 °C and 20% starch concentration. PR-103 starch showed the lowest TG', breakdown in G' and highest peak tan δ. These results clearly illustrate that the starches with lower amylose contents showed lower peak G' and G'' during heating. Lii, Tsai, and Tseng (1996) observed higher G' in rice starches having higher amylose content. Differences in G' and G'' may be attributed to differences in amylose contents in starches. PR-113 starch, with high amylose content, showed stronger structure, as was evident from

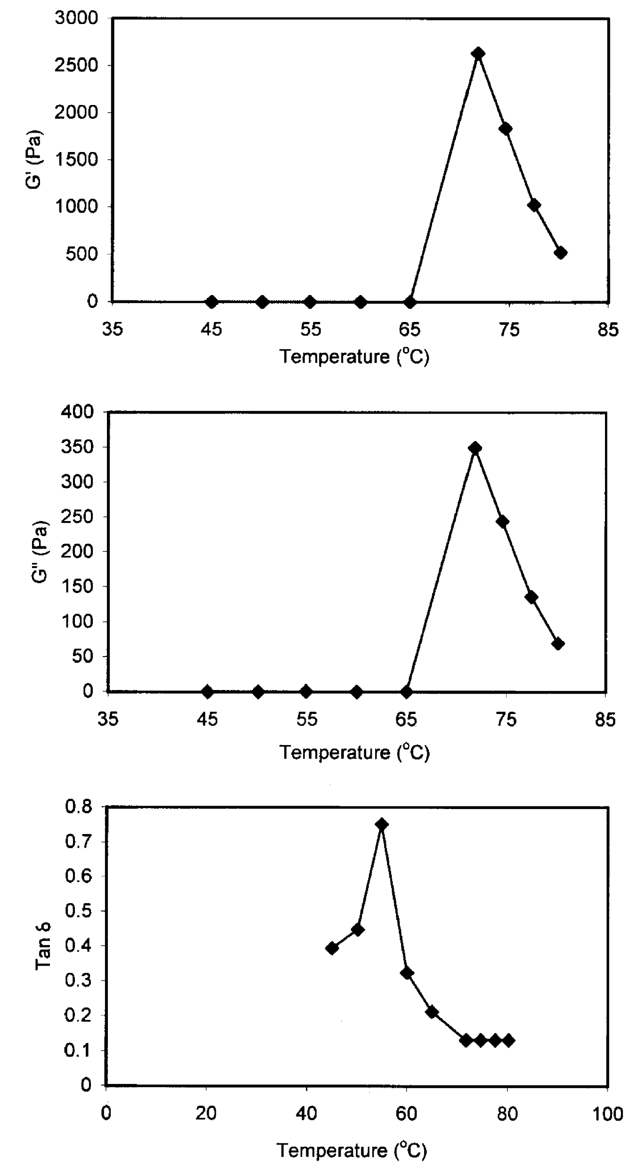

Fig. 6. Storage modulus (G'), Loss modulus (G'') and Loss factor (tan δ) of starch from cv.PR-103 during heating.

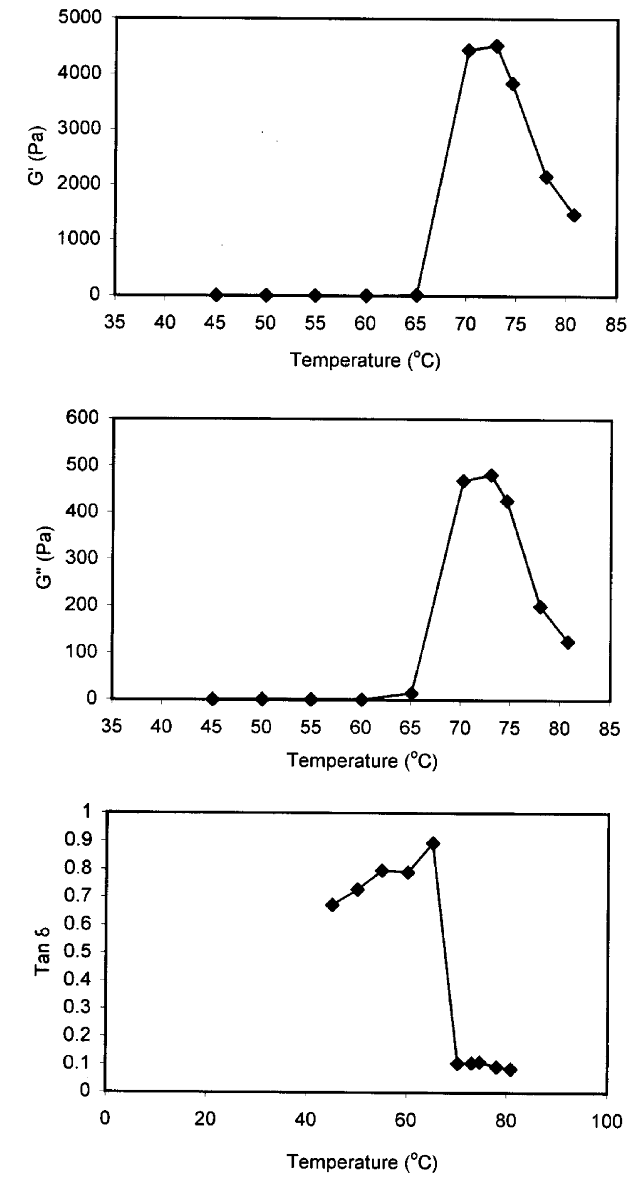

Fig. 7. Storage modulus (G'), Loss modulus (G'') and Loss factor (tan δ) of starch from cv. PR-113 during heating.

its lowest swelling power, while PR-103 starch granules, having lowest amylose contents, may have swelled more readily during heating, making themselves less rigid. The breakdown in G' is the difference between peak G' at TG' and minimum G' at 80 °C. The breakdown in G' differs significantly in starches from different rice cultivars. PR-103 starch showed the lowest breakdown whereas PR-113 starch showed the highest. The breakdowns in G' of IR-8 and PR-114 did not differ significantly. These differences may be attributed to the differences in morphological and peak G'. Similar conclusions have been drawn earlier in studies on potato starches (Singh & Singh, 2001). Peak tan δ, in all rice starches, ranged from 0.097 to 0.133, highest for PR-103 starch and lowest for IR-8 starch. The variation in tan δ among different rice cultivars may be attributed to difference in Peak G' and Peak G''. Lii et al. (1996) also reported that rigidity is inversely proportional to the swelling ratio. Their results clearly showed that amylose leached from starch granules could build stronger gel networks with amylose remaining in the particles showing the breakdown of crystalline regions. The disentanglement of amylopectin branches could be reduced due to the amylose that remained in particles (Hsu et al., 2000).

3.5. Syneresis of rice starches

The syneresis of gels prepared from starches separated from different rice cultivars was measured as amount of water released from gels during storage (up to 168 h) at 4 °C (Table 5). The syneresis of starches progressively increased with the increase in storage duration in all

Table 4
Rheological properties of starches from different rice cultivars during heating

Cultivar	*TG′* (°C)	Peak *G′* (Pa)	Peak *G″* (Pa)	Breakdown in *G′* (Pa)	Peak tanδ
PR-106	72.2ab	4052c	442c	2831c	0.1091a
PR-114	72.3ab	3958bc	435c	2584b	0.1100b
IR-8	72.4b	3929b	381b	2658b	0.0970a
PR-103	71.8a	2630a	350a	2106a	0.1331c
PR-113	73.0c	4524d	483d	3053d	0.1068a

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

Table 5
Syneresis (%) of starches from different rice cultivars

Cultivar	48 h	72 h	96 h	168 h
PR-106	2.41d	3.22c	3.82d	6.60d
PR-114	1.54b	2.71b	2.79b	6.00c
IR-8	1.51b	2.57b	3.15c	4.61b
PR-103	0.04a	0.04a	0.04a	0.07a
PR-113	1.79c	3.20c	6.38e	8.74e

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

rice starches except PR-103. The starch separated from PR-103 showed the lowest syneresis among all the rice starches. The starch gel from this cultivar did not show any significant change in syneresis during storage. The retrogradation (%), measured using DSC, also showed the highest retrogradation in PR-113 and lowest in PR-103 starch. The increase in % syneresis during storage has been attributed to the interaction between leached amylose and amylopectin chains, which leads to development of functional zones (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 occur during later stages (Miles et al., 1985).

4. Conclusion

Starches separated from various rice cultivars showed significant differences in physico-chemical, morphological, thermal and rheological properties. Starches with lower amylose contents had higher swelling power, transition temperatures, ΔH_{gel}, ΔH_{ret} and lower G', G'' and breakdown in G' than the starches with higher amylose contents. The amylose content in rice starches was observed to vary with granule size, starches having larger average granule size showed more amylose content than those with smaller average granule size. The starches with greater average granule size and amylose content showed more tendencies towards retrogradation, as indicated by $\Delta H_{ret}/\Delta H_{gel}$, turbidity and syneresis. The amylose content and granular size seemed to be major factors responsible for differences in various properties in starches separated from different rice cultivars. However, variation of these properties due to differences in monophosphate derivatives and phospholipids contents cannot be ruled out.

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